Inappropriate Discharges

INAPPROPRIATE DISCHARGES



Industrial discharge in storm sewer system in Toronto

The U. S. Environmental Protection Agency's Office of Research and Development's Storm and Combined Sewer Pollution Control Program and the Environmental Engineering & Technology Demonstration Branch, along with the Office of Water's Nonpoint Source Branch, have supported the development of this research for the investigation of inappropriate entries to storm drainage systems. This material is designed to provide information and guidance to local agencies by meeting the following objectives:

1. Identify and describe the most common potential sources of non-stormwater pollutant entries into storm drainage systems.
2. Describe an investigative procedure that will allow a user to determine whether significant non-stormwater entries are present in a storm drain, and then to identify the particular source, as an aid to the ultimate location of the source.

METHODS FOR DETECTION OF INNAPROPRIATE DISCHARGES TO STORM DRAINAGE SYSTEMS

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MAPPING

Map with location of the outfalls	Excel File
Description sites 1 to 9	Excel File
Description sites 10 to 19	Excel File
Description sites 20 to 29	Excel File
Description sites 30 to 39	Excel File
Description sites 40 to 49	Excel File

Description sites 50 to 59	Excel File
Description sites 60 to 69	Excel File
Description sites 70 to 77	Excel File

SURVEY

Outfall Diameters and Materials	Excel File
Sample parameters	Excel File

TRACERS

HORIBA MULTIPARAMETER	Pictures
IDEXX	Pictures
FLUOROMETER	Pictures

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November 2001

METHODS FOR DETECTION OF INAPROPRIATE DISCHARGES TO STORM DRAINAGE SYSTEMS

Background Literature and Summary of Findings

by

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Notice

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Foreward

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Abstract

A number of past projects have found that dry-weather flows discharging from storm drainage systems can contribute significant pollutant loadings to receiving waters. If these loadings are ignored (by only considering wet-weather stormwater runoff, for example), little improvement in receiving water conditions may occur with many stormwater control programs. These dry-weather flows may originate from many sources, the most important sources may include sanitary wastewater or industrial and commercial pollutant entries, failing septic tank systems, and vehicle maintenance activities. After identification of the outfalls that are affected by polluted dry-weather flows, additional survey activities are needed to locate and correct the non-stormwater entries into the storm drainage systems.

This report contains background information for the design and conduct of local investigations of non-stormwater entries into storm drainage systems. It also includes details associated with the development of the previously published User's Guide (Pitt, *et. al*, 1993) along with a description and the results of the later field verification study. In addition, the evaluation of numerous field and laboratory procedures is also presented, along with a review of emerging technologies that may be useful during future investigations. This is the first phase of a three year project. Future project activities will include summarizing the efforts that various communities have used to meet the inappropriate discharge investigation requirements contained in the Phase I NPDES stormwater permit program, and will present a recommended procedures for Phase II communities.

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Acknowledgments

This report contains information that has been developed and tested in a number of separate research reports investigating inappropriate pollutant entries, or discharges, into storm drainage systems. Many case studies were reviewed during early parts of this research to identify the most appropriate methods of investigation. Information that was obtained from these cities is gratefully acknowledged.

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A006205

Section 1
Introduction

Overview

Current interest in illicit or inappropriate connections to storm drainage systems is an outgrowth of investigations into the larger problem of determining the role urban stormwater runoff plays as a contributor to receiving water quality problems. Urban stormwater runoff is traditionally defined as that portion of precipitation which drains from city surfaces exposed to precipitation and flows via natural or man-made drainage systems into receiving waters. Urban stormwater runoff also includes waters from many other sources which find their way into storm drainage systems. For example, Montoya (1987) found that slightly less than half the water discharged from Sacramento's stormwater drainage system was not directly attributable to precipitation. Sources of some of this water can be identified and accounted for by examining current NPDES (National Pollutant Discharge Elimination System) permit records, for permitted industrial wastewaters that can be discharged to the storm drainage system. However, most of the water comes from other sources, including illicit and/or inappropriate entries to the storm drainage system. These entries can account for a significant amount of the pollutants discharged from storm sewerage systems (Pitt and McLean 1986).

The U. S. Environmental Protection Agency's Office of Research and Development's Storm and Combined Sewer Pollution Control Program and the Environmental Engineering & Technology Demonstration Branch, along with the Office of Water's Nonpoint Source Branch, have supported the development of this research for the investigation of inappropriate entries to storm drainage systems. This report is designed to provide information and guidance to local agencies by meeting the following objectives:

1. Identify and describe the most common potential sources of non-stormwater pollutant entries into storm drainage systems.
2. Describe an investigative procedure that will allow a user to determine whether significant non-stormwater entries are present in a storm drain, and then to identify the particular source, as an aid to the ultimate location of the source.

This research identified three categories of non-stormwater outfall discharges: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water. The most important category is for outfalls contributing pathogens or toxicants. The most likely sources for this category are sanitary or industrial wastewaters. The outfall analyses should have a high probability of identifying all of the outfalls in this most critical category. High probabilities of detection of other contaminated outfalls are also likely when using these procedures. After identification of the contaminated outfalls, their associated drainage areas are then subjected to a detailed source identification investigation. The identified pollutant sources are then corrected.

Section 402 (p)(3)(B)(ii) of the 1987 reenactment of the federal Clean Water Act requires that National Pollutant Discharge Elimination System (NPDES) permits for municipal separate storm sewers shall include a requirement to effectively prohibit problematic non-stormwater discharges into storm sewers. This research report can be used by local governments to evaluate and help locate these non-stormwater discharges.

This report includes a brief summary of the magnitude of the problems that may be associated with dry-weather flows discharged from separate storm sewer systems. It also discusses the potential sources and associated characteristics of these flows from a variety of land use activities. This source flow information is then used to present a method to investigate and evaluate the potential contributions of these sources, based on dry-weather flow observations.

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Procedures to statistically describe the likelihood and magnitude of the potential flow components are also presented, along with statistically based procedures to help in the selection of the analysis methodology. A large-scale demonstration of these procedures, carried out in Birmingham, Alabama, is also described in this report.

Many of the proposed methods are based on the experiences of a number of non-stormwater flow investigations conducted in many locations throughout North America. However, the specific techniques that should be used at any location should be strongly based on local conditions, especially the characteristics of potential non-stormwater flow components and the land uses in the watershed areas served by the storm sewer outfalls under investigation.

Background

Urban stormwater runoff has been shown to contain many pollutants. There are cases where pollutant levels in storm drainage are much higher than they would otherwise be because of excessive amounts of contaminants that are introduced into the storm drainage system by various non-stormwater discharges. Additionally, baseflows (during dry weather) are also common in storm drainage systems. In many cases, these baseflows have also been found to be contaminated and responsible for the majority of the annual pollutant emissions from urban storm drainage systems.

Provisions of the Clean Water Act (1987) require National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges. Section 402 (p)(3)(B)(ii) requires that permits for municipal separate storm sewers shall include a requirement to effectively prohibit problematic non-stormwater discharges into storm sewers. Emphasis will therefore be placed on the elimination of inappropriate connections to urban storm drains. This will require affected agencies to identify and locate any sources of non-stormwater discharges into storm drains so they may institute appropriate actions for their elimination.

Direct sources of non-stormwater discharges usually involve physical sanitary or industrial piping hookups to storm drainage systems. These non-stormwater discharges into storm drainage systems are for the most part, unauthorized and illicit. They will usually (but not always) result in continuous flows into the storm drainage system. They can originate from private homes, apartment buildings, commercial, industrial, or institutional establishments.

Indirect non-stormwater discharge sources in some cases may be authorized. They may be continuous or intermittent. Examples would include sources, conditions or activities that result in elevated levels of contaminants either on the ground surface or in the groundwater. Surface washoff during storms, washing down of surfaces (such as following small spills or during general maintenance clean-up), or subsurface infiltration, introduces the contaminants into the storm drainage systems.

Discharges from storm drain outfalls can be a combination of dry-weather base flows; stormwater runoff; snowmelt water; intermittent discharges of debris, wash-waters, and other waste materials into storm drains; and the relatively continuous discharges of sanitary and industrial cross-connected wastes. These discharges include stormwater that contains the washoff of pollutants from all land surfaces during rains, including washoff of pollutants from areas such as industrial material and waste storage areas, gas station service areas, parking lots, and other industrial and commercial areas, etc. Therefore, the quality of urban runoff can vary greatly with time (dry versus wet-weather, cold versus warm weather, etc.) and location.

The discharge of sanitary and industrial wastes into storm drainage can lead to serious water pollution problems. In many cases, urban receiving waters are badly polluted by stormwater alone, without additional pollutant loadings associated with sanitary or industrial non-stormwater discharges into the storm drainage system. The addition of sanitary wastes increases the concentrations of oxygen-demanding organic solids and nutrients, and increases the number of pathogenic microorganisms in the storm-induced discharge. Industrial wastes can be highly variable, but can substantially increase the concentrations of many filterable heavy metals in runoff, as an example. In many cases, annual discharge loadings from stormwater outfalls can be greatly affected by dry-weather discharges.

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Recognition of Urban Runoff as an Important Source of Pollutants

Historically, concern with urban runoff has focused primarily on flooding. With urban development came an increase in land area made impervious to rain as a result of paving, building, soil compaction and the like. This increased the volume of runoff from any given storm event as well as the rate of flow. These factors often have had a decided effect on flooding and erosion rates. For this reason, quantity considerations with regard to urban runoff have been and continue to be a principal concern.

In recent years, however, concern over the role of urban runoff as a contributor to receiving water quality problems has increased. As point source discharges have been increasingly brought under control, the role of nonpoint sources of pollutants (including urban runoff) as potential contributors to water quality degradation has become more apparent. Areawide Water Quality Management Agencies, established as a result of Section 208 of the 1972 Federal Water Pollution Control Amendments, were among the first to call attention to water quality problems associated with non-point sources.

In 1973, the Council on Environmental Quality published a report entitled, "Total Urban Pollutant Loads: Sources and Abatement Strategies." The primary conclusion of this report was that much pollution was caused by urban runoff and that, unless this issue was addressed, the goals of the 1972 Federal Water Pollution Control Act Amendments would not be met (EPA 1983). Examples cited included an EPA study conducted in 1971 in Atlanta, Georgia, which determined that 64 percent of the BOD loading to local streams came from separate storm sewers, 19 percent from combined sewers, and 17 percent from treatment plants.

In spite of this, the Clean Water Act of 1977 (P.L. 95-217) deleted federal funding for the treatment of separate stormwater discharges. Reasons given centered on uncertainties associated with the local nature and extent of urban runoff water quality problems, the effectiveness of possible management and control measures, and their affordability in terms of benefits to be derived. Congress stated that there was simply not enough known about urban runoff loads, impacts, and controls to warrant making major investments in physical control systems (Congressional Quarterly Almanac 1976).

EPA Headquarters then reviewed the results of work on urban runoff by the technical community and various agencies and determined that additional (and more consistent) data were needed. The Nationwide Urban Runoff Program (NURP) was created to provide a better understanding of the nature of urban runoff.

The Nationwide Urban Runoff Program–

The Nationwide Urban Runoff Program (NURP) included 28 projects across the nation, conducted separately at the local level but centrally reviewed, coordinated and guided. The overall objective of the program was to provide credible information regarding urban runoff mechanisms, problems and controls on which to base decisions. The NURP was designed to simply provide a support function to local water quality planning efforts, the results of which would be of value to planning efforts elsewhere (EPA 1983). Data from the various NURP projects allowed many issues to be addressed at a national level. These included topics described in the program's overall objective such as "quantifying the characteristics of urban runoff, assessing the water quality effects on receiving water bodies attributable to urban runoff discharges, and examining the effectiveness of control practices in removing the pollutants found in urban runoff." Unfortunately, only the first and last objectives were really addressed, and produced mixed results (Pitt 1991).

A number of other issues emerged from the individual NURP projects. One of these issues involved illicit connections to storm drainage systems and was summarized as follows in the Final Report of the NURP executive summary: "A number of the NURP projects identified what appeared to be illicit connections of sanitary discharges to stormwater sewer systems, resulting in high bacterial counts and dangers to public health. The costs and complications of locating and eliminating such connections may pose a substantial problem in urban areas, but the opportunities for dramatic improvement in the quality of urban stormwater discharges certainly exist where this can be accomplished. Although not emphasized in the NURP effort, other than to assure that the selected monitoring

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sites were free from sanitary sewage contamination, this BMP (Best Management Practice) is clearly a desirable one to pursue" (EPA 1983).

The illicit discharges noted during NURP were especially surprising, because the monitored watersheds were carefully selected to minimize factors other than stormwater. Presumably, illicit discharge problems in typical watersheds would be much worse.

Role of Dry-weather Flows in Urban Stormwater Runoff Analyses

The EPA's NURP studies highlighted the significance of pollutants from illicit entries into urban storm sewerage (EPA 1983). Such entries may be evidenced by flow from storm sewer outfalls following substantial dry periods. Such flow, frequently referred to as "baseflow" or "dry-weather flow", could be the result of direct "illicit connections" as mentioned in the NURP final report (EPA 1983), or could result from indirect connections (such as leaky sanitary sewerage contributions through infiltration). Many of these dry-weather flows are continuous and would therefore also occur during rain induced runoff periods. Pollutant contributions from the dry-weather flows in some storm drains have been shown to be high enough to significantly degrade water quality because of their substantial contributions to the annual mass pollutant loadings to receiving waters.

Dry-weather flows and wet-weather flows have been monitored during several urban runoff studies. These studies have found that discharges observed at outfalls during dry weather were significantly different from wet-weather discharges. Data collected during the 1984 Toronto Area Watershed Management Strategy Study (TAWMSS) monitored and characterized both stormwater and baseflows (Pitt and McLean 1986). This project involved intensive monitoring in two test areas (one a mixed residential and commercial area, and another that was an industrial area) during both warm and cold weather and during both wet and dry weather. The annual mass discharges of many pollutants were found to be dominated by dry-weather processes.

During the mid-1980s, several individual municipalities and urban counties initiated studies to identify and correct illicit connections to their storm drain systems. This action was usually taken in response to receiving water quality problems or information noted during individual NURP projects. Data from these studies indicate the magnitude of the cross-connection problem in many urban areas. From 1984 to 1986, Washtenaw County, Michigan, dye-tested 160 businesses in an effort to locate direct illicit connections to the county stormwater sewerage. Of the businesses tested, 61 (38%) were found to have improper storm drain connections (Schmidt and Spencer 1986). An investigation of outfalls from the separate storm sewer system in Toronto, Canada revealed 59% with dry-weather flows. Of these, 84 (14% of the total outfalls) were identified as grossly polluted, based on the results of a battery of chemical tests (GLA 1983). In 1987, an inspection of the 90 urban stormwater outfalls draining into Inner Grays Harbor in Washington (Pelletier and Determan 1988) revealed 29 (32%) flowing during dry weather. A total of 19 outfalls (21%) were described as suspect, based on visual observation and/or anomalous pollutant levels as compared to those expected in typical urban stormwater runoff characterized by NURP.

The Huron River Pollution Abatement Program was the most thorough investigation of such improper connections. Beginning in 1987, 1067 businesses, homes and other buildings located in the Huron River watershed were dye tested. The following results were reported. Illicit connections were detected at 60% of the automobile related businesses inspected, including service stations, automobile dealerships, car washes, and auto body and repair shops. All plating shops inspected were found to have improper storm drain connections. Additionally, 67% of the manufacturers tested, 20% of the private service agencies, and 88% of the wholesale/retail establishments tested were found to have improper storm sewer connections. Of 319 homes dye tested, 19 were found to have direct sanitary connections to storm drains. The direct discharge of rug cleaning wastes into storm drains by carpet cleaners was also noted as a common problem. (Washtenaw County 1988).

A Sacramento, California, investigation of urban discharges (1985) identified commercial as well as domestic discharges of oil and other automobile related fluids as a common problem based on visual observations. Visual inspection of stormwater pipes discharging to the Rideau River (Ontario) found leakage from sanitary sewer joints or broken pipes to be a major source of storm drain contamination (Rideau River 1983).

A006209

Castro Valley Creek, Alameda County, California, Nationwide Urban Runoff Program Project–
In 1981, the two year San Francisco Bay Area National Urban Runoff Project was completed (Pitt and Shawley 1982). Information was collected from an urban station (Knox) on the Castro Valley Creek branch of the Castro Valley watershed. Land use in the 268 ha urban area consisted of single family dwellings (70%), commercial use (7%), open space and institutional land use (23%).

Table 1 shows median concentrations of constituents observed in the baseflow and stormwater runoff from this catchment. Obvious differences in water types were found. During baseflows, the water was quite hard and major components included calcium, sodium, chloride, sulfate, and magnesium. Total solids was high as a result of high concentrations of dissolved solids. During storm runoff conditions, the water became noticeably softer and suspended solids and chemical oxygen demand became much more important. In addition, almost all of the heavy metals were significantly greater in concentration during storm runoff, as compared to baseflow conditions. Mercury was an exception, occurring at higher levels in the baseflow.

Table 2 compares annual yields from baseflow and storm runoff. Significant portions of the major ions, alkalinity, hardness and total dissolved solids annual yields were associated with the baseflow. However, the runoff portion of the total annual yield accounted for practically all of the heavy metals, nutrients, suspended solids and organics. Baseflows accounted for approximately 88% of the flow duration and 10% of the total runoff during the monitoring period.

The rainy season in the San Francisco Bay area extends from November to April. Most of the pollutant yields associated with both baseflow and storm runoff occurred during these rainy winter months. Approximately 25% of the total annual baseflow yield occurred during February, while less than 10% occurred during each of the summer months. One third of the annual storm yield occurred in February, and less than 1% in each of the summer months.

Bellevue, Washington, Nationwide Urban Runoff Program Project–
During the Bellevue, Washington Urban Runoff Project (Pitt 1984; Pitt and Bissonnette 1984) baseflows as well as stormwater from two residential urban basins were monitored. The areas included in this study, Surrey Downs and Lake Hills, are about 5 km apart and each covered an area of about 40 ha. Both were fully developed, with predominantly single family residences. No septic tanks were present in either area and the storm drainage systems were thoroughly mapped and investigated to ensure no non-stormwater discharges to storm drainage systems or obvious illegal discharges.

Much runoff quality data was collected during this project. Samples were collected using automatic samplers on a time-sampling mode for baseflows and on a flow-weighted mode for stormwater. Table 3 summarizes the stormwater data. Average, minimum and maximum values for the water quality constituents, along with the flow and rain volumes, are shown for the study period.

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TABLE 1. MEDIAN BASEFLOW AND STORMWATER CONTAMINANT CONCENTRATIONS OBSERVED IN CASTRO VALLEY (MG/L UNLESS NOTED)

	Baseflow	Stormwater
Total solids	1170	306
Total dissolved solids (TDS)	1060	117
Suspended solids (SS)	1	216
Volatile suspended solids (VSS)	1	46
Total alk., as $CaCO_3$	260	42
Non-carb. hardness, as $CaCO_3$	300	21
Total hardness, as $CaCO_3$	550	62
Calcium (diss)	95	15
Magnesium (diss)	70	6.4
Potassium (diss)	3.5	1.7
Sodium (diss)	150	14
Chloride(diss)	290	18
Sulfate (diss)	230	22
COD	32	80
Total N	2.6	2.9
Organic N	0.8	1.6
Total Kjeldahl N	1.1	1.8
Ammonia as N	0.05	0.06
Nitrites and Nitrates as N	1.4	1.1
Total P	0.32	0.39
Diss. Ortho-phosphates, as PO_4	0.71	0.46
Arsenic (µg/L)	2	5
Cadmium (µg/L)	0	1
Chromium (µg/L)	2	10
Copper (µg/L)	0	44
Iron (µg/L)	270	8000
Lead (µg/L)	8	300
Mercury (µg/L)	0.3	0.2
Nickel (µg/L)	0	0
Zinc (µg/L)	70	210

Source: Pitt and Shawley 1982

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TABLE 2. CASTRO VALLEY URBAN BASEFLOW AND STORM RUNOFF ANNUAL YIELDS COMPARED

	Annual Urban Baseflow Total (lbs/acre/yr)	Annual Urban Storm Runoff Total (lbs/acre/yr)	Total Urban Runoff and Urban Baseflow (lbs/acre/yr)	Percentage of Total Urban Yield Due to Runoff Only (%)
Total Alk., as $CaCO_3$	45	70	120	60%
Non-carbonate hardness, as $CaCO_3$	50	30	80	40
Total hardness, as $CaCO_3$	95	100	200	50
Calcium, diss.	20	30	50	60
Magnesium, diss.	10	10	20	50
Potassium, diss.	0.6	3	4	75
Sodium, diss.	30	20	50	40
Chloride, diss.	50	25	75	30
Sulfate, diss.	35	30	70	40
Total Solids	200	600	800	75
Total Dissolved Solids (TDS)	190	200	400	50
Suspended Solids (SS)	1.4	300	300	100
Volatile Suspended Solids (VSS)	0.14	70	70	100
COD	6.5	150	160	90
Total Nitrogen	0.7	5	6	80
Organic Nitrogen	0.1	5	5	100
Total Kjeldahl Nitrogen	0.2	3.5	3.7	95
Ammonia, as N	0.05	0.2	0.3	70
Nitrites plus Nitrates, as N	0.5	3	3	100
Total Phosphorus	0.04	1	1	100
Dissolved Ortho-Phosphates as PO_4	0.1	2	2	100
Arsenic	0.0005	0.01	0.01	100
Cadium	0.00008	0.01	0.01	100
Chromium	0.00007	0.014	0.014	100
Copper	0.003	0.1	0.1	100
Iron	0.06	7	7	100
Lead	0.0065	0.6	0.6	100
Mercury	0.0002	0.001	0.001	100
Nickel	0	0.05	0.05	100
Zinc	0.014	0.5	0.5	100
Flow	0.8 inches	7.5 inches	8.3 inches	90

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Source: Pitt and Shawley 1982

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TABLE 3. STORMWATER RUNOFF QUALITY FOR BELLEVUE SITES
(TOTAL STORM FLOW-WEIGHTED COMPOSITES; mg/L, UNLESS OTHERWISE NOTED)

	Lake Hills (99 samples)			Surrey Downs (107 samples)		
Constituent:	min.	max	average	min	max	average
Runoff volume (ft^3)	1,210	223,000	39,650	1,260	401,000	36,100
Rain (in.)	0.04	1.58	0.40	0.04	4.38	0.49
Total solids	24	440	104	29	620	113
TKN	<0.5	5.9	1.0	<0.5	4.3	1.1
COD	13	120	42	15	150	34
Total phosphorus	0.015	3.6	0.27	0.002	1.2	0.24
Lead	<0.1	0.56	0.17	<0.1	0.82	0.17
Zinc	0.03	0.29	0.11	0.05	0.37	0.13
pH (pH units)	5.2	7.1	6.2	5.2	7.4	6.4
Specific conductance (µmhos/cm)	17	140	37	16	300	45
Turbidity (NTU)	6	150	22	4	67	16

Source: Pitt 1984

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Baseflow samples were collected about once a month during the second year of the project. Table 4 summarizes the baseflow observations at the two sampling sites. The observed baseflow concentrations of COD, TKN, total phosphorus, lead, and zinc were about the same as those found in storm runoff. However, the baseflow total solids and specific conductance values were much greater than observed in the storm runoff.

The total solids during storm runoff events was mostly nonfilterable (suspended solids), while the total solids during baseflow conditions was mostly dissolved solids. The similarities in baseflow and storm runoff nutrient and heavy metal concentrations was surprising. In other areas (especially at the Castro Valley NURP site; Pitt and Shawley, 1982) the baseflow metal and nutrient concentrations were much less than the storm runoff concentrations. However, the Castro Valley baseflow dissolved solids, specific conductance, and major ion concentrations were all much greater than observed in the storm runoff. In Castro Valley, this implied that the baseflow was mostly associated with discharging groundwater that originated in non-urban areas above the study site. At the two Bellevue sites, however, the complete basins are urbanized and the groundwater that discharged into the storm drainage systems between rain events was much more contaminated than the rural groundwater discharges observed at Castro Valley.

An important amount of the total flows in both of the Bellevue test basins occurred between rains as baseflows. This was especially true during the dry months of the year (March to September). The winter months contributed most of the urban runoff flows. Average October, November, and December flows for the study period contributed about half of the total annual runoff flows observed. December through March contributed more than half of the baseflows. Generally, the baseflows were highest in those months also having high storm runoff flows. August was the driest month, with less than two percent of the annual urban runoff flow. The baseflow in the Surrey Downs basin accounted for about 25% of the total volume of urban flow, while baseflow in Lake Hills made up about 12% of the total. Baseflows alone accounted for approximately 87% of the flow duration in each area. Therefore, stormwater flows affected the total urban flow only about 13% of the time.

Table 5 summarizes the annual mass yields for baseflow and stormwater runoff in the study areas. Between 15 and 20 percent of the annual mass yields were contributed in both November and December while the summer months, May though August, each contributed only about 5 percent. A larger fraction of the total urban runoff in Surrey Downs occurred as baseflow between rain events. The runoff events in Lake Hills were more sharply defined, and the baseflows made up a much smaller fraction of the mass yields for urban runoff.

The estimated annual mass yields of the urban pollutants expressed in pounds per acre per year are similar to those reported in Castro Valley, California (Pitt and Shawley, 1982). The much smaller urban runoff pollutant concentrations observed in Bellevue when compared to Castro Valley is compensated for by the much larger amount of runoff that occurred.

The Bellevue, Washington, NURP project also summarized the reported incidents of intermittent discharges and dumpings of pollutants into the local storm drainage system. During a three year period of time, about 50 citizen contacts were made to the Bellevue Storm and Surface Water Utility District concerning water quality problems. About 25 percent of the complaints concerned oil being discharged into storm drain inlets. Another important category of complaints was for aesthetic problems, such as turbid or colored water in the creeks. Various industrial and commercial discharges into the storm drainage system were detected. Concrete wastes flushed from concrete trucks at urban job sites were a frequently occurring problem. Cleaning establishment discharges into creeks were also a common problem. Vehicle accidents also resulted in discharges of gasoline, diesel fuel, hydraulic fluids, and lawn care chemicals into the storm drain inlets.

Toronto, Ontario, Humber River Test Watershed Monitoring--

The 1984 Toronto Area Watershed Management Strategy Study (TAWMSS) monitored and characterized both stormwater and baseflows (Pitt and McLean 1986). The project involved intensive monitoring in two test areas. The Emery catchment area, located near the City of North York, covered approximately 154 ha with predominantly "medium" industrial land uses (processing goods for final consumption). The Thistledown catchment, located in the City of Etobicoke, covered approximately 39 ha with residential and commercial land uses.

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TABLE 4. BELLEVUE BASEFLOW WATER QUALITY
(24-HR. TIME-COMPOSITES; mg/L, UNLESS OTHERWISE NOTED)

	Lake Hills (13 samples)			Surrey Downs (13 samples)		
Constituent:	min.	max	average	min	max	average
Total solids	108	326	210	130	226	193
COD	9.1	67	27	6.8	45	19
TKN	0.20	1.9	0.56	0.34	2.4	1.0
Total phosphorus	0.027	0.22	0.11	0.034	1.2	0.20
Lead	<0.1	0.1	<0.1	<0.1	0.1	<0.1
Zinc	0.03	0.14	0.073	0.026	0.47	0.10
Specific conductance (μmhos/cm)	138	430	270	146	300	240

Source: Pitt 1984

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TABLE 5. ANNUAL BELLEVUE MASS YIELDS FOR BASEFLOW AND STORMWATER RUNOFF (kg/ha)

	Surrey Downs			Lake Hills		
Constituent:	Base Flow	Storm Runoff	Total	Base Flow	Storm Runoff	Total
Total solids	110	205	315	76	280	360
COD	11	90	100	9.9	110	120
Total Kjeldahl nitrogen	0.60	1.8	2.4	0.20	2.7	2.9
Total phosphorus	0.11	0.40	0.51	0.04	0.69	0.73
Lead	0.03	0.26	0.29	0.02	0.45	0.47
Zinc	0.06	0.24	0.30	0.027	0.31	0.34

Source: Pitt 1984

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Table 6 shows median concentrations of some of the pollutants monitored. Baseflows from the residential catchment had surprisingly high concentrations of several pollutants including dissolved solids, pesticides, and fecal coliform bacteria, while the industrial area had dry-weather flows that had high concentrations of organic and metallic toxicants.

During cold weather, the increases in dissolved solids were quite apparent in baseflows and snowmelt for both study catchments. This increase was probably caused by high chlorides from road salt applications. In contrast, bacteria populations were noticeably lower in all outfall discharges during cold weather. Nutrient and heavy metal concentrations at the outfalls remained fairly constant during cold and warm weather.

Table 7 compares the estimated annual discharges from the residential and industrial catchments during the different runoff periods. Warm weather baseflows accounted for more than 70% of the flow duration and about 40% of the runoff volume during the monitoring period. The unit area annual yields for many of the heavy metals and nutrients were greater from the industrial catchment. The industrial catchment contributed most of the chromium to the local receiving water, and approximately equal amounts with the residential and commercial catchment for phosphorus, TOC, copper, and zinc. This table also shows the great importance of warm-weather baseflow discharges to the annual urban runoff pollutant yields. Cold-weather bacteria discharges were insignificant when compared to the warm weather bacteria discharges, but chloride (and dissolved solids) loadings were much more important during cold weather.

Annual yields of several constituents were dominated by cold-weather processes, irrespective of the land use monitored. These constituents included total solids, dissolved solids, chlorides, ammonia nitrogen, and phenolics. The only constituents for which total annual yields were dominated by warm weather processes, irrespective of land use, were bacteria and chromium. Lead and zinc were both dominated by either stormwater or snowmelt runoff, with lower yields of these heavy metals occurring during baseflows.

Either warm- or cold-weather baseflows were responsible for most of the yields for many constituents from the industrial catchment. These constituents included runoff volume, phosphorus, total Kjeldahl nitrogen, chemical oxygen demand and chromium. Important constituents that had high yields in the baseflow from the residential/commercial catchment included total solids, dissolved solids, chlorides, and fecal coliform and pseudomonas aeruginosa bacteria.

A few samples were analyzed for pesticides and PCB's. Industrial stormwater and baseflows typically contained much greater concentrations of these pollutants than the residential waters, however, dieldrin levels seemed to indicate a potential problem in the residential catchment.

Gartner Lee and Associates, Ltd. (GLA 1983) conducted an extensive survey of dry-weather flows in storm drainage systems in the Humber River watershed (Toronto) in an attempt to identify the most significant urban runoff pollutant sources. About 625 outfalls were sampled two times during dry-weather, with analyses conducted for many pollutants, including organics, solids, nutrients, metals, phenols, and bacteria. About 1/3 of the outfalls were discharging at rates greater than 1 L/sec. The dry-weather flows were found to contribute significant loadings of nutrients, phenols, and metals, compared to upstream conditions. About 10 percent of the outfalls were considered significant pollutant sources. Further investigations identified many industrial and sanitary sewage non-stormwater discharges into the storm drainage. An apartment building with the sanitary drains from eight units illegally connected to the storm drainage system was typical of the problems found. Other problem areas were found in industrial areas, including yard storage of animal hides and yard runoff from meat packing plants.

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TABLE 6. MEDIAN CONCENTRATIONS OBSERVED (mg/L) FOR SEVERAL CONSTITUTENTS MONITORED IN TORONTO

Constituent	Warm Weather Baseflow		Warm Weather Stormwater	
	Residential	Industrial	Residential	Industrial
Total Solids	979	554	256	371
Total Dissolved Solids	973	454	230	208
Suspended Solids	<5	43	22	117
Total Phosphorus	0.09	0.73	0.28	0.75
Total Kjeldahl N	0.9	2.4	2.5	2.0
Phenolics (µg/L)	<1.5	2.0	1.2	5.1
COD	22	108	55	106
Fecal Coliforms (#/100mL)	33,000	7,000	40,000	49,000
Fecal Strep (#/100mL)	2,300	8,800	20,000	39,000
Chromium	<0.06	0.42	<0.06	0.32
Copper	0.02	0.045	0.03	0.06
Lead	<0.04	<0.04	<0.06	0.08
Zinc	0.04	0.18	0.06	0.19

Constituent	Cold Weather Baseflow		Cold Weather Melting Periods	
	Residential	Industrial	Residential	Industrial
Total Solids	2,230	1,080	1,580	1,340
Total Dissolved Solids	2,210	1,020	1,530	1,240
Suspended Solids	21	50	30	95
Total Phosphorus	0.18	0.34	0.23	0.50
Total Kjeldahl N	1.4	2.0	1.7	2.5
Phenolics (µg/L)	2.0	7.3	2.5	15.0
COD	48	68	40	94
Fecal Coliforms (#/100mL)	9,800	400	2,320	300
Fecal Strep (#/100mL)	1,400	2,400	1,900	2,500
Chromium	<0.01	0.24	<0.01	0.35
Copper	0.015	0.04	0.04	0.07
Lead	<0.06	<0.04	0.09	0.08
Zinc	0.065	0.15	0.12	0.31

Source: Pitt and McLean 1986

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TABLE 7. ESTIMATED ANNUAL DISCHARGES FOR TORONTO

		Thistledown (Residential/Commercial)					Emery (Industrial)					approx indus./ resid total yield ratios	weighted indus. resid. total yield ratios[1]
		warm		cold			warm		cold				
Constituent	(units)	base flow	storm water	base flow	melt water	approx. total	base flow	storm water	base flow	melt water	approx. total		
Runoff volume	M^3/ha	1700	950	1100	1800	5600	2100	1500	660	830	5,100	0.9	0.3
Total solids	kg/ha	1700	240	2400	1700	6100	110	670	710	1500	4,000	0.7	0.2
Chlorides	kg/ha	480	33	1200	720	2400	160	26	310	700	1,200	0.5	0.2
Total phosphorus	g/ha	150	290	200	570	1200	1500	1300	220	540	3,600	3.0	1.0
Total Kjeldahl N	g/ha	1500	2800	1500	3500	9300	4900	3400	1300	2800	12,000	1.3	0.4
Phenolics	g/ha	<2.6	1.2	2.3	23	26	4.1	8.1	4.8	14	31	1.2	0.4
COD	kg/ha	38	51	52	130	270	220	170	45	91	530	2.0	0.7
Chromium	g/ha	<100	21	<10	15	36	860	600	160	290	1,900	50	18
Copper	g/ha	35	30	16	77	160	92	120	26	76	310	1.9	0.7
Lead	g/ha	<70	41	<70	170	210	<75	170	<25	150	320	1.5	0.5
Zinc	g/ha	70	74	70	270	480	370	430	100	350	1,200	2.5	0.8
Fecal Coliform Bact.	10 org/ha	560	480	110	62	1200	144	760	3	6	910	0.8	0.3

"Warm weather" is for the period from about March 15 through December 15, while "cold weather" is the period from about December 15 through March 15.

(1) If basin is 25% Industrial and 75% Residential and commerical.

Source: Pitt and McLean 1986.

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Current Legislation

With additional data available, the Water Quality Act of 1987 contained provisions specifically addressing discharges from storm drainage systems. Section 402(p)(3)(B) provides that "permits for such discharges:

(i) May be issued on a system or jurisdiction-wide basis

(ii) Shall include a requirement to effectively prohibit non-stormwater discharges into the storm sewers: and

(iii) Shall require controls to reduce the discharge of pollutants to the maximum extent practical including management practices, control techniques and system design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants."

In response to these provisions, the EPA issued a final rule to begin implementation of section 402(p) of the Clean Water Act on November 16, 1990. A screening approach which includes chemical testing of dry-weather flow (defined by a 72-hour antecedent dry period) from outfalls or storm sewers, was adopted. The parameters to be tested were a combination of several pollutants of concern and "tracers" that may be used to help identify contaminated outfalls and predict the source of illicit discharges.

Section 122.26 (d)(1)(iv)(D) of the rule applies specifically to this research effort. The EPA required an initial screening program to provide a means of detecting high levels of pollutants in dry weather flows which should serve as indicators of illicit connections to the storm sewers. Minimum requirements were "a narrative description ... of visual observations made during dry weather periods. If any flow is observed, two grab samples shall be collected during a 24-hour period with a minimum period of four hours between samples. For all such samples, a narrative description of the color, odor, turbidity, the presence of an oil sheen or surface scum as well as any other relevant observations regarding the potential presence of non-stormwater discharges or illegal dumping shall be provided. In addition, a narrative description of the results of a field analysis using suitable methods to estimate pH, total chlorine, total copper, total phenol, and detergents (or surfactants) shall be provided, along with a description of the flow rate. Where the field analysis does not involve analytical methods approved under 40 CFR part 136, the applicant shall provide a description of the method used including the name of the manufacturer of the test method along with the range and accuracy of the test."

General Approach to Identify Sources of Inappropriate Discharges

This report presents a methodology that can determine if a storm drain outfall (and drainage system) is affected by pronounced non-stormwater discharges to the storm drainage system. In many cases, the information to be collected following this methodology will also result in a description of the most likely sources of these discharges into the storm drainage.

An investigation of non-stormwater discharges into storm drainage needs to proceed along a hierarchy of procedures and locations; from those areas in a city with the greatest potential, to those with lesser potential; from using exploratory techniques to confirmatory procedures. The methodology presented in this report recognizes that limited resources are available to municipalities and makes maximum use of information typically available.

Many aspects of this methodology were derived from the experience of many municipalities that have previously investigated non-stormwater discharges into storm sewerage. This report contains references to many of these studies, and Appendix C includes brief summaries of several selected case studies. The case study information described identifies situations and techniques used by these agencies in implementing a program to identify the

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presence of non-stormwater discharges into storm drainage systems. When they eliminated the discharge, pertinent details of the implementation program is also described.

The purpose of the investigative procedures presented is to separate storm drain outfalls into three general categories (with a known level of confidence) to identify which outfalls (and drainage areas) need further analyses and investigations. These categories are outfalls affected by non-stormwater discharges from: (1) pathogenic or toxic pollutant sources, (2) nuisance and aquatic life threatening pollutant sources, and (3) unpolluted water sources. The pathogenic and toxic pollutant source category would be considered the most severe and could cause disease upon water contact or consumption and significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially if they contain soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and industrial wastewater non-stormwater discharges. Other residential area sources (besides sanitary wastewater), such as inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides) may also be considered in this most critical category.

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastes, landscaping irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Clean water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic water from water line leaks, etc.

The recommended monitoring approach is separated into three initial phases:

- initial mapping effort,
- initial field surveys, and
- potential confirmatory analyses.

These three initial phases need to be followed by detailed storm drainage and site investigations to identify specific pollutant contributors and control options, as appropriate.

An important requirement of the methodology is that an initial field screening effort would require minimal effort, but would have little chance of missing a seriously contaminated outfall. This screening program would then be followed by a more in-depth analysis to more accurately determine the significance and source of the non-stormwater pollutant discharges.

If industrial and commercial land uses exist within a stormwater drainage area, additional activities are needed to identify the sources in sufficient detail to allow corrective actions. The control strategy must recognize that even with the removal of directly connected non-stormwater discharges to the storm drains, stormwater originating from industrial and commercial land uses will probably continue to convey unacceptable pollutant loads, as noted by Pitt and McLean (1986). The industrial and commercial area control strategy must be flexible enough to provide overall wet- and dry-weather flow control from a site, rather than simply altering piping to correct the obvious direct connections.

Any control strategy needs to take advantage of existing information. As an example, most communities have reasonable knowledge of their sanitary sewers through infiltration/inflow (I/I) and sewer system evaluation survey (SSES) studies. Municipalities also generally have arrangements with local industries through pretreatment and other regulatory programs. However, many industries that may potentially discharge contaminants into storm drains do not have discharges into the city's sanitary sewer systems, nor have their own process water discharges, and would therefore not have likely been historically regulated.

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Figure 1 is a simplified flow chart for the methodology developed during this research. The initial phase of the investigative protocol includes the initial mapping and field surveys. These activities require minimal effort and result in little chance of missing a seriously contaminated outfall. The initial activities are followed by more detailed watershed surveys to locate and correct the sources of the contamination in the identified problem areas. After corrective action has been taken, repeated outfall field surveys are required to ensure that the outfalls remain uncontaminated. Receiving water monitoring should also be conducted to analyze water quality improvements. If expected improvements are not noted, then additional contaminant sources are likely present and additional outfall and watershed surveys are needed.

Development of Investigative Strategy

This project examined three categories of non-stormwater outfall discharges: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water. The most important category is for outfalls contributing pathogens or toxicants. These are most likely originating from sanitary wastewater or industrial non-stormwater discharges to storm drainage systems. The outfall analyses should have a high probability of identifying all of the outfalls in this most critical category for detailed source identification.

Mapping Effort–

The first step of this procedure is an extensive mapping effort to identify the locations of all outfalls for sampling and to outline and characterize the drainage areas contributing to each outfall.

All outfalls need to be evaluated during the screening analysis. It is not sufficient to only map and examine the largest drainage areas, or largest outfalls, as small areas have been found to contribute significant non-stormwater discharges. For example, if commercial (especially automobile service related facilities) and manufacturing industrial areas are present in a drainage area, the probability for serious non-stormwater discharges is significantly increased. Therefore, this mapping effort is a very important part of the investigation as it will locate the outfalls for sampling and will describe the contributing watershed areas.

Outfall Screening Analyses–

The screening analyses at the outfalls include several visual measures (color, turbidity, oil sheens, floatables, coarse solids, etc.) along with measurements for chemical tracers (fluorides, potassium, ammonia, and surfactants). The visual measures have been found during many studies to be very good indicators of serious non-stormwater flow contamination at outfalls. The chemical tracers are needed to identify (and possibly quantify) the general source categories of non-stormwater flows.

Fluorides can be used to indicate if the water originated as treated domestic water (instead of infiltrating untreated groundwater). This may indicate sanitary sewage or other non-stormwater discharges to the drainage system. Surfactants can help in identifying sanitary sewage or wash water connections, in contrast to landscaped area irrigation runoff, rinse waters, or industrial waters. Potassium and ammonia can be very useful in separating the more important sanitary sewage sources from wash waters and other treated water sources. Some of these chemical tracer tests indicate similar sources, but the duplication is needed because of potential interferences and some uncertainty in the tracer concentrations associated with the source flows.

Appropriate analytical methods must be selected before the chemical analyses are made. This selection requires accurate estimates of the tracer concentration characteristics of the potential source flows. The desired contamination level to be detected and the variation of the chemical tracer concentrations expected affect the required detection limit and analytical precision needed.

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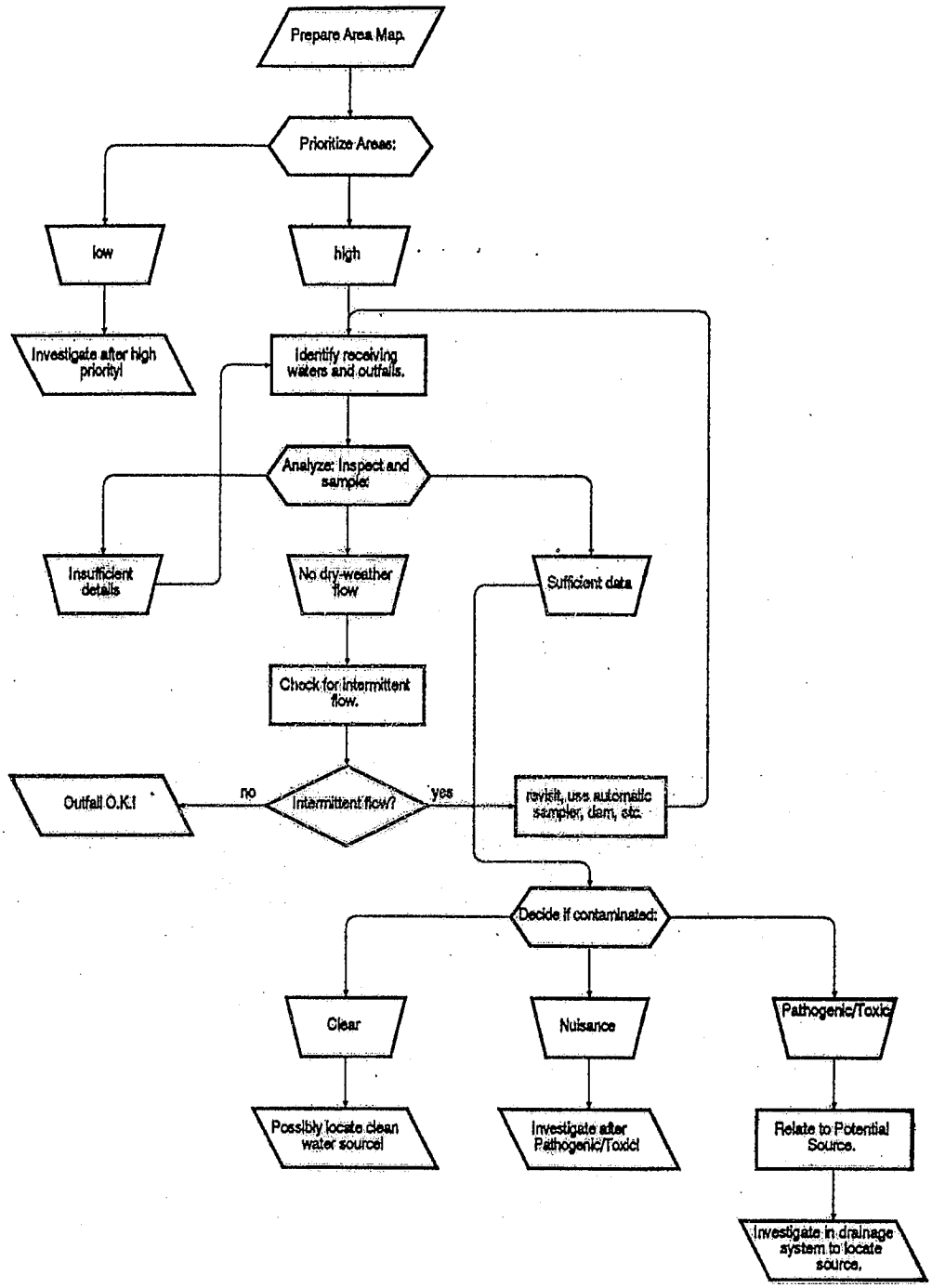

Figure 1. Flow chart for investigative procedures.

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In addition, in order to estimate the source flow contributions affecting an outfall, the potential source flows must also be described with as much detail as possible. If the source flows cannot be described with narrow pollutant concentration ranges, for example, it is difficult to estimate the magnitude of source flow contributions, especially if they make up less than about 20 percent of the outfall flow. However, it is still possible to quantify the certainty that the different source flows are present at the outfall.

Confirmatory Analyses--

More sophisticated analyses are available to confirm and to make more accurate estimates of the potential sources. However, they most likely cannot be frequently employed for all outfall samples because of the high level of analytical skill and expensive equipment required. These analyses may include specific bacteria or biochemicals to examine sanitary sewage sources, for example. Metallic and organic toxicants could also be effectively used when examining problems at industrial and commercial areas.

Follow-up Sewerage and Site Investigations--

After an outfall has been identified as having significant non-stormwater flow sources, certain follow-up investigations are needed to locate the specific source locations and to correct the problem. The first step of these additional investigations would be to continue the same visual and chemical analyses at selected locations along the sewerage.

It may be efficient to divide the main trunk sewer into about ten reaches for these additional tests. Reaches of the sewerage affected by the unwanted sources could then be identified. Branch sewers contributing to the affected main sewer reaches could also be subdivided (into about three sections) for similar analyses. These subdivisions can be continued until relatively small areas of the watershed are isolated as contributors of important non-stormwater discharges. Establishments within these isolated areas would then be individually evaluated by inspecting all possible direct connections to the storm sewerage, inspecting all floor and yard drains, etc. Situations that would produce unusual wet-weather pollutant sources (such as material and equipment storage areas) also need to be identified for mitigation. When problems are found, the site owners need to be informed and required to make corrections.

Recommendations

This report should be used as part of a comprehensive stormwater management plan which addresses all sources of stormwater pollution. Correction of pollutant entries identified by use of only this report is unlikely to achieve a significant improvement in the quality of stormwater discharges or receiving waters. Similarly, if only wet-weather stormwater discharges are mitigated, inappropriate dry-weather discharges may prohibit receiving water beneficial uses from being obtained. An effective urban runoff management program must consider all sources of pollutants.

A municipality will need to plan their investigation of inappropriate entries to a storm drainage system to suit local conditions. The User's Guide (Pitt, *et al.* 1993) describes the issues in sufficient depth and provides examples to enable the design of a local investigation. Greater detail and the results of a comprehensive demonstration of these procedures are given in this report which supplements and incorporates much of the information contained in the User's Guide.

The full use of all of the applicable procedures described in this report is most likely necessary to successfully identify pollutant sources. Attempting to reduce costs, for example by only examining a certain class of outfalls, or using inappropriate testing procedures, will significantly reduce the utility of the testing program and result in inaccurate data. Also cursory data analyses is likely to result in inaccurate conclusions.

During investigations of non-stormwater entries to storm drainage systems, consideration should be given to any economic and practical advantages of designating the storm drainage system as a combined sewer system and applying end-of-pipe combined sewer overflow (CSO) control and treatment.

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It is also recommended that the methodology (appropriately modified) described in this report be applied to other types of sewerage systems, such as combined and separate sanitary sewerage systems, to locate inappropriate entries, e.g. untreated or toxic industrial wastewaters/wastes or infiltration/inflow (I/I) in separate sanitary sewers.

It is recommended that this report be updated and refined by incorporating experience gained in its use. Incorporation of information from a wide variety of test locations (e.g., lake and large river receiving waters, tidal receiving waters, areas experiencing long dry periods, areas having short summers, areas having unusual groundwater characteristics, areas where the stormwater is pumped for discharge, etc.) will improve the testing and data analysis protocols described.

Organization of Report

This report contains several main sections and is supported by appendix material, as appropriate:

1. Introduction
2. Sources of non-stormwater discharges into separate storm drainage systems
3. Initial mapping effort to identify sources of non-stormwater discharges into storm drainage
4. Initial field surveys to identify sources of non-stormwater discharges into storm drainage
5. Selection of parameters for field surveys
6. Selection and evaluation of analytical methods
7. Data analyses to identify problem outfalls and flow components
8. Watershed surveys to confirm and locate inappropriate pollutant entries to the storm drainage system
9. Special considerations for industrial and commercial sources of inappropriate pollutant entries to the storm drainage system
10. Corrective techniques after inappropriate sources are identified
11. Birmingham, Alabama, demonstration study
12. References

Appendix A. Field equipment summary
Appendix B. Statistical plots to determine detection limit requirements
Appendix C. Case studies of non-stormwater discharges into separate storm sewer systems
Appendix D. Village Creek outfall and watershed data for Birmingham demonstration study area
Appendix E. Statistical analyses of data collected during the Birmingham demonstration study
Appendix F. Chemical mass balance model with Monte Carlo simulation
Appendix G. Analyses results for all outfall samples collected during Birmingham demonstration study
Glossary

The main information needed to design a local research project is included in Sections 3 through 8. The strategies are heavily based on information presented in Section 2, a discussion of the potential sources of non-stormwater discharges, including the experience of many municipal investigations of these problems, as presented in Appendix C. The selection of equipment (and indicator parameters) is greatly influenced by many characteristics of the local areas under investigation. Section 11 details the Birmingham demonstration study.

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Section 2

Sources of Non-Stormwater Discharges into Separate Storm Drainage Systems

Potential Dry-Weather Discharge Sources

This report presents a methodology for the identification and location of non-stormwater entries into storm drainage systems. It is important to note that for any effective investigation of pollution within a stormwater system, all pollutant sources must be included. Prior research, as summarized in Section 1, has shown that dry-weather flows may contribute a larger annual discharge mass for many pollutants than stormwater. Significant pollutant sources may include dry-weather entries occurring during both warm and cold months and snowmelt runoff, in addition to conventional stormwater associated with rainfall. Consequently, much less pollution reduction benefit will occur if only stormwater is considered in a control plan for controlling storm drainage discharges. The investigations described in this report may also be used to identify illicit point source outfalls that do not carry stormwater. Obviously, these outfalls also need to be controlled. Table 8 summarizes the potential sources of contaminated entries into storm drainage systems, along with their likely flow characteristics. The following subsections summarize these sources.

Direct Connections to Storm Drains

Direct connections refer to physical connections of sanitary, commercial, or industrial piping carrying untreated or partially treated wastewaters to a separate storm drainage system. These connections are usually unauthorized. They may be intentional, or may be accidental due to mistaken identification of sanitary sewerlines. They represent the most common source of entries to storm drains by industry. Direct connections can result in continuous or intermittent dry-weather entries of contaminants into the storm drain. Some common situations are:

- Sanitary sewers that tie into a storm drain.
- Foundation drains or residential sump-pump discharges that are frequently connected to storm drains. While this practice may be quite appropriate in many cases, it can be a source of contamination when the local groundwater is contaminated, as for example by septic tank failures.
- Commercial laundries and car wash establishments that may route process wastewaters to storm drains rather than sanitary sewers.

Infiltration to Storm Drains

Continuous dry weather flows may be caused by groundwater infiltration into storm drains when the storm sewers are located below the local groundwater table. These continuous discharges generally are not a pollution threat to surface waters, since most ground waters which infiltrate into storm sewers are not contaminated, but these flows will have variable flow rates due to fluctuations in the level of the water table and percolation from rainfall events. Underground potable water main breaks are a potential clean source of releases to storm drains. While such occurrences are not a direct pollution source, they should obviously be corrected. However, when groundwater pollution does occur, such as from leaky underground storage tanks, storm drains may become a method of conveyance for these contaminants to the surface waters. Infiltration into storm drains most commonly occurs through leaking pipe joints and poor connections to catch basins, but can also be due to other causes, such as damaged pipes and subsidence. Storm drains, as well as natural drainage channels, can therefore intercept and convey subsurface groundwater and percolating waters.

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TABLE 8. POTENTIAL INAPPROPRIATE ENTRIES INTO STORM DRAINAGE SYSTEMS

Potential Source:	Storm Drain Entry		Flow Characteristics		Contamination Category		
	Direct	Indirect	Cont-inuous	Inter-mittent	Patho-genic/ Toxic	Nuis-ance	Clear
Residential Areas:							
Sanitary wastewater	X	x	X	x	X		
Septic tank effluent		X	X	x	X		
Household chemicals	x	X		X	X		
Laundry wastewater	X			X		X	
Excess landscaping watering		X		X	x	x	X
Leaking potable water pipes		X	X				X
Commercial Areas:							
Gasoline filling station	X	x		X	X		
Vehicle maintenance/repair	X	x		X	X		
Laundry wastewater	X		X	x	x	X	
Construction site de-watering		X	X	x		X	
Sanitary Wastewater	X	x	X		X		
Industrial Areas (see Section 9):							
Leaking tanks and pipes	x	X	X	x	X		
Many process waters	X	x	X	x	X	x	x

Note: **X**: most likely condition
x: may occur
blank: not very likely

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Groundwater may be contaminated, either in localized areas or on a relatively widespread basis. In cases where infiltration into the storm drains occurs, it can be a source of excessive contaminant levels in the storm drains. Potential sources of groundwater contamination include, but are not limited to:

- Failing or nearby septic tank systems.
- Exfiltration from sanitary sewers in poor repair.
- Leaking underground storage tanks and pipes.
- Landfill seepage.
- Hazardous waste disposal sites.
- Naturally occurring toxicants and pollutants due to surrounding geological or natural environment.

Leaks from underground storage tanks and pipes are a common source of soil and groundwater pollution and may lead to continuously contaminated dry-weather entries. These situations are usually found in commercial operations, such as gasoline service stations, or industries involving the piped transfer of process liquids over long distances and the storage of large quantities of fuel, e.g., petroleum refineries. Pipes that are plugged or collapsed as well, as leaking storage tanks, may cause pollution when they release contaminants underground which can infiltrate through the soil into stormwater pipes.

Residential and Commercial Sources

The most common potential non-stormwater entries, which have been identified by a review of documented case studies for commercial and residential areas, are:

- Sanitary wastewater sources:
  - raw sanitary wastewater from improper sewerage connections, exfiltration, or leakage
  - effluent from improperly operating, designed, or nearby septic tanks

- Automobile maintenance and operation sources:
  - car wash wastewaters
  - radiator flushing wastewater
  - engine de-greasing wastes
  - improper oil disposal
  - leaky underground storage tanks

- Relatively clean sources:
  - lawn runoff from over-watering
  - direct spraying of impervious surfaces
  - infiltrating groundwater
  - water routed from pre-existing springs or streams
  - infiltrating potable water from leaking water mains

- Other sources:
  - laundry wastewaters
  - non-contact cooling water
  - metal plating baths
  - dewatering of construction sites
  - washing of concrete ready-mix trucks
  - sump pump discharges
  - improper disposal of household toxic substances
  - spills from roadway and other accidents

From the above list, sanitary wastewater is the most significant source of bacteria, while automobile maintenance and plating baths are the most significant sources of toxicants. Waste discharges associated with the improper disposal

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of oil and household toxicants tend to be intermittent and low volume. These wastes may therefore not reach the stormwater outfalls unless carried by higher flows from another source, or by stormwater during rains.

Sewage Sources–
Sanitary sewage finds its way into separate storm sewers in a number of ways. Cross-connections may tie sanitary lines directly to storm drains, or seepage from leaking joints and cracked pipes in the sanitary collection system can infiltrate storm sewers. Surface malfunctions and insufficiently treated wastewater from septic tanks may contribute pollutants to separate storm sewers directly or by way of contaminated groundwater infiltration. Seepage of sewage or septic tank effluent (septage) into underground portions of buildings may be pumped into separate storm sewers by sump pumps (EPA 1989).

Table 9 summarizes many characteristics of domestic septage (EPA 1989). Alhajjar, *et al.* (1989) examined concentrations of major ions in septage for households using phosphate- and carbonate-built detergents (Table 10). Also included on these tables are the ranges of the constituent concentrations observed. A variety of organic chemicals, particularly solvents, are part of the formulation of many household products that become part of domestic wastewater. Kolega, *et al.* (1986) examined samples from the septic tank, leaching field and surrounding groundwater monitoring wells of condominium units and a business/residential complex in Monroe and Chester, CT. Their results are presented in Tables 11 and 12.

Raw sanitary sewage differs from the above described septage because it has not undergone any treatment. Tables 13 through 16 describe various characteristics of sanitary sewage. Table 13 shows typical constituent increases in sanitary sewage as compared to tap water. Tables 14 through 16 show concentrations of various pollutants in tub, shower, and washing machine wastewater. Ranges of the concentrations are also shown on these tables. A comprehensive characterization of municipal sewage from residential and commercial sources was carried out in Brussels, Belgium (Verbanck 1989). Though water consumption habits differ in the U.S. and Europe, this study provided additional parameter information not typically available from U.S. studies. Verbanck suggested that an appropriate tracer for sanitary sewage would be one which has physiological contributions as its main source. His work indicated that potassium fell into this category (coming directly from urine), while anthropogenic input explained only a minor part of the load for chloride, sodium, calcium and sulfate and was completely negligible for boron and silica. The occurrence of boron and silica was determined to be associated to a large extent with detergent use. Many detergents contain sodium perborate as a bleaching agent and sodium silicate as a corrosion inhibitor and building agent. Phosphate, sulfate, and bicarbonate are also common constituents of many detergent formulations, and occurrences will vary significantly with the choice of detergent (Alhajjar, *et al.* 1989).

Observed differences between weekend and weekday sanitary sewage pollutant concentrations suggested an industrial contribution of sulfate, sodium and chloride from the common industrial use of $NaOH$, HCl, and H_2SO_4. Initial concentrations of calcium, magnesium and bicarbonate in raw water supplies were found to be much more important than the additions due to water use. Verbanck found that ammonia accounts for 80% of total nitrogen in Brussels' sewer waters and would therefore be the most prevalent member of the nitrogen group for which to test. Verbanck's work also suggested that potassium levels might be useful in distinguishing between sanitary wastewaters and commercial wash waters. It would also identify sanitary wastes with more ease and reliability than tests involving fecal bacteria.

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TABLE 9 NATIONWIDE RANGE OF SEPTAGE CHARACTERISTICS
(ALL VALUES IN MG/L, EXCEPT WHERE NOTED)

Parameter	Mean Concentration	Minimum Reported	Maximum Reported	Max. to Min. Ratio
TS	38,800	1,132	130,475	115
TVS	25,300	4,500	71,402	16
TSS	13,300	310	93,378	301
VSS	8,700	3,660	51,500	14
BOD_5	5,000	440	78,600	179
COD	42,900	1,500	703,000	469
TOC	9,900	1,316	96,000	73
TKN	680	66	1,900	29
NH_3-N	160	6	380	63
NO_2-N	---	0.1	1.3	13
NO_3-N	---	0.1	11	110
Total P	250	20	760	38
PO_4	---	10	170	17
Alkalinity	---	522	4,190	8
Grease	9,100	604	23,368	39
pH	6 to 9	1.5	12.6	8
LAS	160	110	200	2
Al	48	2.00	200	100
As	0.16	0.03	0.05	17
Cd	0.71	0.05	10.8	216
Cr	1.1	0.3	3.0	10
Cu	6.4	0.3	34.0	113
Fe	200	3.0	750	250
Hg	0.28	0.0002	4.0	20,000
Mn	5.0	0.5	32.0	64
Ni	0.9	0.2	28.0	140
Pb	8.4	1.5	31.0	20
Se	0.1	0.02	0.3	15
Zn	49.0	33.0	153	5

Source: EPA 1989

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TABLE 10. SUMMARY CHARACTERISTICS OF SEPTIC SYSTEM EFFLUENTS FOR HOUSEHOLDS USING DIFFERENT DETERGENTS

Constituent (mg/L, unless otherwise noted)	PO_4 detergent				CO_3 detergent			
	Number of Samples	Mean	Range	Median	Number of Samples	Mean	Range	Median
Na	168	143	27-523	100	181	83	12-761	72
K	26	34	20-121	27	37	25	1.0-80	24
Ca	168	32	2.8-105	29	181	27	1.0-77	27
Mg	26	23	3.0-57	27	37	16	1.0-36	15
Cl	117	193	16-827	75	124	56	1.0-106	54
Alk (as CO_3)	124	412	128-800	396	142	401	188-908	359
EC (µmhos/cm)	170	1.5	0.5-3.5	1.4	187	1.1	0.5-2.2	1.0
pH	167	7.2	5.6-8.7	7.2	188	7.5	6.2-8.6	7.4
T (°C(	169	14	0.0-27	14	185	13	1.5-28	13

Source: Alhajjar, et al. 1989

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TABLE 11. ORGANIC COMPOUNDS FOUND IN CONDOMINIUM SEPTIC TANK EFFLUENTS AND SURROUNDING GROUNDWATERS (MONROE, CT)

Constituent (mg/L)	Septic Tank Filtered Sample)	Leaching field (Unfiltered Sample)	Groundwater Monitoring Wells
Methylene chloride	1.5, 3.6	2.1	Not detected
1,1 dichloroethane	15, 56	1.8	2
t-1,3 dichloro-1-propene	44, 80	22	Not detected
Tetrahydrofuran	463	Not detected	Not detected
1,1,1-trichloroethane	52	15	10
Tetrachloroethylene	14	Not detected	Not detected
Toluene	120, 189	8	50
Trichloroethene	45	28	Not detected

Source: Kolega, et al. 1986.

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TABLE 12. ORGANIC COMPOUNDS FOUND IN COMMERCIAL/RESIDENTIAL SEPTIC TANK EFFLUENTS AND SURROUNDING GROUNDWATERS (CHESTER, CT)

Constituent (mg/L)	Septic Tank (Filetered Sample)	Leaching Field (Unfiltered Sample)	Groundwater Monitoring Wells
February 19, 1985			
Methylene chloride	11	10	Not detected
Chloroform	9	2	Not detected
t-1, 3 dichloro-1-propane	63	13	Not detected
Benzene	1	2	Not detected
Toluene	290	4	Not detected
Trichloroethylene	16	Not detected	Not detected
Chlorobenzene	Not detected	6	Not detected
Ethylbenzene	Not detected	2	Not detected
March 21, 1985			
Methylene chloride	7	4	4
Chloroform	53	2	7, 9
Carbon tetrachloride	4	Not detected	Not detected
t-1, 3 dichloro-1-propene	29	39	Not detected
Chlorobenzene	1	4	Not detected
Dichloroethane	Not detected	Not detected	4
June 7, 1985			
Fluorotrichloromethane	205	234	120
Trans-1,2-dichloroethane	Not detected	Not detected	5
Trans-1,3-dichloropropene	170	220	3
Toluene	High quantity*	High quantity*	**
Chlorobenzene	<1	Not detected	Not detected
Ethyl benzene	<1	Not detected	Not detected

* Recorded values over-scale

** Not reported. Toluene observed in water blank prior to sample analysis.

Source: Kolega, et al. 1986.

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TABLE 13. CONTAMINANT INCREASES FOR SEWAGE, COMPARED TO TAP WATER (mg/L)

Reference:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	California 1954	U. S. 1958	Ohio 1964	U. S. 1964	Illinois 1967	1965 National Average Range	1989 Brussels Mean Increases
Total Dissolved Solids	100-300	120-450		150-500	262-364		
Calcium		7-109	1-43	10-50	17-53	6-16	28.6
Magnesium		1-109	1-111	5-20	7-37	4-10	(-6.9)
Ammonium	26- 48	4-45	9-27	2-20	10-37		42.4
Sodium		14-742	53-106		13-132	40-70	104.1
Phosphate	20-40	8-65	19-35	10-50	24-51	20-40	41.4
Silica		4-18		10-20	8-21	2-10	13.5
Chloride	20-50	22-1262	40-102	25-125	16-34	20-50	91
Nitrate				1-20	0-1	90-180	
Bicarbonate	60-100	12-392	25-130	18-60	34-118	50-100	159
Sulfate	15-30	10-191	15-52	10-40	8-75	15-30	63.6
Potassium	7-15					7-15	17.8
Carbonate						0-10	0
Baron	0.1-0.4					0.1-0.4	0.99
Iron						0.2-0.4	

Sources: (1) State Water Pollution Control Board 1954 (California - 15 communities).
(2) Stone, Ralph, and Merrell 1958 (25 communities).
(3) Bunch and Ettinger 1964 (Ohio - 5 communities).
(4) Connell and Forbes 1964.
(5) Evans 1967 (Illinois - 4 communities - strictly residential).
(6) Tchobanoglons and Eliassen 1965.
(7) Verbanck, Vanderborght and Wollast 1969 (Brussels, Belgium).

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TABLE 14. ORGANICS AND PHYSICAL PROPERTIES FOR TUB, SHOWER, AND WASHING MACHINE WASTEWATER (17 ANALYSES)

Characteristics	Units	Range	Average	Median
Suspended solids	mg/L	<100-128		<100
Total solids	mg/L	183-783	492	489
MBAS (detergent)	mg/L	0.19-96	43	36
TOC	mg/L	11-173	81	57
Urea	mg/L	<1-15.0		<1
Color	Subjective	Brown-Gray		
Conductivity	µmhos/cm	174-480	348	331
pH	pH units	6.9-8.4	7.6	7.7
Turbidity	SiO_2 equiv. mg/L	10-250	102	71

Source: Hypes, *et al.* 1975.

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TABLE 15. MAJOR ION CONCENTRATIONS FOR TUB, SHOWER AND WASHING MACHINE WASTEWATER (17 analyses; all mg/L)

Characteristics	Range	Average	Median
Ammonia	<0.05-1.60		0.14
Calcium	23-31	27	29
Chloride	13-29	19	17
Chlorine			<0.05
Cyanide			<0.02
Fluoride	0.48-0.78	0.62	0.6
Nitrate/Nitrite	<0.05-1.1		<0.05
Phosphates	1.1-200.0	104	103
Potassium	2.5-11.0	6.0	5.5
Sodium	10-114	64	68
Sulfate	10-127	69	64

Source: Hypes, *et al.* 1975.

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TABLE 16. METAL CONCENTRATIONS FOUND IN TUB, SHOWER AND WASHING MACHINE WASTEWATER (17 ANALYSES; ALL mg/L)

Characteristics	Range	Average	Median
Barium			<1
Boron			<1
Cadmium			<0.005
Chromium			<0.01
Copper	<0.1-0.4		0.1
Iron	0.2-0.8	0.4	0.3
Lead			<0.05
Magnesium	1.1-2.0	1.5	1.35
Manganese	<0.01-0.06		<0.01
Mercury			<0.001
Nickel			<0.1
Silver			<0.01
Zinc	0.30-0.84	0.54	0.5

Source: Hypes, *et al.* 1975.

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Household and Automobile Maintenance–
Materials commonly used in residential areas for home maintenance and household automobile maintenance are often improperly disposed of either by direct disposal into storm sewers or disposal onto land with subsequent drainage into the storm sewer system. These materials include paints and thinners, toxic household chemicals, used oil, and radiator fluid.

Russell and Meiorin (1985) conducted a survey of household toxic material disposal practices and found direct disposal to a storm sewer, or street, in the following situations: 3% of households for paints and thinners; 11% of households for used motor oil; 83% of households that flushed their own automobile radiators for used radiator fluid, which was found to heavily contaminated with heavy metals. An additional, 14% of households that changed their own motor oil disposed of it by pouring it on the ground (EPA 1989). A survey of discount store shoppers in Oakland, California indicated that 11% of those changing their own oil poured it down storm sewers, while 36% poured it, or buried it, on their property or neighboring property (Cukor, *et al.* 1973).

The EPA estimated that 267 million gallons of used oil, including 135 million gallons from do-it-yourself automobile oil changes, are annually disposed improperly (EPA 1989). A 1979-80 survey of Providence, R.I., residents indicated that approximately 35% changed their own automotive lubricating oil. Used oil was disposed in the garbage can by 41% of these respondents, 30% dumped it in their backyard, 8% poured it down sewers or storm drains, 7% returned oil to a service station, 5% poured it on the road, and 3% took it to a town dump. The practice of pouring the waste oil on the road or into sewers accounted for 44 metric tons of petroleum hydrocarbons discharged into the city's combined storm and sanitary sewage treatment system annually, or 19% of the total hydrocarbons discharged annually into Narraganset Bay via the Providence River by this plant (Hoffman, *et al.* 1980). In 1976, direct oil spills into Narraganset Bay amounted to approximately 55 metric tons/year (Morgan 1978). Van Vleet and Quinn (1978) estimated that coastal communities release about 51,000 metric tons of petroleum hydrocarbons per year to coastal waters through their sewage treatment facilities. On a nationwide basis, approximately 17 percent of this value can be explained by the practice of do-it-yourselfers dumping their waste lubricating oil down sewers or onto roads.

A 1974 analysis of sediment samples from Colgate Creek in Baltimore harbor of Chesapeake Bay identified a number of benzene extractable hydrocarbons. Colgate Creek is exposed to continuous oil pollution, mainly from tank washings, accidental spills and storm sewer effluent discharges (Wegener 1973). Classes of hydrocarbons included alkanes, 1-ring cycloalkanes, 2-ring cycloalkanes, 3-ring cycloalkanes, alkylbenzenes, benzcycloparaffins, benzdicycloparaffins, naphthalenes, acenaphthenes, fluorenes, phenanthrenes, and cyclopentanaphenalenes (Walker and Colwell 1977).

Residential Irrigation Sources of Contaminants–
Over-watering of landscaped areas can contribute contaminants to storm drainage systems during dry weather. As an indicator of potential contaminant concentrations in this water, data is presented in Table 17 that was obtained from sheetflow samples from landscaped and undeveloped areas. These sheetflow samples are therefore affected by rain and not by domestic water. This, however, should not greatly affect the concentrations shown. Elevated concentrations of TDS, COD, phosphates, and nitrogen compounds are shown. Even though not analyzed in these studies, high concentrations of herbicides and insecticides are also expected to be associated with irrigation runoff.

Roadway and Other Accidental Sources of Contaminants–
A wide variety of materials are subject to spills during transport, transfer, use and storage. Thousands of incident reports are received by the U.S. Coast Guard's National Response Center (NRC) each year. Spilled substances are categorized as oil or CERCLA (Comprehensive Environmental Response Compensation and Liability Act) regulated materials. The term "oil" is used to represent 94 different materials, including various grades of crude oil, naphtha, coal tar, creosote, refined oils, gasoline, and jet fuels. Hazardous substances include 494 materials either regulated by, or containing substances regulated by CERCLA (EPA 1989).

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TABLE 17. SHEETFLOW QUALITY FOR LANDSCAPED AREAS

Pollutants	Landscaped Areas	Undeveloped Areas
Total solids, mg/L	388 (4)	588 (4)
Suspended solids, mg/L	100 (4)	400 (1)
Total dissolved solids, mg/L	288 (4)	390 (1) 193 (4)
BOD_5, mg/L	3 (3)	—
COD, mg/L	70 (3) 26 (4)	72 (1) 54 (4)
Total Phosphorus, mg/L	0.42 (3) 0.56 (4)	0.40 (1) 0.68 (4)
Total Phosphate, mg/L	0.32 (3) 0.14 (4)	0.10 (1) 0.26 (4)
TKN, mg/L	1.32 (3) 3.6 (4)	2.9 (1) 1.8 (4)
Ammonia, mg/L	1.2 (3) 0.4 (4)	0.1 (1) <0.1 (4)
Phenols, µg/L	0.8 (4)	---
Aluminum, µg/L	1.5 (4)	11 (4)
Cadmium, µg/L	<3 (4)	<4 (4)
Chromium, µg/L	10 (3)	<60 (4)
Copper, µg/L	<20 (4) ---	31 (3) <20 (4)
Lead, µg/L	30 (2) 35 (3) <30 (4)	100 (1) 30 (2) <40 (4)
Zinc, µg/L	10 (3)	100 (4)

sources:

(1) Denver Regional Council of Governments 1983
(2) Pitt 1983 (Ottawa)
(3) Pitt and Bozeman 1982 (San Jose)

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(4) Pitt and McLean 1986 (Toronto)

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Spilled substances may drain into storm sewer systems on their own, be washed into storm sewer systems by subsequent rains, or may be flushed into the systems by well meaning, but ill advised, cleanup crews. Even where appropriate cleanup activities are initiated, a significant portion of a spill is usually not recoverable. No data is available to substantiate the number of unreported spills, but Merryman (1989) estimated that the NRC receives information on less than half of the reportable incidents occurring each year. For spills not reported to responsible authorities, little or no cleanup is probably attempted (EPA 1989)

Industrial Sources

There are several ways by which industries can produce dry-weather entries to storm sewers. Common examples include the discharge of cooling water, rinse water, other process wastewater, and sanitary wastewater. Industrial pollutant sources tend to be related to the raw materials used, final product, and the waste or byproducts created. Guidance on typical discharge characteristics and activities associated with common industries is given in Sections 3 and 9.

There is also a high potential for unauthorized connections within older industries. One reason for this is that at the time of an industry's development, sanitary sewers may not have been in existence, since early storm drains preceded the development of many sanitary sewer systems. Also, a lack of accurate maps of sanitary and storm drain lines may lead to confusion as to their proper identification. In addition, when the activities within an industry change or expand, there is a possibility for illicit or inadvertent connections, e.g., floor drains and other storm drain connections receiving industrial discharges which should be treated before disposal. Finally, industries processing large volumes of water may find sanitary sewer flow-carrying capacity inadequate, leading them to improperly remove the excess water through the storm drain system.

Continuous processes, e.g., industrial manufacturing, are important potential sources because any waste streams produced are likely to be constantly flowing. Detection of dry-weather discharges from these sources is therefore made easier, because the continuous and probably undiluted nature of these discharges is more noticeable, e.g., odors produced will be stronger and colors more intense, along with their tracer constituents being more concentrated and more readily detectable by sampling.

Industrial Area Wet Weather Discharges–

Although any of the situations identified above would introduce contaminants during wet as well as dry periods, there are some situations that would introduce excess contaminants into storm drains only during periods of stormwater runoff. These are more difficult to identify and locate, because to a large extent, it must be done by comparing the quality characteristics of the storm drain in question with some base line that reflects typical storm runoff. This report is therefore not recommending that the outfall monitoring activities described in Sections 4 to 7 be used to identify wet weather cross-contamination sources. These sources can be best identified by conducting on-site investigations of industrial and commercial establishments (see Sections 3, 8 and 9). Some typical situations that can introduce excess contaminant levels only during periods of normal runoff include the following:

- Contamination of outdoor areas subject to wash-off by normal rainfall. Loading dock areas, truck wash-down areas, and material handling areas are prime candidates. Parking lots and other outdoor areas in the immediate vicinity of an industrial process with poor control of fugitive air emissions, can be a significant source or surface contaminants subject to washoff by rainfall.
- Uncovered material stockpiles.
- Excessive fertilizer/pesticide applications to landscaped areas.

The most significant of these sources are probably associated with selected commercial and industrial activities, as discussed in Section 9. Conducting an inventory of the land uses in a drainage area, including the identification of specific critical activities, will be most useful in evaluating these potential indirect discharge problems.

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Continuous Industrial Discharges–
Continuous discharges associated with industrial manufacturing processes are usually highly concentrated since they are not diluted by storm runoff or groundwater. Thus, the effects resulting from direct and uninterrupted flows will be more noticeable. For instance, odors produced will be much stronger and colors more intense, making it much easier to identify potential sources. Several sources of continual dry-weather flow exist in industry, including noncontact cooling water, rinse water, and process water.

Non-contact cooling water—
Industrial non-contact cooling water is water that decreases the temperature of a particular part or process without physical contact. "Non-contact" is achieved by allowing cooling waters to circulate around the part or process in a contained jacket or external channel. In order to discharge non-contact cooling waters into a storm drain, an industry must obtain a National Pollution Discharge Elimination System (NPDES) permit from the EPA, or designated state agency. These discharges will not cause pollution as long as cooling waters remain fully separated from the part or process they are cooling, are not above critical temperature limits, and do not contain additional chemicals (such as corrosion inhibitors or algicides). However, when cooling systems are not functioning properly, or when they must be blown down because of an excessive build-up of contaminants due to evaporation, they may become sources of contamination to the storm drainage system.

Industries use large amounts of non-contact cooling water for several purposes. Non-contact water is often used to cool raw materials, final products, and machinery (such as compressors or rectifiers). For example, the turbines and boilers used in coal steam electric power generation are cooled by using non-contact waters. These cooling waters are also frequently used for temperature control of chemical reaction vats or metal plating baths. The temperature of reactor vessels used in the production of plastics and synthetics is controlled by non-contact cooling waters. These cooling waters could become contaminated by leaks and spills from the primary process.

Rinse water—
Another common industrial source of continual dry-weather flow is industrial rinse water. Rinse water is water which cleans or reduces the temperature of an object through actual physical contact with the object. Discharges resulting from rinse waters are often allowed to enter floor drains which may be connected to storm sewers instead of to sanitary sewers. A high potential for continual dry-weather flow exists for those industries in which the raw materials, final products, or production machinery must be sanitized, or cooled, by using rinse waters.

Continual rinse waters may originate from industries that utilize regular washdown procedures. For instance, soft drink bottling plants use rinse waters for removal of waste drink, debris, and labels from returned bottles. Rinse waters can also be used for temperature reduction by dipping, washing, or spraying objects with cool water. For example, rinse water is sometimes sprayed over the final products of the metal plating industry for cooling.

Process water—
Industrial process water may also be discharged into floor drains. Process water is used in industry to perform a variety of functions, or as an actual product ingredient. Process waters which are likely to cause continual dry-weather flows are those used for filtration, dilution, soaking, and conveyance. As examples, large amounts of process water are used by breweries for the soaking and filtration of grain malts. In paper industries, large amounts of water are used for the conveyance of debarked and chipped wood.

Intermittent Industrial Sources–
The presence of regular, but intermittent, flows will usually be a good indication of contaminated entries to the storm drains, and can usually be distinguished from groundwater infiltration flows. This type of discharge may occur on a regular basis, or randomly, depending upon production schedules. However, as drainage areas increase in size, many intermittent flows will combine to create a continuous composite flow. Examples of possible situations or activities that can produce intermittent dry-weather flows are:

- Wash-up operations at the end of a work shift, or job activity.

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- Wash-down following irregular accidents and spills.
- Disposal of process batches or rinse water baths.
- Over-irrigation of lawns.
- Vehicle maintenance, e.g., automobile washing, radiator flushing, and engine de-greasing.

Industries that operate on a seasonal basis, such as fruit canning and tourism can also be a source of longer duration intermittent discharges. Major intermittent industrial sources are described in the following paragraphs.

Rinse Waters—

Industrial rinse waters which are most likely to cause an intermittent flow are those used for clean-up at the end of a work shift, before product changeover, or after raw materials have been unloaded. One such case could be the flushing of a chemical delivery tank at an unloading dock.

Batch Dumps—

A batch dump is the intermittent disposal of process material which may be composed of a wide variety of substances, especially solvents, dyes, paints, or rinse water baths. A common example of batch dump waste comes from the pickling process used in steel mills. To remove dirt and grease, steel is immersed in dilute batches of sulfuric acid. This process produces a waste known as "pickling liquor" which contains mostly iron sulfate. Batch dump disposal occurs when the iron sulfate concentration has increased enough to inhibit the pickling process. At this point, the pickling liquor is replaced by a fresh batch of sulfuric acid. These wastes may periodically be discharged into the storm drain system.

Process Line Discharge—

Process line discharges occur when anything used in, or resulting from, a manufacturing process (including wastes, byproducts, chemicals, and fuels) is disposed. This type of waste is often seen in the food processing industry. For instance, cannery processes for vegetables often produce process line discharges. The process line wastes usually consist of solids from sorting, peeling, and coring operations, as well as can spillage from filling and sealing. These wastes may also be inappropriately discharged into the storm drain system.

Industrial Spills—

The previous situations are most likely to cause intermittent dry weather flows on a fairly regular basis. A primary cause of intermittent industrial dry-weather flows in a storm sewer is industrial spills, which are random. After a spill has taken place, the materials are often washed to floor drains which may be connected to storm sewers. Unless it is raining, this type of pollution can have very high concentrations of contaminants, since there is no dilution by stormwater.

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Section 3
Mapping and Preliminary Watershed Evaluation

Purpose

An investigation of non-stormwater entries into a storm drainage system needs to proceed along a systematic path of action, which investigates areas from high to low potential for causing problems, and focuses in from general outfall screening to pin-pointing specific pollutant sources for correction. A mapping and evaluation methodology, as described in this section, is required to identify the areas to investigate and to provide a basis to prioritize the areas by their potential to contribute non-stormwater entries into the storm drainage system. The data collected in this phase is important as it forms the basis for the rest of the more detailed investigations, described in the subsequent sections of this report.

Mapping

To make this exercise as economical and productive as possible, full advantage should be taken of any existing and available information. Data gained from existing sources will need to be supplemented with information obtained by field investigations. The following summarizes the information required, likely data sources, and how to obtain the information.

Receiving Waters and Storm Sewer Outfalls

The receiving waters and stormwater drainage outfalls must be identified and accurately located on appropriate maps. However, records of all outfalls are unlikely to be found, and even for those that are, the locations of the outfalls may not be accurately shown. It is therefore important that the field survey described in Section 4 be used to supplement the data collected during this initial stage.

Possible sources of documented information include:

- City records, drainage maps and storm drain maps.
- Previous surveys e.g., sanitary sewer infiltration/inflow (I/I) and sewer system evaluation survey (SSES) studies.
- Topographic maps.
- Existing GIS (Geographic Information System) data.
- Pre-development stream locations.
- Drainage department personnel with knowledge of the area.
- Aerial surveys.

An important objective of these mapping activities is to identify the locations of all of the stormwater outfalls. Finding the outfalls is not trivial. In the case studies examined, repeated trips typically uncovered additional outfalls that were not be found during earlier excursions. In Toronto (GLA 1983), for example, most outfalls were located during the first field trip, but two more trips were needed before almost all of the outfalls were located. However, additional outfalls were periodically found that were not identified on the city storm drainage maps. It is very difficult for communities to maintain up-to-date mapping of drainage facilities.

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The outfall locations must be identified for all outfalls, not just those that are greater than a certain diameter or serve a watershed greater than a specific area (see Section 4). There is currently no information to indicate a good relationship between the most significant sources of non-stormwater discharges and the largest drainage areas, or the largest diameter outfalls. There are relationships between significant sources and land uses, however, and that will be used in later aspects of this initial mapping effort.

Drainage Area for Each Outfall

The drainage area for each outfall must be determined and marked on the map. This will enable known potential pollutant source locations to be assigned to the correct outfall. Sources for this information are storm drain maps and topographical maps. These should be at least 1"=200' scale and have no greater than 5 ft contour intervals (depending on the steepness of the area).

Land Uses for Each Outfall Drainage Area

Local planning departments should have detailed zoning maps of the study area. These maps should designate residential, commercial, and industrial land uses in each outfall's drainage area. In addition, local revenue departments should have lists of business licenses for the entire municipality, but they may not be usefully organized. The public health department should know where septic tanks are used. Aerial photographs can provide useful information to identify and or confirm land use areas. Historical land uses, especially land fills and industrial areas, should also be noted.

An effective method to obtain this information may be to examine the municipality's zoning maps and to drive to the critical areas to conduct on-site inspections. The land uses of most interest are all industrial, most commercial, and some municipal activities. The activities in the commercial areas of most concern include vehicle related activities (sales, parts, service, or repair), laundry or dry cleaning (including hospitals and hotels), and restaurants. The municipal activities of most concern include land fills, bus barns, airports, and sanitary wastewater treatment facilities.

Table 18 can be used to identify the local industries in each drainage area most likely to contribute non-stormwater entries into the storm drainage system. The categories considered in this table include loading and unloading of dry bulk or liquid materials, outdoor storage or processing, water usage (cooling and process waters), dust or particulate generating processes, and illicit or inadvertent industrial connections. The likelihood of an industry producing dry-weather or wet-weather discharges in each of these categories was rated on the basis of high potential, moderate potential, low potential, and not applicable, if the activity is not likely at that land use. Section 9 discusses special considerations for the field screening activities in industrial areas.

The industrial categories listed in Table 18 were defined according to the 1987 Standard Industrial Classification Manual (SIC code). The industries were classified according to six main categories. The category for "Primary Industries" includes facilities involved in the production of food products and other basic goods. The category of "Material Manufacturing" includes those industries producing materials such as lumber, paper, glass, and leather. Similarly, the "Chemical Manufacturing" category includes those industries making products such as plastics, paints, detergents, fertilizers, pesticides, and other related substances. "Transportation and Construction" primarily concerns the discharge of contaminants from building or other types of outdoor development. The "Retail" category includes establishments engaged in the selling of merchandise or offering merchandise related services. Finally, all other industries which did not fit into any of the above classifications were placed into a "General" category. Those industries which are not specifically listed should have characteristics resembling the industries of the major groups with which they are classified by SIC code.

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TABLE 18. SOURCES OF INDUSTRIAL NON-STORMWATER ENTRIES INTO STORM DRAINAGE SYSTEMS

Industrial Categories Major Classifications SIC Group Numbers			Loading/Unloading		Outdoor Storage/	Water Usage		Particle Generating	Illicit/ Inadvertent
			Dry Bulk	Liquids	Processing	Cooling	Process	Process	Connections
Primary Industries									
20		Food & Kindred Products							
	201	Meat Products	H	L	H	H	H	L	H
	202	Dairy Products Processing Industry	H	H	NA	H	H	NA	H
	203	Canned & Preserved Fruits & Vegetables	H	H	H	H	H	M	H
	204	Grain Mill Products	H	H	L	H	H	H	H
	205	Bakery Products	H	M	NA	NA	H	M	L
	206	Sugar & Confectionary Products	H	M	NA	L	M	H	L
	207	Fats & Oils	H	H	NA	M	H	NA	M
	208	Beverages	H	H	NA	H	H	M	L
21		Tobacco Manufactures	H	M	NA	NA	M	H	M
22		Textile Mill Products	H	L	NA	H	H	M	H
23		Apparel & Other Finished Products Made from Fabrics & Similar Materials	H	L	NA	NA	M	M	L
Material Manufacture									
24		Lumber & Food Products	H	L	H	NA	M	H	L
25		Furniture & Fixtures	H	M	NA	NA	L	M	L
26		Paper & Allied Products	H	H	H	H	H	H	H
27		Printing, Publishing, & Allied Industries	H	M	NA	NA	M	H	L
31		Leather & Leather Products	H	H	L	L	H	H	H
32		Stone, Clay, Glass, & Concrete Products	H	M	H	L	H	H	L
33		Primary Metal Industries	H	M	H	H	H	H	H
34		Fabricated Metal Products	H	H	L	H	H	H	H
37		Transporation Equipment	L	H	L	H	H	L	H

(continued)

TABLE 18. Continued

Industrial Categories Major Classifications SIC Group Numbers			Loading/Unloading		Outdoor Storage/ Processing	Water Usage		Particle Generating Process	Illicit/ Inadvertent Connections
			Dry Bulk	Liquids		Cooling	Process		
Chemical Manufacture									
28		Chemicals & Allied Products							
	281	Industrial Inorganic Chemicals	H	H	NA	H	H	H	H
	282	Plastic Materials & Synthetics	H	H	L	H	M	L	H
	283	Drugs	L	L	NA	H	M	L	L
	284	Soap, Detergents, & Cleaning Preparations	H	H	NA	H	H	H	H
	285	Paints, Varnishes, Lacquers Enamels & Allied Products	H	H	NA	L	H	H	L
	286	Industrial Organic Chemicals	H	H	NA	H	H	H	M
	287	Agricultural Chemicals	L	L	NA	H	L	L	L
29		Petroleum Refining & Related Industries							
	291	Petroleum Refining	L	H	H	H	L	NA	H
	295	Paving & Roofing Materials	H	H	H	NA	M	M	L
30		Rubber & Misc. Plastic Products	H	H	NA	H	H	H	M
Transportation & Construction									
15		Building Construction	M	L	H	NA	L	H	L
16		Heavy Construction	M	L	H	NA	L	H	L
Retail									
52		Building Materials, Hardware Garden Supply, & Mobile Home Dealers	H	L	H	NA	L	NA	L
53		General Merchandise Stores	H	M	L	NA	L	NA	L
54		Food Stores	H	H	NA	NA	M	L	L
55		Automotive Dealers & Gasoline Service Stations	H	H	H	NA	M	L	M
56		Apparel & Accessory Stores	H	L	NA	NA	L	NA	L
57		Home Furniture, Furnishings and Equipment Stores	H	L	L	NA	L	NA	L
58		Eating & Drinking Places	H	M	NA	NA	M	NA	M
Other									
		Coal Steam Electric Power	H	L	H	H	L	H	L
		Nuclear Steam Electric Power	NA	L	NA	H	L	NA	NA

NOTE: H: High potential M Medium potential L Low potential NA: Not applicable

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Investigators should take care to include any area where the land use has a potential to contribute pollutant sources to a storm drainage system. As stated above, these land uses may not be covered by Table 18. Some common examples of land use areas to be included are given below:

- Landfill areas can be a source of leachate and polluted runoff.
- Airports have a high potential for fuel spillage. Aircraft deicing agents, and other maintenance operations, produce wastewaters that may be discharged into the storm drainage system.
- Government facilities, such as military bases, may store or use polluting materials and have many vehicle maintenance facilities.
- Agricultural impacts are likely to be greater for wet-weather flows, but practices such as irrigation and drainage tiles may also produce dry-weather flows.

Finally, it is necessary to identify and locate existing permitted discharges to streams and storm drainage. The National Pollutant Discharge Elimination System (NPDES) permits, administered by most states or, if not, by the EPA Regional Offices, contain this information for the facilities currently having discharge permits. Only a small fraction of all industries have NPDES permits, as most have no direct wastewater discharges to waters of the United States. Pretreatment programs for municipal sewage treatment plants would also contain additional industrial information.

Other Relevant Information and Features

It is important that investigators be alert to any relevant features or information which may be specific to their drainage area. Examples of some items that need to be included are discussed in this subsection.

Information on pre-development streams and springs, which may have been routed into the storm drainage system, will aid in the identification of natural uncontaminated or contaminated dry-weather flows. Information regarding depth to the water table will be helpful. If the water table is well below the storm drains at all times, then groundwater infiltration may be less important as a potential source of dry-weather flow. However, the accumulation of percolating shallow groundwater will still occur in storm drainage fill material and be a potential source of some infiltration water. Groundwater conditions for the study area may be available from special studies conducted by the U.S. Geological Survey (USGS), the state water agency, or other sources. Utility construction and repair crews and earth moving companies should know of areas having shallow groundwater. Local I/I and SSES studies also include information concerning shallow groundwater. Well log data collected during drilling of water supply wells, and information from geotechnical investigations, may also be useful.

Areas serviced by sanitary sewerage and areas serviced by septic tanks should be determined in order to identify the areas most likely to have direct connections and infiltration sources, respectively. Local health, sewerage, utility, environmental, and public works departments may have information on the location of these areas.

Older residential areas with failing infrastructure (especially sanitary sewerage in poor condition), and high density residential areas with septic tanks, should be designated as areas with a high potential for pollutant entries into the storm drainage system.

Preliminary Watershed Evaluation

The above activities should produce maps with complete descriptions of the drainage areas, including outfall locations, NPDES permittees, critical land uses, drainage boundaries for each outfall, city limits, major streets, streams, etc. The investigators need to classify drainage areas for their potential for causing non-stormwater entries. This mapping information, together with the information to be obtained as described in Sections 4 through 6, and analyzed as described in Section 7, will form the basis to rank the drainage areas in order of priority for further detailed drainage area investigations (Sections 8 and 10).

The investigation of non-stormwater entries will have a cost associated with it, which will increase with the drainage system size and complexity, and with the number of sources being investigated. All pollutant sources, including both

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wet- and dry-weather pollutant entries, will need to be controlled to have an effective improvement in the quality of the stormwater system discharge. Pitt and McLean (1986) noted that even with the removal of directly connected non-stormwater entries, stormwater originating from industrial and commercial land uses has a high probability of having unacceptable pollutant loads. It would therefore be prudent, at an early stage in the investigation, to review the costs of the investigation and corrective action versus the cost for treatment of the stormwater system discharge. The classification of the storm drainage system as a combined sewer, and subsequent treatment of the flow, may prove to be a more economical and practical alternative. An appropriate time for such a review would be after the mapping and field screening activities to avoid complex, costly, and time consuming drainage system investigations into inappropriate non-stormwater entries, and instead direct resources to pollution control.

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Section 4
Initial Field Surveys

Once the background data has been identified, as described in Section 3, the field investigation activities can begin. It is important to note that the field investigations do not require a massive amount of resources to be successful. The initial field surveys are to be used as a screening effort: to identify the outfalls needing more detailed investigations which would identify pollutant sources and control options. These initial surveys would include physical and limited chemical evaluations of outfall conditions and would be conducted to minimize "false negatives" (outfalls actually having important non-stormwater discharges, but falsely classified as not needing further investigation).

Different flow and pollutant characteristics of the potential discharge sources can be used to identify and quantify non-stormwater discharge problems. The initial surveys to obtain this key information should be repeated at all outfalls over several seasons. Many of the dry-weather discharges are intermittent and may not be noted during any one investigation. Various physical characteristics near the outfall can provide evidence that inappropriate discharges periodically occur. Repeated trips to the outfalls significantly increase the probability of identifying problem outfalls. It is also important to time outfall investigations during the times of day when possible activities may be contributing non-stormwater discharges.

It is difficult to develop a procedure that will separate the outfalls into clear "problem" and "no problem" categories. In some of the case studies investigated, correcting problems in watersheds above only the most critical outfalls resulted in insufficient receiving water quality improvements. It may be important to eventually correct all non-stormwater discharge problems throughout a city, not just the most severe problems. The first dry-weather outfall investigations should therefore only be considered as an initial effort that needs to be followed-up with repeated investigations at the outfalls. The purpose of these field surveys is to rank the outfalls in order of problem priorities. The watersheds associated with the highest priority problems should receive the initial clean-up efforts. Receiving water monitoring is also needed to document improvements after different stages of the control program. If the improvements are not adequate, then additional lower priority problems should be addressed.

Sampling Strategy

The importance of sampling all outfalls, regardless of size, should be stressed. Figure 2 shows the distribution of outfalls for the Birmingham, Alabama, area surveyed for the city's stormwater discharge permit application. The median equivalent diameter of the 566 outfalls was 36 inches. About 20% of the outfalls were greater than 60 inches in diameter and about 20% were less than 20 inches in diameter. Most of the largest outfalls were drainage ditches. There was an average of about 70 acres draining to each outfall, but the drainage areas ranged from much less than one acre to over 1500 acres. About 40% of the outfalls were affected by either commercial or industrial land uses and would therefore be considered as critical drainage areas for both dry-weather flows and stormwater runoff.

The Birmingham, Alabama, demonstration project that tested this protocol (as described in Section 11) was concentrated in a residential and commercial area having about 70 outfalls. The median outfall size of the outfalls in this study area was 16 in., and more than 75% of the outfalls were less than 36 in. in diameter, as shown in Figure 2. Examination of the outfalls during seven separate sampling occasions found that while some of the dry-weather flows occurred intermittently, most were continuous. About 25% of the outfalls were found to be consistently flowing during dry weather, with about two-thirds of the flows discharging from pipes that were less than 36 in. in diameter. About five percent of the outfalls exhibited dry-weather flows which were extremely toxic, or were raw, undiluted,

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sanitary wastewater. Each of these contaminated outfalls were 20 in., or less, in diameter. Some of the worst dry-weather flow discharge problems were associated with very small (4 in. diameter) pipes draining automobile service areas adjacent to the creek. It was found that small outfalls can contribute significant pollutant loads to receiving waters and should not be neglected if receiving water improvement is a serious goal.

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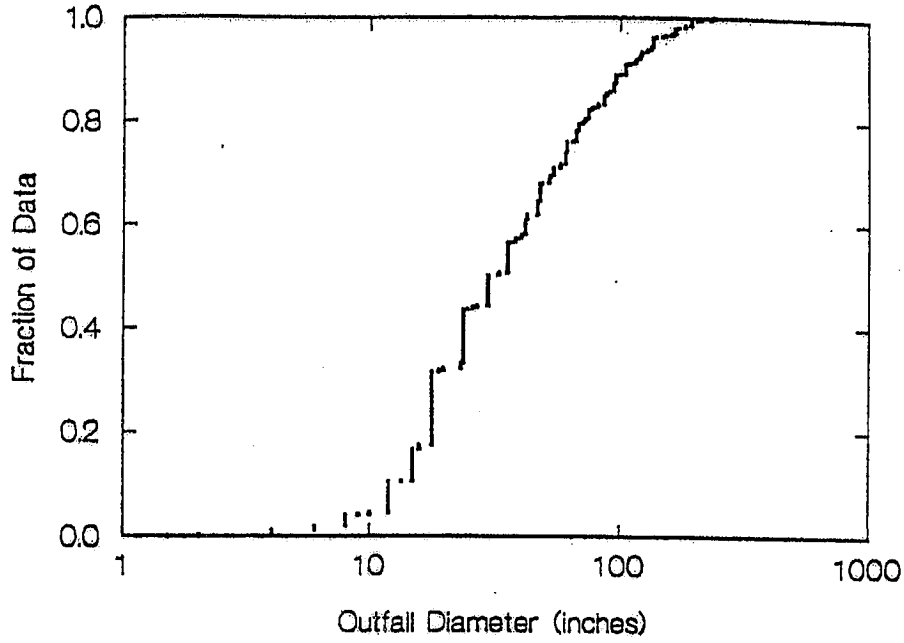

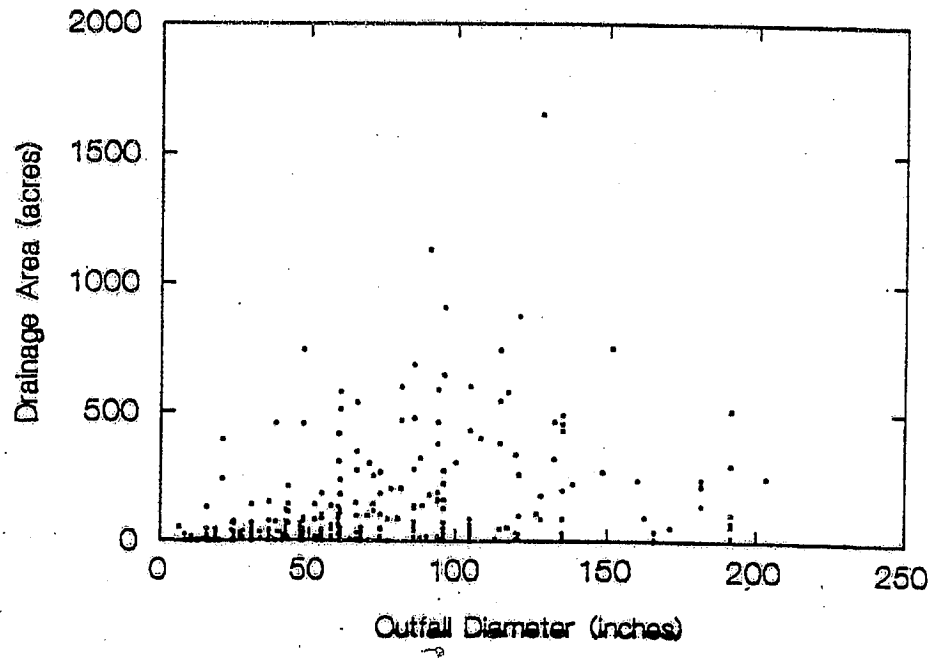

Figure 2. Outfall characteristics for Birmingham, AL, demonstration project.

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Field Data Collection

Before the field data can be collected, preliminary mapping and land use evaluation work is needed. Section 3 described the preliminary work and the likely data sources for the information that is needed before the field investigations can begin. The most important preliminary information required is:

- outfall locations,
- outfall drainage areas,
- commercial and industrial activities in each drainage area, and
- locations of septic tanks in the individual drainage areas.

Outfall Locations

Frequently, city maps of known outfall locations are inadequate. Many outfalls are not located on city drainage maps because of infrequent or improper updating, or unauthorized installations. Because it is very difficult for communities to maintain up-to-date maps of drainage facilities, actual stream surveys are therefore needed to verify and update existing information. Illicit outfalls will not be shown on any maps and field surveys are therefore also needed to detect flagrant illegal discharges. Most newer developments do have accurate drainage and outfall maps, but the outfall locations may not be transferred to an overall city map. A few cities have Geographic Information Systems (GIS) in place and are including the storm drainage systems on appropriate data overlays. It is important to identify all outfalls as there is currently no information to indicate a good relationship between the most significant sources of non-stormwater discharges and the largest drainage areas, or the largest diameter outfalls.

Because of the likelihood of poor data concerning the outfall locations, it will probably be necessary to "walk" the creeks and actively look for outfalls. In most cases, it requires several trips (about three) to locate all outfalls. The initial outfall surveys should be conducted during times when riparian vegetation is minimal. Whenever an outfall is located, it needs to be marked (coded using spray paint).

If the receiving water is a small creek, it can be waded in a downstream direction. If the creek cannot be waded, a small boat or canoe can be used to look for outfalls above the water. Submerged outfalls are more difficult to find and require more careful examinations for storm drain man-holes along the shore. In a tidal area, surveys should be conducted during low tides which would expose more outfalls. In many cities, streets follow the banks of creeks or drainage canals that contain outfalls. It may be possible to carefully search the opposite bank from a moving automobile. It may also be cost-effective to use light aircraft (including helicopters) to search for outfalls from the air. Submerged outfalls would be much easier to identify from the air than from the water in cases where discharge plumes are visible.

Obviously, outfall flow characterizations should be conducted during these surveys, if possible. In all cases, at least two people are needed to look for outfalls, especially if wading a creek. Another person can drive a shuttle car to a convenient downstream location for crew rotation.

Field Survey

The main elements of the field sampling plan are the collection of necessary information and equipment, and preliminary screening of outfalls.

Maps –

Maps are the most important part of the field equipment. Adequate field maps can be prepared by enlarging standard USGS 7-1/2 minute quadrangle maps to appropriate scales. In addition, detailed street maps are also needed to locate specific street crossings and to identify locations of outfalls in the field.

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Field Sampling and Analysis Equipment–
Table 19 lists the equipment that is needed for a field survey. In no case should personnel conduct the field surveys alone, wade streams without wearing waders, or be in boats without wearing life preservers. Heavy duty waders (heavy Cordura™ nylon) are preferred. Urban streams contain appreciable debris (broken bottles, etc.). In addition, urban streams are isolated wildlife areas which tend to concentrate certain wildlife species that live in close proximity to man (including cottonmouth, water moccasin, copperhead, and rattlesnakes), plus contain lush growths of poison ivy or oak. The self protection pepper spray may be especially handy in case of harassing dogs.

This equipment would supplement needed boating equipment, if boats are used. Some of this equipment (ice coolers and ice, along with extra bottles) would be kept in the vehicle. In most cases, the vehicle should be moved in about 1/2 mile increments. This length would typically contain up to ten outfalls, with relatively few flowing outfalls to sample. The collected samples would therefore be iced within about 1/2 hour of collection. It is possible that the vehicle driver could conduct critical analyses (chlorine, pH, and ammonia) while waiting. It is suggested that a three person crew rotate, with a new driver at each new shuttle location.

Arrange for Lab Testing and Other Support Equipment–
Before the field crew goes into the field to collect samples, the laboratory needs to be notified and ready to analyze the samples soon after they are available. As shown in Section 6, the laboratory testing procedures for the basic tracer parameters are all simple and can be conducted in an unsophisticated laboratory. It may be feasible for the field crew to conduct the sample analyses in the afternoon of the day when they are collected.

Preliminary Screening of Outfalls

Location of Outfalls–
Outfall locations need to be transferred to field maps and the daily activities planned. The number of outfalls that can be visited and sampled in a single day is highly dependent on outfall accessibility and mobility along the receiving water. The initial survey requires the longest time, after which repeated surveys require much less effort. In a small creek having shallow and slow water with numerous road crossings, about three miles of creek can be walked (with about 40 outfalls visited and ten outfall samples obtained) in a half-day of field activity with a crew of three people. Most other conditions would require additional labor for the same sampling effort. In all cases, careful planning, especially having an idea of where the outfalls are located, would greatly reduce the labor involved.

Scheduling Field Surveys–
It is important to schedule the field surveys during low water levels (during low tides or low flows) because outfalls will likely be submerged and concealed during high water conditions. It is also best not to conduct the field surveys during periods of high flow in the receiving waters because of safety concerns. The field surveys will also reveal more dry-weather discharges during anticipated periods of highest periods of flow from likely contaminating dry-weather flow sources (diurnal, or seasonally). As an example, morning periods usually experience the greatest sanitary wastewater flows. Scheduling sampling during these morning hours would be most successful in identifying sanitary wastewater contamination of the storm drainage system. Many inappropriate industrial entries to the storm drainage system also occur on a scheduled basis, e.g., cleaning up work areas between work shifts, or increased wastewater flows during periods of the year when a specific industry is especially busy. Again, investigating potentially affected storm drain outfalls during these critical periods would result in better data.

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TABLE 19. FIELD EQUIPMENT LIST

Temperature and specific conductivity meter

Field notebook containing maps and non-stormwater flow evaluation field sheets

Waterproof marker/pen

Camera and film

Spray paint

Tape measures (both 3m and 30m)

Flashlight

Watch (with second hand)

Glass sample containers with waterproof labels (500 mL)

Plastic sample containers with waterproof labels (1 to 2 liter)

Ice boxes with ice (left in vehicle)

Backpack

Grab water sampler (dipper on long pole)

Hand operated vacuum pump sampler for shallow flows

Waders and walking stick

First aid kit and pocket knife

Self protection pepper spray

Two-way radios for communication between field crew and van driver

Hand held GPS (global positioning satellite) system receiver (only capable of locating positions within about 100 to 350 feet)

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The field survey schedule will need to be flexible to avoid sampling during and immediately after a storm event to ensure only dry-weather flows are evaluated. In most urban areas, storm runoff flows will cease within 12 hours following the storm, but this will need to be reviewed with local experience. The time required for the runoff to flow through the upstream drainage system, if detention facilities are used, could extend beyond this 12 hour period.

Sampling Techniques–
After an outfall is located, it is labeled with paint and the form shown on Table 20 is completed in the field. The use of field sheets and laboratory record keeping is very important because of the large number of outfalls that will likely be surveyed in each municipality. Table 20 is a field sheet that can be used to record the observations and analytical results for the outfall survey. The top of the sheet includes basic outfall descriptive and weather information, a flow rate estimate, and an indication if industrial or commercial activities are known to occur in the area. The physical observation data section requires simple circling of the most appropriate value, or writing in another response. Samples should be obtained of floatable and staining materials for further laboratory microscopic analyses. If unusual vegetative conditions or damage to structures is found, then the extent of the damage should be described. In all cases, several photographs need to be taken of outfall conditions for each site visit. The analyses results are written on the form, along with a short descriptions of the equipment used.

Flows are estimated and visually characterized for each outfall visit. Field temperature (and possibly specific conductivity) measurements are made in the field, and dry-weather discharge water samples are collected for later (same day) laboratory analyses. A single water sample of 1 to 2 L is sufficient for almost all analyses that may be conducted on the sample. This sample can be collected in a polyethylene collapsible container. In addition, another 500 mL sample can be collected in a glass bottle (having a Teflon lined lid) if a toxicity screening procedure (like Microtox™) and selected organic tracers are to be analyzed. Specific sample volume requirements need to be determined in conjunction with the laboratory personnel. Excess samples should be placed in smaller polyethylene bottles and frozen for potential future analyses (such as heavy metals and major ions).

Sample Preservation–
Usually icing of samples after collection and same-day laboratory analyses is adequate. Ammonia, chlorine and pH are especially bothersome and special local tests may be needed to determine the tolerable delay before laboratory analyses. As noted previously, it is not efficient to generally analyze the samples in the field, especially after each sample is collected.

Field Tests–
The only test recommended for field analysis is temperature. If a multi-purpose temperature/specific conductivity meter is being used for the temperature analyses, then both can be easily determined in the field.

Record Keeping, Sample Preservation, and Analyses–
As noted above, the collected water samples need to be analyzed soon after collection. A central laboratory is much more effective than trying to analyze each sample in the field as it is collected. A later discussion in Section 6 presents the recommended laboratory procedures.

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TABLE 20. SAMPLE EVALUATION SHEET

Outfall # _____ Photograph # _____ Date:_____

Location:_____

Weather: air temp.: ____ °C rain: Y N sunny cloudy

Outfall flow rate estimate: _____ L/sec

Known industrial or commercial uses in drainage area? Y N
describe:_____

PHYSICAL OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other:_____

Color: clear yellow brown green red gray other:_____

Turbidity: clear cloudy opaque

Floatables: none oil sheen sewage other:_____ (collect sample)

Deposits/stains: none sediment oily describe:_____ (collect sample)

Vegetation conditions: normal excessive growth inhibited growth
extent: _____

Damage to outfall structures:
none / concrete cracking /concrete spalling/ peeling paint / metal corrosion
other:_____
identify structure:_____
extent:_____

ANALYSES: EQUIPMENT USED:

Specific conductivity:	_____ µS/cm	_____
Temperature:	_____ °C	_____
Fluoride:	_____ mg/L	_____
Hardness:	_____ mg/L	_____
Surfactants:	_____ mg/L	_____
Florescence:	_____ % of scale	_____
Potassium:	_____ mg/L	_____
Ammonia:	_____ mg/L as N	_____
pH:	_____	_____

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Data Analyses and Correction of Problems

Identification of Contaminated Outfalls–

Section 7 discusses several methods to identify the likely components in each flowing outfall. This information is then used to identify the most contaminated dry-weather flows.

Isolation and Correction of Contaminating Flow Sources–

After the problem outfalls are identified, drainage system surveys are used to find the sources of the contaminating flows. These procedures are discussed later in Section 8 of this report.

Evaluating Intermittent Flows

Irregular flows pose a special problem during the field surveys. Outfall dry-weather flows can be intermittent in nature, only flowing soon after rains and then remaining dry, or may flow when inappropriate water sources enter the storm drainage system. If associated with rains, outfall surveys should be postponed until sufficient time has lapsed since the last major rain. For most urban areas, storm runoff drainage ends after several (usually less than 6) hours after the rain stops. Extended, but decreasing flows, after rains could be associated with shallow groundwater infiltration into the drainage system. In this case, most outfall surveys should be further delayed. However, some pollutant sources may be associated with these flows, especially contaminated groundwaters (septic tank problems, leaky underground storage tanks, etc.). Therefore, it may be important to sample these flows, especially if these contaminant sources may occur.

Basic field indicators, such as the presence of oily deposits, coarse solids deposits, odors, etc. near the outfall in the absence of a flow, indicate the likelihood of intermittent dry-weather flows. Outfalls exhibiting these signs of non-continuous discharges should be visited several times to increase the probability of observing and sampling a dry-weather discharge. Analyzing pooled water immediately below the outfall or collected between visits in small, constructed dams within the storm drain can greatly assist in identifying non-continuous discharges. Similarly, coarse solids and/or floatables can be similarly captured through the erection of coarse screens and/or booms at the mouth of the outfall or in the receiving stream. It may be necessary to visit suspect outfalls frequently. However, it is virtually impossible to be able to capture a short-term intermittent flow (such as from the illegal dumping of wastes into the storm drainage system) from outfall visits.

Simple outfall area characteristics, noted above, are the most reliable indicator of a potential intermittent source at an outfall. In addition to using a dam, or other indicator device (such as a small screen to capture particulate debris), it may be desirable to use an automatic water sampler at especially important outfalls. Automatic samplers would be unreasonable and expensive to use at many outfalls in an area and test locations would need to be carefully selected. A sampler located in a close-by manhole and set to sample every fifteen minutes (with four samples placed in each bottle) can monitor for intermittent flows for a period of 24 hours. Automatic samplers can also be used to characterize variable quality flows. This information can be a highly valuable help in identifying possible discharge sources.

The presence of intermittent flows in outfalls labeled "dry" was investigated during the field study. Of special interest were the possibility of intermittent commercial flows which might occur on a regular basis. Such flows could be associated with shift changes or end of the day/end of the week wash-ups from commercial establishments. To explore the presence of such flows, small impoundments were created in outfall and discharge pipes located in the most commercial portion of the watershed. The impoundments were formed by placing a bead of latex caulk one half to one inch in height across the invert of the pipes. A total of 31 pipes were investigated during a dry period in August of 1992. Twenty-eight dry pipes were originally fitted with temporary dams shortly after noon. Pipes were inspected for flow at 6:30 p.m. and again shortly after noon the following day. One storm sewer outfall was found to have had flow, as evidenced by water in the impoundment, during the test period.

To further check the validity of the test method, dams were then placed in three additional direct discharge pipes known to have frequent intermittent flows during the day. Dams were put in place prior to facility operation in the

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morning and checked 6 hours later. All three dams showed evidence of flow. Impoundments in two pipes, which traditionally carried small, low velocity flows, were filled with water. In the third pipe, which traditionally carried high velocity, warm water flows, the caulk dam had been washed away by the flow. This simple method of investigation increases the likelihood of detecting intermittent flows which are relatively frequent, or periodic, in nature.

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Section 5
Selection of Tracer Parameters

Introduction

The detection and identification of inappropriate entries requires the quantification of specific characteristics of the observed outfall baseflow. The characteristics of most interest should be relatively unique for each potential flow source. This will enable the presence of each flow source to be noted, based on the presence (or absence) of these unique characteristics. The selected characteristics are termed tracers, because they have been selected to enable the identification of the sources of these waters.

One approach presented in this report is based on the identification and quantification of clean baseflow and contaminated components. If the relative amounts of potential components are known, then the importance of the baseflow can be determined. As an example, if a baseflow is mostly uncontaminated groundwater, but contains 5% raw sanitary wastewater, it would be a likely important source of pathogenic bacteria. Typical raw sanitary wastewater parameters (such as BOD_5 or suspended solids) would be in low concentrations and the sanitary wastewater source would be difficult to detect. Fecal coliform bacteria measurements would not help much because they originate from many possible sources, besides sanitary wastewater. Expensive unique microorganism or biochemical measurements would probably be needed to detect the presence of the wastewater directly. A tracer may be identified that can be used to identify relatively low concentrations of important source flows in storm drain dry-weather baseflows.

The ideal tracer should have the following characteristics:

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

In order to identify tracers meeting the above criteria, literature characterizing potential inappropriate entries into storm drainage systems was examined. Several case studies which identified procedures used by individual municipalities or regional agencies were also examined. Though most of the investigations resorted to expensive and time consuming smoke or dye testing to locate individual illicit pollutant entries, a few provided information regarding test parameters or tracers. These screening tests were proven useful in identifying drainage systems with problems before the smoke and dye tests were used. The case studies also revealed the types of illicit pollutant entries most commonly found in storm drainage systems.

This list of potential illicit sources (see Section 2) led to a search for information regarding the chemical and physical characteristics of these specific flows. This search yielded typical characteristics for sanitary wastewater, septic tank effluent, coin-operated laundries and car wash effluents, as well as potable water and "natural waters". This information, along with specifics obtained from case studies, provided the basis for selecting parameters for further study. Specific analyses will be needed to identify the characteristics of local potential inappropriate entries and uncontaminated water sources, as described in Section 6.

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Characterizations of Potential Dry-Weather Flows From Existing Literature

Table 21 summarizes available information characterizing potential flow sources. This information was used to identify parameters which occurred at different concentrations in natural and potable waters, as compared to sanitary, septage, car wash, and laundry wastewaters. Based on this very general information, several parameters looked promising when considered as part of a group of parameters to be used to characterize potential dry weather flow sources. Measurement of total dissolved solids (TDS) appeared to have good potential for distinguishing between potable water and sanitary wastewaters, though TDS in natural waters varies considerably. No information was available to indicate its usefulness in distinguishing between laundry, carwash and sanitary wastewaters. BOD, COD, and TOC measurements could perhaps accomplish the same thing, but available information indicated they would not be useful in distinguishing between commercial wash waters and sanitary flows. Values for TDS can be approximated by specific conductivity, which is considerably easier to measure than BOD, COD, or TOC (which are not very conservative anyways).

Although not conservative, ammonia and nitrate appeared to have potential for separating natural and potable waters from sanitary wastewaters, as did phosphate. Again, no information was available regarding levels of the compounds in laundry and carwash wastewaters. Alkalinity information was only available for potable water and sanitary wastewaters, but differences were noted between the two.

Total coliform bacteria counts might seem an obvious choice to identify sanitary wastewaters, but numerous researchers have noted problems in using coliforms for evaluation of water from storm drainage systems (Geldreich 1965; Geldreich, *et al.* 1968; Van Donsel, *et al.* 1969; Feachem 1975; Olivieri, *et al.* 1977; Matson, *et al.* 1978; Pitt and Bozeman 1982; Rideau River 1983; and Huron River 1988).

Candidate Parameters

Many different candidate parameters were evaluated before the suggested list was developed. It is recommended that the initial field screening effort include at least the following, in the absence of known commercial and industrial areas in the watershed:

- placement of outfall identification number;
- outfall discharge flow estimate;
- floatables, coarse solids, color, turbidity, oil sheen, and odor characteristics of water;
- other outfall area characteristics, such as stains, debris, damage to concrete, corrosion, unusual plant growth, or absence of plants;
- water temperature;
- specific conductivity;
- fluoride and/or hardness concentrations;
- ammonia and/or potassium concentrations;
- surfactant concentration and/or fluorescence; and
- chlorine concentration and pH.

If commercial or industrial activities occur in the drainage area, then it is important to add additional parameters (such as a toxicity screening procedure and specific metallic and organic toxicant analyses, and others, as noted in Section 9) to the above list.

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TABLE 21. SUMMARY OF POTENTIAL FLOW SOURCE CHARACTERISTICS
(UNITS IN MG/L UNLESS NOTED)

Parameter	Natural[1]	Tap[2]	Sewage[3]	Septage[4]	Car Wash[5]	Laundry[6]
TDS	25-5000	47-63	250-850	291-2250		149-607
Conductivity (µmhos/cm)				500-2220		
BOD			110-400	34-547	<6-220	34-196
TOC	5	0.6-4.7	80-290		16-173	
COD			250-1000		61-1120	73-840
Total N			20-85	10-141		
Organic N			8-35	<0.5-72		
Ammonia	0-1	0.01-0.07	12-50	23-129		
Nitrites		0.2-0.4	0	<0.5-0.9		
Nitrate (NO_3	>0.1,<5	0.28-0.4	20-40			
Total P			4-15	2.8-39	0.25-24	
Organic P			1-5	<0.01-28		
Inorganic P			3-10			
Phosphate (PO_4)	>0.01,<0.1	0.02-0.04	5-15			
Total Alkalinity ($CaCO_3$)		18-36	50-200	128-908		
Bicarbonate (as $CaCO_3$)	5-500	18-36	50-100			
Carbonate (as $CaCO_3$)		0	0-10			
Grease			50-150		5.7-404	
Total Coliforms (org/mL)		0	10^6-10^9			
Chlorides	10-100	3.8-6	20-50	1-827		
Sulfate (SO_4)	5-200	9-12	15-50			
Calcium (Ca)	5-500	11-13	6-16	1-105		
Magnesium (Mg)	10-50	1-3	4-10	1-57		
Potassium (K)	>0.1,<5		7-15	1-121		
Sodium (Na)	10-100	1.6-3.6	40-70	12-761		
Aluminum (Al)	>0.01,<0.1	90-500ppb	0.1-0.2			
Boron (B)			0.1-0.4			
Fluoride (F)	>0.1,<5	0.9-1.1	0.2-0.4			
Manganese (Mn)			0.2-0.4			
Silica (SiO_2)	1-100	3-5	2-10			
pH		7.6-8.8		5.6-8.6	6.2-9	7.9-9.2
Total Hardness		32-40				
Manganese	>0.01,<0.1	<0.05				
Copper	>0.01,<0.1	<0.01			0-0.86	
Phenolics		<1ppb				
Zinc	>0.01,<0.1	10-130ppb			0-2.4	
Lead	>0.01,<0.1	<10ppb			0-4.2	
Detergents (as MBAS)		<0.01				12.6-101.3

[1]Kemmer & McCallien, 1979: NALCO
[2]Birmingham Water Works Board, 1992
[3]Metcalf & Eddy, 1991
[4]Alhajjar et al., 1989
[5]International Carwash Association
[6]International Coin Laundry Association

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Most of the parameter characteristics listed above can be obtained at the outfall location using field procedures. It is much easier, more cost-effective, and much more accurate to collect samples in the field for later laboratory analyses. Analyzing multiple samples for the same parameter is much more efficient than trying to analyze a single sample for many parameters, especially under adverse field conditions.

The selection of the analysis procedures will depend on many conditions, most notably the expected concentrations in the uncontaminated baseflows and in the potential non-stormwater discharge flows, along with the needed probabilities of detection at the minimum contamination level. A description of the techniques developed as part of this study to help in the selection of the analytical procedures is given later in this section. Other factors affecting procedure selection include ease of use, analytical interferences, cost of equipment, training requirements, and time requirements to conduct the analyses.

Simple outfall estimates of discharge, and noting the presence of oil sheens, floatables, coarse solids, color, odors, etc. will probably be the most useful indicators of outfall problems. These observations will need to be repeated several times, especially if non-continuous discharges are likely. The presence of stains and structural damage will greatly assist in identifying significant non-continuous discharges, in addition to continuous discharges. In addition, the following optional characteristics may also be obtained at each outfall, depending on probable pollutant sources:

- hardness;
- toxicity screening; and
- specific metals.

Notably absent from the above list are fecal coliform bacteria, pH, and dissolved oxygen. These have been included in several previous non-stormwater discharge studies, but with limited value. These parameters have not been found to be extremely useful in identifying or categorizing non-stormwater sources. However, in areas having known industrial sources, pH may be an important parameter that would have to be added to this list. Specific analytical recommendations are given in Section 6.

Visual Inspection

Visual observations of outfall conditions have been noted in many case studies to be very useful in determining the significance of contaminated dry-weather baseflows. There was a good correlation between drains judged contaminated after physical inspection and those judged contaminated after chemical tests at Inner Grays Harbor (Pelletier and Determan 1988) and in Toronto (GLA 1983). Visual inspections also provided most of the information for prioritizing drains in Fort Worth (Falkenbury 1988). Correlations between corrections of improper drain connections and improvements in visual evaluations were also evident in Fort Worth. EPA stormwater permit application regulations require a narrative description of visual observations including color, odor, turbidity, the presence of an oil sheen or surface scum, along with a description of the flow rate.

Odor–

The odor of a discharge can vary widely and often directly reflects the source of contamination. Industrial dry-weather discharges will often cause the flow to smell like a particular spoiled product, oil, gasoline, specific chemical, or solvent. In particular, industries involved in the production of meats, dairy products, and the preservation of vegetables or fruits, are commonly found to discharge organic materials into storm drains. As these organic products or byproducts spoil and decay, the sulfur production creates this highly apparent and unpleasant smell. Significant sewage contributions to a dry-weather flow will cause pronounced and distinctive odors.

Color–

Color is another important indicator of inappropriate discharges, especially from industrial sources. During a field sampling program in Toronto (Pitt and McLean 1986), many periods of highly colored baseflows (red, brown, gray, etc.) were observed at an industrial outfall. Chemical analyses showed elevated concentrations of many pollutants. Specific sources of these flows could not be determined, except that the washing of work areas in cement and stone working plants could have been responsible for some of the cloudy dry-weather discharges, and metal plating wastes

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were probably responsible for many of the filterable metal discharges. Other potential dry-weather sources causing various colored contaminated waters from the industrial area could have included "non-contact" cooling water, process water (both slug or continuous discharges), equipment and work area cleaning water discharged to floor drains, spills during loading operations (and subsequent washing of the material into the storm drain).

Industrial dry-weather discharges may be of any color. Dark shades, such as brown, gray, or black, are most common. For instance, the color contributed by meat processing industries is usually a deep reddish-brown. Paper mill wastes are also brown. In contrast, textile wastes are varied. Other intense colors, such as plating-mill wastes, are often yellow. Section 9 further describes these characteristics for many different industries.

Turbidity–
Turbidity, or the clarity, of water is often affected by the degree of gross contamination. Dry-weather industrial flows with moderate turbidity can be cloudy and difficult to see through, while high turbidity flows will be opaque and practically impossible to see through. High turbidity is often a characteristic of undiluted dry-weather industrial discharges, such as those coming from some continual flow sources, or some intermittent spills. Sanitary sewage is also often cloudy in nature.

Floatable Material–
A contaminated flow may also contain floatables (floating solids or liquids). Evaluation of floatables often leads to the identity of the source of industrial or sanitary wastewater pollution, since these substances are usually direct products or byproducts of the manufacturing process, or distinctive of sewage discharges. Floatables of industrial origin may include substances such as animal fats, spoiled food products, oils, plant parts, solvents, sawdust, foams, packing materials, or fuel, as examples.

Deposits and Stains–
Deposits and stains (residue) refer to any type of coating which remains after a non-stormwater discharge has ceased. They will cover the area surrounding the outfall and are usually of a dark color. Deposits and stains often will contain fragments of floatable substances and, at times, take the form of a crystalline or amorphous powder. These situations are illustrated by the grayish-black deposits that contain fragments of animal flesh and hair which often are produced by leather tanneries, or the white crystalline powder which commonly coats sewer outfalls due to nitrogenous fertilizer wastes.

Vegetation–
Vegetation surrounding an outfall will also show the effects of intermittent or random non-stormwater discharges. Industrial pollutants will often cause a substantial alteration in the chemical composition and pH of the discharge water. This alteration will affect plant growth, even when the source of contamination is intermittent. For example, decaying organic materials coming from various food product wastes would cause an increase in plant life. In contrast, the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation, as these dry-weather discharges often have a very acidic pH. In either case, even when the cause of industrial pollution is gone, the vegetation surrounding the outfall will continue to show the effects of the contamination.

In order to accurately judge if the vegetation surrounding an outfall is normal, the observer must take into account the current weather conditions, as well as the time of year in the area. Thus, flourishing or inhibited plant growth, as well as dead and decaying plant life, are all signs of pollution when the condition of the vegetation just beyond the outfall disagrees with the plant conditions near the outfall.

Structural Damage–
Structural damage is another readily visible indication of both continual and intermittent industrial dry-weather discharge contamination. Cracking, deterioration, and spauling of concrete or peeling of surface paint, occurring at an outfall are usually caused by severely contaminated discharges, usually of industrial origin. These contaminants are usually very acidic or basic in nature. For instance, primary metal industries have a strong potential for structural

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damage because their batch dumps are highly acidic. However, confusion is possible due to the effects poor construction, hydraulic scour, and old age may have had on the condition of the outfall structure or sewerage system.

Chemical Parameters

Chemical tests are needed to supplement the above described physical inspection parameters. Chemical tests are needed to quantify the approximate components of a mixture at the outfall. In most cases, dry-weather discharges are made-up of many separate source flows (such as leaking domestic water, groundwaters, sanitary wastewater, and automobile washwaters). Statistical analyses of the chemical test results can be used to estimate the relative magnitudes of the various flow sources.

Based on water and wastewater characteristics discussed in Section 2, along with information obtained from case studies, the following parameters were chosen for study: specific conductivity, fluoride, hardness, detergents (as MBAS), fluorescence, potassium and ammonia. These parameters, and the reasons for choosing them, are discussed below. In addition to these, the following parameters were investigated due to their inclusion on the list of parameters for which municipalities must test to comply with the 1990 EPA Stormwater Regulations: pH, total chlorine, total copper and total phenol (monitoring of detergents was also required). The EPA's list applies to all types of land use areas. Some of these parameters may be useful in industrial areas, but of little use in commercial and residential areas.

Conductivity–

Conductivity can be used as an indicator of total dissolved solids. Conductivity measurements can be conducted relatively easily in the field, while total dissolved solids measurements must be made in a laboratory.

Specific conductance was judged to be a reliable and quick field indicator of general outfall contamination by Gartner Lee and Associates in Toronto (1983). Observed levels ranged from 25 to 100,000 µS/cm. Conductivity levels less than 1000 µS/cm indicated significant levels of rainwater in the drainage.

The reported range of conductivity in naturally occurring waters in the U.S. were from less than 50 µS/cm in Greenville, SC to greater than 1000 µS/cm in Los Angeles (Nalco 1979). Brussels tap water had conductivity values of about 620 µS/cm, while Brussels sewage had conductivity values of about 1,540 µS/cm (Verbanck, *et al.* 1990). The Langely Research Center, Hampton, VA, examined conductivity for tub, shower and washing machine wastewater (Hypes, *et al.* 1975):

Baseline tap water	180 µS/cm
Combined bath and laundry waters	414
Range for bath and laundry waters	174-480

Samples from 17 household septic systems in Wisconsin were collected over a two year period (Alhajjar, *et al.* 1989). The following list shows the conductivity values observed (no tap water data available):

8 households using PO_4 detergent:

Number of samples:	170
Mean:	1500 µS/cm
Range:	500-3500
Median:	1400

9 households using CO_3 detergent:

Number of samples:	187
Mean:	1100 µS/cm
Range:	500-2200
Median:	1000

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The Allen Creek Drainage study reported that 92 percent of the known improper connections to storm sewers were corrected between 1984 and 1986 (Washtenaw Co. 1984). These were all from businesses, with very few known sanitary cross-connections. The following shows the average conductivity values observed during the year immediately before and after these corrections were made, along with the control value:

Conductivity: 1984: 910 µS/cm; 1986: 687; control: 620

These conductivity values apparently reflected the decreased discharges of non-stormwater discharges into the storm sewers.

The literature indicated that differences in conductivity between clean water and wastewater sources could be substantial enough to indicate the source of dry-weather flow in storm sewerage. Conductivity can be measured quickly, easily and cheaply. For these reasons, it was selected as a parameter for further study.

Total dissolved solids –
Total dissolved solids, or TDS, is another parameter to consider in a pollutant analysis for industrial areas. However, it is recommended that conductivity measurements, conducted in the field, be used as an indicator of total dissolved solids concentrations. If more precise total dissolved solids concentrations are needed, then laboratory measurements should then be conducted.

The TDS of uncontaminated baseflows should be between 100 to 200 mg/L (or ppm). The TDS of dry-weather industrial non-stormwater discharges may be greater than 2,000 mg/L. In fact, many undiluted industrial contaminants may have TDS concentrations of 10,000 mg/L, or greater.

Fluoride–
Fluoride measurements have often been used to distinguish treated waters from natural waters. Surface waters generally contain under 0.3 mg/L fluoride, while groundwaters usually contain higher levels (Viessman and Hammer 1985). In "natural waters", monitored fluoride concentrations range from 0.06 to 3 mg/L. More than 90 percent of waters sampled throughout the U.S. by the USGS had fluoride concentrations less than 1 mg/L (Davies and DeWiest 1966).

It is common practice for communities to add fluoride to municipal waters to improve dental health. Concentrations of total fluoride in fluoride-treated tap waters are usually in the range of 1.0 to 2.5 mg/L, while concentration above 5 mg/L are detrimental (Nalco 1979). As of 1970, over 88 million people in 7,458 communities received water with a fluoride concentration adjusted to the optimal level, or had an adequate natural fluoride content (Water Atlas of the U.S. 1973). In 1992, an American Water Works Association survey found that 43% of the public water supplies derived from groundwaters and 64% of the public water supplies derived from surface waters were fluoridated (AWWA 1992). The 1975 National Interim Primary Drinking Water Regulations, U.S. EPA, recommended fluoride limits for public drinking water supplies, as follows (Viessman and Hammer 1985):

	Fluoride Ion Concentrations (mg/L)			
water temp.*	Recommended Limits			Approval
(° F)	lower	optimum	upper	Limits
50.0-53.7	0.9	1.2	1.7	1.8
53.8-58.3	0.8	1.1	1.5	1.7
58.4-63.8	0.8	1.0	1.3	1.5
63.9-70.6	0.7	0.9	1.2	1.4
70.7-79.2	0.7	0.8	1.0	1.2
79.9-90.5	0.6	0.7	0.8	1.1

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* Annual average of maximum daily air temperatures, based on temperature data obtained for a minimum of 5 years.

During the Allen Creek drainage study, the fluoride concentrations of dry-weather flows at outfalls reduced to undetectable concentrations (from previous fluoride concentrations of about 0.5 mg/L), after 92 percent of the known improper connections to storm drains were corrected (Washtenaw Co. 1988). As noted previously, very few of these improper connections were of sanitary wastewater to the storm drainage. Apparently, most of the non-stormwater discharges were treated tap water.

Fluoride measurements would be of limited use in distinguishing treated waters in areas of the country where natural waters contain fluoride near the optimal drinking water range. However, relatively few communities fall into this category, and most are in the southwest or high plains.

Fluoride should be a reliable indicator of water which has been treated for public consumption, in communities where fluoride is added to the water supply. Fluoride could therefore be used to differentiate between natural waters and tap water or sanitary wastewater. Several relatively simple procedures exist for measuring fluoride, and the Allen Creek study did not note matrix interference problems associated with wastewater samples.

Hardness--

Water hardness is caused by the divalent and trivalent metallic cations dissolved in water. In fresh water, these are primarily calcium and magnesium, although other metals such as iron, strontium and manganese may contribute to the extent that appreciable concentrations are present. Hardness is commonly reported as an equivalent concentration of calcium carbonate ($CaCO_3$). The hardness of waters varies considerably from place to place, with ground waters generally being harder (higher in concentration, as equivalent $CaCO_3$) than surface waters. Natural sources of hardness are limestones which are dissolved by percolating rainwater. In the U.S., drinking water supplies vary in hardness from near 1 mg/L as $CaCO_3$ to in excess of 180 mg/L (Sawyer and McCarty 1978). Information regarding the average hardness of tap water, as well as local ground water and surface waters, should be readily available wherever a public water supply system exists. Hypes (1975) found tub, shower and washing machine waters 25%-50% softer than the original tap water, because the addition of soap precipitates hardness-causing ions.

Hardness could be useful in distinguishing between natural waters, clean treated waters, and treated waters which have been subjected to domestic use.

Surfactants and florescence--

Detergents (surfactants) may enter water and wastewater through the discharge of aqueous wastes from household and industrial laundering and other cleaning operations. In the United States, anionic surfactants are commonly used in detergent formulations and account for approximately two-thirds of the total surfactants used.

The Langely Research Center experiment, in Hampton, Virginia, also examined surfactants (Hypes, *et al.* 1975). Average surfactant concentrations (expressed as methylene blue active substances, or MBAS), for tub, shower and washing machine wastewaters, were reported to be:

Baseline tap water:	0.3 mg/L as MBAS
Combined bath and laundry waters:	52 mg/L
Range for bath and laundry waters:	0.19-96 mg/L

Alhajjar, *et al.* (1989) measured septage system effluent, using the MBAS test. They did not find any detectable MBAS substances in the effluents. The surfactants were apparently totally degraded in the septic tanks.

During the Allen Creek drainage study, surfactants (as MBAS) decreased significantly after 92 percent of the improper non-stormwater discharges to storm sewers were corrected between 1984 and 1986 (Washtenaw Co. 1984; 1988):

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1984: 0.187 mg/L as MBAS
1986: 0.03 mg/L
1986 control: 0.02 mg/L

These non-stormwater discharges were all from business, with very few sanitary wastewater cross-connections found.

Water florescence is also an indicator of detergent residue in waters. Most detergents contain fabric whiteners which cause substantial florescence. Florescence can be measured in the laboratory, or in the field using special field fluorometers. Ecoscience, of Moscoe, Pennsylvania, markets a septic leachate detector and service that uses an instrument that is a combination specific conductance meter and fluorometer. Background lake water characteristics are compared to sample characteristics of near-shore water that is pumped to the shipboard detector for analysis. Lakeside failing septic tanks can then be identified by unusual instrument responses for adjacent lake waters. The Madison septic tank studies found that MBAS material was apparently completely degraded in septic tanks. Ecoscience obviously has found that enough florescent indicators remain after discharge from septic tanks to be readily detectable. Therefore, if septic system failures are a potential non-stormwater source of contaminants to a storm drainage system, then florescence should be used as an indicator of detergents in the water, instead of MBAS measurements.

Potassium–
In natural waters, monitored potassium concentrations ranged from 0.4 to 15 mg/L, with 80 percent of the observations less than 5 mg/L (Davies and DeWiest 1985).

Increases of potassium concentrations in sanitary wastewater, over the base concentrations in tap waters, were observed to be about 7 to 15 mg/L during a 1954 California study (Evans 1967). During a 1989 Brussels study, the tapwater potassium concentration was about 2.8 mg/L, while the sanitary wastewater potassium concentration was about 17.8 mg/L (Verbanck, *et al.* 1990). Data from a Langely Research Center experiment, in Hampton, Virginia, examined potassium concentrations in tub, shower and washing machine wastewaters, reported as follows (Hypes, *et al.* 1975):

Baseline tap water:	1.3 mg/L
Combined bath and laundry waters:	5.6 mg/L
Range for bath and laundry waters:	2.5 to 11 mg/L

Early 1958-1959 potassium concentration observations found sanitary wastewater potassium concentrations of about 6 mg/L. Settled sewage samples had potassium concentrations of about 20 mg/L (Painter 1971). Samples from 17 household septic systems in Wisconsin, collected monthly over a two year period, found the following potassium concentrations (Alhajjor, *et al.* 1989):

8 households using PO_4 detergent:

Number of samples:	26
Mean :	34 mg/L
Range:	20-121 mg/L
Median:	27 mg/L

9 households using CO_3 detergent:

Number of samples:	37
Mean:	25 mg/L
Range:	1-80 mg/L
Median:	24 mg/L

Potassium should be useful in distinguishing natural waters from waters which have been used domestically, or commercial wash waters.

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Ammonia/Ammonium–

The presence or absence of ammonia (NH_3), or ammonium ion (NH_4^+), has been commonly used as a chemical indicator for prioritizing sanitary wastewater cross-connection drainage problems. Ammonia concentrations in "natural waters" can range from 0.2 to 20 mg/L. Eighty percent of these waters sampled had concentrations less than 5 mg/L (Davies and DeWiest 1966). In Brussels, ammonium concentrations averaged less than 1 mg/L in the tap water, while the ammonium concentrations in sewage averaged 42 mg/L (Verbanck, *et al.* 1990). The U.S. mean ammonia nitrogen concentrations in septage were reported to be 160 mg/L, while the minimum reported concentration was 6 mg/L and the maximum reported concentration was 380 mg/L (Lombardo and Assoc. undated). Increases of ammonium ion (the increased sanitary wastewater concentrations, compared to tap water concentrations) were:

Calif 1954	U.S. 1958	Ohio 1964	U.S. 1964	Ill. 1967
26-48	4-45	9-27	2-20	10-37 mg/L

(as reported by Evans 1968). A 1958-1959 study reported ammonia concentrations in sanitary wastewater that ranged from 4 to 35 mg/L, with a mean of 21 mg/L. Settled sewage ammonia concentrations ranged from 41 to 53 mg/L, with a mean 46 mg/L (Painter 1971). The Langley Research Center, Hampton, Virginia, examined wastewater from showers, tubs and washing machines. The ammonia levels in these wastewaters ranged from 0.09 mg/L to 1.6 mg/L (no tap water ammonia levels were reported, but can be assumed to be close to zero) (Hypes, *et al.* 1975).

Correlations between corrections of improper sanitary wastewater cross-connections into storm drainage and reduced numbers of sewer outfalls with ammonia present were noted in Fort Worth (Falkenbury 1988). During studies in Toronto, more "problem" storm sewer outfalls had high NH_3-N values (>1 mg/L) than any other single parameter, except TKN (GLA 1983). Ammonia nitrogen concentrations ranged from less than 0.1 mg/L to 360 mg/L for 239 outfalls that were sampled. During the Huron River study, ammonia levels were found to be greater at all "problem" storm drain outfalls than at controls locations (Washentaw Co. 1988). However, the Allen Creek Drainage study reported that with 92 percent of the improper non-stormwater discharges to storm sewers corrected, the ammonia concentrations did not change significantly (all were about 0.44 mg/L). Very few of the flow corrections were sanitary sewage wastewater cross-connections (Washentaw Co. 1984; 1988).

At Inner Grays Harbor, the range of ammonia and ammonium ion (as nitrogen) found in 29 storm drain outfalls having dry-weather discharges was 0.01 to 12 mg/L, with a mean concentration of 0.175 mg/L. An outfall with a confirmed sanitary cross-connection to the storm drainage had an ammonia concentration of 0.39 mg/L (Pelletier and Determan 1988). This information indicated that ammonia should be useful in identifying sanitary wastes and distinguishing them from laundry and carwash wastes.

pH–

During 1958-1959 studies, 43 sanitary sewage samples had pH values in the range of 6.7 to 7.5, with a mean 7.2. Seven settled sewage samples had a range of 7.6 to 8.2, with a mean of 7.8 (Painter 1971). Samples from 17 household septic systems in Wisconsin, collected monthly over a two year period, had the following pH values (Alhajjar, *et al.* 1989):

8 households using PO_4 detergent system:

Number of samples:	167
Mean:	7.2
Range:	5.6-8.7
Median:	7.2

9 households using CO_3 detergent systems:

Number of samples:	188
Mean:	7.5
Range:	6.2-8.6

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Median: 7.4

During the Inner Grays Harbor study, the observed pH dry-weather flow values from 27 of 29 stormwater outfalls ranged from 6.2 to 8.0. The extreme values were 4.6 and 10.1. The mean pH value observed was 7.2 (Pelletier and Determan 1988). Only five of 200 stormwater outfalls tested during dry-weather in Fort Worth had pH values either below 6 or above 9 (Falkenbury 1988). Of 239 stormwater outfalls sampled in Toronto, 84 were judged contaminated enough to justify intensive sampling. None of the 239 were reported to have unusually acidic or caustic discharges (GLA 1983).

Contaminants in industrial non-stormwater discharges to storm sewers tend to alter the pH of unaffected baseflows by making it either more basic or more acidic. The normal pH of most uncontaminated baseflows is usually quite close to neutral (pH of 7). However, the pH at an outfall near an industrial source may vary in the range from 3 to 12. Acids and alkalis released into storm sewers by chemically-oriented industries are frequently the cause of pH fluctuations.

Industries that commonly release acidic dry-weather discharges include textile mills, pharmaceutical manufacturers, metal fabricators, as well as companies producing resins, fertilizers, pesticides, or any other similar materials. A low pH range of 3 to 5 indicates an acidic discharge. Wastes containing sulfuric, hydrochloric, or nitric acids are the most common industrial sources of acidic discharges.

Alkaline wastes cause dry weather flows to become more basic (higher pH). Many industrial alkaline wastes contain chemicals such as cyanide, sodium sulfide, and sodium hydroxide. High concentrations of these contaminants are found in discharges from soap manufacturers, textile mills, metal plating industries, steel mills, and producers of rubber or plastic.

Based on this information, pH values were expected to be of very little use in identifying inappropriate discharges in commercial/residential land use areas. Most dry-weather flows anticipated in these areas would have similar pH values, with the possible exception of cleaning operations or repair shops having metal plating operations. Anomalous pH measurements could indicate discharges from industries on the fringes of commercial/residential zones or the illegal dumping of industrial wastes from waste haulers.

Temperature–
Temperature measurements may be useful in situations where the screening activities are conducted during cold months, or in areas having industrial activity. It may be possible to identify an outfall that is grossly contaminated with sanitary wastewater or cooling water during very cold weather. Both sanitary wastewater and cooling water could substantially increase outfall discharge temperatures. Elevated baseflow temperatures (compared to baseflows at other outfalls being screened) could be an indicator of substantial contamination by these warmer source flows.

Toxicity Screening Tests–
In addition to the parameters described above, relative toxicity can be an important outfall screening parameter. Short-term toxicity tests, such as the Microtox™ test (from Microbics) are valuable for quickly and cheaply assessing the relative toxicity of different storm drain baseflows, to a selected test organism. These tests can be used to directly identify outfalls that contain flows in the most serious (toxic) category and that require immediate investigation. These tests are also very useful in identifying likely sources of toxicants to the drainage system by utilizing a toxicity reduction evaluation (TRE) procedure in the drainage system. If an outfall contains a highly toxic flow, then specific metallic and organic toxicants can be analyzed to support source identification.

Total Chlorine–
EPA regulations require testing for total chlorine. Chlorine can be present in water as free available chlorine and as combined available chlorine (usually as chloramines). Both forms can exist in the same water and be determined together as total available chlorine. Chlorine was selected as an indicator by the EPA because chlorination of public drinking water supplies is widespread, and members of the EPA evaluation team felt that chlorine measurements would be useful in virtually every community for identifying water which had been through a treatment process.

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Chlorine is not very stable in water, especially in the presence of organic compounds. Tests of clean potable water during the Birmingham demonstration project phase of this research found that total available chlorine only decreased by about 25 percent in 24-hours during an aerated bench-scale test. However, the chlorine demand of contaminated water can be very large, with chlorine concentrations decreasing to very small values after short periods of time. As an example, sheetflow samples from irrigated lawns had undetectable chlorine concentrations, even after very short (10 feet) flow paths and relatively high tap water chlorine concentrations (1.5 mg/L). Chlorine therefore cannot be used to reliably quantify flow sources because of its instability, but the presence of chlorine in baseflow waters (very unlikely) could indicate a significant and very close domestic water flow source, or industrial discharges, or illegal dumping.

Total Copper--
EPA regulations require testing for total copper. Copper was cited as the major toxic metal in urban runoff during NURP, with a median urban runoff value of 34 µg/L copper (EPA 1983). Measurement of copper levels may have merit in industrial areas, but is not expected to be of use in residential and commercial districts. Although levels of copper might be slightly elevated in wastewaters from domestic and commercial use which have come in contact with copper pipes, relatively expensive techniques would be necessary to quantify such small additions. Other suggested parameters should be able to identify water subjected to domestic use more easily and with less expense.

Total Phenol--
Phenols are industrial compounds used primarily in the production of synthetic polymers, pigments, and pesticides, and they occur naturally in fossil fuels (Viessman and Hammer 1985). Phenols are generally rather tedious and expensive to quantify. A new direct colorimetric comparator test is now available, but detection limits and precision have not been evaluated. Measurement of phenols in dry-weather flows from residential and commercial areas is not expected to provide useful illicit discharge information.

Fecal Coliform Bacteria as an Indicator of Inappropriate Discharges

During the Inner Grays Harbor study, a storm drain outfall with a confirmed domestic sewage connection was not reported to have exhibited an elevated fecal coliform level (Pelletier and Determan 1988). In the final report of the Nationwide Urban Runoff Project (NURP), it was noted that the seasonal differences noted in stormwater runoff quality did not correspond to differences in land use (EPA 1983). However, this comparison did not include dry-weather flows.

High fecal coliform bacteria populations were observed at storm sewer outfalls at all times in both industrial and residential/commercial areas during a study in Toronto (Pitt and McLean 1986). During the warm-weather storm sampling period, surface sheetflows were thought to be responsible for most of the observations of bacteria at the outfalls. However, during cold weather, very few detectable surface snowmelt sheetflow or snow pack fecal coliform observations were obtained, while the outfall observations were still quite high. High fecal coliform bacteria populations were also observed during dry-weather flow conditions at the storm sewer outfalls during both warm and cold weather. Leaking, or cross-connected, sanitary sewerage was therefore suspected at both study areas. Sump pump drainage contaminated with bacteria, or accumulated bacteria in the storm drainage sediments was not thought to be significant in these Toronto sampling areas. Contaminated sump pump water (from poorly operating septic tank systems in medium density residential areas) in the Milwaukee area, has been noted as a potentially significant source of bacteria to storm drainage systems (R. Bannerman, Wisconsin Department of Natural Resources, personal communication).

Bacteria Sources

The presence of bacteria in stormwater runoff, dry-weather flows and in urban receiving waters has caused much concern. Most of the attention has been given to fecal coliform populations and associated water quality standards. Research projects conducted in Toronto, Ontario (Pitt and McLean 1986) and in Madison, Wisconsin (Bannerman, personal communication, WI DNR) have investigated the abundance of common indicator bacteria, potential

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pathogenic bacteria, and bacterial types that may indicate the source of bacterial contamination. The monitoring efforts included sampling from residential, industrial and commercial areas.

As in many previous studies, fecal coliforms were found to commonly exceed water quality standards by large amounts. Fecal coliform populations were very large at all land uses investigated during warm weather (typical median outfall values were 10,000 to 30,000 organisms per 100 mL). Dry-weather baseflow fecal coliform populations were found to be statistically similar to the stormwater runoff populations. The cold weather fecal coliform populations were much lower, but still exceeded the water quality standards (typical median outfall values were 300 to 10,000 per 100 mL).

Samples were obtained from many potential source areas, in addition to the outfall, during the Toronto study (Pitt and McLean 1986). Source area fecal coliform populations were very similar for different land uses for the same types of areas, but different source areas within the watersheds varied significantly. Generally, roof runoff had the lowest fecal coliform populations, while roads and roadside ditches had the largest populations. Even though source area fecal coliform populations were very low during the winter, the outfall snowmelt and cold weather baseflow fecal coliform populations frequently were greater than 1000 organisms per 100 mL in areas "known" to have no sanitary sewage cross-connections.

The fecal coliform test is not specific for any one coliform type, or groups of types, but instead has an excellent positive correlation for coliform bacteria derived from the intestinal tract of warm blooded animals (Geldreich, *et al.* 1968). The fecal coliform test measures *Escherichia coli* as well as all other coliforms that can ferment lactose at 44.5 °C and are found in warm blooded fecal discharges. Geldreich (1976) found that the fecal coliform test represents over 96 percent of the coliforms derived from human feces and from 93 to 98 percent of those discharged in feces from other warm blooded animals, including livestock, poultry, cats, dogs, and rodents. Variations in specific fecal coliform bacteria biotypes are related to both fecal moisture content and diet. Moisture and diet may also affect the variety of bacteria biotypes found in the fecal coliform populations from different animal groups. In many urban runoff studies, all of the fecal coliforms were *E. coli* (Quresh and Dutka 1979). Fecal streptococci bacteria are all of the intestinal Streptococci bacteria from warm blooded animal feces (Geldreich and Kenner 1969). The types and concentrations of different bacteria biotypes varies for different animal sources. Quresh and Dutka (1979) found that pathogenic bacteria biotypes are present in urban runoff and are probably from several different sources.

Pseudomonas aeruginosa is reported to be the most abundant pathogenic bacteria organism in urban runoff and streams (Olivieri, *et al.* 1977b). This pathogen is associated with eye and ear infections and is resistant to antibiotics. They also stated that past studies have failed to show any relationships between *P. aeruginosa* concentrations in bathing waters and ear infections. However, Pseudomonas concentrations in urban runoff are at significantly greater concentrations (approximately 100 times) than the values associated with past bathing beach studies. Cabelli, *et al.* (1976) stated that *P. aeruginosa* is indigenous in approximately 15 percent of the human population. Swimmer's ear or other Pseudomonas infections may, therefore, be caused by trauma to the ear canals associated with swimming and diving, and not exposure to Pseudomonas in the bathing water.

Pseudomonas aeruginosa is expected to be the most common bacterial pathogen found in urban runoff, however, Salmonella has also been infrequently reported during urban runoff studies. Large outfall *Pseudomonas aeruginosa* populations were found during all warm weather study phases for these Madison and Toronto studies: median dry weather baseflow populations were about 2500 organisms per 100 mL and median stormwater runoff populations ranged from 2000 to 10,000 organisms per 100 mL. Cold weather observed populations were significantly less: median dry weather baseflow populations were about 50 to 100 organisms per 100 mL and median snowmelt populations were about 25 organisms per 100 mL.

The sources (nonhuman versus human) of bacteria in urban runoff is difficult to determine. Geldreich and Kenner (1969) caution against using the ratio of fecal coliform to fecal streptococci as an indicator, unless the waste stream is known to be "fresh". Unfortunately, urban runoff bacteria may have been lying on the ground for some time before rain washed it into the runoff waters. Delays may also be associated with some dry-weather bacteria sources. This

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aging process can modify the fecal coliform to fecal streptococci ratio to make the bacteria appear to be of human origin. In fact, samples collected in runoff source areas usually have the lowest FC/FS ratio in a catchment, followed by urban runoff, and finally the receiving water (Pitt 1983). This transition probably indicates an aging process and not a change in bacteria source. The best way to determine the possible source of bacteria may be to monitor for certain specific biotypes. The best biotypes to monitor may be *S. bovis, S. equinus* (only associated with nonhumans), and *S. faecalis* (the predominant human fecal streptococci).

Therefore, bacteria are usually poor indicators of the sources of dry-weather flows. Past use of fecal strep. to fecal coliform ratios to indicate human versus nonhuman bacteria sources in mixed and old wastewaters (such as most nonpoint waters) has not been successful. There may be some value in investigating specific bacteria types, such as fecal strep. biotypes, but much care needs to be taken in the analysis and interpretation of the results. A more certain indicator of human wastes may be the use of certain human-specific molecular markers, specifically the linear alkylbenzenes and fecal sterols, such as coprostanol and epicoprostanol (Eaganhouse, *et al.* 1988).

Coprostanol, and Other Organic Compounds, Utilized as Tracers of Sanitary Sewage Contamination

Neutral sterols are a class of compounds which include cholesterol and its main degradation products coprostanol, coprosterol and coprostanone. These compounds are formed in the colon by the action of microbial enzymes. Plants also produce a class of sterols called phytosterols and include campesterol, brassicasterol, stigmasterol, and b-sitosterol.

Coprostanol, a major fecal sterol in humans has been suggested as an indicator for sewage (Eaganhouse, *et al.* 1988). It has been quantified at the 75 ng level by gas chromatography/mass spectroscopy of Mercenaria mercenaria (bivalvia) taken from sewage-polluted water (Matusik, *et al.* 1988). Particulates and sediments collected from coastal areas in Spain and Cuba receiving municipal sewage loads were analyzed (Grimalt, *et al.* 1990) to determine the utility of coprostanol as a chemical marker of sewage contamination. Coprostanol can not by itself be attributed to fecal matter inputs. However, relative contributions of steroid components can be a useful indicator. When the relative concentrations of coprostanol and coprostanone are higher than their 5a epimers, or more realistically, other sterol components of background or natural occurrence, it can provide useful information. Sediment cores from Santa Monica Basin, CA and effluent from two local municipal wastewater discharges were also analyzed (Venkatesan and Kaplan 1990) for coprostanol to determine the degree of sewage addition to the sediment. Coprostanols were distributed throughout the basin sediments in association with fine particles. Some stations contained elevated levels, either due to their proximity to outfalls or because of preferential advection of fine-grained sediments. A noted decline of coprostanols relative to total sterols from outfalls seaward indicated dilution of sewage by biogenic sterols.

The range of concentrations of coprostanol found in sediments and mussels of Venice, Italy were reported by Sherwin (Sherwin, *et al.* 1993). Raw sewage is still discharged directly into the Venice lagoon. Coprostanol concentrations were determined in sediment and mussel samples from the lagoon using gas chromatography/mass spectroscopy. Samples were collected in interior canals and compared to open-bay concentrations. Sediment concentrations ranged from 0.2-41.0 mg/g (dry weight). Interior canal sediment samples averaged 16 mg/g compared to 2 mg/g found in open bay sediment samples. Total coprostanol concentrations in mussels ranged 80-620 ng/g (wet weight). No mussels were found in the four most polluted interior canal sites. Sediment samples collected from Humber River, ON, Canada and within the vicinity of the Humber sewage treatment plant were analyzed for organic compounds. Sediment organic matter samples were found to contain concentrations of coprostanol, a-tocopheryl acetate, linear-chain n-alkane hydrocarbons, and carbon and nitrogen isotopes (Coakley, *et al.* 1992). The potential for coprostanol to be used as an indicator for sewage is good when background levels, relationship to total sterol concentration, sediment advection, and possibly ionic strength of the body of water is known. Imperative is development of sensitive and selective analytical techniques which are capable of quantifying a range of sterols.

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Other chemical compounds have been utilized for sewage tracer work. Saturated hydrocarbons with 16-18 carbons, saturated hydrocarbons with 16-21 carbons and coprostanol were chosen as markers for sewage in water, particulate, and sediment samples near the Cocoa, FL domestic wastewater treatment plant. The concentration of the markers was highest at points close to the outfall pipe and diminished with distance. However the concentration of C16-C21 compounds was high at a site 800 m from the outfall indicating that these compounds were unsuitable markers for locating areas exposed to sewage plume. The concentrations for the other markers were very low at this station (Holm, *et al.* 1990). Linear alkylbenzene sulphonates (LAS) from synthetic surfactants (Terzic and Ahel 1993) which do not degrade rapidly have been utilized as markers, as well as nonionic detergents (Zoller, *et al.* 1991). LAS was quickly dispersed from wastewater outfalls except in areas where wind was calm. In these areas LAS concentration increased in freshwater but was unaffected in saline water. After time, lower alkyl groups predominated, possibly as a result of degradation or settling of longer alkyl chain compounds with sediments.

Selection of Field Parameters

Table 22 is an assessment of the usefulness of the various field survey parameters in identifying different potential non-stormwater flow sources. Natural and domestic waters should be uncontaminated (exc ept in the presence of contaminated groundwaters entering the drainage system, for example). Sanitary sewage, septage, and industrial waters can produce toxic or pathogenic conditions. The other source flows (wash and rinse waters and irrigation return flows) may cause nuisance conditions, or critically affect aquatic life.

The parameters marked with a plus sign can probably be used to identify the specific source flows by their presence. Negative signs indicate that the potential source flow probably does not contain the listed parameter, and may help confirm the presence of the source by its absence.

The list of recommended field parameters offers specific "fingerprints" that can be used to identify the flow sources. It is still necessary that local data be used to confirm these "absences and presences" and to obtain likely concentration ranges for the source flows. Knowing the concentration ranges will enable predictions of the mixture quantities to be made, as shown in the hypothetical investigative examples. Simple to complex data interpretation methods are given in Section 7 and a detailed demonstration study description, using these methods, is given in Section 11.

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TABLE 22. FIELD SURVEY PARAMETERS AND ASSOCIATED NON-STORMWATER FLOW SOURCES

Parameter	Natural Water	Potable Water	Sanitary Sewage	Septage Water	Indus. Water	Wash Water	Rinse Water	Irrig. Water
Fluorides	-	+	+	+	+/-	+	+	+
Hardness change	-	+/-	+	+	+/-	+	+	-
Surfactants	-	-	+	-	-	+	+	-
Florescence	-	-	+	+	-	+	+	-
Potassium	-	-	+	+	-	-	-	-
Ammonia	-	-	+	+	-	-	-	-
Odor	-	-	+	+	+	+/-	-	-
Color	-	-	-	-	+	-	-	-
Clarity	-	-	+	+	+	+	+/-	-
Floatables	-	-	+	-	+	+/-	+/-	-
Deposits and stains	-	-	+	-	+	+/-	+/-	-
Vegetation change	-	-	+	+	+	+/-	-	+
Structural damage	-	-	-	-	+	-	-	-
Conductivity	-	-	+	+	+	+/-	+	+
Temperature change	-	-	+/-	-	+	+/-	+/-	-
pH	-	-	-	-	+	-	-	-

Note: - implies relatively low concentration
+ implies relatively high concentration
+/- implies variable conditions

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Tracer Characteristics of Local Source Flows

Table 23 is a summary of the tracer parameter measurements found in Birmingham, Alabama. This table is a summary of the "library" that describes the tracer conditions for each potential source category. The important information shown on this table includes the median and coefficient of variation (COV) values for each tracer parameter for each source category. The COV is the ratio of the standard deviation to the mean. A low COV value indicates a much smaller spread of data compared to a data set having a large COV value. It is apparent that some of the generalized relationships shown on Table 22 did not exist during the demonstration project. This stresses the need for obtaining local data describing likely source flows.

The fluorescence values shown on Table 23 are direct measurements from the Turner™ Model 111 fluorometer having general purpose filters and lamps and at the least sensitive setting (number 1 aperture). The toxicity screening test results are expressed as the toxicity response noted after 25 minutes of exposure. The Microtox™ unit measures the light output from phosfluorescent algae. The I_{25} values are therefore the percentage light output decreases observed after 25 minutes of exposure to the sample. If an outfall sample has a very high light attenuation value, it is typically subjected to additional organic and metallic toxicant tests. Fresh potable water has a relatively high response because of the chlorine levels present. Aged, or dechlorinated, potable water has much smaller toxicity responses.

Appropriate tracers are characterized by having significantly different concentrations in flow categories that need to be distinguished. In addition, effective tracers also need low COV values within each flow category. Table 22 showed the expected changes in concentrations per category and Table 23 indicates how these expectations compared with the results of an extensive local sampling effort. The study indicated that the COV values were quite low for each category, with the exception of chlorine, which had much greater COV values. Chlorine is therefore not recommended as a quantitative tracer to estimate the flow components. Similar data must be collected in each community where these procedures are to be used. Section 6 discusses how the number of samples needed per category can be estimated.

Recommended Parameters for Measurement

Observations made during the demonstration phase of this research (reported in Section 11) included color, odor, clarity, presence of floatables and deposits, and rate of flow, in addition to the chemical measurements shown on Table 24.

TABLE 23. TRACER CONCENTRATIONS FOUND IN BIRMINGHAM, ALABAMA, WATERS (MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION, COV)

	Spring water	Treated potable water	Laundry wastewater	Sanitary wastewater	Septic tank effluent	Car wash water	Radiator flush water
Fluorescence (% scale)	6.8	4.6	1020	250	430	1200	22,000
	2.9	0.35	125	50	100	130	950
	0.43	0.08	0.12	0.20	0.23	0.11	0.04
Potassium (mg/L)	0.73	1.6	3.5	6.0	20	43	2800
	0.070	0.059	0.38	1.4	9.5	16	375
	0.10	0.04	0.11	0.23	0.47	0.37	0.13

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Ammonia	0.009	0.028	0.82	10	90	0.24	0.03
(mg/L)	0.016	0.006	0.12	3.3	40	0.066	0.01
	1.7	0.23	0.14	0.34	0.44	0.28	0.3
Fluoride	0.031	0.97	33	0.77	0.99	12	150
(mg/L)	0.027	0.014	13	0.17	0.33	2.4	24
	0.87	0.02	0.38	0.23	0.33	0.20	0.16
Toxicity	<5	47	99.9	43	99.9	99.9	99.9
(% light decrease after	n/a	20	<1	26	<1	<1	<1
25 minutes, I_{25})	n/a	0.44	n/a	0.59	n/a	n/a	n/a
Surfactants	<0.5	<0.5	27	1.5	3.1	49	15
(mg/L as MBAS)	n/a	n/a	6.7	1.2	4.8	5.1	1.6
	n/a	n/a	0.25	0.82	1.5	0.11	0.11
Hardness	240	49	14	140	235	160	50
(mg/L)	7.8	1.4	8.0	15	150	9.2	1.5
	0.03	0.03	0.57	0.11	0.64	0.06	0.03
pH	7.0	6.9	9.1	7.1	6.8	6.7	7.0
(pH units)	0.05	0.29	0.35	0.13	0.34	0.22	0.39
	0.01	0.04	0.04	0.02	0.05	0.03	0.06
Color	<1	<1	47	38	59	220	3000
(color units)	n/a	n/a	12	21	25	78	44
	n/a	n/a	0.27	0.55	0.41	0.35	0.02
Chlorine	0.003	0.88	0.40	0.014	0.013	0.070	0.03
(mg/L)	0.005	0.60	0.10	0.020	0.013	0.080	0.016
	1.6	0.68	0.26	1.4	1.0	1.1	0.52
Specific conductivity	300	110	560	420	430	485	3300
(µS/cm)	12	1.1	120	55	311	29	700
	0.04	0.01	0.21	0.13	0.72	0.06	0.22
Number of samples	10	10	10	36	9	10	10

Table 24. Parameters Selected for Investigation

Parameters Initially Selected	Additional Parameters Selected by EPA
Physical Observations Detergents Fluorescence Potassium	pH Total Chlorine Total Copper Total Phenols
Ammonia Fluoride Conductivity Hardness	

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Toxicity	

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Section 6
Experimental Design And Selection/Evaluation Of Analytical Methods

Determining Number of Observations Needed for Tracer Data Library

It is very important to determine the number of observations needed for each tracer parameter for each source category in order to build a useful data library for analyzing the outfall data. The number of samples needed is a function of the tolerable error level in the data means and the concentration variations (usually expressed as the standard deviations). The following subsections briefly describe a method that can be used to estimate the sampling effort required to develop a useful library of source flow characteristic data.

Estimating Number of Samples Needed

One equation that can be used to calculate the number of analyses needed, based on the allowable error is (Cochran 1963):

$$\text{Number of samples} = 4(\text{standard deviation})^2/(\text{allowable error})^2$$

With a 95 percent level of confidence, this relationship determines the number of samples needed to obtain a value within the range of the sample mean, plus and minus the error. Figure 3 (Pitt 1979) shows the approximate sample size needed to obtain different allowable errors for different coefficient of variance (COV) values (COV = standard deviation/mean). This is a simplified equation that doesn't consider false negatives and assumes that the data is normally distributed. A later example shows how log-normally distributed data can be transformed for use with this equation. More comprehensive experimental design equations for environmental samples can be found in Gilbert (1990) and Berthoux (1994).

The above equation can also be used to predict the 95 percent confidence interval, based on the measured (or estimated) standard deviation and number of samples obtained (again ignoring false negatives):

$$\text{Error} = 2(\text{standard deviation})/(\text{number of samples})^{0.5}$$

where the confidence interval is the mean plus and minus the calculated error value.

Determining Sample Concentration Variations

Figure 4 can be used to estimate the COV value for a parameter by knowing the 10th and 90th percentile ratios (the "range ratio"), assuming a log-normal distribution. This is used to make initial estimates for COV that are needed to calculate the approximate number of samples that actually need to be sampled and analyzed. In many cases, the approximate range of likely concentrations can be estimated for a parameter of interest. The extreme values are not well known, but the approximate 10th and 90th percentile values can be estimated with better confidence. As an example, the likely 10th and 90th percentile values of fluoride in tap water can be estimated to be about 0.7 and 1.5 mg/L, respectively. The resulting range ratio is therefore 1.5/0.7 = 2.1 and the estimated COV value is about 0.25 from Figure 4.

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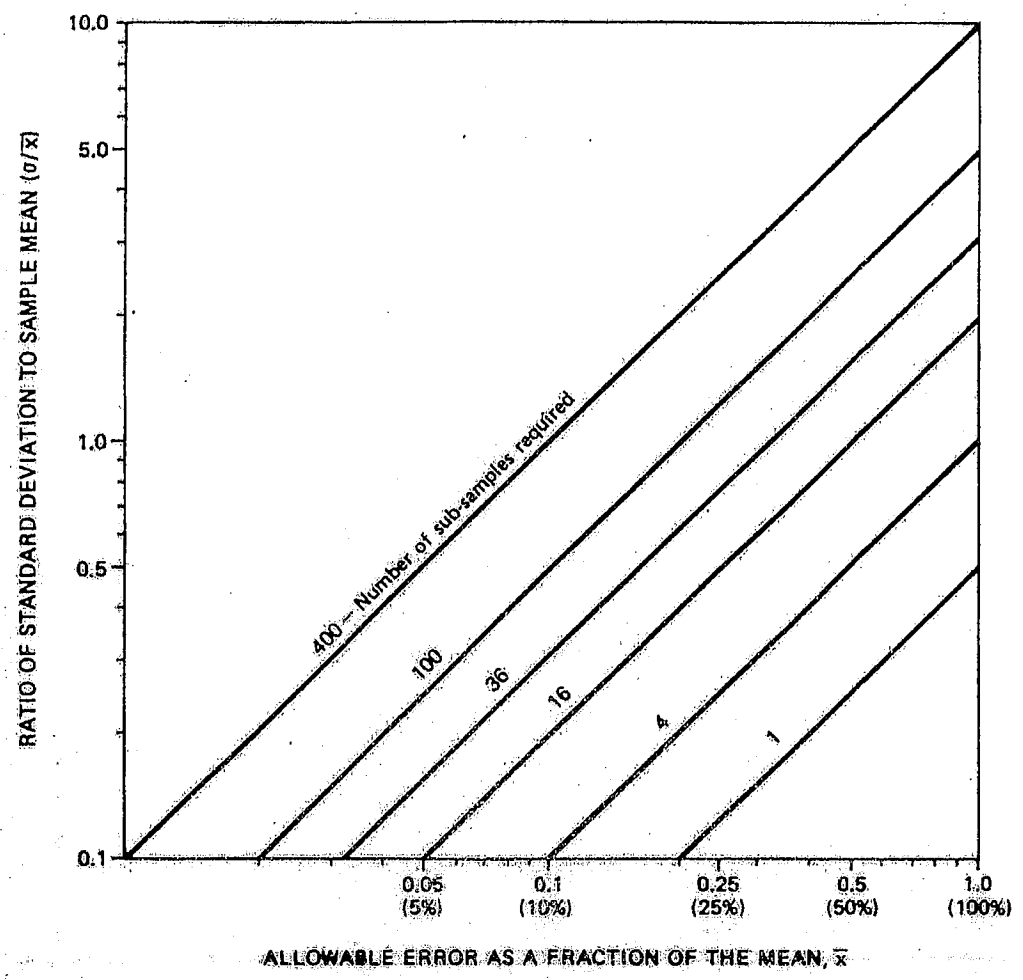

Figure 3. Required number of samples for allowable error and COV.

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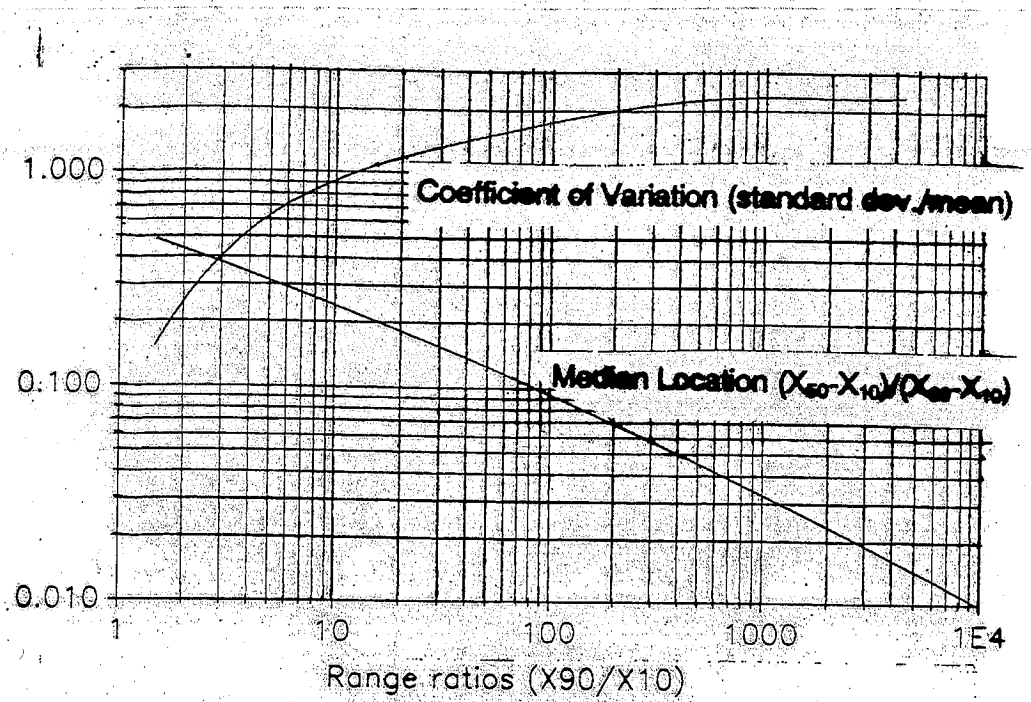

Figure 4. Relationship between data range ratios, coefficient of variation, and median values.

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Also shown on Figure 4 is an indication of the location of the median value, compared to the 10 percentile value and the range ratio. As the range ratio decreases, the median becomes close to the midpoint between the 10th and 90th percentile values. Therefore, at low COV values, the differences between normal distributions and log-normal distributions diminish. As the COV values increase, the mean values are located much closer to the 10th percentile value. In log-normal distributions, no negative concentration values are allowed, but very large positive "outliers" can occur. In the above example, the median location is about 0.4 for a range ratio of 2.1. The following calculation shows how the median value can be estimated using this "median location" value:

median location = 0.4 = $(X_{50}-X_{10})/(X_{90}-X_{10})$

therefore $X_{50}-X_{10}= 0.4(X_{90}-X_{10})$.

$(X_{90}-X_{10}) = 1.5$ mg/L - 0.7 mg/L = 0.8 mg/L.

Therefore $X_{50}-X_{10} = 0.4\ (0.8) = 0.32$ mg/L

and then, $X_{50}-X_{10} = 0.32$.

With $X_{10} = 0.7$ mg/L, $X_{50} = 0.32$ mg/L + 0.7 mg/L = 1.0 mg/L.

For comparison, the average of the 10th and 90th percentile values is 1.1 mg/L. Because these two values are quite close, the fluoride distribution is likely close to being normally distributed and the simple equation shown previously can be used to estimate the required number of samples needed.

In order to more precisely determine this value, actual water samples must be collected and analyzed. Using Figure 3, the following sampling effort may be needed for different allowable error levels (using the estimated COV value of 0.25):

Allowable Error (% of mean)	Approximate Number of Samples Needed
5%	100
10	25
25	4
50	1
100	1

Obviously, the sampling effort increases dramatically as the desired allowable error decreases.

This preliminary procedure is helpful when estimating the sampling effort needed for all parameters of interest for all source areas. As an example, it may be desirable to obtain estimates of the mean with a 25% allowable error for each parameter and each source area. This procedure can be used to estimate the minimum number of analyses that may be needed to meet this goal. After the samples are analyzed, it may be necessary to perform additional analyses from additional samples for some of the source areas to meet the goal.

Example of Log_{10} Transformations for Experimental Design Calculations

For relatively large COV values, it may be necessary to transform the data from known log-normal distributions (checked using log-normal probability paper, for example) before calculating the actual error associated with the collected data. Log-normal probability distributions are commonly used to describe the concentration distributions of

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water quality data, including stormwater data (EPA 1983). The data ranging from the 10th to 90th percentile typically can be suitably described as a normal probability distribution, after $\log_{10}$ transformations of the data. However, values less than the 10th percentile value are usually less than predicted from the log-normal probability plot, while values greater than the 90th percentile value are usually greater than predicted from the log-normal probability plot. Non-transformed water quality data do not typically fit normal probability distributions very well, except for pH (which are log transformed, by definition).

Figure 5 presents a relationship between the COV value in real space (non-transformed), as determined from Figure 4, and the standard deviation of $\log_{10}$ transformed data. Knowing the $\log_{10}$ transformed standard deviation values enables certain statistical experimental design features to be determined. The most significant feature is determining the number of observations needed to enable the data to be described with a specific error level. It can also be used to calculate the error associated with any observation, based on the assumed population distribution characteristics and the number of observations.

As an example, consider a tracer having a COV of 0.23 and a median value of 0.14. The resulting $\log_{10}$ transformed standard deviation would be about 0.12. For ten samples, the resulting 95 percent confidence range of the median observation (0.14 mg/L) is:

$$\text{Error} = 2(0.12)/(10)^{0.5} = 0.076 \text{ in } \log_{10} \text{ space}$$

The confidence interval is therefore $\log_{10}(0.14)$ +/- 0.076, which is -0.778 to -0.930 in $\log_{10}$ space. This results in a conventional 95 percent confidence range of $10^{-0.930}$ (= 0.12) to $10^{-0.778}$ (= 0.17). The absolute value for the error in the estimate of the median value is therefore between 14% (100x(0.14-0.12)/0.14) and 21% (100x(0.17-0.14)/0.14) for ten samples. If the original untransformed data were used, the error associated with 10 samples is 15%, within the range of the estimate after log transformations. These results are close because of the low COV value (0.23). If the COV value is large, the need for log transformations increases.

The COV value in the above example (0.23) was close to the typical COV value for all of the source categories and tracer parameters found in the Birmingham test, as shown on Table 23 in Section 5. About 10 samples per source flow category should generally result in less than a 25% error for the mean values obtained.

As shown in a later subsection, narrow confidence intervals are needed for useful tracer parameters in order to estimate the relative mixes of the non-stormwater sources as measured at the outfall. Therefore, much care needs to be taken in order to estimate the characteristics of the potential non-stormwater flow sources, especially the COV values and means.

Understanding the mechanisms affecting the non-stormwater sources (such as time of day, season, area of town, type and magnitude of land use activities, etc.) and obtaining a relatively large data base library for the source flow tracer concentrations is very important and should be a significant portion of a dry-weather flow source identification project.

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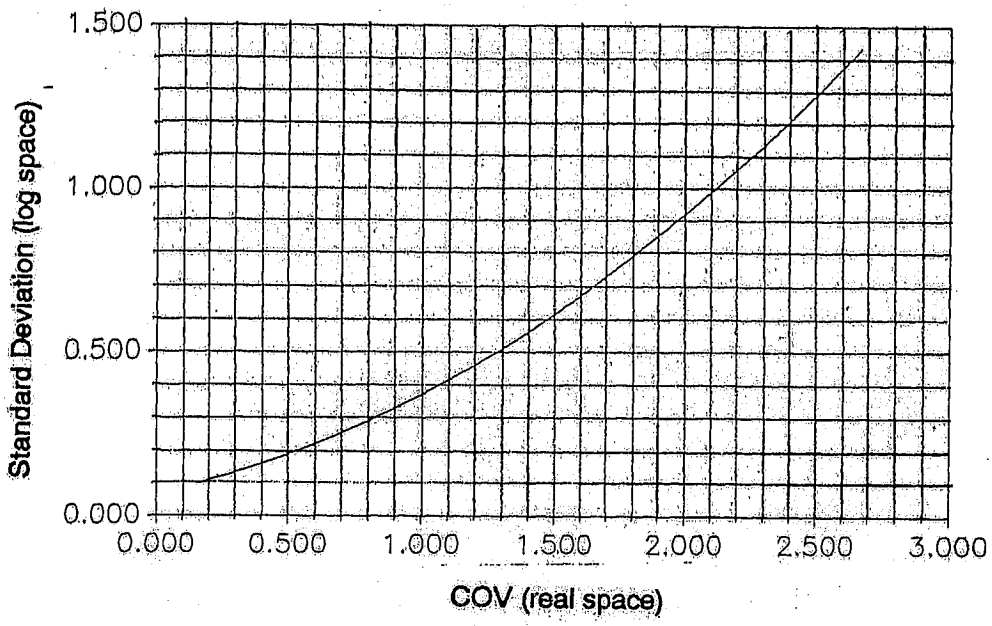

Figure 5. Relationship between standard deviations (log_{10} space) and coefficient of variation (real space).

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Selection of Analytical Methods

The selection of the analytical procedure to be used is dependent on a number of factors, including (in order of importance):

- appropriate detection limits
- freedom from interferences
- good analytical precision (repeatability)
- low cost and good durability
- minimal operator training required

The following subsections discuss these requirements and present the recommended analytical procedures. Tracer characteristics in likely local source flows affect most of these requirements. Therefore, the suggested analytical procedures may not be the most cost-effective for all areas.

Detection Limit Requirements

In order to identify potential non-stormwater sources, it is necessary to have a basic knowledge about each potential source flow component. As shown above, a significant sampling and analysis effort is needed to develop a library of source area flow tracer concentrations. This subsection will show how the COV values and means of the tracer concentrations can be used to estimate the needed detection limits of the analytical procedures.

There are a number of different types of detection limits defined for laboratory use. Most instrument manufactures present a minimum readable value as the instrument detection limit (IDL) in their specifications for simple test kits. The usual definition of IDL, however, is a concentration that produces a signal to noise ratio of five. The method detection limit (MDL) is a more conservative value and is established for the complete preparation and analysis procedure. The practical quantification limit (PQL) is higher yet and is defined as a routinely achievable detection limit with a relatively good certainty that any reported value is reliable. *Standard Methods* (APHA, *et al.* 1989) estimates that the relationship between these detection limits is approximately: IDL:MDL:PQL = 1:4:20. Therefore, the detection limit shown in much of the manufacturer's literature is much less than what would be used by most analytical laboratories.

Because of the screening nature of the outfall field surveys, the instrument detection capabilities are appropriate for the methodology described in this report. The larger uncontrollable errors associated with obtaining representative outfall samples and in the variations of the tracer concentrations in the potential source flows would tend to diminish the significance of errors associated with reading concentration values from the instrument that are lower than the PQL.

A quick (and conservative) estimate of the needed detection limit can be made by only knowing the median concentration and the concentration variation of the tracer in the least contaminated component flow. Any amount of another component having a greater tracer concentration will increase the tracer concentration of the mixture. By ignoring this increase, minimum detection limits can be estimated based on the numerous probability calculations presented in Appendix B:

COV value:	Multiplier for detection limit:
<0.5 (low)	0.8
0.5 to 1.25 (medium)	0.23
>1.25 (high)	0.12

As an example, if the baseflow tracer has a low COV (<0.5), then the estimated required detection limit is about 0.8 times the median tracer concentration.

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More than 80% of the library categories (source flows and tracers) examined in Birmingham, Alabama, during the demonstration of these procedures (shown on Table 23 in Section 5 and described in detail in Section 11) had low COV values. About 15% had medium COV values, and about 5% had high COV values. As an example, free available chlorine had medium or high COV values for almost all source categories. This is a major reason why chlorine should not be used quantitatively to identify source flow components in outfall samples. Chlorine is used in a similar manner as the aesthetic parameters (e.g. turbidity or odor). If high chlorine concentrations are found at the outfall (greater than about 0.5 mg/L), then a major treated potable water leak is likely associated with the dry-weather flow.

Table 25 lists the detection limit requirements for the tracer parameter concentrations found during the Birmingham, Alabama, demonstration project. The recommended analytical methods satisfy most of the required detection limits, except for ammonia and surfactants in spring water and surfactants in potable water. The spring water ammonia concentrations were about equal to the detection limit, but because the variation in the ammonia concentrations were so large, a much lower detection limit would be preferable.

Monte Carlo tests (using the microcomputer program PRISM, version 2.01, from Palisade Corporation, Newfield, NY) were used to examine the sensitivity of different concentration characteristics (10 to 90 percentile range) and mixtures on detection limits. These data can be compared to detection limits available for different analysis methods that can be used in the field (Appendix A).

Figures were prepared showing the required detection limits for different mixtures at different detection probabilities. If the median concentrations of two components of a mixture are close, and their concentration variabilities are large, it is very difficult to detect small portions of one component of the mixture with much significance, even if the equipment detection limit is very good. This situation would require the use of another tracer parameter to calculate the mixture sources.

Figures 6 through 9 are probability plots showing the required analytical detection limits for mixtures of two source area flows both having low COV values (similar to the majority of expected conditions). Appendix B contains similar plots for all possible combinations of COV values. Table 26 is an index of the 72 Appendix B figures for the different median concentration ratios and variabilities examined. In order to use these figures, an estimate of the median concentrations and variations associated with the mixture components must be made.

The Appendix B figures show four curves corresponding to four mixtures. PER100 is for a 100% solution of the flow having the higher tracer concentration, PER50 is for a solution having 50% each of two components, PER15 is for a solution of 15% of the component having the higher tracer concentration and 85% of the component having the lower tracer concentration, while PER0 is a solution only made of the component having the lower tracer concentration. Figure 6 is for two components that have mean concentrations differing by 1.33 times, Figure 7 is for a mixture where the component mean concentrations differ by five times, Figure 8 is for two components with mean concentrations differing by 20 times, and Figure 9 is for two components with mean concentrations differing by 75 times. Each figure shows the detection limits, relative to the lower base concentrations, for different probability of detection values. The detection limits required are reduced significantly as the means of the tracer components differ by greater amounts, especially for low probabilities of detection.

For example, if the two tracer mean concentrations vary by about five times (such as for treated potable water and sanitary wastewater potassium concentrations, as shown on Table 23) and a mixture of 15% sanitary wastewater and 85% potable water needs to be identified with a 90% probability of detection, the required detection limit would be about:

1.4 [factor from Figure 7] x 1.6 mg/L [potassium of treated water, from Table 23] = 2.2 mg/L.

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TABLE 25. DETECTION LIMIT REQUIREMENTS

Tracer Parameter and units	Median Conc. of Least Contaminated Sources: median (COV)	Required Detection Limit	Available Detection Limit
Fluorescence % of full scale	Potable water: 4.6 (0.08) Spring water: 6.8 (0.43)	3.7 5.4	0.1
Potassium mg/L	Spring water: 0.73 (0.10) Potable water: 1.6 (0.04)	0.58 1.3	0.01
Ammonia mg/L	Spring water: 0.01 (1.7) Potable and radiator water: 0.03 (0.23)	0.001 0.024	0.01
Fluoride mg/L	Spring water: 0.031 (0.87) Sanitary wastewater: 0.77 (0.23)	0.01 0.62	0.01
Surfactants mg/L as MBAS	Spring and potable water: <1 Sanitary wastewater: 1.5 (0.82)	- 0.35	0.01
Hardness mg/L as $CaCO_3$	Laundry water: 14 (0.57) Potable and radiator water: 49 (0.03)	3.2 39	1
Color HACH™ color units	Spring and potable water: <1 Sanitary wastewater: 38 (0.55)	- 8.7	1
Specific conductivity µS/cm	Potable water: 110 (0.01) Spring water: 300 (0.04)	88 240	10

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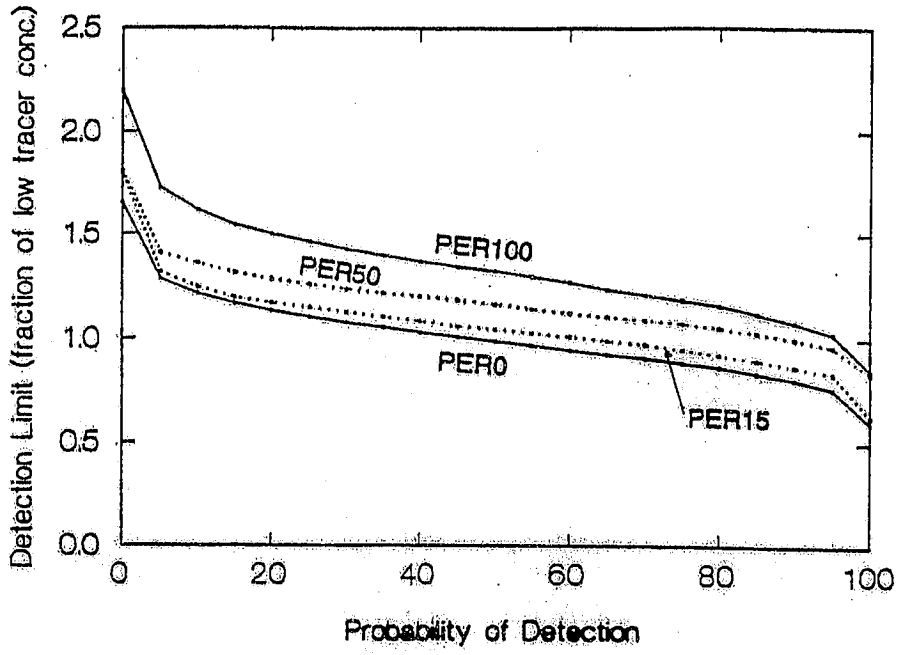

Figure 6. Required detection limits for low COV mixture components having means differing by 1.3 times.

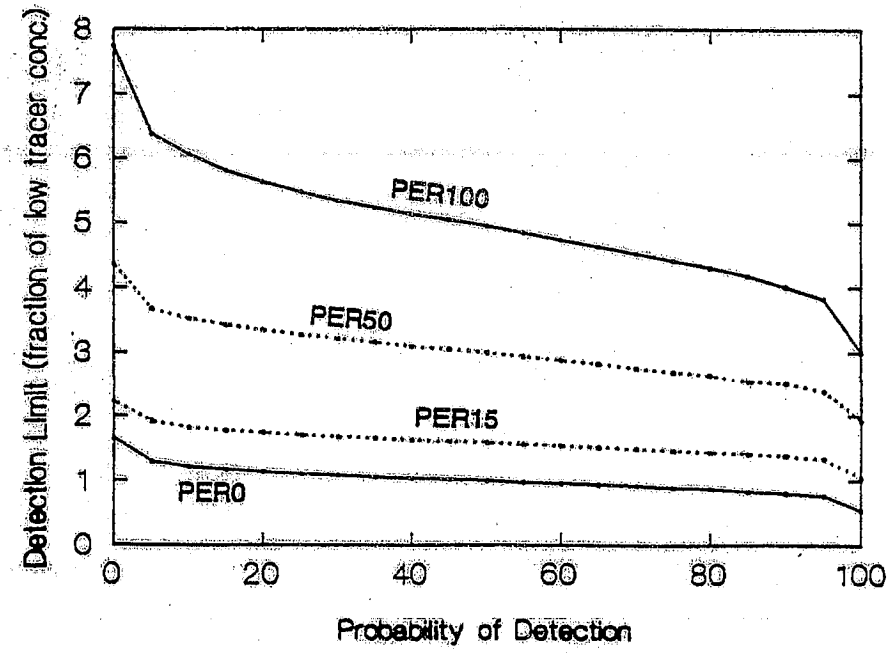

Figure 7. Required detection limits for low COV mixture components having means differing by 5 times.

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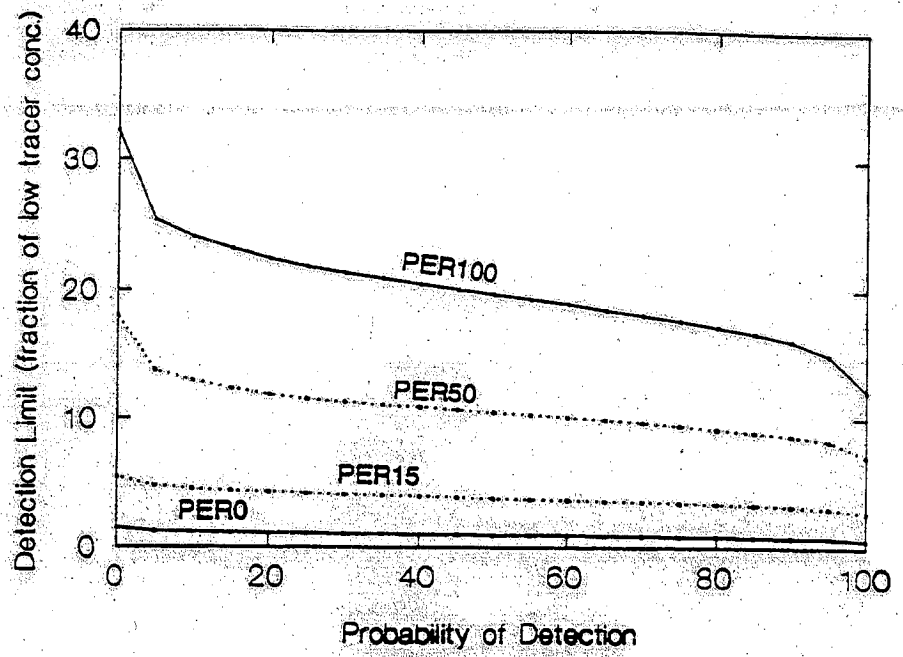

Figure 8. Required detection limits for low COV mixture components having means differing by 20 times.

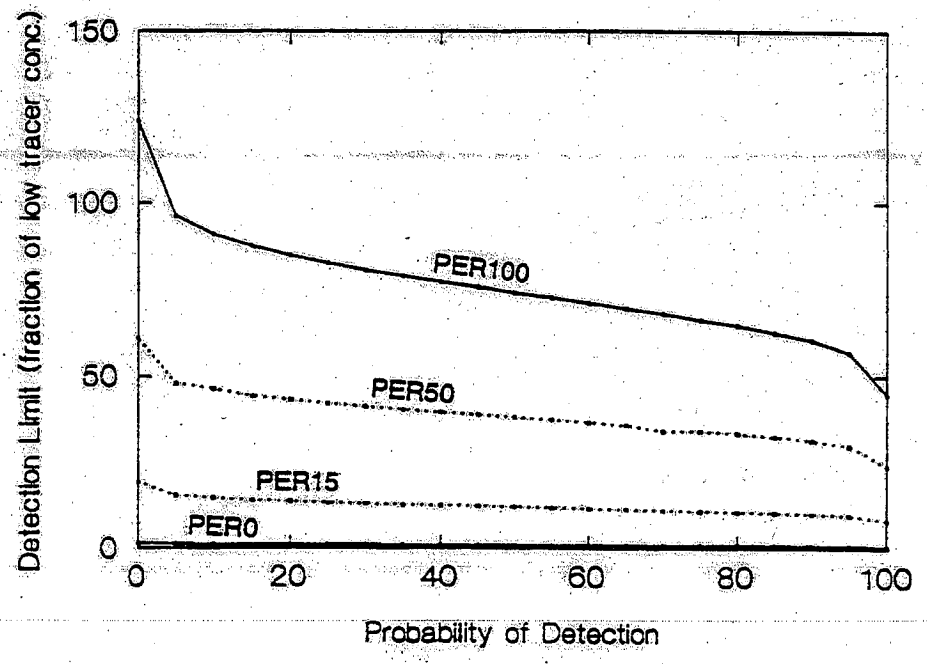

Figure 9. Required detection limits for low COV mixture components having means differing by 20 times.

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TABLE 26. INDEX FOR PROBABILITY PLOTS (APPENDIX B FIGURE NUMBERS)

Contaminent/ Base concen. Ratio	Baseflow Tracer Variability - Contaminated Flow Tracer Variability								
	L-L	L-M	L-H	M-L	M-M	M-H	H-L	H-M	H-H
1.33	1	2	3	4	5	6	7	8	9
2.14	10	11	12	13	14	15	16	17	18
2.86	19	20	21	22	23	24	25	26	27
5	28	29	30	31	32	33	34	35	36
7	37	38	39	40	41	42	43	44	45
20	46	47	48	49	50	51	52	53	54
35	55	56	57	58	59	60	61	62	63
75	64	65	66	67	68	69	70	71	72

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The more conservative approach, stated previously, would result in a minimum detection limit of:

0.8 [factor for COV < 0.5] x 1.6 mg/L = 1.2 mg/L.

Even with the above analytical requirements satisfied, it may still be difficult to precisely estimate the degree of contamination, especially for low contamination levels and for high COVs. The tracer concentrations in the contaminating source flows must be much greater than the tracer concentrations in the cleaner baseflows when detecting small contaminating flow components. The list below shows (for 90% confidence levels and low COV values) the increasing tracer concentration requirements for the contaminating flows (compared to the cleaner baseflows) when trying to detect small amounts of contamination. The differences in tracer concentrations would be even greater for higher COV conditions.

Percent of Source Flow Contamination:	Required Concentration Ratios (for low COV values):
1%	50
5	10
10	7
25	3
35	1.5
50	1.2

As an example, the median tracer concentration in the contaminated flow must be about 10 times greater than the median tracer concentration in the cleaner baseflow to detect a five percent contamination level. If the tracer COV values are "medium" or "high", then the required concentration differences are much greater (up to 250 times difference in concentrations may be required). Few tracers exhibit such a wide range in characteristics between flow categories.

Therefore, the differences in tracer concentrations must be quite large, and the concentration variations quite small, in order to have confident estimates of low levels of contamination. This is the main reason why the use of multiple tracers for different flow categories is important. Some tracers may not uniformly produce good estimates of contamination levels, but the use of redundant tracers for the same decision (such as ammonia and potassium to identify sanitary wastewater; fluorides and hardness to identify treated potable water; and surfactants and fluorescence to identify wash waters) and good estimates of local contaminant characteristics, will minimize these errors.

The actual minimum mixture level of contamination that would be detectable would also be dependent on the analytical precision, as discussed next.

Required Sample Analytical Precision

The repeatability of the analytical method is another important consideration in its selection. Precision, as defined in *Standard Methods* (APHA, *et al.* 1989), is a measure of the closeness with which multiple analyses of a given sample agree with each other. It is determined by repeated analyses of a stable standard, conducting replicate analyses on the samples, or by analyzing known standard additions to samples. Precision is expressed as the standard deviation of the multiple analysis results.

Figure 10 is a summary of the probability plots contained in Appendix B and indicates the needed analytical precision (repeatability) as a fraction of the median tracer concentration to resolve one percent contamination levels at a 90 percent confidence level. This figure was developed for COV values of the tracer parameters in the contaminating

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flows ranging from 0.16 to 1.67, and indicates the needed analytical precision (as a fraction of the baseflow tracer concentration) to resolve one percent contamination levels at a 90 percent confidence level. This figure was developed for contamination levels between zero and 15 percent. If the analytical precision is worse than these required values, then small contamination levels may not be detected. Therefore, even with adequate analytical detection limits, poor analytical precision may not allow adequate identification of low levels of contamination. In many cases, it is expected that a contamination level of just a few percent can cause significant toxic and pathogenic problems. Examples include gasoline spills, direct connections of raw sanitary wastewater, and metal plating bath wastewaters.

If the tracer concentrations of the flow components are close in value and the variation of the concentrations are high, then it will be very difficult to adequately separate flow components. In contrast, if the tracer concentrations of the flow components are widely different and have low variabilities, then much smaller levels of contamination could be detectable. As an example, if the median contaminant tracer concentrations differ by a factor of 10 in two flow components, but have high concentration variations (high COV values), a precision of between 0.015 to 0.03 of the lower baseflow median tracer concentration is needed, for each percent contamination that needs to be detected. If the median tracer concentration in the cleaner baseflow is 0.15 mg/L (with a corresponding tracer median concentration of 10 times this amount, or 1.5 mg/L, in the contaminating source flow), then the required analytical precision is about 0.015 X 0.15 = 0.002 mg/L to 0.03 X 0.15 = 0.005 mg/L per one percent contamination detection. If at least five percent contamination is needed to be detected, then the minimum precision would have to be 5 X 0.002 = 0.01 mg/L.

The conservative method noted previously can be used to estimate the detection limit requirements for the above example:

- low COV in the cleaner baseflow: 0.8 X 0.15 mg/L = 0.12 mg/L
- medium COV in the cleaner baseflow: 0.23 X 0.15 mg/L = 0.035 mg/L
- high COV in the cleaner baseflow: 0.12 X 0.15 mg/L = 0.018 mg/L.

The required analytical precision would therefore be about one-half of the lowest detection limit needed, and about 1/12 of the largest estimated required detection limit.

By examining the probability plots in Appendix B, it was possible to calculate the margin between the estimated detection limits (for zero percent contamination) and the concentrations associated with a ten percent chance that the concentrations would actually be greater than assumed. The ratios of the tracer concentrations in the contaminated flows to the tracer concentrations in the baseflows must increase as the desired contamination levels for detection decrease, as shown on Table 27 (for ten percent frequencies of errors). As an example, for low variations of the tracer in the baseflow, the median tracer concentration in the contaminated flow must be about 50 times greater than the median tracer concentration in the baseflow. If the range ratio of the tracer in the contaminated flow is 10 (a medium variation), then the contaminated flow concentration must be about 150 times the median tracer concentration in the baseflow. Therefore, the differences in tracer concentrations must be quite large, and the concentration variations quite small, in order to have confident estimates of lower levels of contamination. Again, redundant tracer parameters and data analysis methods minimize these problems.

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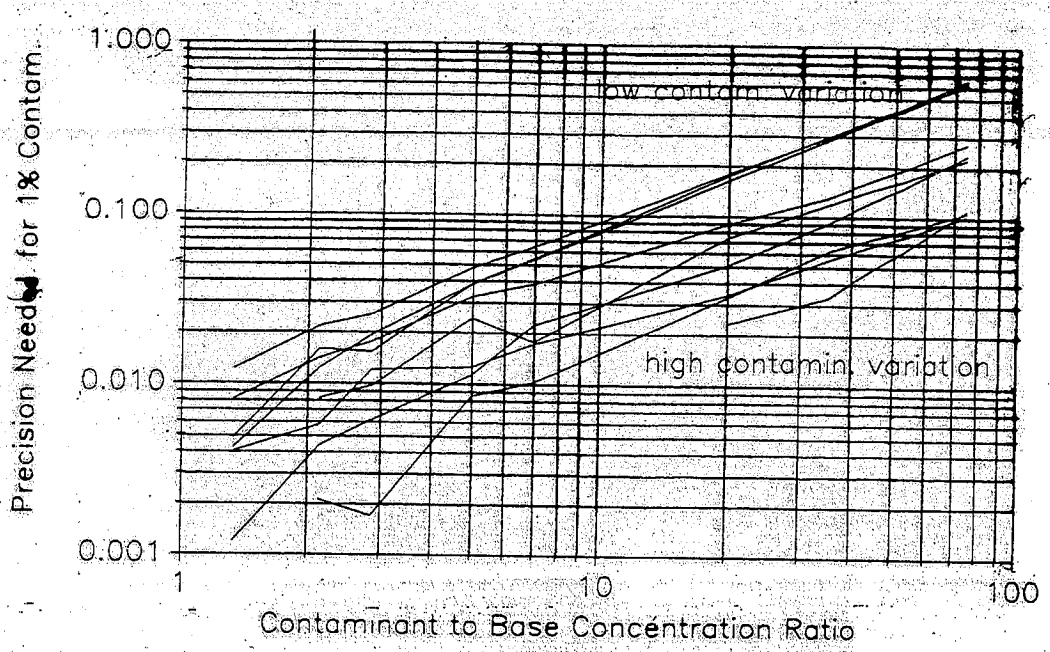

Figure 10. Analysis precision needed for detection of one percent contamination at ninety percent confidence.

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TABLE 27. ALLOWABLE CONTAMINATION MIXTURES FOR DETECTION FOR VARIOUS TRACER VARIATION LEVELS

Required Tracer Concentration in Contaminated Flow, Compared to Baseflow (for Less Than a Ten Percent Frequency of Error):

Contamination Mixture to be Identified	Low Tracer Variation in Baseflow and Tracer Variation in Contaminated Flow:			Medium and High Tracer Variation in Baseflow and Tracer Variation in Contaminated Flow		
	L	M	H	L	M	H
1%	50*	150	300	1,000	>>1,000	>>1,000
5%	10	40	60	50	150	250
10%	7	15	35	25	70	150
25%	3	6	10	10	25	60
35%	1.5	4	7	7	20	50
50%	1.2	2	4	5	15	35

*Example: The tracer concentration in the "contaminated flow" component must be at least 50 times the tracer concentration in the "baseflow" component of the mixture. This would allow a mixture containing at least one percent of the contaminated flow to be identified, with less than a ten percent error frequency.

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Evaluation of Analytical Methods

Analytical methods for the parameters used in this research were selected from a group of methods which had been initially identified with expense, portability and ease of use in mind. Interferences, detection limits, and accuracy (precision and bias) influenced the final selection. The following procedures were used in this selection process.

Initially, dry-weather flows were sampled at 12 locations from a grass swale drainage system serving a residential area containing septic tanks. Samples were obtained during an excessively dry summer period. Each of these 12 samples was analyzed using the entire group of representative methods which had been identified for each of the tracer parameters of interest. Analytical methods tested using these 12 samples are listed in Table 28.

In addition, four representative samples from this area were further examined using standard addition methods (known amounts of standards were added to each sample, and results were then compared to unaltered samples), to identify matrix interference problems. Analysis methods were also tested against a series of standard solutions to identify detection limits and repeatability. A discussion of analytical methods considered and selected follows.

Results of Comparison Tests of Analytical Procedures

Conductivity–

Conductivity is quickly and easily measured in the field using a dual dedicated (temperature/conductivity) meter. A YSI conductivity meter, model 33, was used. Both specific conductivity and temperature must be calibrated against standard specific conductivity solutions and a standard thermometer. Specific conductivity should also be corrected to standard values obtained at 25°C (APHA, *et al.* 1989):

$$K = (K_m C)/[1+0.0191(t-25)]$$

where K = specific conductivity at 25°C
K_m = measured specific conductivity at temperature t°C
and C = cell constant

The cell constant is a correction factor determined by measuring a 0.01M KCl solution at 25°C, after three rinses, compared to 1413 µS/cm, the expected value. This equation results in about a 2% change in specific conductivity for every degree in temperature difference from 25°C. The SI specific conductivity unit of measurement is the µS/cm which is numerically equivalent to the U.S. Customary unit, µmhos/cm.

Fluoride–

An ion selective electrode (ISE) with millivolt meter and a spectrophotometric method (utilizing the SPADNS method without distillation) were tested. Fluorides are easily detected using a field spectrophotometer (HACH DR/2000) and evacuated reagent and sample vessels (AccuVac). The AccuVac procedure works well for samples with concentrations of less than 2.5 mg/L fluoride. Higher concentrations of fluoride require sample dilution because of non-linear responses. Standard addition tests showed error levels at or below 5%. Multiple measurements of fluoride standards resulted in a standard deviation of 0.02 mg/L (coefficient of variation 0.02). Resolution (the level of detail, or significant figures achievable) for this method was 0.01 mg/L.

Ion selective electrode membranes fouled quickly in wastewater and had to be changed often (after 5 to 10 samples). Again, error levels were at, or below, 5%. However, use of the spectrophotometer was chosen due to the inconvenience and cost of frequent membrane replacement with the ISE method.

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TABLE 28. ANALYTICAL PROCEDURES INVESTIGATED

Parameter	Analysis Method
Conductivity & Temperature	YSI Conductivity Meter (Model 33)
Fluoride	HACH Ion Specific Electrode (ISE) HACH DR/2000 Spectrophotometer (AccuVac: SPADNS Method)
Hardness	HACH DR/2000 Spectrophotometer (Calmagite Method) HACH Field Titration Kit (EDTA Titration) Quant Test Strips
Detergents	HACH Detergent Test Kit (MBAS Colorimetric) Orion Surfactants Kit (ISE)
Fluorescence	Turner Filter Fluorometer (Model 111)
Potassium	HACH DR/2000 Spectrophotometer (Tetraphenylborate Method) HACH ISE Flame Atomic Absorption
Ammonia	HACH DR/20000 Spectrophotometer (Nessler Method - direct) HACH ISE Quant Test Strips Hanna Field Test Kit Chemet Field Test Kit
Color	HACH Color Kit
Toxicity	Microtox™ (Microbics, Inc.)
pH	Fisher Accument Model 610A Test Strips
Total Chlorine	HACH DR/2000 Spectrophotometer (AccuVac: DPD Method) HACH Titration Quant Test Strips
Total Copper	HACH DR/2000 Spectrophotometer (AccuVac: Bicinchonianate Method) Quant Test Strips Chemet Field Test Kit
Total Phenols	HACH Colorimetric Method

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Hardness–
A digital titration kit, test strips, and a spectrophotometric method were tested. The HACH digital titration kit has a suitable range, was easy to use, and standard addition techniques revealed errors of less than 2.5%. A standard deviation of 0.02 mg/L (coefficient of variation 0.0002) as $CaCO_3$ was obtained, and the resolution of this method was 1 mg/L. The range for the spectrophotometric technique proved to be much too low for the samples being studied. Test strips identified hardness within a relatively wide range only, and were therefore not specific enough for this application. However, the hardness test paper can be used to estimate the titration end point. The HACH digital titration kit was selected for use.

Detergents–
A comparative colorimetric method and titration in combination with an ion selective electrode (ISE) were tested. Although sample dilution was sometimes necessary, the HACH comparative color detergent test kit proved much easier to use and was more sensitive than the ion selective surfactant electrode, which required prior knowledge of the expected sample range in order to select an appropriate concentration of titrant. The comparative colorimetric procedure must be carried out under a laboratory fume hood. Tests on standards revealed a standard deviation of 0.02 mg/L (coefficient of variation 0.03) MBAS using the comparative colorimetric method. The resolution of this method was 0.01 mg/L.

Fluorescence–
A Turner Filter Fluorometer (Model 111) was used to measure relative fluorescence. The repeatability was determined to be ± 2% of full scale (3.5 ppb as Rhodamine WT). General purpose filters (#546 primary filter and #590 secondary filter) and lamp (G4T4/1) were used to be most sensitive to detergent fluorescence, and dilutions of Intracid Rhodamine WT liquid (Compton and Knowles, Reading, PA) were tested as a reference. For the smallest aperture (slit 1x, the least sensitive position), the following equation relating % scale and ppb Rhodamine WT dye (standard 20% stock solution) was found:

$$\text{ppb Rhodamine WT} = 0.975 + 1.271\ (\text{percent scale reading})$$

Potassium–
Ion selective electrode, spectrophotometric, and flame atomic absorption methods were tested. During standard addition tests, the HACH tetraphenylborate spectrophotometric method yielded errors at or below 8% and was quite easy to use. A standard deviation of 0.13 mg/L K (coefficient of variation 0.03) was obtained. The resolution for this method was 0.01 mg/L. Flame atomic absorption resulted in smaller errors, but is a more costly technique. A specific-ion probe was also evaluated, but was not chosen because of rapid membrane fouling, long analysis times and inconsistent results. Error levels with standard additions were as high as 50% using the ion probe method.

Ammonia–
Ion specific electrode, spectrophotometric, and test strip methods were evaluated. Ammonia can be easily measured in the laboratory using a direct Nesslerization procedure and a spectrophotometer (HACH DR/2000). The standard deviation for this method was found to be 0.038 mg/L ammonia, and the resolution was 0.01 mg/L.

Errors and standard deviation were unacceptably high using a simpler salicylate spectrophotometric technique. The use of various indicator test papers for ammonia determination gave poor results and had insufficient resolution. As before, specific ion probe membranes fouled quickly in wastewater and gave inconsistent results. Typical problems encountered for other ammonia field test kit procedures, except for the direct Nesslerization procedure, were color interferences, long analysis times, inconsistent results, and poor performance when standard solutions were analyzed.

A006299

pH–
An accurately calibrated pH meter was used to measure pH on fresh samples in the laboratory. Measurements using pH test paper were found to be within one unit of the laboratory meter, but this difference was too large. The resolution and standard deviation of the Fisher Accumet Model 610A pH meter used was 0.01 pH unit.

Small "pen" pH meters most suitable for field use can easily be off by a 0.5 pH unit and are relatively hard to calibrate. They accordingly must be used with care.

Total Chlorine–
Titration (utilizing a digital titrator), a spectrophotometric method and test strip methods were evaluated. The DPD spectrophotometric method (HACH DR/2000 and AccuVac) proved to be the method of choice. The resolution was 0.01 mg/L using this method, and the standard deviation was found to be 0.02 mg/L (coefficient of variation was 0.05). Digital titration with phenylarsine oxide only provided 1 mg/L resolution, which is insufficient for this application. Test strips also had insufficient resolution.

Total Copper–
Test strip and spectrophotometric methods were tested. The bicinchoninate spectrophotometric method (HACH DR/2000 with AccuVac) provided a resolution of 0.01 mg/L copper, with a standard deviation of 0.009 mg/L (coefficient of variation 0.009). The resolution and detection limits provided by test strips were not sufficient.

Total Phenols–
A new direct colorimetric technique developed by HACH specifically for stormwater testing was used to measure total phenols. This technique is based on the 4-aminoantipyrine method and has a range of 0 to 5 mg/L phenol with a resolution of 0.1 mg/L. Repeatability was found to be within 0.2 mg/L.

Color–
Color was quantified using a simple colorimetric comp arator with a resolution of 1 unit (HACH). The apparent color is measured in APHA Platinum Cobalt Units.

Toxicity–
The Microtox™ (Microbics, Inc.) screening test was evaluated for use as an indicator of relative baseflow toxicity. Microtox is relatively easy and inexpensive, as bioassays go, and it was hoped that this test might be an efficient indicator of general outfall contamination, identifying outfalls requiring further investigation, and eliminating the need for other tests.

The Microtox procedure utilizes a luminescent marine bacteria, *Photobacterium phosphoreum.* The living microorganisms emit light as a product of their metabolic processes. Any change in those processes, caused by exposure to a toxic test sample, causes a decrease in light output. Reduction of the light is proportional to the toxicity of the sample. Toxicity values reported in this research reflect the percent reduction in light emitted by the test organisms in a sample matrix, as compared to a control organism mixture, after 25 minutes of exposure (I25).

The Microtox Analyzer is a temperature-controlled photometer that brings test organisms and samples to standard temperatures, and measures the light output of the microorganisms under controlled test conditions. Test results demonstrate an average coefficient of variation of 0.16. Good repeatability (precision) and good sensitivity allows small changes in toxicity to be noted.

Toxicity screening tests have been found to be very useful as indicators of contamination of storm drains. The Microtox™ (from Microbics) toxicity-screening test can be used for relative toxicity values. The 100 percent screening test was most commonly used. If the light output decrease after 25 minutes (the I_{25} value) was greater than 50 percent, then the standard Microtox test was used to determine the sample dilution required for a 50 percent light decrease (the EC50 value). If a sample results in a large toxic response, then specific toxicant analyses (organics and metals) could be performed to better identify the toxicant source. In general, the Microtox™ screening test was found

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to be an efficient method for toxicity analysis, particularly for identifying samples requiring further analyses. (A number of simple test kits were used for specific heavy metal analyses, but with very poor results. High-detection limits and interferences make these methods impractical, unless an outfall is grossly contaminated with a concentrated source, such as raw plating bath wastewater.)

Results of Dilution Studies

After suitable analytical methods were identified, mixtures of some potential contaminating flow sources and local spring waters were prepared and analyzed in order to determine functional limitations of procedures when trying to identify small levels of contamination. Mixtures of sanitary sewage, septage, and plating bath waters with spring water were prepared in the following percentages: 0, 0.1, 1, 5, 10, 25, 50, 75, 90, 99, 99.9, and 100. These wastewaters were chosen because they were readily available and were thought to represent extremes, in terms of pathogenicity and toxicity, of wastewaters likely to be encountered in dry-weather flow. One liter of each mixture was prepared.

Results from the sewage dilution study are presented in Table A-4 in Appendix A. The sewage sample used for this test was collected from influent to Jefferson County's Cahaba Wastewater Treatment Plant in Birmingham, Alabama. No chlorine, copper or phenols were detected in the sewage sample or spring water. Prior to measuring fluorescence, samples were filtered through a washed 0.45 μm glass fiber filter. This was necessary in order to achieve a stable reading on the fluorometer. With the exception of color, errors for all parameters, ((measured - expected)/expected) x 100), were less than, or equal to, 10% for dilutions containing 5% or more sewage. Errors observed in color measurements were high. The spring water had no color, and small additions of sewage (with a color of 30 units) resulted in color changes too small to be discerned by the human eye. The resolution of the manual color wheel used was 1 unit. Working with such relatively colorless samples, even half unit discrepancies between observed and expected values resulted in large errors. Expected values were calculated based on anticipated linearity. Toxicity and pH measurements will not be linear, and the dilution tests results confirmed the absence of linearity.

Table A-5 presents results from the septage dilution study. Septage, rather than septic tank discharge, was chosen for this portion of the study because it was much more easily accessible. The septage used was obtained from a residential septage tank cleaning truck. The septage was pre-filtered through a quarter-inch stainless steel sieve, followed by an eighth-inch sieve. Final filtration was through 1.5 feet of coarse sand supported by 3 inches of river rock on a quarter-inch sieve in order to simulate septic tank effluent after partially traveling through a leaching field. Before fluoride, fluorescence, detergent or hardness measurements were taken, samples were filtered through a washed 0.45 μm glass fiber filter in order to minimize color interference. With the exception of color and fluorescence, errors for all parameters were less than 8% for samples containing at least 5% septage. At 5% septage, the fluorescence value measured differed from the expected value by 12%. Color values exhibited errors of less than 8%, with the exception of samples containing 0.1% and 99% septage. Septage is much more highly colored than sewage, with a value of about 1000 color units at full strength. Therefore, even small additions of septage to spring water resulted in color additions which were discernible. Once again, toxicity and pH data confirmed their lack of linearity.

Results from the dilution study using metal plating bath wastes are presented in Table A-6. Plating bath wastewater was obtained from a local metal plating company, and samples were filtered through a washed 0.45 μm glass fiber filter before fluoride, fluorescence, detergent and hardness measurements were taken. With the exception of fluorescence, errors observed in all samples containing at least 5% plating wastes were below 8%. An error of 9% was noted between expected and observed fluorescence values for the 10% plating waste mixture. Toxicity and pH values were again observed to be non-linear on dilution.

These results indicate that, with the exception of color and fluorescence, measurements made using the analytical methods selected should be accurate to within 10%, even if inappropriate flows comprise as little as 5% of the total outfall flow. In addition, with the exception of toxicity and pH, the dilutions affected the measurements in a linear manner over the complete concentration ranges. Figures A-1 through A-10 are plots of the mixture fraction versus observed concentration for each of the 10 parameters measured. The spring water that was used as dilution water in the tests was obtained from three different springs. This explains the difference in the zero level concentrations obvious on some of the graphs.

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Recommended Analytical Methodology

An important part of the development of these investigation procedures and the demonstration project was the laboratory and field testing of the alternative analytical methods, described previously. Dry-weather outfall samples were subjected to different tests which compared several analytical methods for each of the major tracer parameters of interest. Tests were conducted to enable comparison of the results of alternative tests with standard procedures and to identify which methods had suitable detection limits, based on real samples. In addition, representative samples were further examined using standard addition methods (known amounts of standards added to the sample and results compared to unaltered samples) in order to identify matrix interferences. Matrix interferences are generally caused by contaminants in the samples interfering with the analysis of interest. Many of the analysis methods were also tested against a series of standard solutions to identify analytical precision (repeatability), linearity, and detection limits.

Table 29 lists the analytical methods selected and the lower limit of detection determined for each of these methods. The lower limit of detection is defined in *Standard Methods* as the standard deviation multiplied by 3.29 (APHA 1989).

Most of the recommended analyses are conducted using small "field-type" instruments. However, despite their portability, the use of these instruments in the field can introduce many errors. Temperature and specific conductivity are the only analyses that are recommended for field analyses. For the other analyses, samples are collected at the site, iced, and taken back to the laboratory for analyses. The recommended analysis procedures can be easily conducted in a temporary laboratory; all that is needed is a work space and adequate ventilation. Access to power and water would be helpful, but all of the equipment can be operated with batteries. At each outfall, a 2 L sample of dry-weather discharge needs to be collected and stored in a polyethylene container. Another (500 mL) sample can also be collected in a glass container having a Teflon-lined lid for toxicity screening and selected toxicant analyses. All samples must be analyzed (or extracted) within accepted time limits. Table 30 is an example of the laboratory analyses reporting sheet for the above analyses.

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TABLE 29. ANALYTICAL PROCEDURES SELECTED

Parameter	Analysis Method	Lower Limit of Detection
Conductivity & Temperature	YSI Conductivity Meter (Model 33)	17 µS/cm
Fluoride	HACH DR/2000 Spectrophotometer (AccuVac: SPADNS Method)	0.07 mg/L
Hardness	HACH Field Titration Kit (EDTA Titration)	0.07 mg/L
Detergents	HACH Detergent Test Kit (MBAS Colorimetric)	0.06 mg/L
Fluorescence	Turner Filter Fluorometer (Model 111)	3% of scale (4 ppb Rhodamine equiv.)
Potassium	HACH DR/2000 Spectrophotometer (Tetraphenylborate Method)	0.4 mg/L
Ammonia	HACH DR/2000 Spectrophotometer (Nessler Method - direct)	0.12 mg/L
Color	HACH Color Kit	3 color units
Toxicity	Microtox™ (Microbics, Inc.)	I_{25} = 0.15 (15% light attenuation after 25 minutes exposure)
pH	Fisher Accumet Model 610A	0.03 units
Total Chlorine	HACH DR/2000 Spectrophotometer (AccuVac: DPD Method)	0.07 mg/L
Total Copper	HACH DR/2000 Spectrophotometer (AccuVac: Bicinchonianate Method)	0.03 mg/L
Total Phenols	HACH Colorimetric Method	0.66 mg/L

NA: Not Applicable

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TABLE 30. SAMPLE ANALYSES LAB SHEET

Sample number: _____

Date: _____

Location: _____

Outfall #: _____

Specific conductivity YSI™ SCT meter (field) _____

Temperature YSI™ SCT meter (field) _____

pH pH meter (lab) _____

Ammonia Direct Nesslerization (lab) _____

Color HACH™ color kit (lab) _____

Fluoride HACH DR/2000™ spect. with AccuVacs™ (lab) _____

Hardness HACH™ field titration kit (lab) _____

Surfactants HACH™ detergent field kit (lab) _____

Fluorescence Turner™ fluorometer (lab) _____

Potassium HACH DR/2000™ spect. (lab) _____

Turbidity HACH™ Nephelometer (lab) _____

Chlorine HACH DR/2000™ spect. with AccuVacs™ (lab) _____

Toxicity Microtox™ 100% sample screen (lab) _____

A006304

Section 7
Data Analysis to Identify Problem Outfalls and Flow Components

The purpose of the procedures presented in this report is to separate storm drain outfalls into general categories of causing problems (with a known level of confidence) and to identify which outfalls (and drainage areas) need control, or further analyses and investigations. The categories used in this report are outfalls affected by non-stormwater entries from: (1) pathogenic or toxic pollutant sources, (2) nuisance and aquatic life threatening pollutant sources, and (3) unpolluted water sources, as discussed in Section 2 of this report.

The pathogenic and toxic pollutant source category should be considered the most severe because it could cause disease upon water contact or consumption and cause significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially if they contain soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and industrial wastewater non-stormwater entries. Other important residential area activities that may also be considered in this most critical category (in addition to sanitary wastewater) include inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides).

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastewater, landscaped area irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix concrete trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Relatively clean or unpolluted water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, and infiltrating domestic water from water line leaks.

A method must be used to compare data from individual outfall dry-weather samples to the library of dry-weather flow source data to identify which outfalls belong in which general category of contamination listed above. This comparison should result, at the very least, in the identification of the outfalls that are considered as major pollutant sources for immediate remediation. The degree of detail which can be determined regarding any outfall will depend on the results of the local data collected to describe the likely source flows.

The procedures that can be used to identify outfall flow components may begin with simple yes/no checks. For example, if no surfactants are measured in an outfall sample, then sanitary wastewater is unlikely to be a contributor to the outfall flow. If no fluoride is measured, then fluoride treated potable water sources could be ruled out as contributors. The probability that remaining contenders are present alone or in a mixture may be determined using a combination of matrix algebra and the selecting of random values from within specified ranges using a Monte Carlo process and many iterations.

Most contaminated outfalls will require correction before the receiving water quality recovers to acceptable levels. However, ranking the outfalls allows the most serious outfalls to be recognized and enables corrective action to be initially concentrated in the most cost-effective manner. In some of the case studies investigated, correcting only problems at the most critical outfalls resulted in insufficient receiving water quality improvements. It may be important to eventually correct all non-stormwater discharge problems throughout a city, not just the most severe problems. The field screening program should therefore be considered as an initial effort that needs to be followed-up

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with more detailed watershed drainage surveys in most of the areas having observed dry-weather flows. The follow-up watershed surveys are to identify and correct inappropriate pollutant entries into storm drainage systems, as discussed in Section 8.

The identification of flow components of the dry-weather storm drain flow can be used to determine which outfalls have the greatest pollution potential. As an example, if an outfall contains sanitary wastewater, it could be a significant source of pathogenic microorganisms. Similarly, if an outfall contains plating bath water from a metal finisher, it could be a significant source of toxicants. These outfalls would be grouped into the most critical category of toxicants/pathogens. If an outfall contains washwaters from a commercial laundry or car wash, the wastewater could be a major source of nutrients and foaming material. These outfalls would be grouped into an intermediate category of nuisances. Finally, if an outfall only contains unpolluted groundwater or water from leaky potable water mains, the water would be non-polluting and the outfall would be grouped into the last category of clean water sources.

The seven methods of data analyses presented in the following discussions present a hierarchy of methods, ranging from relatively simple reviews of the outfall characteristics to more sophisticated methods requiring computer modeling for evaluation. It is suggested that as many of the procedures be used as possible in evaluating the data, as each method provides some unique insights of the problems. Most of these procedures were evaluated during the Birmingham demonstration project phase (Lalor 1994) which is reviewed in Section 11 of this report.

Indicators of Contamination

Indicators of contamination (negative indicators) are clearly apparent visual or physical parameters indicating obvious problems and are readily observable at the outfall during the field screening activities. These observations are very important during the field survey because they are the simplest method of identifying grossly contaminated dry-weather outfall flows. The direct examination of outfall characteristics for unusual conditions of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions, and damage to drainage structures is therefore an important part of these investigations. Table 31 presents a summary of these indicators, along with narratives of the descriptors to be selected in the field.

This method does not allow quantifiable estimates of the flow components and it will very likely result in many incorrect negative determinations (missing outfalls that have important levels of contamination). These simple characteristics are most useful for identifying gross contamination. Only the most significant outfalls and drainage areas would therefore be recognized from this method. The other methods, requiring chemical determinations, can be used to quantify the flow contributions and to identify the less obviously contaminated outfalls.

Indications of intermittent flows (especially stains or damage to the structure of the outfall) could indicate serious illegal toxic pollutant entries into the storm drainage system that will be very difficult to detect and correct. Highly irregular dry-weather outfall flow rates or chemical characteristics could indicate industrial or commercial inappropriate entries into the storm drain system.

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TABLE 31. INTERPRETATIONS OF PHYSICAL OBSERVATION PARAMETERS AND LIKELY ASSOCIATED FLOW SOURCES

Odor - Most strong odors, especially gasoline, oils, and solvents, are likely associated with high responses on the toxicity screening test. Typical obvious odors include: gasoline, oil, sanitary wastewater, industrial chemicals, decomposing organic wastes, etc.

sewage: smell associated with stale sanitary wastewater, especially in pools near outfall.
sulfur ("rotten eggs"): industries that discharge sulfide compounds or organics (meat packers, canneries, dairies, etc.).
oil and gas: petroleum refineries or many facilities associated with vehicle maintenance or petroleum product storage.
rancid-sour: food preparation facilities (restaurants, hotels, etc.).

Color - Important indicator of inappropriate industrial sources. Industrial dry-weather discharges may be of any color, but dark colors, such as brown, gray, or black, are most common.

yellow: chemical plants, textile and tanning plants.
brown: meat packers, printing plants, metal works, stone and concrete, fertilizers, and petroleum refining facilities.
green: chemical plants, textile facilities.
red: meat packers.
gray: dairies.

Turbidity - Often affected by the degree of gross contamination. Dry-weather industrial flows with moderate turbidity can be cloudy, while highly turbid flows can be opaque. High turbidity is often a characteristic of undiluted dry-weather industrial discharges.

cloudy: sanitary wastewater, concrete or stone operations, fertilizer facilities, automotive dealers.
opaque: food processors, lumber mills, metal operations, pigment plants.

Floatable Matter - A contaminated flow may contain floating solids or liquids directly related to industrial or sanitary wastewater pollution. Floatables of industrial origin may include animal fats, spoiled food, oils, solvents, sawdust, foams, packing materials, or fuel.

oil sheen: petroleum refineries or storage facilities and vehicle service facilities.
sewage: sanitary wastewater.

(continued)

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TABLE 31 (continued).

Deposits and Stains - Refer to any type of coating near the outfall and are usually of a dark color. Deposits and stains often will contain fragments of floatable substances. These situations are illustrated by the grayish-black deposits that contain fragments of animal flesh and hair which often are produced by leather tanneries, or the white crystalline powder which commonly coats outfalls due to nitrogenous fertilizer wastes.

sediment: construction site erosion.
olly: petroleum refineries or storage facilities and vehicle service facilities.

Vegetation - Vegetation surrounding an outfall may show the effects of industrial pollutants. Decaying organic materials coming from various food product wastes would cause an increase in plant life, while the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation. It is important not to confuse the adverse effects of high stormwater flows on vegetation with highly toxic dry-weather intermittent flows.

excessive growth: food product facilities.
inhibited growth: high stormwater flows, beverage facilities, printing plants, metal product facilities, drug manufacturing, petroleum facilities, vehicle service facilities and automobile dealers.

Damage to Outfall Structures - Another readily visible indication industrial contamination. Cracking, deterioration, and spalling of concrete or peeling of surface paint, occurring at an outfall are usually caused by severely contaminated discharges, usually of industrial origin. These contaminants are usually very acidic or basic in nature. Primary metal industries have a strong potential for causing outfall structural damage because their batch dumps are highly acidic. Poor construction, hydraulic scour, and old age may also adversely affect the condition of the outfall structure.

concrete cracking: industrial flows
concrete spalling: industrial flows
peeling paint: industrial flows
metal corrosion: industrial flows

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Correlation tests were conducted to identify relationships between outfalls that were known to have severe contamination problems and the negative indicators during the Birmingham demonstration phase of this research project (Lalor 1994, and as summarized in Section 11). Review of the Pearson correlation results (to be presented in Section 11, Table 45) indicates that high turbidity (lack of clarity) and odors appeared to be the most useful physical indicators of contamination when contamination was defined by toxicity and the presence of detergents. Lack of clarity best indicated the presence of detergents with an 80% correlation. (As noted later, the detergent test was the most useful of the chemical tests for distinguishing between contaminated and uncontaminated flows.) Based on the Pearson correlation results, noticeable odor was the best indicator of toxicity, with a 77% correlation, although there is no theoretical connection between the two.

During the Birmingham demonstration project activities (Section 11), high turbidity was noted in 66 of 89 (or 74%) contaminated source flow samples (Table 44). This represented a 26% false negative rate (indication of no contamination when contamination actually exists), if one relied on turbidity alone as an indicator of contamination. Turbidity was noted in only 5% of the uncontaminated source flow samples. This represents the rate of false positives (indication of contamination when none actually exists) when relying on turbidity alone. Noticeable odor was indicated in 67% of flow samples from contaminated sources, but in none of the flow samples from uncontaminated sources. This translates to 37% false negatives, but no false positives. Typical obvious odors include gasoline, oil, sanitary wastewater, industrial chemicals or detergents, decomposing organic wastes, etc.

A 65% correlation was also found to exist between color and Microtox™ toxicity (Table 45) during the Birmingham demonstration project activities (Section 11). Color is an important indicator of inappropriate industrial sources, but it was also associated with some of the residential and commercial flow sources that were sampled during this research. Color was noted in 100% of the flow samples from contaminated sources, but it was also noted in 40% of the flow samples from uncontaminated sources (Table 44 of Section 11). This represents 60% false positives, but no false negatives. Finally, a 63% correlation between the presence of sediments (assessed as settleable solids in the collection jars of these source samples) and Microtox™ toxicity was also found. Sediments were noted in 34% of the samples from contaminated sources and in none of the samples from uncontaminated sources. The presence of sediments in the sanitary sewage samples collected could not be adequately determined. Samples entered the automatic sampler through a sampler inlet strainer which may have prevented the entry of some solids. Sediments in pipes could not be directly observed.

The Pearson correlation tests are based on analysis of pure samples taken directly from potential dry-weather flow sources. Analysis of diluted samples (as are possible from outfalls) would likely result in a much higher percentage of false negatives. False negatives are more of a concern than a reasonable number of false positives when working with a screening methodology, such as required by EPA. Screening methodologies are used to direct further, more detailed investigations. False positives would be discarded after further investigation. However, a false negative during a screening investigation results in the dismissal of a problem outfall for at least the near future. Missed contributors to stream contamination may result in unsatisfactory in-stream results following the application of costly corrective measures elsewhere.

This method, using physical characteristics to indicate contamination in outfall flows, does not allow quantifiable estimates of the flow components and, if used alone, will likely result in many incorrect determinations, especially false negatives. These simple characteristics are most useful for identifying gross contamination: only the most significantly contaminated outfalls and drainage areas would therefore be recognized from this method.

Detergents as Indicators of Contamination

Results from the Mann-Whitney U tests conducted during the Birmingham demonstration project (Lalor 1994, and as summarized in Section 11 and Appendix E) indicated that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly

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different between the two groups. If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated outfalls from clean outfalls. However, since multi-source flows occur, measured levels of color or conductivity could fall within acceptable levels because of dilution, even though a contaminating source was contributing to the flow. Detergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. "Presence" in this research translates to the lower limit of detection for the HACH detergent test kit, which is 3.29 times the standard deviation, or 0.06 mg/L of detergents. This reduces the probability of a false nondetection or a false detection to 5% (Standard Methods 1989). All samples analyzed from contaminated sources contained detergents in excess of this amount (with the exception of three septage samples collected from homes discharging only toilet flushing water). No clean source samples were found to contain detergents. Using 0.06 mg/L as the lower limit of detection, 85 of the 86 samples collected from contaminated sources in this investigation would be detected in mixtures with uncontaminated waters if they made up at least 10% of the mixture.

Simple Checklist for Major Flow Component Identification

Figure 11 is a simplification of the analysis strategy to separate the major non-stormwater discharge sources for areas having no industrial activity. The first indicator is the presence or absence of flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and outfall structural damage can all indicate intermittent non-stormwater flows. However, multiple visits to outfalls over long time periods are needed to confirm that only stormwater flows occur.

The following paragraphs summarize the rational used to distinguish between treated potable water and sanitary wastewater, the two most common dry-weather flow sources in storm drainage systems in residential and commercial areas.

Treated Potable Water

A number of tracer parameters may be useful for distinguishing treated potable water from natural waters:

- Major ions or other chemical/physical characteristics of the flow components can vary substantially depending upon whether the water supply sources are groundwater or surface water, and whether the sources are treated or not. Specific conductance may also serve as an indicator of the major water source.

- Fluoride can often be used to separate treated potable water from untreated water sources. This latter group may include local springs, groundwater, regional surface flows or non-potable industrial waters. If the treated water has no fluoride added, or if the natural water has fluoride concentrations close to potable water fluoride concentrations, then fluoride may not be an appropriate indicator. Water from treated water supplies (that test positive for fluorides, or other suitable tracer) can be relatively uncontaminated (domestic water line leakage or irrigation runoff), or it may be heavily contaminated. If the drainage area has industries that have their own water supplies (quite rare for most urban drainage areas), then further investigations are needed to check for industrial non-stormwater discharges (as described in Section 9). Toxicity screening methods would be very useful in areas known to have commercial or industrial activity, or to check for intermittent residential area discharges of toxicants.

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Figure 11. Simplified Checklist to Identify Residential Area Non-Stormwater Flow Sources.

1) Flow? If yes, go to 2; if no, go to 3.

2) Fluorides (or different hardness)? If yes, probably treated water (may be contaminated), go to 4; if no, then untreated natural water (probably uncontaminated), or untreated industrial water (may be toxic), go to industrial checklist.

3) Check for intermittent dry-weather flow signs (may be contaminated). If yes, recheck outfall at later date; if no, then not likely a significant non-stormwater source.

4) Surfactants (or florescence, if septic systems in area)? If yes, may be sanitary wastewater, laundry water, or other wash water (may be pathogenic, or nuisance), go to 5; if no, then may be domestic water line leak, irrigation runoff, or rinse water (probably not a contaminated non-stormwater source, but may be a nuisance).

5) Elevated potassium (or ammonia)? If yes, then likely sanitary wastewater source (pathogenic); if no, likely wash water (probably not a contaminated non-stormwater source, but may be a nuisance).

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- Hardness can also be used as an indicator if the potable water source and the baseflow are from different water sources. An example would be if the baseflow is from hard groundwater, and the potable water is from softer surface supplies.

- If the concentration of chlorine is high, then a major leak of disinfected potable water is likely close to the outfall. Because of the rapid loss of chlorine in water (especially if some organic contamination is present) it is not a good parameter for quantifying the amount of treated potable water observed at the outfall.

Water from potable water supplies (that test positive for fluorides, or other suitable tracers) can be relatively uncontaminated, e.g., domestic waterline leakage or irrigation runoff, or heavily contaminated, e.g., sanitary wastewater.

Sanitary Wastewaters

In areas containing no industrial or commercial sources, sanitary wastewater is probably the most important dry-weather source of storm drain flows. The following parameters can be used for quantifying the sanitary wastewater components of the treated domestic water portion:

- Surfactant (detergent) analyses may be useful in determining the presence of sanitary wastewaters, as noted previously. However, surfactants present in water originating from potable water sources could indicate sanitary wastewaters, laundry wastewaters, car washing wastewater, or any other waters containing surfactants. If surfactants are not present, then the potable water could be relatively uncontaminated (domestic water line leaks or irrigation runoff).

- The presence of fabric whiteners (as measured by fluorescence using a fluorometer in the laboratory or in the field) can also be used in distinguishing laundry and sanitary wastewaters.

- Sanitary wastewaters often exhibit predictable trends during the day in flow and quality. In order to maximize the ability to detect direct sanitary wastewater connections into the storm drainage system, it would be best to survey the outfalls during periods of highest sanitary wastewater flows (mid to late morning hours).

- The ratio of surfactants to ammonia or potassium concentrations may be an effective indicator of the presence of sanitary wastewaters or septic tank effluents. If the surfactant concentrations are high, but the ammonia and potassium concentrations are low, then the contaminated source may be laundry wastewaters. Conversely, if ammonia, potassium, and surfactant concentrations are all high, then sanitary wastewater is the likely source. Some researchers have reported low surfactants in septic tank effluents. Therefore, if surfactants are low, but potassium and ammonia are both high, septic tank effluent may be present. However, research during this study found high surfactant concentrations in septic tank effluent in the Birmingham, Alabama, area (section 11). This further stresses the need to obtain local characterization data for potential contaminating sources.

- Obviously, odor and other physical appearances such as turbidity, coarse and floating "tell-tale" solids, foaming, color, and temperature would also be very useful in distinguishing sanitary wastewater from washwater or laundry wastewater sources, as noted previously. However, these indicators may not be very obvious for small levels of sanitary wastewater contamination.

Flow Chart for Most Significant Flow Component Identification

A further refinement of the above checklist is the flow chart shown on Figure 12. This flow chart describes an analysis strategy which may be used to identify the major component of dry-weather flow samples in residential and

A006312

commercial areas. This method does not attempt to distinguish among all potential sources of dry-weather flow identified earlier, but rather the following four major groups of flow are identified: (1) tap waters (tap water, irrigation water and rinse water), (2) natural waters (spring water and shallow ground water), (3) sanitary wastewaters (sanitary sewage and septic tank discharge), and (4) wash waters (commercial laundry waters, commercial car wash waters, radiator flushing wastes, and plating bath wastewaters). The use of this method would not only allow outfall flows to be categorized as contaminated or uncontaminated, but would allow outfalls carrying sanitary wastewaters to be identified. These outfalls could then receive highest priority for further investigation leading to source control. This flow chart was designed for use in residential and/or commercial areas only. Investigations in industrial or industrial/commercial land use areas must be approached in an entirely different manner (EPA 1993).

Flowchart Procedures

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

If dry-weather flow exists at an outfall, then the flow should be sampled and tested for detergents. If detergents are not present, the flow is probably from a non-contaminated non-stormwater source. The lower limit of detection for the detergent test used in this research was 0.06 mg/L.

If detergents are not present, fluoride levels can be used to distinguish between flows with treated water sources and flows with natural sources in communities where water supplies are fluoridated and natural fluoride levels are low. In the absence of detergents, high fluoride levels would indicate a potable water line leak, irrigation water, or rinse water. Low fluoride levels would indicate waters originating from springs or shallow groundwater. Based on the flow source samples tested in this research (Table 32), fluoride levels above 0.13 mg/L would most likely indicate that a tap water source was contributing to the dry-weather flow in the Birmingham, Alabama, study area. This number was calculated from the mean plus 3 standard deviations for all natural water samples (spring waters and shallow ground waters) collected here. Fluoride values greater than 0.13 mg/L would be considered outliers for this source group. This number will vary from one geographic area to the next, based on the amount of fluoride naturally occurring in the water.

If detergents are present, the flow is probably from a contaminated non-stormwater source, as indicated on Table 32. The ratio of ammonia to potassium can be used to indicate whether or not the source is sanitary wastewater. Ammonia/potassium ratios greater than 0.60 would indicate likely sanitary wastewater contamination. The value of 0.60 is equal to the mean, plus 3 standard deviations, as calculated from car wash, laundry, plating bath, and radiator waste data as a group. Ammonia/potassium ratios were above 0.9 for all septage and sewage samples collected in Birmingham (values ranged from 0.97 to 15.37, averaging 2.55, with a median value of 1.72). Ammonia/potassium ratios for all other samples containing detergents were below 0.7. Values for these samp les ranged from 0.00 to 0.65, averaging 0.11, with a median value of 0.01. One sample of radiator wastes had an ammonia/potassium ratio of 0.65.

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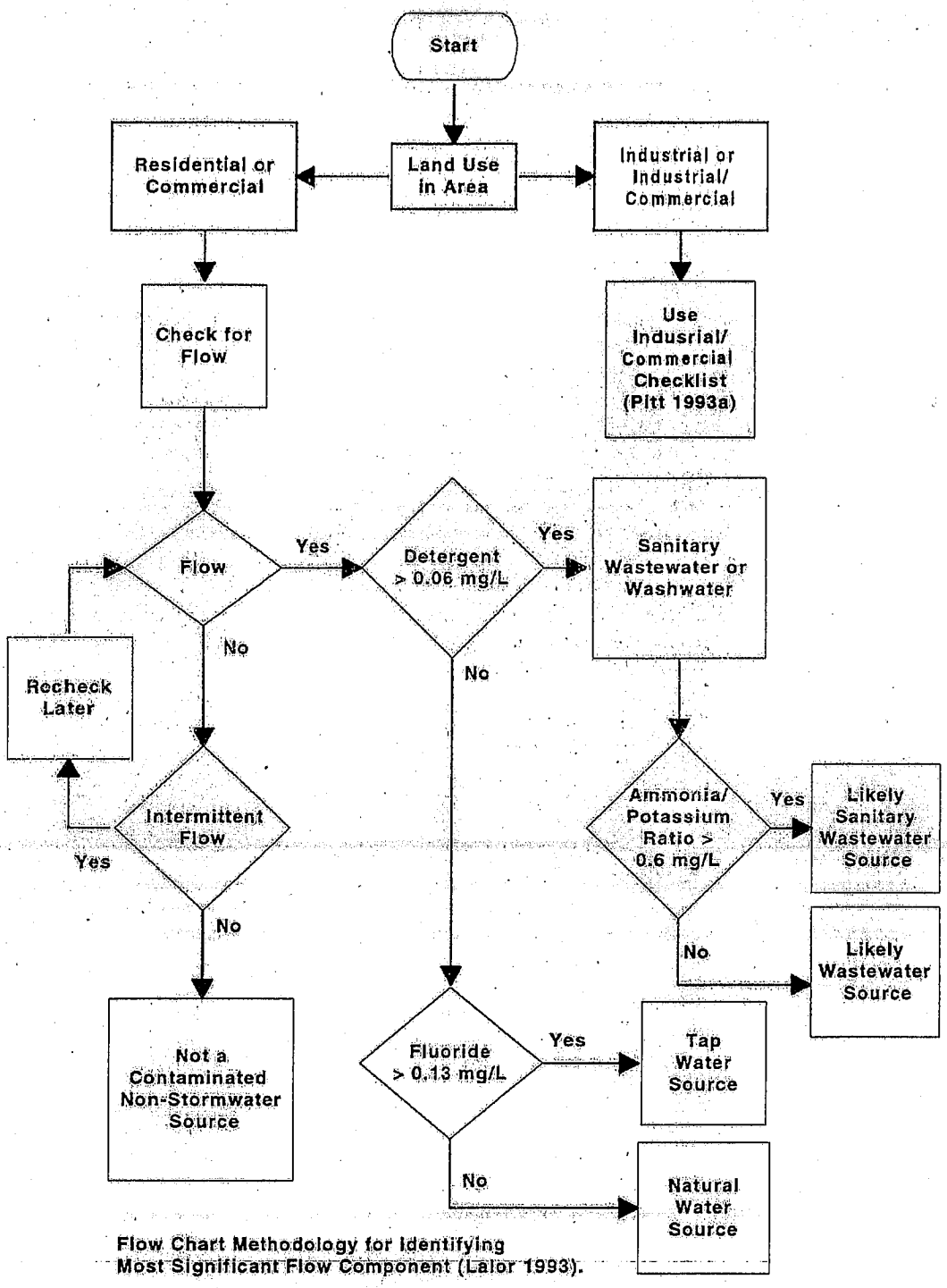

Figure 12. Simple Flow Chart Method to Identify Significant Contaminating Sources

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TABLE 32. SUMMARY OF DETERGENT, FLUORIDE, AMMONIA AND POTASSIUM DATA FOR SOURCE SAMPLES COLLECTED IN BIRMINGHAM, ALABAMA

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH_3 (mg/L)	K (mg/L)	NH_3/K
Shallow Ground	1	0.00	0.08	NA	NA	-
	2	0.00	0.03	NA	NA	-
	3	0.00	0.14	NA	NA	-
	4	0.00	0.07	0.38	1.70	0.22
	5	0.00	0.05	0.89	2.15	0.41
	6	0.00	0.04	0.08	0.81	0.10
	7	0.00	0.05	0.05	0.91	0.05
	8	0.00	0.06	0.09	0.89	0.10
	9	0.00	0.04	0.13	1.01	0.13
	10	0.00	0.07	0.08	0.83	0.10
Spring	1	0.00	0.09	0.02	0.83	0.02
	2	0.00	0.01	0.00	0.76	0.00
	3	0.00	0.01	0.01	0.69	0.01
	4	0.00	0.03	0.05	0.72	0.07
	5	0.00	0.05	0.00	0.74	0.00
	6	0.00	0.00	0.00	0.73	0.00
	7	0.00	0.03	0.00	0.56	0.00
	8	0.00	0.03	0.00	0.72	0.00
	9	0.00	0.05	0.00	0.76	0.00
	10	0.00	0.01	0.01	0.77	0.01
Tap	1	0.00	0.98	0.02	1.48	0.01
	2	0.00	0.97	0.03	1.55	0.02
	3	0.00	1.00	0.04	1.46	0.03
	4	0.00	0.96	0.02	1.50	0.01
	5	0.00	0.95	0.03	1.66	0.02
	6	0.00	0.96	0.03	1.58	0.02
	7	0.00	0.96	0.02	1.57	0.01
	8	0.00	0.96	0.03	1.56	0.02
	9	0.00	0.97	0.03	1.60	0.02
	10	0.00	0.96	0.03	1.57	0.02
Irrigation	1	0.00	0.98	0.28	6046	0.04
	2	0.00	0.93	0.24	9.42	0.03
	3	0.00	0.65	0.55	3.21	0.17
	4	0.00	0.94	0.40	6.32	0.06
	5	0.00	0.97	0.41	5.44	0.08
	6	0.00	0.81	0.37	6.71	0.06
	7	0.00	0.93	0.31	6.49	0.05
	8	0.00	0.89	0.48	4.98	0.10
	9	0.00	0.91	0.35	5.79	0.06
	10	0.00	0.98	0.32	6.01	0.05

NA: Data not available

(Continued)

A006315

TABLE 32. CONTINUED

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH_3 (mg/L)	K (mg/L)	NH_3/K
Laundry	1	37.0	15.89	0.94	3.47	0.27
	2	21.5	23.98	0.96	3.97	0.24
	3	17.0	54.48	0.62	3.37	0.18
	4	32.5	42.48	0.70	3.67	0.19
	5	35.0	48.98	0.84	3.57	0.24
	6	31.0	31.48	0.91	3.27	0.28
	7	20.0	22.48	0.78	3.77	0.21
	8	25.0	26.98	0.88	2.57	0.34
	9	24.0	35.98	0.69	3.67	0.19
	10	26.0	25.48	0.84	3.47	0.24
Carwash	1	50.4	16.50	0.28	22.00	0.01
	2	52.2	11.50	0.32	22.00	0.01
	3	52.5	12.50	0.20	78.40	0.00
	4	49.0	15.50	0.23	40.70	0.01
	5	56.7	12.50	0.19	47.70	0.00
	6	50.3	8.00	0.14	35.40	0.00
	7	38.0	10.20	0.23	48.20	0.00
	8	49.0	11.80	0.25	46.20	0.01
	9	43.5	12.30	0.19	16.70	0.01
	10	48.0	12.20	0.36	39.60	0.01
Radiator	1	17.4	136.50	16.90	3230.00	0.01
	2	13.8	177.00	32.40	2446.00	0.01
	3	14.7	172.50	21.00	3473.00	0.01
	4	14.2	133.30	18.10	2694.00	0.01
	5	15.1	129.80	22.30	2902.00	0.01
	6	18.3	121.50	12.20	2907.00	0.00
	7	13.5	183.00	8.90	2282.00	0.00
	8	13.5	124.50	90.10	2364.00	0.04
	9	14.6	170.10	23.80	2899.00	0.01
	10	15.3	145.00	17.50	2821.00	0.01
Plating	1	15.0	9.00	105.00	774.00	0.14
	2	1.80	1.68	74.20	552.00	0.13
	3	10.0	1.86	3.05	1730.00	0.00
	4	9.00	6.00	139.37	186.00	0.65
	5	11.4	5.52	29.33	220.00	0.13
	6	1.45	5.85	76.00	490.00	0.16
	7	1.60	6.00	58.60	356.00	0.16
	8	6.90	7.95	60.90	380.00	0.16
	9	3.90	4.20	101.00	1100.00	0.09
	10	7.00	3.20	9.05	4300.00	0.00

NA: Data not available

(continued)

A006316

TABLE 32. CONTINUED

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH_3 (mg/L)	K (mg/L)	NH_3/K
Sewage	1	0.96	0.90	8.59	5.25	1.64
	2	3.80	0.72	7.25	4.79	1.51
	3	0.58	0.46	5.02	3.44	1.46
	4	0.54	0.58	5.22	3.09	1.69
	5	0.54	0.74	13.04	4.51	2.89
	6	0.99	0.87	14.23	5.88	2.42
	7	0.48	1.08	13.03	5.99	2.18
	8	3.60	0.77	9.67	5.70	1.70
	9	0.54	0.83	8.00	7.50	1.07
	10	0.95	0.93	8.81	7.20	1.22
	11	0.98	0.88	7.82	6.78	1.15
	12	0.96	0.88	7.32	7.56	0.97
	13	4.20	0.69	10.03	7.00	1.43
	14	4.40	0.64	9.18	6.73	1.36
	15	0.97	0.74	11.82	6.05	1.95
	16	0.99	0.60	11.04	4.03	2.74
	17	0.65	0.54	6.38	3.55	1.80
	18	0.64	0.43	6.00	4.94	1.21
	19	0.62	0.60	12.83	7.47	1.72
	20	0.65	1.04	19.49	7.13	2.73
	21	0.96	0.80	12.34	6.87	1.80
	22	0.98	0.97	10.67	6.88	1.55
	23	0.90	0.85	8.57	7.07	1.21
	24	0.94	0.83	9.25	7.55	1.23
	25	2.40	0.81	11.00	7.14	1.54
	26	1.60	0.66	9.99	6.75	1.48
	27	0.97	0.77	10.66	6.12	1.74
	28	0.96	0.67	8.29	5.06	1.64
	29	0.89	0.44	5.53	3.59	1.54
	30	0.76	0.43	5.84	3.57	1.64
	31	0.98	0.68	19.28	6.65	2.60
	32	0.95	1.04	15.74	5.68	2.77
	33	3.00	.94	10.99	6.69	1.64
	34	3.60	0.89	10.03	6.93	1.45
	35	4.00	0.85	7.43	7.11	1.05
	36	2.00	0.83	8.58	6.69	1.28
Septage	4	10.00	1.19	26.07	8.16	3.19
	5	5.00	0.70	135.75	8.83	15.37
	6	12.00	1.21	26.77	8.16	3.28
	7	0.50	0.92	89.60	20.85	4.30
	8	0.45	1.55	91.60	23.25	3.94
	9	0.57	1.26	86.10	22.25	3.87
	10	2.50	0.61	95.90	24.51	3.91
	11	1.00	0.42	107.80	18.66	5.78
	12	0.50	0.56	99.30	21.73	4.57
	13	0.45	0.87	113.20	31.81	3.56

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Non-contaminated samples collected in Birmingham had ammonia/potassium ratios ranging from 0.00 to 0.41, with a mean value of 0.06 and a median value of 0.03. Using the mean values for non-contaminated samples (0.06) and sanitary wastewaters (2.55), flows comprised of mixtures containing at least 25% sanitary wastes with the remainder of the flow from uncontaminated sources would likely be identified as sanitary wastewaters using this method. Flows containing smaller percent contributions from sanitary wastewaters might be identified as having a wash water source, but would not be identified as uncontaminated.

In mixed flows made up of water from uncontaminated sources and water from one contaminating source, only the contaminating source would be identified. Wash water flows would always be correctly identified in Birmingham, because all uncontaminated sources, as well as all wash water sources, have ammonia/potassium ratios less than 0.9. Diluted sanitary wastewaters could be incorrectly identified as wash waters if the ammonia/potassium ratio were sufficiently reduced due to the presence of the uncontaminated water. The presence of flow from both categories of contaminated sources (wash waters and sanitary wastewaters) would result in the identification of only one of the contaminated flow components.

Flow-Weighted Mixing Calculations

This method was developed to quantify different major components that may be present in an outfall flow made up of multiple sources. Before any flow-weighted mixing calculations can be made, the characteristics of potential contaminating sources must be identified, as described in Sections 2, 5, and 6). Table 33 is a hypothetical example and summarizes example concentration means and COV values for various tracers. This method is an extension of the checklist method described previously and attempts to quantify the likely source flow components at the outfall during dry weather.

Analytical Equipment Selection to Support Analysis Methods

Two general groupings of flow sources can be recognized for each of these tracers. Table 34 describes these groups, along with their composite ranges, COV values, and medians. This information can also be used to determine the needed equipment to detect the tracer concentrations over the expected range of conditions, as described in Section 6. Required detection limits were determined based on the variations of the tracer concentrations in the lowest concentration component. Required precisions in the measurement techniques were also estimated for errors less than ten percent. Finally, minimum portions of the component having the higher concentration that could be resolved with less than ten percent errors were also estimated. These conservative tracer characteristics are summarized below:

Fluorides:

- detection limit: 0.05 mg/L
- precision: 0.01 mg/L
- minimum contamination detectable: 20 percent

Hardness:

- detection limit: 30 mg/L
- precision: 2 mg/L
- minimum contamination detectable: 10 percent

A006318

TABLE 33. ASSUMED SOURCE FLOW QUALITY (mg/L)

		Fluoride	Hardness	Surfactants	Potassium	Ammonia
Surface waters	range	0.1 to 0.2	30 to 50	0.30 to 0.4	0.5 to 1	0.2 to 3
	variation*	L (0.23)	L (0.20)	L (0.13)	L (0.23)	M/H (1.1)
	median	0.14	39	0.35	0.72	0.76
Groundwaters	range	0.2 to 0.4	200 to 300	<0.1	1 to 3	0.1 to 0.5
	variation	L (0.23)	L (0.14)	L	M (0.40)	M (0.63)
	median	0.29	250	0.05	1.7	0.22
Septage	range	1.0 to 1.5	30 to 50	<0.1	10 to 100	6 to 380
	variation	L (0.14)	L (0.20)	L	M (0.91)	H (1.5)
	median	1.3	39	0.05	21	47
Raw sewage	range	1.0 to 1.5	30 to 50	0.2 to 100	10 to 100	10 to 50
	variation	L (0.14)	L (0.20)	H+ (2.2)	M (0.91)	M- (0.63)
	median	1.3	39	4.6	21	22
Wash water	range	1.0 to 1.5	30 to 50	0.2 to 100	2.5 to 11	0.1 to 1
	variation	L (0.14)	L (0.20)	H+ (2.2)	M- (0.57)	M (0.91)
	median	1.3	39	4.6	5.3	0.31
Irrigation	range	1.0 to 1.5	30 to 50	0.3 to 0.4	0.5 to 1	0.1 to 1.5
	variation	L (0.14)	L (0.20)	L (0.13)	L (0.23)	M/H (1.1)
	median	1.3	39	0.35	0.72	0.38
Tap water	range	1.0 to 1.5	30 to 50	0.3 to 0.4	0.5 to 1	0.1 to 0.5
(surface	variation	L (0.14)	L (0.20)	L (0.13)	L (0.23)	M- (0.63)
source)	median	1.3	39	0.35	0.72	0.22

* Variation is described with variation category and COV (σ/x_{avg} not transformed):

range ration (x_{90}/x_{10})	COV (σ/x_{avg})	variation category
1.5	0.16	low
10	0.73	medium

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100	1.67	high

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TABLE 34. CHARACTERISTICS OF SOURCE GROUPINGS

Fluorides

	surface & groundwaters	all other categories
overall range:	0.1→0.4 mg/L	1→1.5 mg/L
COV:	0.54 (L/M)	0.14 (L)
median:	0.20 mg/L	1.3 mg/L

concentration ratio of medians: 6.5

Hardness

	groundwaters	all other categories
overall range:	200→300 mg/L	30→50 mg/L
COV:	0.14 (L)	0.20 (L)
median:	250 mg/L	39 mg/L

concentration ration of medians: 6.4

Surfactants

	raw sanitary wastewater & washwater	all other categories
overall range:	0.2→100 mg/L	0.04→0.4 mg/L
COV:	2.2 (H)	0.83 (M)
median:	4.6 mg/L	0.14 mg/L

concentration ratio of medians: 33

Potassium

	septic tank effluent & raw sanitary wastewater	all other categories
overall range:	10→100 mg/L	0.5→11 mg/L
COV:	0.91 (M)	1.2 (M/H)
median:	21 mg/L	2.3

concentration ratio of medians: 9.1

Ammonia

	septic tank effluent & raw sanitary wastewater	all other categories
overall range:	6→380 mg/L	0.1→3 mg/L
COV:	1.5 (H)	1.3 (M/H)
median:	47 mg/L	0.44 mg/L

concentration ratio of medians: 107

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Surfactants:

- detection limit: 0.03 mg/L
- precision: 0.014 mg/L
- minimum contamination detectable: 50 percent

Potassium:

- detection limit: 0.3 mg/L
- precision: 0.07 mg/L
- minimum contamination detectable: 50 percent

Ammonia:

- detection limit: 0.05 mg/L
- precision: 0.09 mg/L
- minimum contamination detectable: 15 percent

The available equipment that can be used to measure these tracers, based on the detection limits, can be selected from the summaries presented in Appendix A. This appendix does not indicate analytical precision, so care must be taken to review that requirement. The following list summarizes the equipment that may be used for these analyses:

- Fluorides (50 µg/L detection limit)--Any of the indicated procedures, except possibly the comparative colorimetric method, may be suitable. Spectrophotometric and ion-selective probe methods should provide detection limits of less than 20 µg/L. Their precisions should also be less than the needed 10 µg/L value. Both of these methods require sample preparation and may take several minutes to 30 minutes to conduct.

- Hardness (30 mg/L detection limit)--Titrimetric, ion-selective probes, and indicator paper may all provide the necessary detection limit. The indicator paper would not provide the needed analytical precision and is probably subject to interferences, but would be the simplest and quickest method to use in the field, by far.

- Surfactants (30 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 3 µg/L and suitable precision. However, these methods could require up to 30 minutes for analyses.

- Potassium (300 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 70 µg/L and suitable precision. However, these methods could again require up to 30 minutes for analyses.

- Ammonia (50 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 10 µg/L and suitable precision.

For the above situation, ion-selective probes seem to provide the most consistent method for all of the required tracers. It may be possible to construct a probe rack with an electrode switch to simplify the analyses. With careful temperature measurements during the analyses, it may be possible to suitably compare the field ion-selective measurements with calibration curves prepared in the laboratory. Otherwise, probe standardizations would have to be conducted in the field. Unfortunately, the laboratory and field tests using ion-selective probes conducted during the Birmingham demonstration study were all disappointing, as noted in Section 6. Until ion-selective probes improve substantially, they are not recommended for field use, and should only be used in the laboratory by experienced technicians. Therefore, the titration and spectrophotometric procedures are recommended for these analyses.

A006322

Example Calculations

The following example shows the calculations necessary for this procedure. A hypothetical drainage area for a sampled outfall had no septic tanks or commercial or industrial land uses. The likely flow sources had source flow characteristics as described in Table 33. The required detection limits and precision for outfall characterizations must be determined, as previously described, for these source flow characteristics and desired study results. This outfall had the following tracer concentrations in a dry-weather sample:

Fluoride: 0.6 mg/L
Hardness: 200 mg/L as $CaCO_3$
Surfactants: 0.6 mg/L as MBAS
Potassium: 3 mg/L
Ammonia: 3 mg/L

The water had a slight septic odor, with some floatables of obvious sanitary wastewater origin. In addition, flow was observed at the outfall during all visits.

It is apparent that this outfall has a direct connection of raw sanitary wastewater. This method can determine the approximate mix of sanitary wastewater in the outfall flow and to identify the other flow components. Table 35 summarizes the example calculations used in this analysis. The following list indicates the approximate expected source components at this outfall from this analysis:

Sanitary wastewater: 5%
Wash wastewater: 5%
Groundwater: 70%
Remainder (most likely potable water, but may also contain irrigation water): 20%

This analysis did not consider the potential ranges in observed tracer concentrations and the resulting errors that may be associated with the above mixture portions. The following procedures are better suited for error analyses.

At a confidence level of 90 percent (based on the variabilities of the potential flow components and using Table 27 in Section 6), fluorides could detect contamination at the 20 percent level, hardness could detect contamination at the 10 percent level, surfactants and potassium could detect contamination at the 50 percent levels, and ammonia could detect contamination at the 15 percent level. Contamination is used here as the percentage of the component having the higher tracer concentration mixed with the component having the lower tracer concentration. Fluoride concentrations were used to separate treated and untreated water sources, hardness was used to separate groundwater and surface water sources, surfactant concentrations were used to separate sewage and wash water from other water sources, and potassium and ammonia concentrations were used to separate sewage from other water sources. The following list estimates the flow components, including the approximate confidence values:

Raw sewage: 5%, at less than 90% confidence
Wash water: 5%, at less than 90% confidence
Groundwater: 70%, at greater than 90% confidence
Irrigation water plus water supply: 20%, at about the 90% confidence level.

The number of samples obtained at the outfall and used to obtain the outfall tracer concentrations can also affect these estimates, as shown earlier.

A qualitative analysis can be used to describe the probability of contamination at the outfall, without estimating the degree of contamination, independent of the number of samples obtained. The observed fluoride outfall concentration was 0.6 mg/L, and the median concentration of the component having the lowest fluoride concentrations (non-treated water) was 0.2 mg/L. The variability of fluorides in the non-treated water component was estimated to be low to medium. For a factor of 3.0 (the observed outfall concentration divided by the median

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concentration of the non-treated water component) and using Table A-7 (probability values for different points on a log-probability scale), there is less than a one percent (for low variability conditions) to about a 15 percent (for medium variability conditions) probability that the non-treated water component alone could have caused the observed outfall concentration. Therefore it is very likely that the outfall flow contained at least some treated water. Similar analyses can be made for the other tracers to determine the probability of contamination of the outfall flow. The following list summarizes these results:

- Fluorides: less than 1 to 15% probability that raw water alone could have produced the observed outfall fluoride concentrations, without any treated water components.

- Hardness: much less than 1% probability that non-groundwater sources alone could have produced the observed outfall hardness concentrations, without any groundwater.

- Surfactants: about 5% probability that non-sewage or non-wash water sources alone could have produced the observed outfall surfactant concentrations.

- Potassium: about 40 to 45% probability that non-sewage sources alone could have produced the observed outfall potassium concentrations.

- Ammonia: about 2 to 15% probability that non-sewage sources alone could have produced the observed outfall ammonia concentrations, without any sewage contamination.

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TABLE 35. MIXTURE CALCULATIONS TO IDENTIFY SOURCE FLOW COMPONENTS

Fluorides: 0.6 mg/L observed at outfall

x: treated water: 1.3 mg/L
y: raw water: 0.2 mg/L

$$x\,(1.3) + y\,(0.2) = \frac{0.6}{x+y}$$

x = 0.37 (treated water fraction = water supply, sewage, washwater, and irrigation water, with fluoride added)
y = 0.63 (raw water fraction = surface and/or groundwater)

Hardness: 200 mg/L as $CaCO_3$ observed at outfall

x: groundwater: 250 mg/L as $CaCO_3$
y: all others: 39 mg/L as $CaCO_3$

$$x\,(250) + y\,(39) = \frac{200}{x+y}$$

x = 0.76 (groundwater fraction)
y = 0.24 (all other fractions)

Therefore:

Groundwater & Surface water =	0.63
Groundwater alone =	0.76
Surface water alone = -	0.13→0

$$\text{and groundwater} = \frac{0.63 + 0.76}{2} = 0.7$$

Surfactants: 0.6 mg/L as MBAS observed at outfall

x: raw sanitary wastewater& washwater: 4.6 mg/L as MBAS
y: all others: 0.14 mg/L as MBAS

$$x\,(4.6) + y\,(0.14) = \frac{0.6}{x+y}$$

x = 0.10 (raw wastewater & washwater)
y = 0.90 (all others)

(continued)

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TABLE 35. (continued)

Potassium: 3 mg/L observed at outfall

x: raw sanitary wastewater: 21mg/L
y: all others: 2.3 mg/L

$$x\,(21) + y\,(2.3) = \frac{3}{x+y}$$

x = 0.04 (raw sanitary wastewater)
y = 0.96 (all others)

Ammonia: 3 mg/L observed at outfall

x: raw sanitary wastewater: 47 mg/L
y: all others: 0.44 mg/L

$$x\,(47) + y\,(0.44) = \frac{3}{x+y}$$

x = 0.06 (raw sanitary wastewater)
y = 0.94 (all others)

Therefore: Raw sanitary wastewater = $\frac{0.04 + 0.06}{2} = 0.05$

Washwater = 0.05

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Even without the visual observations, it can be determined, at least to the 85 percent confidence level, that raw sewage was affecting the outfall non-stormwater flow. There was also a very large probability (greater than 99 percent significance level) that groundwater was also affecting the outfall flow. However, the specific portions of some of the different source components in this example could not be determined to a high level of significance. The groundwater and irrigation runoff plus water supply component portions were estimated at the 90 percent, or greater level of confidence. The more important sewage component would have to be present at least at a 15 percent level of contamination before the ammonia analyses could predict its contamination level with a 90 percent, or greater, confidence level. These results would certainly have been sufficient to target this outfall and drainage area for further investigations to locate the highly probable sewage source(s) discharging into the storm drainage system. The water utility should also be contacted concerning the high potential of treated water, possibly from leaky water mains, in the drainage area.

It is obvious from this example that more precisely defining the tracer characteristics of the potential non-stormwater flow components would have enabled much better estimates of the portions of each of these flow components affecting the outfall flow.

Matrix Algebra Solution of Simultaneous Equations

Other approaches can also be used to calculate the source components of mixed outfall flows. One approach is the use of matrix algebra to simultaneously solve a series of chemical mass balance equations. This method can be used to predict the most likely flow source, or sources, making up an outfall sample, and is discussed in the following paragraphs.

It is possible to estimate the outfall source flow components using a set of simultaneous equations. The number of unknowns should equal the number of equations available, resulting in a square matrix. If there are seven likely source categories, then there should be seven tracer parameters used. If there are only four possible sources, then only four tracer parameters should be used.

Further site specific statistical analyses may be needed to rank the usefulness of the tracers for distinguishing different flow sources. As an example, chlorine is generally not useful for these analyses because the concentration variability within many source categories is high (it is also not a conservative parameter). Chlorine may still be a useful parameter, but only to identify possible large potable water line leaks. Another parameter having problems for most situations is pH. The variation of pH between sources is very low (they are all very similar). However, pH may still be useful to identify industrial wastewater problems, but it cannot be used to quantify flow components. pH is also not linearly affected by mass balance mixtures (a solution of 50%/50% of two components would not result in a pH value that is the average of the two individual pH values). Toxicity is another parameter that was used during this research that was not found to be linearly additive. The following paragraphs describe this procedure, and contains an example.

This method estimates flow contributions from various sources using a "receptor model", based on a set of chemical mass balance equations. Such models, which assess the contributions from various sources based on observations at sampling sites (the receptors), have been applied to the investigation of air pollutant sources for many years (Scheff and Wadden 1993; Daisey, Lioy and Kneip 1985; Gordon 1980; Cooper and Watson 1980; Friedlander 1973). The characteristic "signatures" of the different types of sources, as identified in the library of source flow data developed during this research, allowed the development of a set of mass balance equations. These equations described the measured concentrations in an outfall's flow as a linear combination of the contributions from the different potential sources. A major requirement for this method was the physical and chemical characterization of waters collected directly from potential sources of dry-weather flow. This allowed concentration patterns (fingerprints) for the parameters of interest to be established for each type of source. Theoretically, if these patterns are different for each source, the observed concentrations at the outfall would be a linear combination of the concentration patterns from the different component sources, each weighted by a source strength term (m_n). This source strength term would indicate the fraction of outfall flow originating from each likely source. By measuring a

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number of parameters equal to, or greater than, the number of potential source types, the source strength term could be obtained by solving a set of chemical mass balance equations of the type:

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

where C_p is the concentration of parameter p in the outfall flow and x_{pn} is the concentration of parameter p in source type n.

As an example of this method, consider 8 possible flow sources and 8 parameters, as presented in Table 36. The number of parameters evaluated for each outfall must equal the number of probable dry-weather flow sources in the drainage area. Mathematical methods are available which provide for the solution of overspecified sets of equations (more equations than unknowns) but these are not addressed here.

The selection of parameters for measurement should reflect evaluated parameter usefulness. Evaluation of the Mann-Whitney U Test results (Lalor 1994 and as presented in Section 11 and Appendix E) suggested the following groupings of parameters, ranked by their usefulness for distinguishing between all the types of flow sources sampled. The first category of most useful parameters would include potassium and hardness, followed by a second category of useful parameters including fluorescence, conductivity, fluoride, ammonia, detergents, and color. Chlorine would be included in a third category of less useful parameters, and would only be used if more than 8 potential source categories were being considered (which is unlikely for any given outfall).

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TABLE 36. SET OF CHEMICAL MASS BALANCE EQUATIONS

	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Outfall
Parameter 1:	(m1)(x11)	+ (m2)(x12)	+ (m3)(x13)	+ (m4)(x14)	+ (m5)(x15)	+ (m6)(x16)	+(m7)(x17)	+ (m8)(x18)	= C1
Parameter 2:	(m1)(x21)	+ (m2)(x22)	+ (m3)(x23)	+ (m4)(x24)	+ (m5)(x25)	+ (m6)(x26)	+(m7)(x27)	+ (m8)(x28)	= C2
Parameter 3:	(m1)(x31)	+ (m2)(x32)	+ (m3)(x33)	+ (m4)(x34)	+ (m5)(x35)	+ (m6)(x36)	+(m7)(x37)	+ (m8)(x38)	= C3
Parameter 4:	(m1)(x41)	+ (m2)(x42)	+ (m3)(x43)	+ (m4)(x44)	+ (m5)(x45)	+ (m6)(x46)	+(m7)(x47)	+ (m8)(x48)	= C4
Parameter 5:	(m1)(x51)	+ (m2)(x52)	+ (m3)(x53)	+ (m4)(x54)	+ (m5)(x55)	+ (m6)(x56)	+(m7)(x57)	+ (m8)(x58)	= C5
Parameter 6:	(m1)(x61)	+ (m2)(x62)	+ (m3)(x63)	+ (m4)(x64)	+ (m5)(x65)	+ (m6)(x66)	+(m7)(x67)	+ (m8)(x68)	= C6
Parameter 7:	(m1)(x71)	+ (m2)(x72)	+ (m3)(x73)	+ (m4)(x74)	+ (m5)(x75)	+ (m6)(x76)	+(m7)(x77)	+ (m8)(x78)	= C7
Parameter 8:	(m1)(x81)	+ (m2)(x82)	+ (m3)(x83)	+ (m4)(x84)	+ (m5)(x85)	+ (m6)(x86)	+(m7)(x87)	+ (m8)(x88)	= C8

Equations of the Form $C_p = \sum_n m_n x_{pn}$

where: C_p = the concentration of parameter p in the outfall flow

m_n = the fraction of flow from source type n

x_{pn} = the concentration of parameter p in source type n

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If parameter variations within the sources are not accounted for, the equations would take the form presented in Table 37. Here, the x terms, representing parameter concentrations within the specified source, have been replaced with the mean concentrations noted in the source library (Table 38). After measured values are substituted into the equations for parameter concentrations in the outfall flow (C_p), this set of simultaneous equations can be solved using matrix algebra. The use of mean concentration values in the equation set was evaluated by entering the potential dry-weather flow source samples from Birmingham as unknowns (as if they were outfall samples) and solving for fractions of flow (the m terms in Table 37). This exercise resulted in 4 false negatives (6%) and 27 false positives (73%). The results of these simple preliminary tests indicated that there was too much variation of parameter concentrations within the various source types to allow them to be adequately characterized by simple use of the mean concentrations alone. The following procedure was therefore developed and tested that considers uncertainty of the source area concentration values (Lalor 1994).

Matrix Algebra Solution Considering Uncertainty

A stochastic version of this procedure, developed by Lalor (1994) enabled the variation within the library values for each source type to be considered. Instead of using a single value (i.e. mean value) to represent the parameter concentration (x_{pn}) for each likely type of source flow, a Monte Carlo simulation is used to randomly select values from a statistical distribution. Monte Carlo sampling is a traditional method of random sampling across an entire input variable distribution. Any value across the range of the distribution is possible, although the sampling is influenced by the relative probability assigned to each value. The more probable values will have a greater chance of being selected.

Based on samples collected from known sources in Birmingham, probability distributions were calculated, for each parameter, within each potential source flow (Table 38). Distributions considered in this procedure include normal, log-normal, and uniform. Local source flow quality monitoring is necessary to obtain this information, as discussed previously.

Monte Carlo simulation generates sets of concentration values based on the mean, coefficient of variation, and distribution of each parameter within each source. A set of equations in the form of Table 36 is established for each set of sampled concentration values generated by the Monte Carlo simulation. The fraction of flow from each potential source (represented by the m terms in Table 36) is calculated by solving each set of equations. These flow values are then stored. Multiple trials are used to calculate the most probable sources of contaminants for each outfall.

This procedure assumes a mass balance at the outfall, with the outfall concentrations affected by the magnitude of each contributing source. If the outfall flow is contaminated solely by sanitary wastewater and no other flows are present, then the outfall quality should obviously be very similar to sanitary wastewater quality as reflected in the library data. If the outfall is contaminated by a mixture of 25% sanitary wastewater and 75% infiltrating groundwater, then the outfall quality would be represented by a weighted fraction of the quality parameters of these individual flows. The values used to describe the individual potential source concentrations are randomly selected from a calculated distribution. The distribution description (mean, standard deviation, and distribution type) is based on actual local measurements of likely dry-weather flow source types, as presented in Table 38.

A computer program was developed (using TurboPascal, version 6) to perform the Monte Carlo trials, and prepare probability plots of the solutions (Lalor 1994). Appendix G contains the source code for this program and an example of its use. Each source concentration value (x_{pn}) is randomly selected from the calculated probability distribution by the Monte Carlo simulation based on the locally obtained source library data. The program is designed to evaluate a maximum of 12 potential sources per outfall. Three distribution options are available for each parameter within each type of source: normal, log- normal, and uniform. The uniform distribution option is assumed if the coefficient of variation is entered as 0 (all of the observations had identical concentrations). The parameter concentration (x_{pn}) is then always taken to be the mean value.

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TABLE 37. CHEMICAL MASS BALANCE EQUATIONS WITH PARAMETER MEANS

Parameters	Spring Water 1	Ground Water 2	Tap Water 3	Irrigation Water 4	Sanitary Sewage 5	Septic Tank 6	Car Wash 7	Laundry Water 8	Unknown Sample
Potassium	(m1)(0.73)	+ (m2)(1.19)	+ (m3)(1.55)	+ (m4)(6.08)	+ (m5)(5.97)	+ (m6)(18.82)	+ (m7)(42.69)	+ (m8)(3.48)	= (1)(C_p)
Hardness	(m1)(240)	+ (m2)(27)	+ (m3)(49)	+ (m4)(40)	+ (m5)(143)	+ (m6)(57)	+ (m7)(157)	+ (m8)(36)	= (1)(C_p)
Fluorescence	(m1)(6.8)	+ (m2)(29.9)	+ (m3)(4.6)	+ (m4)(214)	+ (m5)(251)	+ (m6)(382)	+ (m7)(1190)	+ (m8)(1024)	= (1)(C_p)
Conductivity	(m1)(301)	+ (m2)(51)	+ (m3)(112)	+ (m4)(105)	+ (m5)(420)	+ (m6)(502)	+ (m7)(485)	+ (m8)(563)	= (1)(C_p)
Fluoride	(m1)(0.03)	+ (m2)(0.06)	+ (m3)(0.97)	+ (m4)(0.90)	+ (m5)(0.76)	+ (m6)(0.93)	+ (m7)(12.3)	+ (m8)(32.82)	= (1)(C_p)
Ammonia	(m1)(0.01)	+ (m2)(0.24)	+ (m3)(0.03)	+ (m4)(0.37)	+ (m5)(9.92)	+ (m6)(87.21)	+ (m7)(0.24)	+ (m8)(0.82)	= (1)(C_p)
Detergents	(m1)(0.00)	+ (m2)(0.00)	+ (m3)(0.00)	+ (m4)(0.00)	+ (m5)(1.50)	+ (m6)(3.27)	+ (m7)(49.00)	+ (m8)(26.90)	= (1)(C_p)
Color	(m1)(0.0)	+ (m2)(8.0)	+ (m3)(0.0)	+ (m4)(10.0)	+ (m5)(37.9)	+ (m6)(70.6)	+ (m7)(221.5)	+ (m8)(46.7)	= (1)(C_p)

Equations of the Form $C_p = \sum_n m_n x_{pn}$

where: C_p = the concentration of parameter p in the outfall flow

m_n = the fraction of flow from source type n

x_{pn} = the mean concentration of parameter p in source type n

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TABLE 38. SUMMARY OF CHEMICAL CHARACTERISTICS OF SOURCE SAMPLES COLLECTED IN BIRMINGHAM, ALABAMA

Source	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L as $CaCO_3$)	Detergent (mg/L)	Fluorescence % scale	Potassium (mg/L)	Ammonia (mg/L)	Color (units)	Chlorine (mg/L)
Spring Water									
mean	301	0.03	240	0.00	6.80	0.73	0.01	0.0	0.00
COV	0.04	1.00	0.03	--	0.43	0.10	2.00	--	--
distribution	normal	normal	normal	uniform	normal	normal	L-norm	uniform	uniform
Shallow Ground Water									
mean	51.4	0.06	27.3	0.00	29.9	1.19	0.24	8.0	0.02
COV	0.84	0.50	0.39	--	1.55	0.44	1.26	1.42	1.62
distribution	normal	L-norm	normal	uniform	L-norm	normal	normal	L-norm	normal
Tap Water									
mean	112	0.97	49.3	0.00	4.63	1.55	0.03	0.0	0.88
COV	0.01	0.01	0.03	--	0.08	0.04	0.23	--	0.68
distribution	normal	normal	normal	uniform	normal	normal	normal	uniform	bi-modal
Landscaping Irrigation									
mean	105	0.90	40.2	0.00	214.4	6.08	0.37	10.0	0.03
COV	0.07	0.11	0.04	--	0.16	0.26	0.25	0.36	1.02
distribution	normal	normal	normal	uniform	normal	normal	normal	normal	normal
Sewage									
mean	420	0.76	143	1.50	251.0	5.97	9.92	37.9	.01
COV	0.13	0.23	0.11	0.82	0.20	0.23	0.34	0.55	2.00
distribution	normal	normal	normal	normal	normal	normal	L-norm	normal	L-norm
Septic Tank Discharge									
mean	502	0.93	56.8	3.27	382	18.82	87.21	70.6	0.07
COV	0.42	0.39	0.36	1.33	0.22	0.42	0.40	0.39	1.30
distribution	normal	normal	L-norm	L-norm	normal	normal	normal	normal	normal
Carwash									
mean	485	12.30	157	49.0	1190	42.69	0.24	221.5	0.07
COV	0.06	0.19	0.05	0.10	0.11	0.37	0.28	0.35	1.14
distribution	normal	normal	normal	normal	normal	normal	normal	normal	bi-modal
Laundry									
mean	563	32.82	36.2	26.9	1024	3.48	0.82	46.7	0.40
COV	0.21	0.38	0.08	0.25	0.12	0.11	0.14	0.27	0.26
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal
Radiator Waste									
mean	3280	149.32	5.60	15.0	22046	2801.80	26.32	2999	0.03
COV	0.21	0.16	1.88	0.11	0.04	0.13	0.89	0.01	0.52
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal
Plating Waste									
mean	10352	5.13	1430	6.81	293	1008.80	65.65	103.8	0.08
COV	0.45	0.47	0.32	0.68	0.70	1.24	0.66	0.91	1.20

distribution	normal	normal	normal	normal	normal	L-norm	normal	normal	L-norm

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During program execution, 2000 random simulations are conducted for each outfall. The solutions are saved, sorted by source, and plotted by probability. The program output is in the form of plots, one for each potential source type selected for consideration. Each output plot shows the most likely fraction of flow (the 50th percentile value) contributed by one source type. The 10th and 90th percentile values are also noted in order to give an idea of the spread of solutions calculated. Appendix G contains an example showing the program input and output.

The most probable percent of flow being contributed to an outfall by each potential flow source is based on the 50th percentile value in the set of solutions for m which the program generates for each identified potential flow source. Each 50th percentile value represents the most likely fraction of flow from one particular source based on all calculated values of m for that source, but is independent of the numbers which happen to represent the 50th percentile values for other sources. As a result, the sum of the most likely fraction of flows from each source does not equal 1.00. The most likely flow contributions from each source can be normalized (divided by $\sum m_{50th}$). This allows contributions to be evaluated as percent of flow, while maintaining their relative level of importance.

Initial tests of the algorithm for solving the system of linear equations were carried out using the mean concentrations from each source group and allowing for no variation in concentration values. Therefore, coefficient of variation values were entered as 0, and mean concentration values for each parameter within each source type were used in solving the equation sets. When mean values for each potential source type were then entered as samples, the algorithm correctly predicted the source of the sample, indicating that the algorithm was working correctly.

Coefficients of variation and distributions types, from Table 38, were then added to the model. This allowed the Monte Carlo simulation to take place, choosing parameter concentrations to be used in solving the linear equation sets. Once again, mean values (Table 38) from each of the source types were entered as samples. Results are shown in Table 39. The correct source type was identified as the main contributor in each case. However, uncontaminated sources showed up as contributors in most of the tests and sewage was identified as contributing flow to the septage sample. This was not unexpected, given the high level of parameter variation noted in some source and parameter types. Negative fractions of flow were noted in some instances, as m was not constrained to be ≥ 0. Negative fractions of flow have no real meaning and result, in part, from concentration distributions which allow negative numbers to be selected as parameter concentrations. The distribution curve for some parameters, in some sources, extends beyond zero into the negative range. The program was revised to truncate concentration distributions at zero. This revision maintained the shape of the distribution curve but simply required the Monte Carlo program to sample again when a negative value was selected as a concentration.

In order to gain a better understanding of how the Monte Carlo program outputs should be interpreted, 103 of the samples collected directly from dry-weather flow sources were entered as "outfall" samples. Data from these runs are presented in Table 40, with most likely flow contributions from each source normalized to equal 100% of flow. The predictions resulted in no false negatives, but 11 false positives, an great improvement over the solutions achieved using only parameter concentration means to characterize flow sources. However, many extraneous contributions of flow were also predicted.

In this simple test, percent contributions below 16 never represented the actual flow source, but appear to be "background noise" generated by the variation allowed in the program. These results indicated that false positives could be minimized, without creating false negatives, if a threshold were established and all apparent percent contributions less than this threshold were ignored. The lower detection limits of the analytical methods used, and the dilution study results discussed earlier, indicated that a contaminating source would be difficult to detect in mixtures in which it made up less than 10% of the flow. This suggested using percent contributions of 10 as a lower threshold of detection for the program. Using this criterion, there were no false negatives (samples from a contaminated source identified as containing flow from only uncontaminated sources) and only 3 false positives (samples from an uncontaminated source identified as containing flow from a contaminated source) out of 103 samples.

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TABLE 39. RESULTS FROM SOLUTION OF MASS BALANCE EQUATIONS USING MONTECARLO SIMULATON TO OBTAIN SOURCE PARAMETER CONCENTRATIONS

	Most Likely Fraction of Flow From Each Source							
Sample Source	Spring	Irrigation	Tap Water	Shallow Ground	Sewage	Septic Tank Discharge	Carwash	Laundry
100% Spring	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100% Irrigation	-0.02	1.01	0.05	0.07	0.01	0.00	0.00	0.00
100% Tap Water	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
100% Shallow Ground	0.01	0.05	0.13	0.40	0.04	0.00	0.00	0.00
100% Sewage	0.05	0.04	0.00	0.63	0.86	0.02	0.00	0.00
100% Septic Tank Discharge	-0.23	0.04	0.54	0.08	0.22	1.01	-0.02	-0.01
100% Carwash	-0.16	0.09	0.55	0.44	0.02	0.00	1.03	-0.02
100%Laundry	-0.08	-0.21	0.89	0.08	-0.09	0.00	0.02	1.02

Notes: Concentration means from each source type were used as samples

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TABLE 40. RESULTS OBTAINED USING THE CHEMICAL MASS BALANCE PROGRAM TO ANALYZE SOURCE DATA (DATA NORMALIZED TO EQUAL 100% OF FLOW)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic Tank Discharge	Laundry	Carwash
Spring								
1	90		6		4			
2	98	1						
3	99				1			
4	100							
5	99			1				
6	98	2						
7	99	1						
8	100							
9	99			1				
10	99			1				
Tap								
1			100					
2			100					
3			100					
4	5	9	78	8				
5	1		98	1				
6			100					
7			100					
8	1		99					
9			100					
10			100					
Irrigation								
1			45	54				1
2		6	41	52				1
3	7	20		64	7		2	
4		5	17	78				
5		6		91	2			
6		8		91	1			
7		3	8	89				
8	4			94	1		1	
9	3			97				
10		4	9	87				
Shallow Ground								
4		63		4	33			
5		76		4	20			
6	3	64			33			
7	36	32		32				
8	36	33		31				
9	20	49		31				

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10	35	25		39				

(continued)

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TABLE 40. (continued)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic Tank Discharge	Laundry	Carwash
Sewage								
1	14	54		13	16	3		
2	45			17	30	4		4
3	37			17	44	1	1	
4	45			18	35	1	1	
5	30			16	47	6	1	
6	19			23	51	6	1	
7	18			31	43	6	2	
8	22			3	68	3	1	3
9	5	17	11	29	36	2		
10		8	26	16	49	1		
11	13		5	34	46	2		
12	9		2	39	49	1		
13		29	2	21	48			1
14		48			50			2
15		38	14		48			
16	1	58			39	1	1	
17	16	40			44			
18	12	11	46	1	29	1		
19	9		25	27	33	6		
20		33	6	36	25			
21		60			39	1		
22		66	1		32	1		
23		55	5	6	34			
24		42	18	3	37			
25		58	5		36	1		
26		50		1	49			
27		50		4	44	2		
28	11			16	72	1		
29	31			14	53	1		
30	12		9		79			
31		47			46	7		
32		64	4		30	2		
33		67	3		30			
34		46			52			2
35		31	16		51			2
36		60	5		35			

(continued)

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TABLE 40. (Continued)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic tank Discharge	Laundry	Carwash
Septic Discharge								
4		8			69	15		8
5	15	20			13	47	5	
6		10			66	16	1	7
7			41	5	29	25		
8			59	3	16	22		
9		22	42	1	17	18		
10			25	37		38		
11	21		3	29		46		
12	5	54		17		24		
13		30	38	12		19		
Carwash								
1		74	7				3	16
2	3	61			14		3	19
3			59	23		1		17
4			65			1	3	31
5			61			2		37
6	5	32						36
7		17	49	15		1		18
8	6		32	30		1		31
9	29				38		11	22
10	13			36			2	49
Laundry								
1	8				61		24	7
2	8	19		25	20		28	
3		30	48	2		2	18	
4		6	75			1	17	1
5		11	64			1	24	
6	12				12		71	5
7		24		12	29		35	
8			10		51		39	
9		36	39				25	
10	16				15		62	7

A006340

More specifically, Table 40 yields the following information. All tap water samples were correctly identified as containing only tap water. No other source types were identified as contributing ≥10% of the sample. Likewise, all spring water samples were correctly identified. Relatively small parameter variations within both these source types are responsible for the precision of these results. All samples from landscape irrigation runoff were correctly identified as coming from that source, but, tap water showed up as a contributor in three samples and shallow ground water in one.

Source predictions for the infiltrating shallow ground water samples were the least accurate of any uncontaminated sources. This result was linked to high parameter variations within the source type. The program identified infiltrating shallow ground water as contributing ≥10% in all samples, but landscape irrigation runoff, and spring water were predicted to make up ≥10% of some shallow groundwater samples. Also, all 3 false positives resulted from these samples. Sewage was identified as making up ≥10% of 3 samples of shallow ground water.

Car wash waters were correctly identified as major contributors in all 10 car wash samples and laundry water was correctly identified in all 10 laundry samples. However, spring water, shallow ground water, tap water, landscape irrigation runoff and sewage were also predicted to make up ≥10% of some samples.

Sewage was identified as a major contaminating source in all sewage samples and septic tank discharge was identified as a major contaminating source in all septic tank discharge samp les. Sewage was also identified as a component in 6 of the 10 septic tank discharge samples. Spring water, shallow ground water, tap water and landscape irrigation runoff was also identified in some samples.

These results indicated that in spite of the theoretical results obtained using cluster analysis (see Section 11), the degree of variation which exists within many of the potential source types identified will reduce the effectiveness of a chemical mass balance solution at stormwater outfalls. The method was evaluated against actual outfall flows during the Birmingham demonstration project phase (Lalor 1994) and is summarized in Section 11.

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Section 8
Watershed Surveys to Confirm and Locate Inappropriate Pollutant Entries to the Storm Drainage System

After initial outfall surveys have indicated the presence of contamination, further detailed analyses are needed to identify and locate the specific contaminant sources in the drainage area. For source identification and location, upstream survey techniques should be used in conjunction with an in-depth watershed evaluation. Information on watershed activities can be obtained from aerial photography and/or zoning maps, while upstream survey techniques will include the analysis of the dry-weather flow at several manhole sampling points along the storm drainage system to narrow the location of the contaminating source; tests for specific pollutants or ions associated with known activities within the outfall catchment area; and the measurement of water flow rate and temperature, visual and video camera inspections, and smoke and dye tests.

Detailed Outfall Analyses

Several confirmatory chemical analyses could be conducted at the outfall to verify the more significant sources of dry-weather flows. These analyses require highly trained personnel and specialized equipment that would not be available in most laboratories. It may not be feasible to analyze samples from each of the hundreds of outfalls several times a year for these materials, as would be required for the routine analyses discussed previously. These analyses may be very useful to check for false negatives and for more specific results on a random basis. These confirmatory analyses may include:

- trihalomethanes
- specific bacteria biotypes
- coprostanol, or other biochemicals

Trihalomethanes (THMs) are formed when chlorine reacts with certain natural organics (including tannins) present in most waters. The detection of these compounds in groundwaters has been used as a positive indication of treated city water leakage (Hargesheimer 1985). Chloroform and dichlorobromethane are the THMs most frequently used because of their very low detection limits and specific indicators of treated domestic water. Chlorine was found to rapidly "disappear" during sheetflow sampling of irrigation runoff water during the Birmingham demonstration tests, even with concentrations in the tap water source. In contrast, chlorine only very slowly disappeared during laboratory tests of aerated tap water samples. It is expected that the chlorine reacted with the organics in the lawn areas to form THMs, while the chlorine in the glass beakers in the laboratory could only dissipate through volatilization. Therefore, THM analyses are expected to be useful in identifying treated domestic water sources, if a cost-effective analysis procedure is available.

As noted previously in Section 5, specific bacteria biotypes and coprostanol may be useful to confirm sanitary sewage sources. However, the experience during the Birmingham demonstration project did not find that coprostanol was very helpful. The other methods described earlier in Section 7 for identifying sanitary sewage were much more cost-effective, accurate, and sensitive.

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Using Tracer Parameters in the Drainage System

In order to identify the specific contaminant sources in the drainage system, further detailed watershed analyses are needed. These may include:

- drainage system surveys (tests for specific pollutants, visual inspections, video camera drainage pipe inspections, and smoke and dye tests),
- in-depth watershed evaluation (including aerial photographs), and
- industrial and commercial site studies (see Section 9)

Follow-up Drainage Area and On-Site Investigations.

Further drainage area investigations upstream of identified problem outfalls need to be conducted after the outfall studies have indicated dry-weather discharge problems. In order to be cost-effective, only a sub-sample of manholes located in a drainage area identified as having significant non-stormwater sources should be tested for the tracers. As an example, the main storm drain trunk sewer could be divided into tenths and the manholes closest to these subdivisions would be sampled. This would identify the upper limit of the drainage area above which the major sources are not located. A location may also be identified where the downstream manhole tracer mass yields (concentration times flow rate) are the same. This would mark the downstream limit of the contributing area for the tracers of concern. After the main trunk drainage reach is identified that contains the major non-stormwater sources, the branch storm drain lines can be similarly subdivided (but probably into fewer sections each, perhaps about three) and evaluated. Depending on the drainage area and complexity of the storm drainage system, this scheme could be suitably modified to enable the identification of relatively small areas responsible for the non-stormwater pollutant entries into the storm drainage system. These small areas would then be subject to more intensive on-site investigations that would include smoke tests, dye studies, and remote video inspections.

The above drainage system analysis procedure may find that the drainage system is contaminated by widespread sanitary wastewater entries, possibly due to sanitary and storm drainage systems in extremely poor condition. This condition may require that the drainage system undergo extensive and costly repairs. It may be more appropriate to consider the storm drainage system as a combined sewer and examine control alternatives that have been developed for combined sewer systems. This would also save further detailed drainage system analyses costs.

These drainage system surveys would be followed by industrial and commercial on-site investigations (such as dye and smoke studies) to locate specific sources of non-stormwater pollutant entries into the drainage system. Additionally, aerial photography can be very useful during later phases of non-stormwater discharge control projects. As an example, aerial photography can help identify areas having failing septic systems located in residential areas served by storm drainage systems. Aerial photography can also be used to identify continuous discharges to surface drainages, such as sump discharges, and to identify storage areas that may be contributing significant amounts of pollutants during rains. For example, the Tennessee Valley Authority (TVA), among other agencies, has extensively used aerial photography (stereo color infrared) to identify pollution sources, especially from failing septic tanks (Perchalski and Higgins 1988). The TVA's flights are made in early spring when investigating septic tank failures, to be able to identify unusual grass conditions, with minimal interference from trees. The flights are made at 6,000 feet, with resulting image scales of 1 inch to 1,000 feet. Their photography costs have been about $40 to $150 per square mile.

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Section 9
Specific Considerations for Industrial and Commercial Sources of Inappropriate Pollutant Entries to the Storm Drainage System

Industrial Site Surveys

Additional pollutants associated with local commercial and industrial activities need to be monitored during the outfall screening activities, if these activities may be present in the watersheds of interest. This monitoring will assist in identifying the classes of commercial or industrial activities responsible for the contamination. The first step in this process is to identify which industrial and commercial activities exist in a watershed and what activities they be doing that may contribute non-stormwater discharges to the drainage system. The review of industrial user surveys or reports that are available needs to be done initially. It may be necessary to also send a questionnaire to industries in the watershed that are draining to the storm drainage system to identify the specific activities that may affect runoff quality and dry-weather discharges. Site inspections will still be required because questionnaires may not be returned or may give incorrect details (either deliberately or unknowingly).

Industrial areas are known to contribute excessive wet-weather stormwater discharges, along with contaminated dry-weather entries into the storm drainage system. Additional industrial site investigations are therefore needed to identify activities that most obviously contribute these contaminants to the storm drainage system. Figure 13 is an example industrial site survey form prepared by the Non-Point Source and Land Management Section of the Wisconsin Department of Natural Resources (R. Bannerman, personal communication). This form has been used to help identify industrial activities that contribute dry- and wet-weather non-stormwater entries into the storm drainage system.

This form only considers outside sources that would affect the storm drainage system by entering through inlets or through sheetflow runoff into drainage channels. This sheet does not include any information concerning indoor activities, or direct plumbing connections to the storm drainage system. However, the information included on this sheet can be very helpful in devising runoff control programs for industrial areas. This information most likely affects wet-weather discharges much more than dry-weather discharges. Obvious dry-weather leaching or spillage problems are also noted on the form.

Table 18 in Section 3 presents the types of activities in industrial areas that may contribute dry-weather discharges to storm drainage systems. This table can be used to rank the most likely industries that may produce non-stormwater discharges to a storm drainage system in an area. This table is used in conjunction with the industrial site survey form to catalog specific activities in the watershed that may need correction. After a listing of the candidate activities are known in the watersheds, additional tracer parameters may then be selected to add to the screening efforts.

Likely Dry-Weather Discharge Characteristics for Different Industries

Chemical and Physical Properties

Table 41 summarizes possible chemical and physical characteristics of non-stormwater discharges which could come from various industries. The properties considered are pH, total dissolved solids, odor, color, clarity, floatable materials, vegetation, and structural damage potential. The descriptions in each of these categories contain the most likely conditions for a non-stormwater discharge coming from a particular industry. It should be noted that a combination of just a few of these characteristics, or perhaps all of them, may occur at an outfall affected by a

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potential source. In addition, outfalls are likely to be affected by several sources simultaneously, further confusing the situation. Again, a complete watershed analysis describing the industrial and commercial facilities operating in each outfall watershed will be of great assistance in identifying which industries may be contributing harmful dry-weather discharges to the storm system.

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City: _____ Industry Name: _____
Site Number: _____ Photo # _____
Street Address: _____ Roll# _____
Type of industry: _____
Instructions: Fill in blanks or circle best answer in following (use back of sheet if necessary):

Material/waste Storage Areas
1. Type of material/waste: _____
2. Method of storage: pile tank dumpster other: _____
3. Area occupied by material/waste (acres): _____
4. Type of surface under material/waste: paved unpaved
5. Material/waste is disturbed: often sometimes never unsure
6. Description of spills (material, quantity & frequency): _____
7. Nearest drainage (feet) and drainage type: _____
8. Control practice: berm tarp buffer none other: _____
9. Tributary drainage area, including roofs (acres): _____
10. Does storage area drain to parking lot: yes no unsure

Heavy equipment storage
1. Type of equipment: _____
2. Area covered by equipment (acres): _____
3. Type of surface under equipment: paved unpaved
4. Nearest drainage (feet) and drainage type: _____
5. Control practice: berm tarp buffer none other: _____
6. Tributary drainage area, including roofs (acres): _____
7. Does storage area drain to parking lot: yes no unsure

Air pollution
1. Description of settleable air pollutants (types & quantities): _____
2. Description of particulate air pollutant controls: _____

Railroad yard
1. Size of yard (number of tracks): _____
2. General condition of yard: _____
3. Description of spills in yard (material, quantity & frequency): _____
4. Type of surface in yard: paved unpaved
5. Nearest drainage (feet) and drainage type: _____
6. Type of control practice: berm buffer other: _____
7. Does yard drain to parking lot: yes no unsure
8. Tributary drainage area, including roofs (acres): _____

Loading Docks
1. Number of truck bays: _____
2. Type of surface: paved unpaved
3. Description of spills in yard (material, quantity & frequency): _____
4. Nearest drainage (feet) and drainage type: _____
5. Type of control practice: berm buffer other: _____
6. Does loading area drain to parking lot: yes no unsure
7. Tributary drainage area, including roofs (acres): _____

Source: From Wisconsin Dept. of Natural Resources (R. Bannerman, Personal communication)

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Figure 13. Industrial inventory field sheet (WI DNR).

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TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Primary Industries									
20 Food and Kindred Products									
201 Meat Products	Spoiled Meats, Rotten Eggs and Flesh	Brown to Reddish-Brown	High	Animal Fats, Byproducts, Pieces of Processed Meats	Brown to Black	High	Flourish	Normal	High
202 Dairy Products	Spoiled Milk, Rancid Butter	Grey to White	High	Animal Fats, Spoiled Milk Products	Grey to Light Brown	High	Flourish	Acidic	High
203 Canned and Preserved Fruits and Vegetables	Decaying Products Compost Pile	Various	High	Vegetable Waxes, Seeds, Skins, Cores, Leaves	Brown	Low	Normal	Wide Range	High
204 Grain Mill Products	Slightly Sweet & Musty, Grainy	Brown to Reddish Brown	High	Grain Hulls and Skins, Straw &i Plant Fragments	Light Brown	Low	Normal	Normal	High
205 Bakery Products	Sweet and or Spoiled	Brown to Black	High	Cooking Oils, Lard, Flour, Sugar	Grey to Light Brown	Low	Normal	Normal	High
206 Sugar and Confectionary Products	NA	NA	Low	Low Potentiai	White Crystals	Low	Normal	Normal	High
207 Fats and Oils	Spoiled Meats, Lard or Grease	Brown to Black	High	Animal Fats, Lard	Grey to Light Brown	Low	Normal	Normal	High
208 Beverages	Flat Soda, Beer or Wine, Alcohol, Yeast	Various	Mod.	Grains 6 Hops, Broken Glass, Discarded Canning Items	Light Brown	High	Inhibited	Wide Range	High
21 Tobacco Manufactures	Dried Tobacco, Cigars, Cigarettes	Brown to Black	Low	Tobacco Stems& Leaves, Papers and Fillers	Brown	Low	Normal	Normal	Low
22 Textile Mill Products	Wet Burlap, Bleach, Soap, Detergents	Various	High	Fibers, Oils, Grease	Grey to Black	Low	Inhibited	Basic	High
23 Apparel and Other Finished Products	NA	Various	Low	Some Fabric Particles	NA	Low	Normal	Normal	Low

(continued)

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TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Material Manufacture									
24 Lumber & Wood Products	NA	NA	Low	Some Sawdust	Light Brown	Low	Normal	Normal	Low
25 Furniture & Fixtures	Various	Various	Low	Some Sawdust, Solvents	Light Brown	Low	Normal	Normal	Low
26 Paper & Allied Products	Bleach, Various Chemicals	Various	Mod.	Sawdust, Pulp Paper, Waxes, Oils	Light Brown	Low	Normal	Wide Range	Low
27 Printing, Publishing, and Allied Industries	Ink, Solvents	Brown to Black	Mod.	Paper Dust, Solvents	Grey to Light Brown	Low	Inhibited	Normal	High
31 Leather & Leather Products	Leather, Bleach, Rotten Eggs or Flesh	Various	High	Animal Flesh & Hair, Oils, Grease	Grey to Black, Salt Crystals	High	Highly Inhibited	Wide Range	High
33 Primary Metal Industries	Various	Brown to Black	Mod.	Ore, Coke, Limestone, Millscale, Oils	Grey to Black	High	Inhibited	Acidic	High
34 Fabricated Metal Products	Detergents, Rotten Eggs	Brown to Black	High	Dirt, Grease, Oils, Sand, Clay Dust	Grey to Black	Low	Inhibited	Wide Range	High
32 Stone, Clay, Glass, and Concrete Products	Wet Clay, Mud, Detergents	Brown to Reddish-Brown	Mod.	Glass Particles Dust from Clay or Stone	Grey to Light Brown	Low	Normal	Basic	Low
Chemical Manufacture									
28 Chemicals & Allied Products									
2812 Alkalies and Chlorine	Strong Halogen or Chlorine, Pungent, Burning	Alkalies - NA Chlorine - Yellow to Green	Low	NA	Alkalies – White Carbonate Scale Chlorine - NA	High	Highly Inhibited	Basic	High
2816 Inorganic Pigments	NA	Various	High	Low Potential	Various	Low	Highly Inhibited	Wide Range	High
282 Plastic Materials and Synthetics	Pungent, Fishy	Various	High	Plastic Fragments, Pieces of Synthetic Products	Various	Low	Inhibited	Wide Range	High

(continued)

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Chemical Manufacture (continued)									
283 Drugs	NA	Various	High	Gelatin Byproducts for Capsulating Drugs	Various	Low	Highly Inhibited	Normal	High
284 Soap, Detergents & Cleaning Preparations	Sweet or Flowery	Various	High	Oils, Grease	Grey to Black	Low	Inhibited	Basic	High
285 Paints, Varnishes, Lacquers, Enamels and Allied Products (SB - Solvent Base)	Latex - Ammonia SB - Dependent Upon Solvent (Paint Thinner, Mineral Spirits)	Various	High	Latex - NA SB - All Solvents	Grey to Black	Low	Inhibited	Latex-Basic SB - Normal	High
286 Indust. Organic Chemicals									
2861 Gum and Wood Chemicals	Pine Spirits	Brown to Black	High	Rosins and Pine Tars	Grey to Black	Low	Inhibited	Acidic	High
2865 Cyclic Crudes, & Cyclic Intermediates Dyes, & Organic Pigments	Sweet Organic Smell	NA	Low	Translucent Sheen	NA	Low	Highly Inhibited	Normal	Low
287 Agricultural Chemicals									
2873 Nitrogenous Fertilizers	NA	NA	Low	NA	White Crystalline Powder	High	Inhibited	Acidic	High
2874 Phosphatic Fertilizers	Pungent Sweet	Milky White	High	NA	White Emorphous Powder	High	Inhibited	Acidic	High
2875 Fertilizers, Mixing Only	Various	Brown to Black	High	Pelletized Fertilizers	Brown Emorphous Powder	Low	Normal	Normal	High
29 Petroleux Refining and Related Industries									
291 Petroleum Refining	Rotten Eggs, Kerosene, Gasoline	Brown to Black	High	Any Crude or Processed Fuel	Black Salt Crystals	Low	Inhibited	Wide Range	High
30 Rubber & Miscellaneous Plastic Products	Rotten Eggs, Chlorine, Peroxide	Brown to Black	Mod.	Shredded Rubber Pieces of Fabric or Metal	Grey to Black	Low	Inhibited	Wide Range	High

(continued)

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Transportation & Construction									
15 Building Construction	Various	Brown to Black	High	Oils, Grease, Fuels	Grey to Black	Low	Normal	Normal	High
16 Heavy Construction	Various	Brown to Black	High	Oils, Grease, Fuels, Diluted Asphalt or Cement	Grey to Black	Low	Normal	Normal	High
Retail									
52 Building Materials, Hardware, Garden Supply, and Mobil Home Dealers	NA	Brown to Black	Low	Some Seeds, Plant Parts, Dirt, Sawdust, or Oil	Light Brown	Low	Normal	Normal	Low
53 Gen. Merchandise Stores	NA	NA	NA	NA	NA	Low	Normal	Normal	Low
54 Food Stores	Spoiled Produce, Rancid, Sour	Various	Low	Fragments of Food, Decaying Produce	Light Brown	Low	Flourish	Normal	Low
55 Automotive Dealers & Gasoline Service Stations	Oil or Gasoline	Brown to Black	Mod.	Oil or Gasoline	Brown	Low	Inhibited	Normal	Low
56 Apparel & Accessory Stores	NA	NA	Low	NA	NA	Low	Normal	Normal	Low
57 Home Furniture, Furnishings, & Equip. Stores	NA	NA	Low	NA	NA	Low	Normal	Normal	Low
58 Eating & Drinking Places	Spoiled Foods Oil & Grease	Brown to Black	Low	Spoiled or Leftover Foods	Brown	Low	Normal	Normal	Low
Coal Steam Electric Power	NA	Brown to Black	High	Coal Dust	Black Emorphous Powder	Low	Normal	Slightly Acidic	Low
Nuclear Steam Electric Power	NA	Light Brown	Low	Oils, Lubricants	Light Brown	Low	Normal	Normal	Low

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Other Chemicals Indicative of Manufacturing Industrial Activities

Table 42 is a listing of various chemicals that may be associated with a variety of different industrial activities (from Klein 1962). It may be possible to examine non-stormwater outfall flow for specific chemicals, such as shown on this list, to identify which manufacturing industrial activities may be contributing the flows.

Example Problems for Locating an Industrial Source

Locating An Industrial Source

Hypothetical examples have been created to demonstrate how dry-weather discharges can be characterized so that their likely industrial sources can be identified. These examples show how observations of outfall conditions and simple chemical analyses, combined with a basic knowledge of wastewater characteristics of industrial and commercial operations located in the drainage area, can be used to identify the possible pollutant sources. The initial activities include pollutant analyses of outfalls being investigated. This requires the characterization on the non-stormwater flows, the identification of the likely industries responsible for the observed discharges, and finally, locating the possible specific sources in the watershed.

The industries which were identified as being located in a hypothetical stormwater drainage area (from the watershed analysis) included a vegetable cannery, general food store, fast food restaurant, cheese factory, used car dealer, cardboard box producer, and a wood treatment company. The methods used to determine the most likely industrial source of the dry-weather discharges are considered for three hypothetical situations of outfall contamination.

Case Example One

The hypothetical results of the pollutant analysis for the first situation found constant dry-weather flow at the outfall. The measurements indicated a normal pH (6) and low total dissolved solids concentrations (300 mg/L). Other outfall characteristics included a strong odor of bleach, no distinguishing color, moderate turbidity, sawdust floatables, a small amount of structural corrosion, and normal vegetation.

The significant characteristic in this situation is the sawdust floatables (see Figure 14). The industries which could produce sawdust and have dry-weather flow drainage to this pipe are the cardboard box company and the wood treatment company. According to SIC code, the cardboard box company would fall under the category of "Paper Products" (SIC# 26) while the wood treatment company would be under that of "Lumber and Wood" products (SIC# 24). Looking up these two industries by their corresponding SIC group numbers in Table 41 and comparing the listed properties, indicates that the paper industry has a strong potential for the odor of bleach. Wood products does not indicate any particular smell.

Based upon this data, the most likely industrial source of the industrial non-stormwater discharge would be the cardboard box company. Table 18 (Section 3) under SIC# 26 indicates that there is a high potential for direct connections in paper industries under the categories of water usage and illicit or inadvertent connections. At this point, further testing should be conducted at the cardboard box company to find if the constant source of contamination is coming from cooling waters, process waters, or direct piping connections (process waters are the most likely source, given the bleach and sawdust characteristics).

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TABLE 42. SIGNIFICANT CHEMICALS IN INDUSTRIAL WASTEWATERS

Chemical:	Industry:
Acetic acid	Acetate rayon, pickle and beetroot manufacture
Alkalies	Cotton and straw kiering, cotton manufacture, mercerizing, wool scouring, laundries
Ammonia	Gas and coke manufacture, chemical manufacture
Arsenic	Sheep-dipping, fell mongering
Chlorine	Laundries, paper mills, textile bleaching
Chromium	Plating, chrome tanning, aluminum anodizing
Cadmium	Plating
Citric acid	Soft drinks and citrus fruit processing
Copper	Plating, pickling, rayon manufacture
Cyanides	Plating, metal cleaning, case-hardening, gas manufacture
Fats, oils	Wool scouring, laundries, textiles, oil refineries
Fluorides	Gas and coke manufacture, chemical manufacture, fertilizer plants, transistor manufacture, metal refining, ceramic plants, glass etching
Formalin	Manufacture of synthetic resins and penicillin
Hydrocarbons	Petrochemical and rubber factories
Hydrogen peroxide	Textile bleaching, rocket motor testing
Lead	Battery manufacture, lead mining, paint manufacture, gasoline manufacture
Mercaptans	Oil refining, pulp mills
Mineral acids	Chemical manufacture, mines, Fe and Cu pickling, brewing, textiles, photo-engraving, battery manufacture
Nickel	Plating
Nitro compounds	Explosives and chemical works
Organic acids	Distilleries and fermentation plants
Phenols	Gas and coke manufacture; synthetic resin manufacture; textiles; tanneries; tar, chemical, and dye manufacture; sheep-dipping
Silver	Plating, photography
Starch	Food, textile, wallpaper manufacture
Sugars	Dairies, foods, sugar refining, preserves, wood process
Sulfides	Textiles, tanneries, gas manufacture, rayon manufacture
Sulfites	Wood process, viscose manufacture, bleaching
Tannic acid	Tanning, sawmills
Tartaric acid	Dyeing; wine, leather, and chemical manufacture
Zinc	Galvanizing, plating, viscose manufacture, rubber process

Source: from Klein. *River Pollution, 2: Causes and Effects*. Butterworth & Co., 1962, presented in *The Water Encyclopedia*, D. Todd, Water Information Center, Port Washington, N.Y., 1979.

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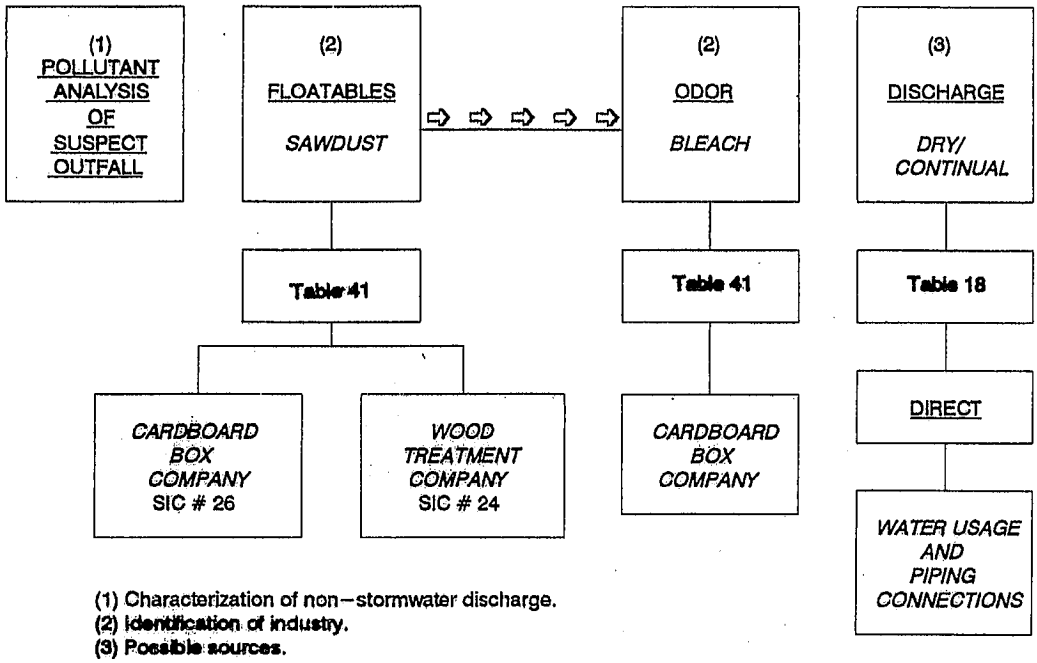

Figure 14. Flowsheet for industrial case example 1.

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Case Example 2

The results of the pollutant analysis for the second situation found intermittent dry-weather discharges at the outfall. The test measurements indicated an acidic pH (3) and high total dissolved solids concentrations (approximately 6,000 mg/L). Other characteristics included a rancid-sour odor, grayish color, high turbidity, gray deposits containing white gelatin-like floatable material, structural damage in the form of spalling concrete, and an unusually large amount of plant life.

The rancid-sour smell and the presence of floatable substances at this outfall indicates that some type of food product is probably spoiling. This narrows the possible suspect industries to the fast food restaurant, cheese factory, vegetable cannery, and food store (see Figure 15). The corresponding SIC categories for each of these industries are "Eating and Drinking Places" (SIC# 58), "Dairy Products" (SIC# 202), "Canned and Preserved Fruits and Vegetables" (SIC# 203), and "Food Stores" (SIC# 54). Comparison of the properties listed in Table 41 for these SIC numbers indicates that elevated plant life is common to industrial wastes for the "Dairy Products" and "Food Stores" categories. However, the deciding factor is the acidic pH, which is only listed for "Dairy Products". Thus, the white gelatin-like floatables are most likely spoiled cheese byproducts which are also the probable cause of the sour-rancid smell.

Since the dry-weather entry to the storm drainage system occurs intermittently, the flow could be caused by either a direct or indirect connection. To locate the ultimate source of this discharge coming from the cheese factory, both direct and indirect industrial situations are considered under the category of "Dairy Products" in Table 18 in Section 3. Thus, further examination of the loading dock procedures, water usage, and direct piping connections should be conducted since these categories all exhibit high potential for pollution in dairy production.

Case Example 3

The results of the test measurements for the final situation found a normal pH (6) and low total dissolved solids (about 500 mg/L). Signs of contaminated discharges were found at the outfall only during and immediately following rainfalls. Other outfall properties observed included an odor of oil, deep brown to black color, a floating oil film, no structural damage, and inhibited plant growth (see Figure 16).

According to Table 41, the fast food restaurant and the used car dealer are the only two industrial sources in this area with high potential for causing oily discharges. Their respective SIC categories are "Eating and Drinking Places" (SIC# 58) and "Automotive Dealers" (SIC# 55). Comparison of the properties shown on Table 41 indicates inhibited vegetation only for the second category. Thus, the most likely source of the discharge is the used car dealer.

Furthermore, the source of contamination must likely be indirect, since the discharge occurs only during wet weather. Reference to Table 18 (Section 3), under the category of "Automotive Dealers", indicates a high potential for contamination due to outdoor storage. This fact, plus the knowledge that most used cars are displayed outdoors, makes it fairly clear that surface runoff is probably carrying spilled automotive oil into the storm drain during rains.

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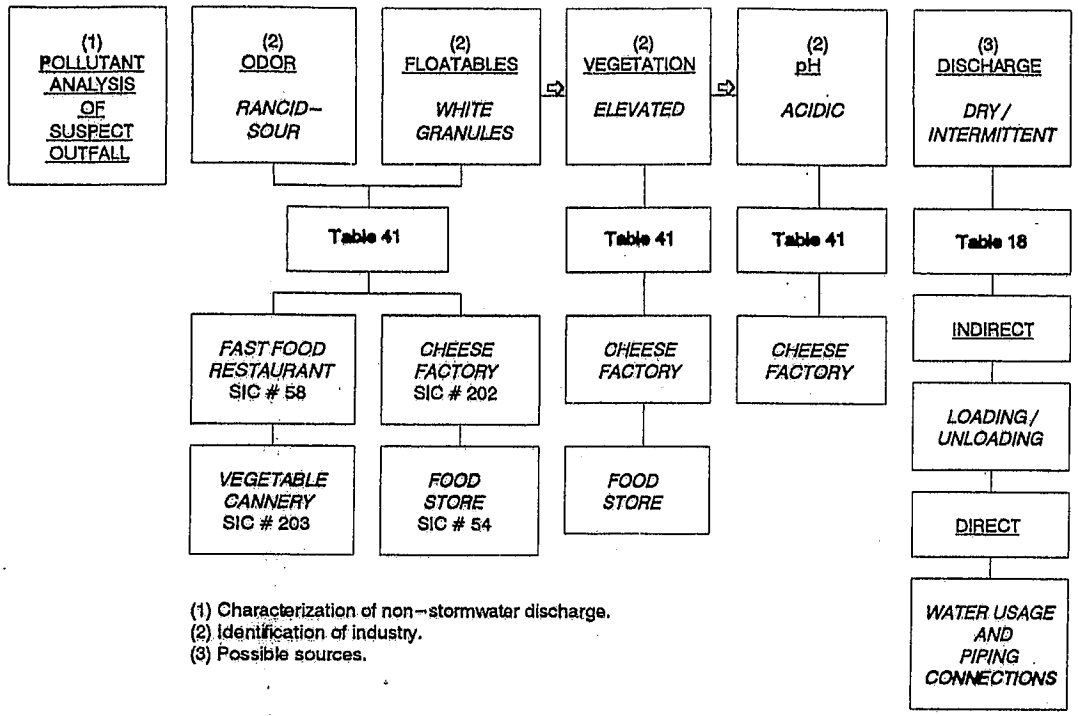

Figure 15. Flowsheet for industrial case example 2.

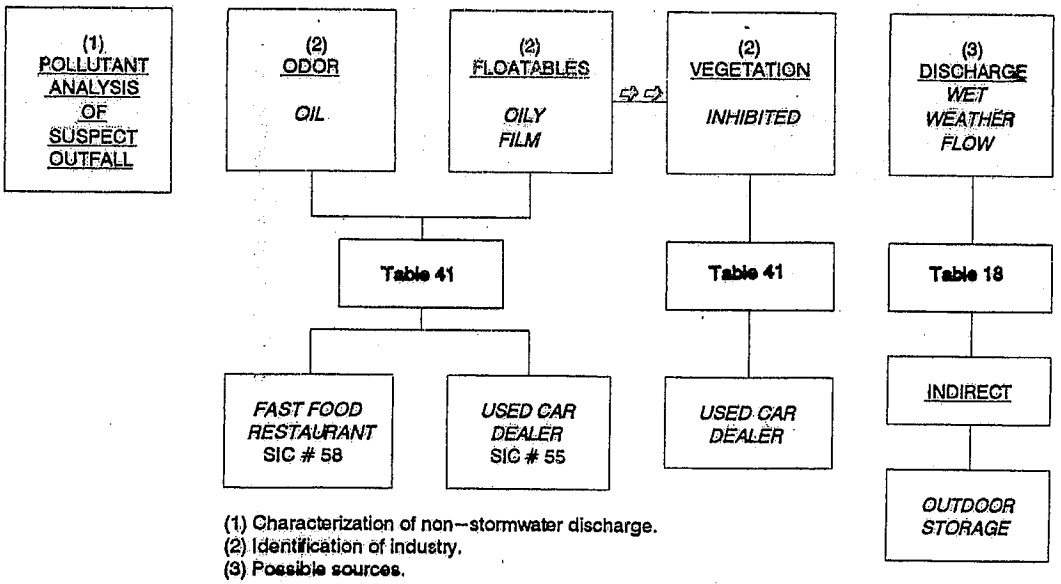

Figure 16. Flowsheet for industrial case example 3.

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Section 10
Corrective Techniques

In addition to identifying problems of unauthorized or inappropriate entries to stormwater systems, it is even more important to prevent problems from developing at all, and to provide an environment in which future problems will be avoided. Thus, a combined approach of identifying and correcting existing problems and avoiding future problems has considerable merit. In this section, the focus is on discussing ways in which future problems can be avoided. However it should be noted that this is not an in-depth review, but has been included to provide the reader with suggestions that could be incorporated into a pollution prevention program.

There are also situations in which the sanitary system is so connected to the stormwater system that good intentions, vigilance, and reasonable remedial actions will not be sufficient to solve the problems. In an extreme case, it may be that while it was thought that a community had a separate sanitary sewer system and a separate storm drainage system, in reality the storm drainage system is acting as a combined sewer system. When recognized for what it really is, the alternatives for the future become clearer: undertake the considerable investment and commitment to rebuild the system as a truly separate system, or recognize the system as a combined sewer system, and operate it as such, without the disillusionment that it is a problem-plagued storm drainage system which can be rehabilitated.

Less extreme than designating a polluted stormwater drainage system a combined sewer system, is the action of focusing on pollution prevention by:

- public education,
- an organized systematic program of disconnecting commercial and industrial non-stormwater entries into the storm drainage system,
- tackling the problem of widespread septic system failure,
- disconnecting direct sanitary sewerage connections,
- rehabilitating storm or sanitary sewers to abate contaminated water infiltration, and
- developing zoning and ordinances.

In this section, the above items will be discussed, together with a section on treatment of wide spread sanitary sewerage failure.

Public Education

One can argue that an ill informed and apathetic public has condoned the past actions of private citizens, commercial entities, industrial concerns, and public officials which led to some of the past and present problems with unauthorized entries to storm drainage systems. One also knows the power of an aroused, concerned public in altering behavior at all levels. Thus, public education has a role to play. It can be effective in altering the behavior of an individual who had assumed that the inlet on the curb was the place to discharge used crankcase oil. It can be effective when organized groups lobby for the return of a stream or a reservoir to a clean and attractive condition.

Public education carries with it the implicit assumption that an educated public will make the "right" decisions, the educated public will be concerned about the "right" problems, and it will encourage private and public organizations to develop solutions to the "right" problems. Fortunately, most of the problems, issues, and corrective measures are clear cut with respect to unauthorized entries to the stormwater system. Public education is a communication art associated with significant changes when successful, and imperceptible change when unsuccessful. As with all

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education, it does not end, but is a continuing process. The following paragraphs describe some of the ways in which public officials can help to educate the public. The "public" has been subdivided into categories which are representative of the problem areas with respect to unauthorized entries to storm drainage systems. The subcategories of the public are:

- industrial
- commercial
- residential
- governmental

Industrial decision makers can be educated by public officials through direct contact when they seek information, by education of the consultants from whom industry seeks advice, and by education of trade associations. Indirect educational opportunities are provided by speaking to meetings of professional organizations and by writing in professional newsletters and journals. Industrial decision makers are a small group which is likely to respond as they recognize that they have to address the problem of unauthorized entries to the stormwater system.

Commercial storm drainage system users are a larger group to educate. The educational process will have to focus on both proprietors and their employees. It will have to recognize the state of both groups, new businesses opening; existing businesses moving, expanding, and closing; and employees entering the work force and changing jobs. Education will have to be focused in the local community. The role of trade and professional associations will be less than was the case with industrial groups. News announcements in the local press will play a role as well as mailed news items. Individual contact between a public official and the proprietor of a commercial establishment will play a larger role. Follow up and repeated contact may be necessary to answer questions and cope with employee turnover. Public education can also benefit from failures. For example, certain violations of discharge practices may be so serious, or flagrant, that a citation or fine results. The local press, if informed, may find such an incident newsworthy. The general public, or other potential offenders, may benefit from this educational procedure.

An informed public willing to act on their convictions is the product sought from public education. The public educator focuses on large groups, as one-on-one contact is unlikely to be either time or cost effective. Long range educational goals may be tackled through school programs, while shorter range educational goals may focus on community groups. Public education will have to focus on broader environmental issues than inappropriate entries to storm drains. Subgroups in the community may play important roles in public education. For example, scouts may undertake community improvement projects including placing signs on curbside storm drains informing the public that the drain is for stormwater only, and not for discharge of wastes. Thus, public education must take advantage of opportunities presented by groups looking for community improvement projects, the opportunities that are available in working with the school system, and opportunities arising from the news media being supplied with newsworthy items.

The final group that public officials should address in public education is other public officials and governmental institutions. Some small governmental units may not know about precautions to be taken with discharges to storm drainage systems unless they are properly informed. Such subgroups may include road departments, sanitation workers, and workers at public institutions such as hospitals and prisons. A multilevel, multitarget public education program can help to avoid problems.

Commercial and Industrial Site Disconnections of Non-Stormwater Sources

Out of convenience and out of ignorance, commercial and industrial sites may impose an increasing load on the storm drainage system. This may be through direct discharges to the storm drainage system, or it may be through diffuse and indirect sources in which the site grounds are contaminated by spills and discharges which are then washed off by storm runoff to the storm drain during rainfall events or by wash water during wash-down operations. The problem is compounded by the vast array of sizes of commercial and industrial enterprises. A single person enterprise has little opportunity to build expertise on the subject of stormwater pollution, while a large industrial

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enterprise may have an environmental division. To the uninformed person, any curb opening may be thought to be part of a comprehensive sanitary wastewater treatment system and the proper entrance point for polluted water discharges or other debris.

Corrective measures for improper uses of storm drains have to be developed recognizing the differences in knowledge and sophistication of the client. Industrial users are few in number but are expected to have the most complex problems. If industrial users are aware, or made aware, of existing and or new federal, state, or local regulations to prevent pollution of stormwater drainage systems, they will usually comply with the regulation. If not, these regulations provide the authority and communication means to instigate corrective action.

Commercial groups are heterogeneous. An appropriate way of working with them to institute changes in their use of storm drainage systems, may be to work with one category of commercial groups at a time. For example, consider gasoline filling stations as a single category. It is possible to focus on correcting similar problems at many facilities that exist in this category. The flushing of radiators may be seasonally common. A typical practice is to let radiator flushing waters (including coolants) to drain to an inlet to the storm drainage system. Education followed by assurance that there will be strict enforcement of discharge regulations or ordinances may be effective. However, a group such as gasoline filling stations cannot be expected to have a long institutional memory as new operators take over and others drop out. Thus, vigilance and follow-up are important to insure that there is not a gradual diminution of appropriate practices.

For both small commercial and large industrial enterprises, willful and knowledgeable violation of the regulations limiting entries to storm drainage systems have to be dealt with firmly and promptly or the enforcement program runs the chance of becoming ineffective. Thus the governmental unit undertaking responsibility for improving the practices regarding entries to storm drainage systems must have an enforcement plan ready.

Failing Septic Tank Systems

Failing septic tank systems can have an impact on an otherwise well functioning storm drainage system. Before discussing corrective measures, it is important to identify the relationship that may develop between a septic tank system and a storm drainage system.

A septic tank system consists of two major components: a septic tank and a leaching field (a waste spreading or soil absorption system). In addition, of course, there is piping associated with the system. Domestic sanitary wastewaters are piped directly to the septic tank. The septic tank typically is made of concrete, is rectangular in shape, is usually divided into two compartments, and has a capacity of one to several thousand gallons. The septic tank serves as an anaerobic digestion and settling unit in which biological action converts the biodegradable liquid and solid waste particles into stable end products. Gravity separates a significant portion of both biodegradable and non-biodegradable particulate matter to the tank bottom or top (depending on whether the particles sink or rise, respectively). Some of the products of this partial treatment process are carbon dioxide, methane, hydrogen sulfide and other odor producing gases, digested and refractory or relatively non-biodegradable sludge, and floating scum. Because the septic tank remains full, it must discharge a volume of wastewater each time a volume of wastewater is discharged into it. This discharged water enters a leaching field where some additional treatment occurs and the final effluent is discharged to the groundwater.

A septic tank may be a low maintenance treatment unit, but it is not entirely maintenance free. As the septic tank continues to be loaded, the scum and sludge layers build up so that the remaining volume available for treatment is reduced. Thus, some of the partially digested or undigested solids, scum, and sludge may be carried from the septic tank to the leaching field where the soil void space may become clogged. As the soil voids become clogged, the ability of the leaching field to handle the liquid portion of the waste is reduced, and surface ponding of the wastewater may result. Of course, ponding could have been prevented by having the septic tank serviced; that is, by having the septic tank pumped. Pumping removes the sludge, scum, and other contents of the septic tank so that its storage and treatment capacity is restored. Pumping frequency varies depending on the size of the septic tank and its

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loading rate. Residential septic tanks may need to be pumped every two to five years. Commercial and institutional septic tanks may need more frequent pumping.

Failed septic tank systems have the potential to pollute stormwater because the leaching field will saturate the ground, and possibly form ponded water on the ground surface. The ponded water may run off and enter a storm drain inlet or drainage ditch, or infiltrate the ground in another area which is intercepted by a storm drain through infiltration. When it rains, any remaining ponded water may be washed off with the runoff to the storm drainage system. Depending on the severity of the septic tank failure, the ponded water can have the characteristics of partially treated sanitary wastewater or nearly untreated sanitary wastewater. Thus, septic tank failures can contaminate the stormwater drainage system during both wet and dry weather.

Septic tank systems may fail even with good maintenance practices. Such failure can result when the soil is simply not permeable enough for the leaching field, or when the soil absorbance capacity is exceeded through long use. A tight clay soil may have such low permeability that the leaching capacity is very limited. If a number of homes are built in close proximity, their septic tank leaching fields may collectively exceed the soil's capacity, leading to a stormwater pollution problem. Even properly operating septic tank systems are a potential pollutant source. Because the basic function of the leaching field is to discharge partially treated effluent to the groundwater, this septic tank effluent can infiltrate into nearby stormwater drainage systems.

Various corrective methods exist for failing septic tank systems that pollute stormwater. These methods include: improve maintenance, institute preventative measures to avoid problems, and abandon the septic tank system with connections made to a sanitary sewerage system. In some cases, improved maintenance may be the answer. Some persons will not do any maintenance to their septic tank system until it fails (they note ponded water in the leaching field area). Then they call for the septic tank to be pumped. In many cases, this is not sufficient to correct the problem: it may be too little action too late. The preventative action of having the septic tank pumped should have taken place prior to failure of the system. Education may provide part of the remedy. The septic tank user may respond to exhortations to have the septic tank pumped on a regular basis, before failure. Coercion through ordinances may be another answer. Ordinances may require that the septic tank be pumped at a specified frequency, with a public body monitoring the program to ensure that maintenance has been carried out.

It sometimes happens that soil conditions and population density rule out both voluntary or involuntary maintenance. In this case, it may be necessary to consider abandoning the septic tank system and installing a system consisting of sanitary sewers leading to a treatment plant. Another option consists of abandoning the septic tank treatment method in favor of small package treatment units that provide aerobic treatment of the domestic sanitary wastewater which is then discharged to a regional leaching field. This option may succeed where the septic tank system has failed, because wastes treated in an aerobic unit may not have the leaching field clogging potential of wastes treated in an anaerobic septic tank. However, experience has shown that these advantages are only obtained with proper control and maintenance. Aerobic systems are more sensitive than conventional septic tank systems to improper maintenance and may therefore not offer any real benefits.

Direct Sanitary Sewerage Connections

Due to indifference, ignorance, poor enforcement of ordinances, or other reasons, a stormwater drainage system may have sanitary wastewater sewerage direct connections. Obviously, the sanitary wastewater entering the storm drain will not receive any treatment and will pollute a large flow of stormwater, in addition to the receiving water. If the storm drain has a low dry-weather flow rate, the presence of sanitary wastewater may be obvious due to toilet paper, feces, and odors. In cases of high dry-weather flows, it may be more difficult to obviously detect raw sanitary wastewaters due to the low percentage of sanitary wastewater in the mixture. Even though the sanitary wastewater fraction may be low, the pathogenic microorganism counts may be exceedingly high.

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The previously discussed field testing procedures (including detergents, ammonia, potassium, and fluorides) will assist in the detection and quantification of sanitary wastewater contamination in the storm drainage system. Flow monitoring may show the variations in the flow rate that are typical of domestic sanitary wastewater.

Dye testing can be effective in finding specific sanitary wastewater connections between a house and a storm drainage system. Dye, such as diluted rhodamine or fluorescein, is flushed down the toilet of a house and the storm drain is monitored to determine whether the dye appears. Care has to be exercised when using this method, as these dyes may stain fixtures that are being tested, and any spillage in the house causes stains that are very difficult to remove.

Monitoring of the storm drainage system with remote video cameras can show the locations of breaks in the storm drain where a domestic wastewater sewer was attached. Video cameras may also show discharges taking place at these locations, demonstrating that the lines are in active use.

Corrective measures involve undertaking a program of disconnecting the sanitary sewer connections to the storm drainage system and reconnecting them to a proper sanitary wastewater sewerage system. The storm drainage system then has to be repaired so that the holes left by the disconnected sanitary sewer entrances do not become a location for dirt and groundwater to enter.

Rehabilitating Storm or Sanitary Sewers to Abate Contaminated Water Infiltration

Infiltration of contaminated water into a stormwater drainage system can cause substantial pollution of the system. This could occur where a sanitary sewer overlies and crosses (or parallels) a storm drain, with sanitary wastewater exfiltrating from the sanitary sewer and infiltrating the storm drain. Other instances would be in areas of polluted groundwater, where the storm drainage is below the water table or intercepts infiltrating groundwater, or in areas having septic tank systems, as discussed previously.

It would be best to correct the sanitary sewer if only one drainage system can be corrected. This would have the dual advantage of preventing infiltration of high or percolating groundwaters and preventing pollution of stormwater with exfiltrating sanitary wastewater. Rehabilitation of the drainage systems by use of inserted liners, or otherwise patching leaking areas, are possible corrective measures. It is important that all drains with infiltration problems be corrected for this corrective action to be effective. This would also include repairing house lateral sanitary wastewater lines, as well as the main drainage runs. However, these corrective measures are more likely to be cost effective when only a relatively small part of the complete drainage systems require rehabilitation.

Zoning and Ordinances

Land use controls achieved by zoning have the potential to exacerbate problems or diminish them. For example, in an area with soils that are ill suited for septic tanks and leaching fields, the potential for future problems is increased if zoning allows small lots for single family residential development and allows septic tank systems. As the area develops, septic tank failures will become common, resulting in increased pollution of stormwater and groundwater. On the other hand, in areas having poor soils, zoning can require correspondingly larger lot sizes and larger leaching fields, resulting in fewer future problems. Ordinances may specify the results that have to be achieved by infiltration tests used to size leaching fields. Also, ordinances can require that a responsible public official be present when the infiltration test is run to decrease the likelihood of false or spurious results being reported. Certified septic tank installers, also checked by public official inspectors, should also be required to increase the likelihood of the system being installed correctly.

Zoning can also have a role to play in avoiding development of land that is subject to frequent flooding. In such land, flooding and high groundwater conditions can result in the sanitary sewerage system being gradually overloaded by infiltration so that cross flow to the storm drainage system can occur.

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Ordinances can help to control problems by putting the force of law and public policy behind desirable practices. For example, ordinances can make mandatory practices such as septic tank maintenance that otherwise would be voluntary. By making the practice mandatory, desirable practices are performed on a regular schedule so that large problems have less opportunity to develop. Ordinances can also regulate the persons doing the pumping of septic tanks so that they discharge the septage to wastewater treatment plants where it can be properly treated rather than it being discharged improperly where the pollution problem is just transferred from one location to another.

Ordinances can also help prevent and or control pollution from many other sources by restrictions on: disposal of household toxic substances to storm drains, storage of chemicals by industry, disposal of industrial wash down water, etc.

Zoning and ordinances represent important means for governing bodies to anticipate problems, to avoid problems, and to manage problems, so that desirable ends are achieved and undesirable consequences are avoided. Enactment of zoning and ordinances occurs in the public arena where interested persons can participate and express their views and concerns. The public can become educated in this process, but zoning and ordinances have the desirable characteristic of being remembered and remaining enforceable long after an individual forgets, becomes disinterested, or becomes recalcitrant.

Another important step that municipalities can take is the development of policies and procedures for the management of spills from transportation (including both roadway and rail) and pipeline accidents. Spills should not be merely washed into the storm drainage system, but should be collected for proper treatment and disposal.

Widespread Sanitary Sewerage Failure

Connections (whether directly by piping or indirectly by exfiltration or infiltration) of sanitary sewers to the storm drainage system may be so widespread that the storm drainage system has to be recognized as a combined sewer system. This could also be the case when the prevalence of septic tank failures leads to widespread sanitary wastewater runoff to the storm drainage system. One usually thinks of a combined sewer system as having all of the sanitary sewer connections to the same sewers that carry stormwater, but the previous discussion suggests that there are degrees of a storm drainage system becoming a combined sewer system. Previously, the recommendations have been made that widespread failure of septic tank systems might necessitate the construction of a sanitary sewer to replace the septic tanks. Also recommended was a program of identifying and disconnecting sanitary sewers from the storm drainage system.

Prior to these actions taking place, the storm drainage system operates to some degree as a combined sewer system. It may be that the sanitary sewerage system is not capable of handling the load that would be imposed on it if a complete sewer separation program were undertaken. Or, in an extreme case, no sanitary sewer system may exist. By recognizing that a combined sewer system does in fact exist may help to focus attention on appropriate remedial measures. The resources may also not be available to undertake construction of a separate sanitary wastewater drainage system.

One should then focus on how to manage the combined sewer system that is in place. Management may require that end-of-pipe storage/treatment be investigated. Also, the combined sewer system may be tied into other combined sewers so that more centralized treatment and storage can be applied. While operation of a combined sewer system is not a desirable option, it may be preferable to having the stormwater and the large number of sanitary entries receive no treatment.

An early identification and decision to designate a storm drainage system a combined sewer system, will prevent abortive time and costs being spent on further investigations. These resources can then be more effectively used to treat the newly designated combined sewer system.

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In essence, recognition of a system as being a combined sewer system provides a focus in the regulatory community so that it may be possible to operate the system so as to minimize the damage to the environment. Plans can then be developed to provide the resources to separate the system.

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Section 11
Birmingham, Alabama, Verification Project

This section describes the demonstration project that was carried out in Birmingham, Alabama, to test the procedures presented in this report (Lalor 1994). Special attention was given to the collection of the library data and in evaluating the outfall data analysis procedures to identify the dry-weather sources.

Collection and Analysis of Background Data from Potential Dry-Weather Flow Sources

Potential sources of dry-weather flows identified within the commercial and residential land use area selected for study during this project included spring water, infiltrating shallow ground water, tap water, irrigation runoff from landscaped areas and a golf course, sewage, septic tank leachate, commercial laundry waters, commercial carwash waters, radiator wastes, and metal plating bath wastes. Obviously, some of these sources would contribute to pollution problems, and some would not. However, all have the potential for showing up in dry-weather flows in storm sewer systems. Therefore, a chemical understanding of each, with respect to the selected tracers, is needed to build a "library" to which outfall dry-weather flows can be compared.

Collection of Source Area Samples

To obtain the background information needed to construct such a library, samples were collected directly from the potential sources identified above. To the extent possible, specific sampling sites were located in the drainage area of the creek reach selected for the field investigation. Sample sets for each source category contained 10 to 12 samples, except where more samples were necessary to better represent large periodic variations (such as for sanitary sewage).

After collection, samples were iced and returned to the laboratory for analysis. All samples were analyzed using the test methods identified in Table 29 of Section 6. Physical characteristics were also noted for each category of samples. Table 43 contains a summary of the physical observations noted for each sample. Numbers in the numerator indicate the number of samples which displayed the characteristic in question. Denominators represent the total number of samples. All references to "sediments", in connection with these directly collected source samples, refer to settleable solids.

Tap Water Samples–

Tap water samples were collected along the length of the distribution system through the study area. Results are presented in Table 44. Chlorine values were inversely related to the distance of the sampling point from the water treatment plant. Values varied from a high of 1.5 mg/L near the plant, to a low of 0.03 mg/L near the end of the distribution branch. Samples 1 through 5 were taken from one branch of the distribution system, with sample site number 1 located nearest the treatment plant. Samples 6 through 10 were taken from another branch, with sample site number 6 located nearest the treatment plant. Ammonia and toxicity also had relatively high COV values for the tap water samples. In contrast, Fluoride concentrations were very consistent, in the narrow range of between 0.96 to 1.0 mg/L, irrespective of sampling location. Specific conductivity, hardness, detergents, fluorescence, potassium, pH, color, and phenols also had very small COV values. All tap water samples were also clear and free of odors, floatables, sheens and sediments.

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TABLE 43. SUMMARY OF PHYSICAL CHARACTERISTICS OF SOURCE SAMPLES

Source	Color	Odor	Turbidity	Floatables/Sheens	Sediments
Spring Water	0/10	0\10	0\10	0\10	0\10
Shallow Ground	6/10	0\10	0\10	0\10	0\10
Tap Water	0\10	0\10	0\10	0\10	0\10
Landscape Irrigation	36/36	0\10	2\10	2\10	0\10
Sanitary Sewage	13\13	36\36	36\36	NA	NA
Septic Tank Discharge	10\10	8\13	0\13	0\13	0\13
Carwash Wastewater	10\10	3\10	10\10	3\10	6\10
Laundry Wastewater	10\10	5\10	10\10	3\10	0\10
Radiator Wastes	10\10	10\10	8\10	10\10	2\10
Plating Wastewaters	10\10	5\10	2\10	0\10	10\10

NA: Data not available

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TABLE 44. TAP WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	112	0.98	49	0	4.5	1.48	0.02	6.98	0	1.50	74.9	NA	NA
2	112	0.97	50	0	4.0	1.55	0.03	7.00	0	1.26	64.4	NA	NA
3	113	1.00	48	0	4.3	1.46	0.04	6.96	0	1.26	56.6	NA	NA
4	113	0.96	82	0	4.5	1.5	0.02	6.07	0	1.24	29.8	NA	NA
5	110	0.95	50	0	5.0	1.66	0.03	6.96	0	0.40	64.9	NA	NA
6	112	0.96	49	0	4.5	1.58	0.03	7.00	0	1.38	41.0	NA	NA
7	112	0.96	50	0	4.5	1.57	0.02	6.99	0	1.37	61.6	0.01	0.00
8	111	0.96	50	0	5.0	1.56	0.03	6.96	0	0.19	35.4	0.00	0.00
9	111	0.97	47	0	5.0	1.60	0.03	6.97	0	0.16	31.4	0.02	0.00
10	110	0.96	48	0	5.0	1.57	0.03	6.97	0	0.03	10.3	0.00	0.00
mean	111	.097	49	0	4.6	1.55	0.03	6.89	0	0.88	47.0	0.01	0.00
st. dev.	1.07	0.01	1.42	0	0.35	0.06	0.01	0.29	0.00	0.60	20.45	0.01	0.00
95%conf. limits (mean +/-)	0.67	0.01	0.88	0	0.22	0.04	0.00	0.18	0.00	0.37	12.6	0.01	0.00
median	112	0.96	49.5	0	4.5	1.57	0.03	6.97	0	1.25	48.8	0.01	0.00
COV	0.01	0.01	0.03	--	0.08	0.04	0.33	0.04	--	0.68	0.43	1.00	--
distribution	normal	normal	normal	uniform	normal	normal	normal	normal	uniform	bi-modal	normal	uniform	uniform

NA: Data not available

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Spring Water Samples–
The field study area was pocked with springs prior to development, and some are still accessible at their source. All spring water samples were collected from these sources, and samples were collected during both rainy and dry seasons. Table E-1 (Appendix E) presents test results from the spring water samples. Hardness and conductivity were the most notable tracer parameters for the groundwater samples, being about 250 mg/L for hardness and about 300 µS/cm for conductivity. All other parameters were in very low concentrations, and the pH was very close to neutral. All spring water samples were clear and odor free, with no floatables, sediments or sheens.

Shallow Groundwater Samples–
Shallow groundwater was collected from flows above impervious layers exposed by road cuts and along river banks in the study area. Table E-2 presents test results from shallow ground water samples. Potassium and ammonia results for samples 1 through 3 were not available, as were pH results for samples 1 and 2. The chemical characteristics for shallow groundwater samples were significantly different from the spring water samples, especially in the lower hardness and conductivity values. Shallow groundwater samples had good clarity, were odor free, and were free of floatables, sediments and sheen. About half of the samples had some color noted.

Irrigation Water Samples–
Irrigation water samples were collected from sprinkler runoff over lawns and landscaped areas, as well as from a public golf course in the study area. Samples were collected using a hand-held vacuum pump which evacuated the sample bottle, drawing the sample through a Teflon™ tube. Results are presented in Table E-3. All chlorine concentrations were quite low (compared to most tap water samples) due to the rapid interaction of the chlorine with organics in the lawn areas. Fluorescence was also very high, compared to the tap water samples. All irrigation water samples had traces of color, and two of the samples were somewhat cloudy due to suspended soil particles. Grass or leaf fragments were observed floating on two samples. No sheens or odors were detected.

Sanitary Sewage Samples–
The characteristics of sanitary sewage were expected to change throughout the day, reflecting domestic activity and a time lag corresponding to the transit time of the wastewater in the sewers. A periodic pattern was observed for each parameter, as shown in Table E-4. Samples were collected from the sanitary sewage trunk line which runs through the study area. This line originates just above the study area, and carries wastes from commercial and residential areas only, with no known industrial discharges (based on maps and discussions with Jefferson County personnel). Fifteen-minute grab samples, compiled bi-hourly, were collected for 24-hour periods using an automatic sampler to identify the variation in sewage quality. Sampling took place on three different days during dry weather. Sanitary sewage samples were gray in color and cloudy. Conductivity, fluoride, detergents, fluorescence, potassium, ammonia, color, and toxicity are all distinguishable for these samples. A distinct and easily recognizable odor was apparent in all samples. No sheens were obvious on the water surfaces. A weighted, perforated (0.6 cm-openings) polypropylene intake was used with the sampler to help prevent clogging, so floatables, if present, were not collected.

Septage Samples–
Septage contributions to dry-weather flows may originate as septage field leachate, or seepage from failing septic systems. A Xitech groundwater sampler was used to collect some septage field leachate samples. Other samples were collected directly from septic tank effluent lines. Test results from these samples are presented in Table E-5. Septage samples number 1, 2 and 3 were collected from homes where only water from toilet flushings ("black water") entered the septic tank. These homes were located in a rural area outside of the project study area, but received tap water from the same water treatment plant. Other wastewaters from these homes were released directly onto adjacent portions of the homeowner's property. This situation would be highly unlikely in an urban area. The black water samples had greater concentrations of most tracer parameters, except for specific conductivity and color. All samples were also found to be extremely toxic, whereas the sanitary sewage samples shown on Table E-4 had only low to moderate toxicity. Color was apparent in all septage samples, but samples were clear, with no sheens or floatables. An indistinct, earthy odor was apparent in most samples.

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Commercial Car Wash and Laundry Samples–
Wastewater was collected from the sumps of commercial carwashes and laundries. Tables E-6 and E-7 present test results from these samples. These two wash water sample groups were generally similar, except that hardness, potassium, and color were substantially greater for the commercial carwash samples than for the commercial laundry water samples. All carwash and laundry samples were highly toxic, colored and cloudy. Oil sheens were apparent on approximately one-third of the carwash samples, and solids often settled out in the sample jars. Some of the laundry samples had a distinguishable detergent odor, and floatables were noted in some samples.

Radiator Flushing Water–
Vehicle maintenance facilities provided radiator flushing wastes. Table E-8 presents data from radiator flushing water samples. Most radiator flushing wastes were intensely iridescent green, and most were cloudy. Oily or metallic odors were noted. The water had very high specific conductivity, very high fluorides, very high fluorescence and potassium and high color. All samples were also extremely toxic.

Metal Plating Bath Water–
Wastes from metal plating baths (pre-treated on site) were collected from three different facilities that had permits to discharge these wastes to the sanitary sewage system within the project study area. Processes at each site differed considerably, and the data collected and presented in Table E-9 reflect this variation. These samples all had very high conductivity, high fluorescence, very high hardness, high potassium, ammonia, copper, and color, and were extremely toxicity. All samples were colored and ranged from gray to green to gold. Sediments were apparent in all samples, and a slightly metallic or acidic odor was associated with half of the samples.

Data Analyses of Source Water Characteristics

Data from the above potential sources of dry-weather flow were also analyzed to: (1) determine which parameters contribute unique and significant information to the source characterizations, and (2) determine the degree to which individual source types could theoretically be separated and identified based on these source characterizations. The statistical analyses included exploratory and pattern recognition techniques including box plots, Pearson correlation matrices, Mann-Whitney U tests, and cluster analyses, as described below.

Box Plots of Source Water Characteristics–
Typical concentration patterns were established for each of the potential sources of dry-weather flow noted above. The extent to which these concentration patterns differed from one source to the next, and the variation observed in the patterns within a single source, would eventually determine the extent to which information from the outfall screening methodology could be used to identify the source or sources of dry-weather flow from a specific outfall.

An intuitive appreciation of this information can be gained from the box plots in Figure 17 for specific conductivity and Figures E-1 through E-12 for the other tracer parameters. The upper and lower boundaries of the "box" itself represent the 25th and 75th percentile values in the data set, and the horizontal line between the two represents the median. The ends of the upper and lower vertical lines, extending from the boxes, denote the 10th and 90th percentile values, while the circles represent the minimum and maximum values in each data set. Each of these figures visually summarize the concentrations at which one parameter occurs within each source category. Boxes that do not overlap (at the 25 and 75 percentile points) are generally significantly different at least at the 95% confidence level.

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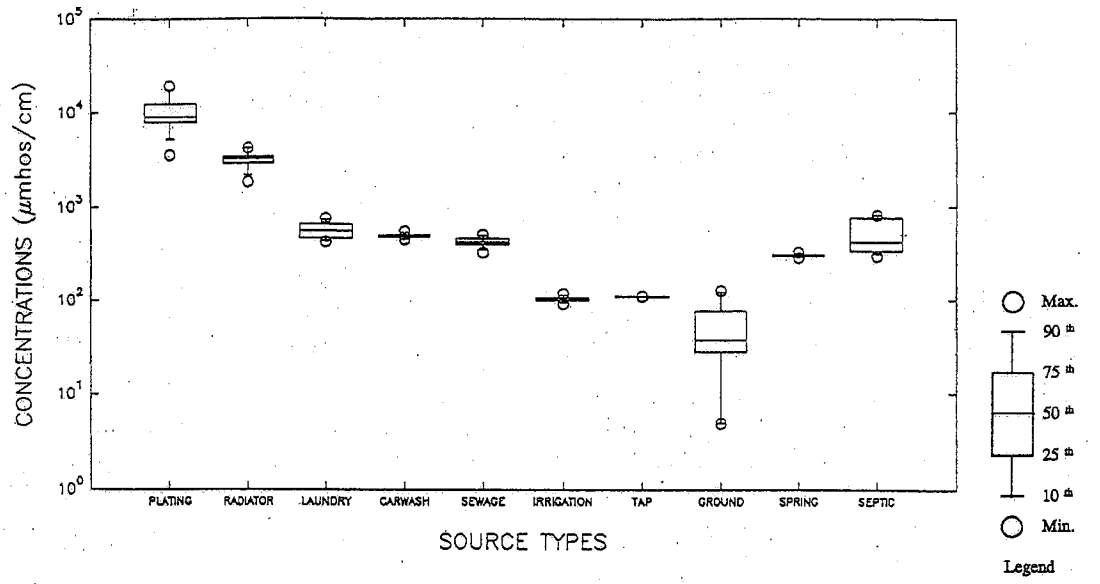

Figure 17. Conductivity comparisons for samples collected from potential dry-weather flow sources.

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These figures graphically show significant groupings of sample types that may be distinguishable for different tracer parameters. The following lists shows these major groupings from these figures (in order of high to low concentrations):

Specific conductivity (Figure 17)

- plating bath water
- radiator flushing water
- laundry, carwash, sewage, septic, and spring waters
- irrigation and tap water
- shallow ground water

Fluoride (Figure E-1)

- radiator flushing water
- laundry wash water
- carwash water
- plating bath water
- sewage, irrigation, tap, and septic waters
- groundwater and spring water

Hardness (Figure E-2)

- plating bath water
- spring water
- carwash and sewage waters
- irrigation, tap, and septic waters
- radiator, laundry, and groundwaters

Detergents (Figure E-3)

- carwash waters
- laundry waters
- radiator flush waters
- plating, sewage, and septic waters
- irrigation, tap, ground, and spring waters

Fluorescence (Figure E-4)

- radiator flush water
- laundry and carwash water
- plating, sewage, irrigation, and septic waters
- tap, ground, and spring waters

Potassium (Figure E-5)

- radiator flush water
- plating bath water
- carwash water
- septic water
- laundry, sewage, and irrigation water
- tap, ground, and spring water

Ammonia (Figure E-6)

- plating and septic waters
- radiator flush water
- sewage water
- laundry water
- irrigation water

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- carwash and groundwater
- tap water
- spring water

pH (Figure E-7)

- laundry water
- radiator, carwash, sewage, irrigation, tap, ground, spring, and septic waters
- plating bath waters

Color (Figure E-8)

- radiator flush water
- carwash water
- plating and septic waters
- laundry and sewage waters
- irrigation and ground waters
- tap and spring waters

Chlorine (Figure E-9)

- laundry and tap waters
- plating, radiator, carwash, sewage, irrigation, groundwater, and septic waters
- spring water

Toxicity (Figure E-10)

- plating, radiator, laundry, carwash, and septic waters
- sewage and tap waters
- irrigation, groundwater, and spring water

Copper (Figure E-11)

No data were available for radiator, laundry, carwash, irrigation, and spring waters

- plating and septic waters
- sewage, tap, and groundwater

Phenols (Figure E-12)

All measurements were less than the detection limits, and no data were available for radiator flushing waters.

The information collected thus far seemed to indicate that the background information collected from potential sources of dry-weather flow was sufficient to allow contaminated source types to be distinguished from non-contaminated source types. The results of the statistical tests presented in the next subsection confirmed this, and indicated that additional source flow information could be derived by more detailed analyses of the outfall data.

Correlation Analyses of Source Water Characteristics--

A Pearson correlation matrix analysis was conducted to investigate linear relationships between parameters. This information could be used to eliminate redundancy in testing. Pearson's correlation is a statistical technique for analyzing the association (or correlation) between variables (in this case measured parameters). This technique is designed to determine if a relationship exists, the strength of the relationship, and the direction of the relationship. Two different parameters are associated if the distributions of y change for the various conditions of x. Pearsons's correlation coefficient (Pearson's r) ranges from -1.00 to +1.00, with 0 indicating no association and +1.00 and -1.00 indicating perfect positive and perfect negative correlations, respectively. Values between these extremes describe relationships in terms of how closely they approach the extremes. For example, coefficients approaching 0.00 can be described as "weak" and those approaching +1.00 or -1.00 as "strong".

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A Pearson correlation matrix for all test parameters, from all likely sources combined, is presented in Table 45. A strong positive relationship (r value of >0.9) was found to exist between fluorescence and detergents. This was not unexpected. Fluorescence was originally included as a means of distinguishing between septic tank discharge and sewage, based on research by Alhajjar (1989) who found that detergents were not found in septic tank discharges. However, samples of septic tank discharges analyzed during this research were all found to contain detergents, when the septic tanks received the full spectrum of wastewaters generated in the household. Results of the Pearson correlation test indicated that testing for both fluorescence and detergents, for the most part, provided redundant information. However, elevated levels of fluorescence were noted in all samples of irrigation runoff from landscaped areas, while detergents were not detected. This information could aide in distinguishing this source from other relatively clean water sources. However, because fluorescence is also much easier to measure in the laboratory (and in the field) than detergents, it may be the more effective tracer parameter to use. Rather strong correlations (r values between 0.8 and 0.9) were also found to exist between hardness and conductivity, as well as between turbidity and detergents, and between turbidity and fluorescence.

Mann-Whitney U-Tests of Source Water Characteristics--
Data collected was also subjected to the Mann-Whitney U test (sometimes called the two-sample Wilcoxon rank test) in an effort to determine which test parameters exhibit significantly different values from one source to another. The Mann-Whitney U test is a non-parametric test and, as such, does not require the assumption of normally distributed data. It is particularly useful when working with small sample sets, especially when the distribution characteristics may not be well understood.

Working with one parameter at a time, individual measurements from two sample sets are pooled and ranked from highest to lowest. The ranks for each of the two sample sets are then totaled and compared. If the two sample sets represent populations not significantly different from each other, then the total ranks for the two sample groups will be similar in value. On the other hand, if the two sample sets represent populations that do differ for the variable of interest, these totals will be very different. The significance of the difference was tested at the 95% confidence level. Minitab statistical software was used to perform the calculations and compute the significance levels (p-values). The tables in Appendix E contain the p-values resulting from these comparisons. Values greater than 0.05 indicate that the differences between the compared data sets were not significant at the 95% confidence level.

Results from the Mann-Whitney U test can be evaluated in two ways. First and most basically, results can be used to indicate which parameters are best able to distinguish between clean flows (spring water, shallow ground water, tap water, landscape irrigation runoff) and contaminated dry-weather flow sources (sewage, septic tank discharges, wash waters, plating wastes, radiator flushing wastes). This is reflected by the percentage of contaminated sources which differ significantly from clean sources, with respect to the parameter of interest. Figure 18 summarizes this information. Secondly, the test results can be used to indicate which parameters are most useful for distinguishing between each of the individual sources of dry-weather flows. Figure 19 summarizes the results of the Mann-Whitney U test from this perspective.

If simply categorizing flows as contaminated or uncontaminated is the objective, it is apparent from Figure 18 that conductivity, detergent (as MBAS) and color tests would provide the most useful basic information in that 100% of the comparisons between individual contaminated and clean sources revealed significant differences at the 95% confidence level. Pairings of clean and contaminated source data for potassium, fluorescence, ammonia and toxicity revealed significant differences 96% of the time, followed by hardness at 92% and fluoride at 88%.

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TABLE 45. PEARSON CORRELATION MATRIX

	Conductivity	Fluoride	Hardness	Detergent	Fluorescence	Potassium	Ammonia	pH	Color
Conductivity	1.000								
Fluoride	0.064	1.000							
Hardness	0.821	0.042	1.000						
Detergent	-0.031	0.688	-0.066	1.000					
Fluorescence	-0.017	0.779	-0.076	0.932	1.000				
Potassium	0.766	-0.027	0.443	-0.033	-0.053	1.000			
Ammonia	0.461	-0.068	0.548	-0.166	-0.034	0.138	1.000		
pH	-0.583	0.287	-0.452	0.076	0.096	-0.291	-0.397	1.000	
Color	0.171	0.416	0.134	0.771	0.704	0.208	0.042	-0.166	1.000
Chlorine	-0.023	0.241	-0.089	0.005	0.083	0.025	0.028	0.200	-0.084
Toxicity	0.457	0.605	0.428	0.614	0.690	0.305	0.523	-0.189	0.654
Copper	0.493	-0.015	0.504	-0.105	-0.009	0.135	0.703	-0.616	0.096
Phenols	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Odor	0.159	0.422	0.140	0.626	0.714	-0.009	0.429	-0.364	0.602
Turbidity	0.088	0.718	-0.096	0.800	0.827	0.157	-0.200	0.149	0.525
Floatables	-0.148	0.303	-0.160	0.407	0.389	-0.101	-0.183	0.150	0.371
Sediments	0.700	0.215	0.737	0.365	0.342	0.471	0.376	-0.495	0.594

BDL: Below Detection Limits for all samples

(continued)

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TABLE 45. (continued)

	Chlorine	Toxicity	Copper	Phenols	Odor	Turbidity	Floatables	Sediments
Conductivity								
Fluoride								
Hardness								
Detergent								
Fluorescence								
Potassium								
Ammonia								
pH								
Color								
Chlorine	1.000							
Toxicity	0.273	1.000						
Copper	-0.010	0.418	1.000					
Phenols	BDL	BDL	BDL	BDL				
Odor	0.007	0.769	0.441	BDL	1.000			
Turbidity	0.117	0.498	-0.158	BDL	0.434	1.000		
Floatables	-0.044	0.134	-0.144	BDL	0.121	0.304	1.000	
Sediments	-0.072	0.629	0.366	BDL	0.434	0.256	0.040	1.000

BDL: Below Detection Limits for all samples

Note: Prepared using SYSTAT™ software version 5.0

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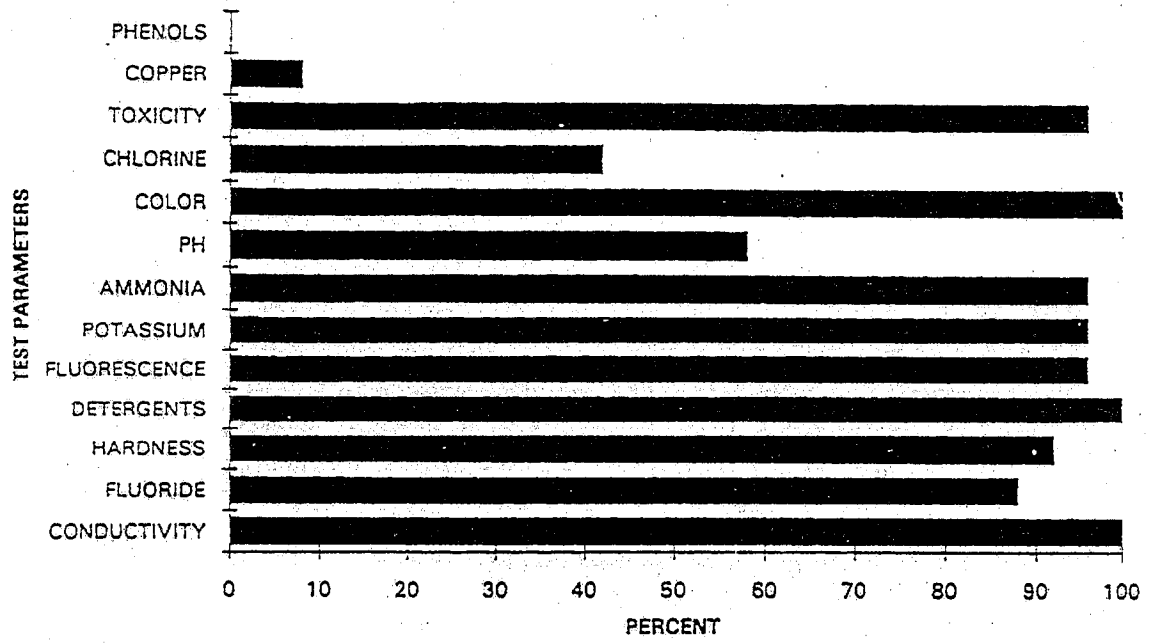

Figure 18. Significant differences when contaminated sources are compared to uncontaminated sources.

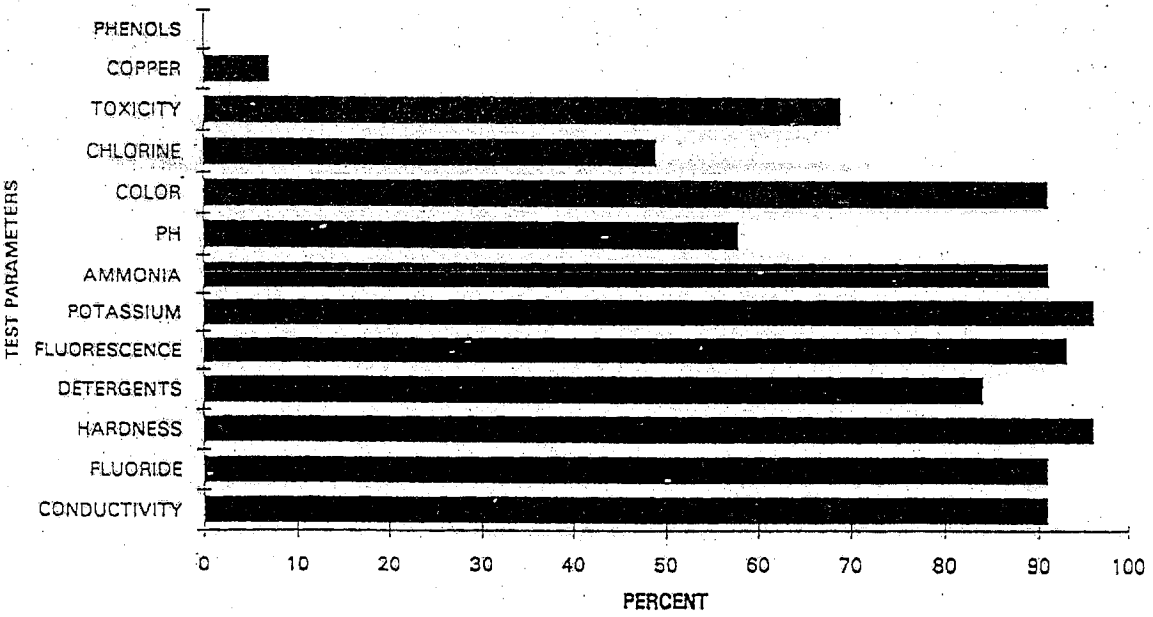

Figure 19. Significant differences when all sources are compared to uncontaminated sources.

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Results from the Mann-Whitney U test indicate that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups. If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated outfalls from clean outfalls. However, since this is not always the case, measured levels in outfalls with multiple dry-weather flow sources could fall within acceptable levels, even though a contaminated source was contributing to the flow. Detergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. All contaminated source samples analyzed contained detergents, with the exception of the three septage samples collected from homes discharging only toilet flushing water to their septic system. This situation is highly unlikely in an urban area. No clean source samples were found to contain detergents. The detergent test used had a range of 0.00 to 1 mg/L, with a resolution of 0.01 mg/L and a standard deviation of about 0.02 mg/L. At this level, 99.2% of the samples collected from contaminated sources in this investigation would be detected in outfall flow mixtures, if they made up at least 6.5% of the flow. One septic tank leachate sample was responsible for the 0.08% exception. This source would not have been detected if it made up less than 20% of a mixed outfall flow with clean waters. The three rural septage samples collected from homes discharging only water from toilet flushings to their septic systems were not included in the Mann-Whitney tests because of the unusual nature of the wastewater.

Parameters which are best able to distinguish between all individual sources of dry-weather flows will be most useful when more detailed investigations are needed when identifying individual flow sources. Figure 19 shows that potassium and hardness levels were found to be significantly different in 96% of the comparisons between all flow source categories. Fluorescence followed at 93%. Conductivity, fluoride, ammonia and color measurements were significantly different in 91% of the comparisons, and detergents were different in 84%. A lower value for detergents was to be expected when analyzing Mann-Whitney results from this perspective since none of the samples from uncontaminated flow sources contained any detergents. These sources would therefore not be significantly differently from each other with respect to detergents, hence lowering the total percentage of comparisons which were significantly different.

Based on these analyses, pH would appear to be of little use in either case, but it is a quick and inexpensive procedure, and could reveal unexpected industrial sources not previously identified in the watershed, including illegal dumping. Chlorine measurements also appear to contribute little useful information to this study, and the analysis of copper and phenol even less.

Cluster Analyses of Source Water Characteristics–

While the Mann-Whitney U tests were performed with one parameter at a time, a cluster analysis was used to detect natural groupings in the data when all valid parameters were considered concurrently. Cluster analysis achieved this, by evaluating the differences in data between, and within, the dry-weather source categories. This information was needed to help determine the number and type of source categories which could be clearly defined and distinguished from one another, based on the test results from direct sampling of potential dry-weather flow sources. The cluster analysis was carried out using SYSTAT™ software (SYSTAT Inc., Evanston, IL).

Cluster analysis is a multivariate procedure for detecting natural groupings in data. It is used to classify a set of objects or cases into subgroups, although neither the number nor members of the subgroups are known. The SYSTAT™ cluster module distributes individual samples (cases) into groups such that between-group variation is as large as possible relative to within-group variation. The SYSTAT™ Cluster function provides two broad classes of clustering: Join and Kmeans. "Join" includes hierarchical, tree, or linkage methods. "Kmeans" uses a splitting method, which is not necessarily hierarchical.

Joining methods are often called hierarchical because they partition a set of objects into a group of nested sets. For example, hierarchical clustering splits four clusters into five by breaking apart one of the clusters. Non-hierarchical methods may rearrange all the objects from four clusters before producing a solution for five clusters. Output from

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hierarchical clustering analyses can be represented as a tree or dendrogram. This display shows the linkages between each object, or group of objects, as a joining of branches in a tree. Kmeans clustering splits a set of objects into a pre-selected number of groups; reassigning members to each group in order to maximize between-cluster variation relative to within-cluster variation.

Each individual sample from every source was entered in SYSTAT™ as a separate case. All data, with the exception of copper and phenol levels, were entered for each individual sample. Copper and phenol values were omitted based on the results of the Mann-Whitney U Tests which showed them to be of little or no use in distinguishing among dry-weather flow sources. Many of the clustering variables (test parameters) were on entirely different measurement scales and had wildly different concentration ranges, so variables were standardized in order to keep the influence of the individual variables comparable. Standardizing puts measurements on a common scale. Using SYSTAT™, this was accomplished by determining the distance (in terms of standard deviations) of each value from the mean ((Value - Mean)/Standard Deviation).

The complete data set was subjected to "Join" clustering. "Join" computes Euclidean distance (root mean squared distance) between objects for its clustering metric. This is an acceptable method for data from continuous or ratio scales (Fisher and Van Ness 1971). As noted previously, data were standardized to put the parameter measurements on a common scale. This is important when Euclidean distances are used. Single linkage clustering (Hartigan 1975) was used to compute the distance between one cluster and another. This linkage method takes the distance between two clusters as the distance between the two closest members of those clusters.

SYSTAT™ displays the output from "Join" as a tree. The tree is printed with a unique ordering, such that every branch is lined up so that the most-similar objects are closest to each other. If a perfect seriation (one-dimensional ordering) exists in the data, the tree reproduces it. The seriation algorithm for ordering trees is given in Gruvaeus and Wainer (1972). Seriation is considered advantageous for single linkage clusterings.

Figures 20 and 21 summarize the results of the cluster analysis. In Figure 20, 100% of the radiator waste samples clustered together, as did all car wash samples, all laundry samples and all plating wastes. Samples within each of these groups were much more similar to each other than they were to members of any other group. All other sample sources clustered together in a group referred to here as "residential waters". The reason for this is a problem of scale. The commercial sample sources were so dissimilar that distances were measured on a 10,000 unit scale. At this level, details of the much smaller differences between residential water sources were lost. Figure 21 examines the "residential waters" group alone.

In Figure 21, septic tank leachates are the most dissimilar group of samples. These septic tank samples split into two groups, based on the presence or absence of detergents. As noted earlier, three septage samples (15% of the total number) were collected from rural homes outside the project field study area where only water from toilet flushings entered the septic tank. Virtually no detergents were measured in these three samples. Therefore, these samples were separated from the 85% of the septage samples in which detergents were measured.

All shallow ground water samples clustered together, as did all spring water samples, all sewage samples and all irrigation water samples. Tap water samples split into two groups, based on chlorine content. The samples included in the 60% grouping were the samples with chlorine values greater than 1.2 mg/L. Samples included in the 40% grouping had chlorine values less than 0.5 mg/L.

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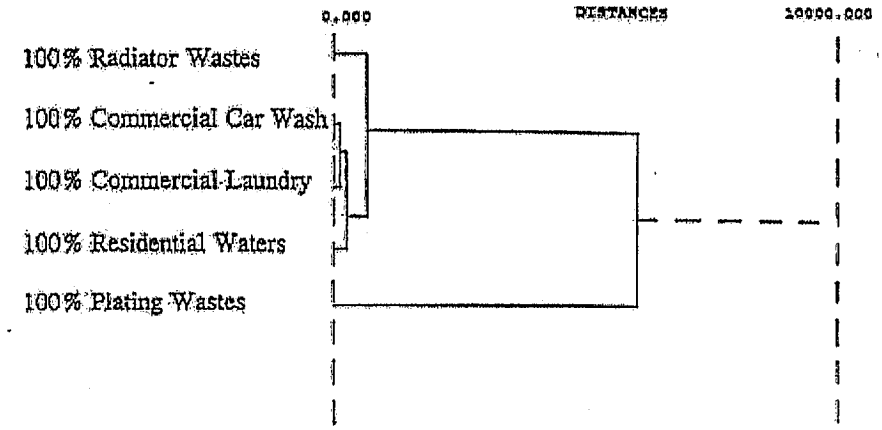

Figure 20. Cluster analysis for all potential dry-weather flow sources.

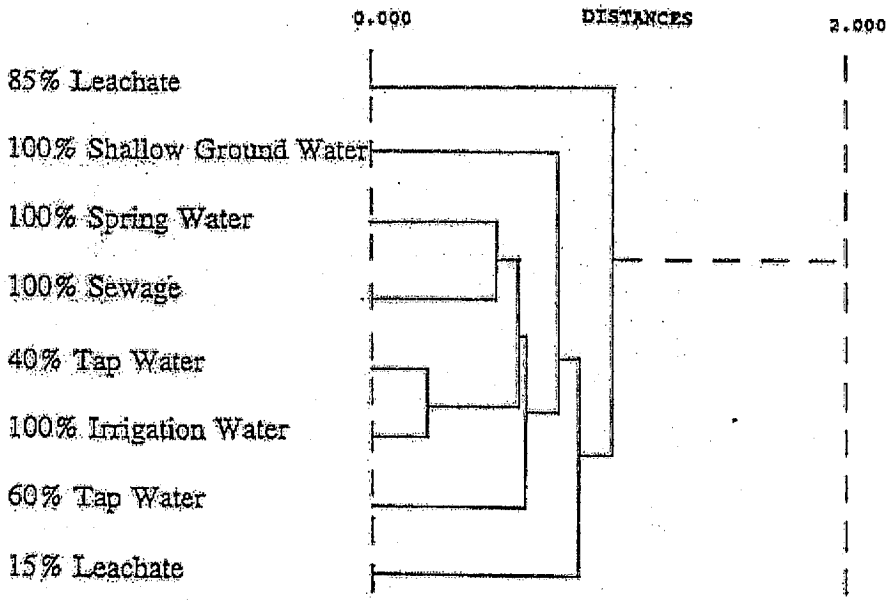

Figure 21. Cluster analysis for residential area dry-weather flow sources only.

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These results indicate that the parameters being measured should be sufficient to distinguish among all of the potential commercial/residential sources of dry-weather flows identified.

Testing of Procedures Using Outfall Samples to Distinguish Flow Sources

A field investigation was carried out to confirm the usefulness of the proposed sampling and analysis schemes. A three-mile section of Village Creek in Birmingham, Alabama, was selected for the investigation. The drainage area for this section of the creek contains about 4500 acres. Figure 22 is a map of this area. Appendix D also contains additional drainage area land use and outfall information. Residential land use comprises approximately 88% of the total area, commercial land use approximately 8%, and industrial land use less than 1%. Approximately 4% of the area is classified as undeveloped, but includes a park and public golf course. The majority of the drainage area is serviced by sanitary sewers, but some septic tanks are also used. This information was developed from zoning maps, aerial photographs of the area, and topographic maps with one-foot contour intervals obtained from the City of Birmingham's Engineering Department. Septic tank information was obtained from the Jefferson County Department of Public Health.

Field Surveys

Maps locating city storm sewer outfalls were not originally available during this demonstration project. Stormwater outfalls, as well as direct discharges to the creek, were located by walking along the creek itself. A total of 88 outfalls and discharges were located and numbered, described as follows: 64 storm drains, 17 direct discharges from creek-side businesses, 1 "both", and 6 "other". Preliminary surveys were carried out during late fall when foliage was less likely to obscure the outfalls. Even so, seven outfalls were initially missed. Outfall diameters were recorded and ranged from 2 inches to 12 feet, excluding open ditches. Dry-weather flow (defined by a 72-hour antecedent dry period) was noted at 14 outfalls or discharges during the preliminary survey. All sites were visited at least 8 times during the field investigation period (September 1990 to March 1993). Appendix F contains all outfall data obtained during these site visits. Table 46 summarizes physical information collected for each outfall and discharge location.

Estimates of individual drainage areas for each storm sewer outfall were determined from topographic maps with one foot-contour intervals. It is understood that there are errors associated with assuming that storm drainage pipes always follow the topography, but in the absence of storm sewer maps, this method represents a logical approach to the problem. Corresponding land use and zoning maps, confirmed by site visits, were used to establish land use in each outfall drainage areas. Pipes and ditches, installed for purposes other than storm drainage (separate point source outfalls), were labeled as direct discharges, and no drainage area was assigned.

Outfall Data Collection

Data used to compile the history of dry-weather flow for each outfall was accumulated during the dry-weather site visits. Visits were conducted during different months of the year, including both rainy and dry seasons in Birmingham. Table 46 indicates the flow histories at the outfall locations. Outfalls and discharge locations described as "dry" were never observed to have dry-weather flow, and those described as "flowing" were found to be flowing during every visit, but not necessarily at the same flow rate. Outfalls and discharges labeled "intermittent" were observed to have flow during at least one site visit. A total of 65 stormwater outfalls were located. Of these, 48 (74%) were always dry, 6 (9%) had flow intermittently, and 11 (17%) were always flowing. Eighteen direct unpermitted discharges to the creek from nearby industries and commercial areas were located; 10 (56%) were dry, 6 (33%) had intermittent flow, and 2 (11%) were always flowing. (Outfall number 65 was counted in both categories, because it carries stormwater and pre-treated industrial wastewater from an NPDES permitted aircraft maintenance facility.) The 6 outfalls placed in the category of "other" included a lake spillway, old direct discharge pipes which were obviously abandoned, a submerged sewer overflow cap, and a PVC pipe placed underneath a stormwater outfall to intercept water leaking through a damaged joint.

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Figure 22. Site of field investigation along Village Creek, Birmingham, AL (Irondale, AL, USGS Quadrangle map).

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TABLE 46. DESCRIPTION OF VILLAGE CREEK OUTFALLS

Outfall Number	Pipe Size and Type	Drainage Area/ Direct Discharge	Land Use	Record of Dry-Weather Flow
1	6'x6' conc	295	R	D
2	30" conc	6.8	R	D
3a	18" conc	1.5	R	D
3b	18" conc	1.7	R	D
3c	18" conc	2.3	R	D
3d	18" conc	2.5	R	D
3e	36" conc	5.4	R	D
4a	24" conc	1.9	R	D
4b	24" conc	2.5	R	D
5	6" steel	DD	R	D
6	16" conc	1.2	R	D
7a	6'x10' con	123.8	R/U	D
7b	36" con	4.8	R/U	D
7c	12" conc	2.1	R/U	D
8	16" conc	9.3	R/U	D
9	open ditch	5.2	R/U	D
10a	16" conc	1.5	R	D
10b	18"x38" con	2.3	R	D
10c	gutter	0.8	R/U	D
10z	ditch	5.22	R	D
DB	dry branch	896.6	R/C	D
11	2" steel	DD	U	D
12	6" pvc	DD	R	D
13	3'x8' open ditch	50.3	R/C	D
14	3" pvc	DD	U	F
14z	open ditch	50.8	R/U	I
15	10" conc.	5.2	U	D
16	3" pvc	DD	U	I
16z	12" conc	56.6	R	D
16zz	10" conc	1.2	R	D
17	18" clay	1.4	R	D
18a	18" clay	4.0	R	D
18b	2' conc	3.9	R/C	D
19a	4" iron	DD	C	D
19b	4" iron	DD	C	D
20	3'x4' stone	52.5	R/C	F
21	6"iron	DD	C	I
22	4" iron	DD	C	I
23	4" iron	DD	C	D
24	2" pvc	DD	C	I
25	4" pvc	DD	C	D
26	48" conc	65.0	R/C	F
27	24" conc	1.4	R	D
28	18" conc	0.8	C	I
29	conc	none		D
29z	5'x12' stone	306.2	R/C	F

(continued)

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TABLE 46. (continued)

Outfall Number	Pipe Size and Type	Drainage Area/ Direct Discharge	Land Use	Record of Dry-Weather Flow
30	12" conc	1.8	C	D
31a	16" conc	DD		I
31b	16" conc	DD		D
32	12" conc	3.1	R	D
33	48" brick	144.8	R	D
34	16" clay	1.3	R	D
35	16" clay	2.1	R/U	D
36	6" steel	DD		D
37	submerged overflow cap	DD		D
38	36" alum	6.9	U	F
39	12" steel	DD		I
40	open ditch	380.6	R/C/U	I
40z	15" clay	3.6	R/U	I
41	15" clay	1.1	C	D
42	36" conc	7.7	R/C	F
43	24" conc	2.2	R/C	D
44	spillway			D
45	4'x6' conc	4.7	R/C	I
46	6" pvc	none		D
47	18" conc	3.8	R/C	D
48	36" conc	4.3	R	F
49	6" stone	none		D
50	9" iron	DD		D
51	ditch	1.2	C	D
52	35" conc	42.6	R/C	F
53	6'x6'	397.8	R/C	F
54	12" clay	1.6	R	D
55	30" conc	7.1	R/C	D
56	20" steel	DD		D
57	18" conc	3.7	R	D
58	24" conc	3.9	R	D
59	24" conc	1.3	R	D
60	48" conc	31.6	R/C	F
60a	48" conc	90	R/C	I
61a	16" clay	1.6	R	D
61b	16" clay	2.1	R	D
61c	16" clay	1.8	R	D
61d	18" conc	3.1	R	D
62	open ditch	53.8	R/C	D
63	48" conc	3.9	R/C	D
64	open ditch	394.9	R/C/N	F
65	open ditch	577.7 and DD	R/C/N	F

Legend - R: Residential Land Use
C: Commercial Land Use
N: Industrial Land Use

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U: Undeveloped Land or Parks
I: Intermittent Flow (dry-weather flow observed at least once)
D: Dry Outfall (no dry-weather flow observed)
F: Flowing (dry-weather flow observed consistently)

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During the field investigation, samples were collected from all flowing outfalls as well as direct discharges, iced and returned to the lab for analysis. A field sheet (Table 47) was completed for each sample collected. This sheet is similar to Table 20 in Section 4, but was expanded for the additional parameters that were evaluated during this demonstration project. Physical observations, along with conductivity and temperature measurements, were made in the field. All other analyses were carried out in the laboratory. Complete analysis results from all outfall samples collected over the course of this research are located in Appendix F.

Watershed Surveys to Identify Flow Sources for Test Outfalls

A total of ten outfalls and direct discharges, representing a variety of parameter characteristics, were selected for source confirmation. Results from four of the outfall analysis methods, summarized in Section 7, were then compared to the actual source or sources of flow which had been identified in the field. Most of these outfall sources were identified at the end of the field investigation. However, some were identified during the course of the investigation in conjunction with observations of anomalous flow characteristics.

A variety of techniques were utilized to determine the actual source, or sources, of dry weather flow for a particular outfall. Open ditches and large pipes could be walked to their source. Other dry-weather flows were followed from manhole to manhole up the storm drainage system until a flow source was located. Samples were taken periodically from manholes along the way to identify changes in flow characteristics which would indicate the entrance of another flow. Most direct discharge pipes identified could be easily traced to the commercial establishment from which they issued.

A single outfall sample, taken at the time the actual source or sources of flow for each outfall was identified, was used for evaluating the various outfall analysis methods. Data from the 10 selected outfalls are presented in Tables 48 and 49. Table 48 contains the results of laboratory analyses of each outfall sample. Table 49 lists physical observations made on site.

• Outfall 14 (spring water/uncontaminated)--
Outfall 14 appeared to be a direct discharge located on a public golf course. The outfall, a 3" PVC pipe, exhibited flow consistently during the study period. Discussions with golf course personnel and a review of course irrigation plans revealed that the pipe was connected to a pressure release valve which was part of an irrigation system covering a small portion of the property. The source of water for this irrigation system was a spring located on the property. Therefore, it was concluded that the source of dry-weather flow from Outfall 14 was spring water. The outfall was designated uncontaminated.

• Outfall 20 (spring water and rinse water/uncontaminated)--
Outfall 20 also exhibited consistent dry-weather flow during the study period. This 3-foot x 4-foot stone outfall receives drainage from approximately 53 acres of residential and commercial property. Tracking the flow up the drainage system from the outfall, the uppermost point with flow was located. Flow at this point was originating from runoff around a wholesale/retail food manufacturing facility. The manager of the facility was consulted and indicated that high pressure potable water was used to rinse product loading areas, parking lots and delivery vans several times a day. A grass-lined ditch surrounded the facility on two sides and served to intercept and store runoff until it gradually percolated into the ground or drained into a culvert connected to the storm drainage system.

Analysis of this water showed it to be unlike the water collected at the outfall, indicating the presence of other flows between the outfall and the uppermost point of flow. Flow was sampled from manholes between these two points in order to locate the section or sections of the drainage system where additional flows were entering. Samples were analyzed, and the results are presented in Table 50. Results indicated that additional flow was entering the system between the outfall and the first manhole upgradient.

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TABLE 47. FIELD SHEET USED DURING VILLAGE CREEK DEMONSTRATION PROJECT

NON-STORMWATER FLOW EVALUATION FIELD SHEET

Outfall #_____Photograph #_____Date: _____ Time: _____

Location: _____

Air temp.: _____ sunny cloudy days since last rain: _____

Outfall flow estimate: _____

Describe known industrial of commercial activities in drainage area: _____

_____

_____

OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other:

Color: clear yellow brown green red gray other: _____

Clarity: clear cloudy opaque

Floatables: none oil sheen other: _____

Deposits/Stains: none sediment oily other: _____

Vegetation conditions: normal excessive growth inhibited growth

Structural damage: none concrete cracking concrete spauling peeling paint metal corrosion

other: _____

ANALYSES:

Conductivity_____	Fluoride _____
Temperature _____	Ammonia _____
pH _____	Potassium _____
Hardness _____	Chlorine _____
Color _____	Total Copper _____
Fluorescence _____	Total Phenols _____
Detergents _____	Toxicity _____

NOTES: _____

_____

_____

_____

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TABLE 48. PARAMETER CHARACTERISTICS FOR SELECTED OUTFALLS

Outfall Number	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L)	Detergent (mg/L)	Fluorescence (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (mg/L)	Chlorine (mg/L)	Toxicity (% reduc.)	Copper (mg/L)	Phenols (mg/L)
14	327	0.04	240	0	9	0.69	0	7.01	0	0	0	0	0
20	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	2.4	0	0
21	480	2.8	85	20	491	5.08	0.11	7.04	120	0.09	100	0.04	0.04
26	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0	0
28	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	5.9	0	0
31	165	1.13	34	18	235	2.96	0.24	8.34	25	0.19	79	0	0
40z	275	0.33	101	0.5	127	4.67	14.1	6.83	20	0	88.7	0	0
42	361	0.07	228	0	6	0.81	0	7.72	0	0	0	0	0
48	482	0.53	162	5	245	5.65	10.46	7.33	32	0	13.7	0	0
60a	197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0	0

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TABLE 49. PHYSICAL CHARACTERISTICS FOR SELECTED OUTFALLS

Outfall	Odor	Color	Turbidity	Floatables	Sediments\Stains	Vegetation Conditions	Structural Damage
14	none	none	none	none	none	normal	none
20	fried food	none	none	none	none	normal	none
21	oily	gray	opaque	oil sheen	oily	inhibited growth	none
26	none	none	none	none	none	normal	none
28	rancid-sour	none	none	yellow particles	yellow slime	normal	none
31	none	none	none	strings	none	normal	none
40z	none	none	none	none	none	normal	none
42	none	none	none	none	none	normal	none
48	none	none	none	none	none	normal	none
60a	none	none	none	none	none	normal	none

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TABLE 50. ANALYSIS OF SAMPLES COLLECTED DURING SOURCE CONFIRMATION

Outfall	Sample Source	Conductivity	Fluoride	Hardness	Detergent	Fluores.	Potassium	Ammonia	pH	Color	Chlorine	Copper	Phenols
20	Ditch	112	0.96	80	0	15	2.69	0.05	7.09	0	0.01	0	0
	Manhole 3	115	0.95	79	0	16	2.68	0.05	7.10	0	0	0	0
		115	0.95	77	0	15	2.69	0.06	7.12	0	0	0	0
	Manhole 2	300	0.03	236	0	11	0.71	0	6.97	0	0.01	0	0
		303	0.04	235	0	10	0.73	0	6.97	0	0	0	0
	Flow 2	190	0.62	127	0	12	1.99	0.02	7.09	0	0	0	0
	Flow 1	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	0	0
	Manhole 1 Outfall												
26	Spring	350	0.06	237	0	9	0.72	0.00	7.70	0	0	0	0
	Manhole 2	355	0.07	237	0	8	NA	NA	7.69	0	0.01	0	0
		355	0.06	240	0	8	NA	NA	7.70	0	0	0	0
	Manhole 1 Outfall	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0
28	Manhole	332	0.81	199	0.25	210	6.01	2.94	7.24	35	0.10	0	0
	Outfall	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	0	0
40z	Sheetflow Outfall	269	0.34	100	0.55	133	4.66	14.2	6.80	23	0	0	0
		275	0.33	101	0.5	127	4.67	14.1	6.83	20	0	0	0
42	Spring	358	0.05	225	0	8	0.79	0	7.70	0	0	0	0
	Manhole	359	0.05	231	0	8	NA	NA	7.70	0	0	0	0
	Outfall	361	0.07	228	0	6	0.81	0	7.72	0	0	0	0
48	Sewage	555	0.98	122	0.96	305	7.49	19.23	7.13	60	0	0	0
	Outfall	482	0.53	162	0.5	245	5.65	10.46	7.33	32	0	0	0
60a	Sheetflow Outfall	189	0.86	50	0	130	3.83	0.30	7.44	0	0	0	0
		197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0

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The drainage system was large enough to permit entry, and research personnel entered at the outfall and walked through the system. Two sites of additional dry-weather flow entry were located. The two entry sites were in close proximity to each other, and flow was entering through cracks or unintended holes in the drainage system. Samples of flow from both sites were collected, using a hand-held vacuum pump, and they were returned to the laboratory for analysis ("Flow 1" and "Flow 2" on Table 50). Analyses indicated that this water was spring water.

The prevalence of springs in the study area was mentioned earlier, and seepage of spring water from the creek bank had been noted in the area of this outfall. Flow estimates made at the outfall and just upgradient from the spring water entry sites indicated that approximately one third of the outfall flow was originating from the spring water on that particular day. In summary, investigation of outfall 20 indicated that approximately one third of the dry-weather flow issuing from the outfall was spring water and approximately two thirds was rinse water (from a tap water source).

This outfall could conceivably have been classified as contaminated or non-contaminated. There was the potential for food residue from the loading facility and the delivery vehicles as well as street dirt from the delivery vehicles and parking lot. In an effort to correctly characterize this outfall, samples were tested for some standard representatives of important categories of pollutants, namely solids, oxygen-consuming constituents, nutrients, and heavy metals. Biochemical oxygen demand was consistently found to be below 1 mg/L, total suspended solids below 10 mg/L, total phosphorous below 0.15 mg/L, and lead below detection limits (0.01 mg/L). These numbers were exceptionally low as compared to typical urban runoff, as characterized during the Nationwide Urban Runoff Program (EPA 1983). Based on this information, the outfall was characterized as uncontaminated.

• Outfall 21 (vehicle and engine wash area/contaminated)--
Outfall 21 was a direct discharge pipe, easily traced to a used auto sales facility. The pipe was connected to a floor drain in an area where used cars were washed and prepared for sale. The manager of the facility would not discuss the nature of the discharges to the floor drain. An employee later indicated that car and engine wash waters were most common, although fluids drained from vehicles, as well as cleaning and painting solvents, were also washed down the floor drain on occasion. The facility was in operation approximately nine hours a day, and wastewaters entered the floor drain intermittently during that period. The outfall was designated contaminated.

• Outfall 26 (spring water/uncontaminated)--
Outfall 26 was a 48-inch concrete pipe draining approximately 65 acres, of which 93% were commercial and 7% were residential. Flow was traced from manhole to manhole upgradient until the uppermost source of flow was discovered. A spring was found feeding a small marshy area which drained into a culvert leading into the storm drainage system. Water samples were taken from the spring and at two points between the spring and the outfall. The results of laboratory analysis are presented in Table 50. All samples were very similar and flow estimates were constant throughout the system. It was concluded that no other flows were contributing to the dry-weather flow from Outfall 26, and the outfall was designated uncontaminated.

• Outfall 28 (restaurant wash area/contaminated)--
Outfall 28, an 18-inch concrete pipe draining less than an acre of commercial property, was observed to have dry weather flow only twice during the study period, with the source of flow confirmed the second time flow was observed. Flow was traced up the drainage system until a manhole was observed to have no flow. Backtracking revealed a restaurant facility where a washdown of food storage and preparation areas was underway. A floor drain collecting wastewater at the rear of the facility was apparently directly connected to the storm sewer system. Floatables observed at the outfall were identifiable in the wastewater. Management would not allow a sample to be taken on site, but the analysis results from the first manhole below the restaurant (presented in Table 50) were comparable to values measured at the outfall. The outfall was designated contaminated.

• Outfall 31 (laundry/contaminated)--
Outfall 31 was a direct discharge pipe traced to a small motel laundry which was visible from the creek bank. The effluent from a single commercial washing machine was directed into the pipe. This information was confirmed by

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hotel management, but a sample could not be collected. The single washing machine serviced linen for the entire motel and operated almost continuously during the day. This was reflected in the intermittent but regular flow observed at the outfall. The outfall was designated contaminated.

• Outfall 40z (septage/contaminated)--
Outfall 40z was a 15-inch clay pipe intended to carry stormwater from an approximately 4-acre residential and undeveloped area. Dry-weather flow was observed only one time during the study period, and the source of flow was identified at that time. The outfall was observed to be flowing following an extremely wet period. Flow was followed up the pipe, from manhole to manhole, to its source. Water was observed to be flowing out of a property owner's front yard, into the storm gutter and curb inlet. Discussions with the home owner confirmed the fact that the home was serviced by a septic tank, and surface flow from the area of the tank and leaching field took place routinely during extremely wet periods. The first manhole upgrade from the curb inlet was observed to be dry. Flow into the curb inlet was estimated to be approximately equal to outfall flow and laboratory analyses of the two flows were comparable (Table 50). The outfall was designated contaminated.

• Outfall 42 (spring water/uncontaminated)--

Outfall 42 was observed to have dry-weather flow consistently during the study period. The outfall is a 36-inch concrete pipe which drains approximately 8 acres of residential and commercial area. Once again, the pipe was traced back to a marshy area fed by a spring, draining into a culvert connected to the concrete storm drain. Analysis results of water samples taken from the marshy area, the outfall and one manhole in between are presented in Table 50. Flow estimates were comparable, as were analysis results. The outfall was designated uncontaminated.

• Outfall 48 (spring water and sanitary sewage/contaminated)--
Outfall 48 was a 36-inch concrete pipe draining approximately 14 acres of residential area. The outfall flowed consistently, but a change in the quality and quantity of flow was noted approximately halfway through the study period (See Appendix F.), and the source of flow was identified at that time. The majority of the drainage area for this outfall lay across a major highway from Village Creek. Dye was added at the first manhole identified upgrade of the highway to confirm the connection to outfall 48. Moving up the storm drainage system, a creek, once again apparently fed primarily by spring water, was found to be channeled through the storm system. Upgrade from the creek inlet, a discharge was found to be entering through a curb inlet. The source of this discharge was found to be a leaking sanitary sewer line. Further upgrade yet another creek was entering the storm system. Flow from the creeks explained the continuous dry-weather flow noted at the outfall, and the leaking sanitary sewer line was apparently responsible for the change in quality and quantity of flow which had been noted. Flow from the creeks was estimated to be approximately equal to flow from the sanitary sewer. A sample was collected from the sanitary sewer, and analysis results are reported in Table 50. In summary, investigation of outfall 48 indicated that approximately one half of the dry-weather flow issuing from the outfall was from a natural water source, and half was sanitary sewage. The outfall was designated contaminated.

• Outfall 60a (irrigation water/uncontaminated)--
Outfall 60a, a 48-inch concrete pipe draining approximately 90 acres of primarily residential property, was observed to have dry-weather flow on only one occasion during the study period, and the source of flow was investigated at that time. Flow was followed upgrade from manhole to manhole and eventually the source was found to be runoff from an automatic irrigation system in a newly landscaped yard. Flow into the nearest curb inlet was estimated to be approximately the same as the flow at the outfall. The next manhole upgrade from the curb inlet was observed to be dry. A sample was collected, using a hand-held vacuum pump, as the flow entered the curb inlet. Analysis results are presented in Table 50 and are comparable to results from the outfall sample. The outfall was designated uncontaminated.

Comparison of Data Analysis Methods to Predict Source Flows
Predictions of outfall problem ranking and sources of flow were compared to the actual sources of flow at the ten outfalls described above. Four of the outfall analysis methods described in Section 7 were used for this comparison:

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physical indicators of contamination, detergents as indicators of contamination, flowchart for identification of the most significant flow portion, and matrix algebra solutions of simultaneous equations. The following subsections discuss the results of these comparisons for each of the analysis methods.

Physical Indicators of Contamination–
As noted in Section 7, the direct examination of outfalls for unusual condition of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions and damage to drainage structures (negative indicators), is the simplest method of identifying grossly contaminated dry-weather outfall flows. Table 51 summarizes the results of applying this method of investigation to the ten selected outfalls . The actual flow quality column reflects the designation of "contaminated" or "uncontaminated" assigned to each outfall based on the source of flow that was verified in the field. Predicted flow quality is based solely on the presence or absence of negative indicators at the outfall.

Negative indicators would have led to further investigation of outfalls 20, 21, 28, and 31. Commercial sources contributed all or part of the flow to each of these outfalls. Outfalls 21, 28, and 31 were designated contaminated at the time of source confirmation in the field. However, outfall 20 was designated uncontaminated. Odor and/or the presence of floatables were noted at all four of the outfalls in question. A lack of negative indicators would have suggested there was no need for further investigation of outfalls 40z or 48. However, outfall 40z was contaminated with septic tank leachate, and outfall 48 was contaminated with sanitary sewage. Therefore, the presence of negative indicators alone failed to identify 2 of the 5 contaminated outfalls. Based on the 10 selected outfalls tested, this represents a high false negative rate (of 20%).

Uncontaminated outfalls 14, 26, 42 and 60a had no negative indicators. However, the presence of a negative indicator (odor) at outfall 20 incorrectly identified that outfall as contaminated. This represents a false positive rate of 10%.

Detergents as Indicators of Contamination–
The second method tested was a simple contaminated/uncontaminated categorization based on the presence, or absence, of detergents alone. As discussed previously in Section 7, analysis of only detergents correctly identified the samples collected directly from potential dry-weather flow sources as contaminated or uncontaminated. Table 52 shows the results of applying this method of investigation to the ten selected outfalls.

Dry-weather flows from all contaminated outfalls (21, 28, 31, 40, and 48) were found to contain detergents. None of the uncontaminated outfalls were found to contain detergents on the days that sources were verified in the field. Use of this technique therefore resulted in a 100% correct categorization of the ten outfalls selected for testing as contaminated or uncontaminated (no false negatives or positives were identified).

Flow Chart for Most Significant Flow Component Identification–
Data from each of the 10 selected outfall samples were analyzed using the flow chart presented in Figure 12 in Section 7. Conclusions from this analysis are presented in Table 53. This method was not able to distinguish among each of the potential sources of dry-weather flow identified earlier; rather, the following four groups of flow were distinguishable: (1) uncontaminated domestic waters (tap water, irrigation or rinse water); (2) natural groundwaters (spring water or infiltrating shallow groundwater); (3) sanitary wastewaters; and, (4) wash waters.

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TABLE 51. ANALYSIS OF OUTFALLS BASED ON PHYSICAL INDICATORS OF CONTAMINATION

Outfall Number	Negative Indicators	Predicted Flow Quality	Actual Flow Quality	Confirmed Flow Source
14	none	uncontaminated	uncontaminated	Spring Water
20	odor	contaminated	uncontaminated	Rinse Water and Spring Water
21	odor, color, turbidity, floatables, sediment, vegetation	contaminated	contaminated	Wash Water (Automotive)
26	none	uncontaminated	uncontaminated	Spring Water
28	odor, floatables, sediments	contaminated	contaminated	Wash Water (Restaurant)
31	floatables	contaminated	contaminated	Laundry (Motel)
40z	none	uncontaminated	contaminated	Shallow Ground Water and Septic Tank Leachate
42	none	uncontaminated	uncontaminated	Spring Water
48	none	uncontaminated	contaminated	Spring Water and Sewage
60a	none	uncontaminated	uncontaminated	Landscaping Irrigation Water

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TABLE 52. ANALYSIS OF OUTFALLS BASED ON DETERGENTS AS INDICATORS OF CONTAMINATION

Outfall Number	Predicted Flow Quality	Actual Flow Quality
14	uncontaminated	uncontaminated
20	uncontaminated	uncontaminated
21	contaminated	contaminated
26	uncontaminated	uncontaminated
28	contaminated	contaminated
31	contaminated	contaminated
40z	contaminated	contaminated
42	uncontaminated	uncontaminated
48	contaminated	contaminated
60a	uncontaminated	uncontaminated

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TABLE 53. RESULTS OF USING FLOW CHART FOR MAJOR FLOW COMPONENT IDENTIFICATION

Outfall Number	Predicted Flow Quality	Actual Flow Quality	Predicted Flow Source	Confirmed Flow Source
14	uncontaminated	uncontaminated	Natural Waters	Spring Water
20	uncontaminated	uncontaminated	Potable Waters	Rinse Water and Spring Water
21	contaminated	contaminated	Wash Waters	Wash Water (Automotive)
26	uncontaminated	uncontaminated	Natural Waters	Spring Water
28	contaminated	contaminated	Wash Waters	Wash Water (Restaurant)
31	contaminated	contaminated	Wash Waters	Laundry (Motel)
40z	contaminated	contaminated	Sanitary Wastewaters	Shallow Ground Water and Septic Tank Leachate
42	uncontaminated	uncontaminated	Natural Waters	Spring Water
48	contaminated	contaminated	Sanitary Wastewaters	Spring Water and Sewage
60a	uncontaminated	uncontaminated	Potable Waters	Landscaping Irrigation Water

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Flow from outfall 14 contained no detergents and low levels of fluoride, leading to the correct identification of a natural water source. Flow from outfall 20 contained no detergents, but had high fluoride levels, correctly identifying a potable water source. Flow from outfall 21 contained detergents, and had an ammonia/potassium ratio of 0.02 (less than 0.9). This correctly indicated a wash water source. Flow from outfall 26 contained no detergents, and low levels of fluoride, again correctly predicting a natural water source. Flow from outfall 28 contained detergents, and had an ammonia/potassium ratio of 0.5 (less than 0.9). A wash water source was correctly predicted. Flow from outfall 31 contained detergents, and had an ammonia/potassium ratio of 0.08 (less than 0.9). A wash water source was correctly predicted. Flow from outfall 40z contained detergents, and had an ammonia/potassium ratio of 3.0 (greater than 0.9). A sanitary wastewater source was correctly predicted. Flow from outfall 42 contained no detergents, and low fluoride levels; a natural water source was correctly predicted. Flow from outfall 48 contained detergents, and had an ammonia/potassium ratio of 1.85 (greater than 0.9), correctly predicting a sanitary wastewater source. Flow from outfall 60a contained no detergents, and had a high fluoride level. An uncontaminated potable water source was correctly predicted.

Use of this method resulted in the correct categorization of each outfall with respect to contamination. No false negatives or false positives were reported. Furthermore, for all outfalls, the most serious (with respect to potential contamination) type of flow to the outfall was correctly predicted. Source types were ranked from lowest to highest, with respect to contaminating potential as follows: natural water sources, tap water sources, wash water sources, and sanitary wastewater sources.

Chemical Mass Balance at Outfalls–
Results from the chemical mass balance algorithm are shown in Table 54. The following 8 parameters were used in this analysis: specific conductivity, fluoride, hardness, detergents, fluorescence, potassium, ammonia, and color. The choice of parameters was based on results of the Mann-Whitney U tests and linear dilution tests described in Section 6. The eight potential flow sources considered for each outfall were: spring water, tap water, infiltrating shallow groundwater, landscape irrigation runoff water, sewage, septic tank discharge, carwash water, and laundry water. Table 54 shows the most likely percent of the total outfall flow coming from each source. This table also compares these predictions to the confirmed sources of flow for each outfall. All sources predicted to contribute to an outfall's flow are listed. Predicted contributions, and confirmed sources, are listed from highest to lowest order of percent contribution to flow. Contributions in parentheses indicate numbers which would be attributed to "background noise", as they make up less than 10% of the source flow, as discussed in Section 7.

Outfalls 28 and 31 carried dry-weather flow from sources not specifically sampled and evaluated during the source characterization portion of this research. Consequently, a perfect fit was not possible. Outfall 28 carried wash water, but it was from the washing of loading and storage areas of a fast food restaurant. Outfall 31 carried laundry wash water, but the source was the washing machine of a small motel which used a household laundry detergent, rather than one of the commercial varieties used by the laundries which were sampled.

No false negatives resulted from the use of this method. However, the false positive rate would have been 40%, if the 10% threshold value was not used. Additionally, many extraneous sources of flow were predicted for most of the outfalls, thus negating the potential advantage this method had to offer: the ability to accurately predict all specific types of sources contributing to a dry-weather flow.

Summary of Field Demonstration Tests

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

A006395

TABLE 54. ANALYSIS OF OUTFALLS BASED ON RESULTS OF THE CHEMICAL MASS BALANCE PROGRAM

Outfall Number	Predicted Flow Source	Confirmed Flow Source
14	88% Spring (7% Sewage) (5% Tap)	100% Spring
20	60% Tap 32% Spring (8% Irrigation)	67% Tap 33% Spring
21	55% Sewage 35% Ground (8% Car Wash) (2% Laundry)	100% Washwater (Automotive)
26	74% Spring Water 18% Tap Water (8%Sewage)	100% Spring Water
28	46% Ground Water 21% Irrigation Water 18% Sewage 10% Spring Water (5%Tap Water)	100% Wash Water (Restaurant)
31	55% Sewage 25% Spring Water 18% Laundry (1% Carwash Water)	100% Laundry (Motel)
40z	27% Sewage 23% Tap Water 19% Ground Water 12% Spring Water 11% Septic Tank Discharge (8% Irrigation Water)	Shallow Ground Water and Septic Tank Discharge
42	63% Spring Water 28% Tap Water (9% Sewage)	100% Spring Water
48	79% Sewage 15% Spring Water (5% Carwash Water) (1% Septage)	50% Sewage 50% Spring Water

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60a	56% Tap Water 37% Irrigation Water (7% Sewage)	100% Irrigation Water

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

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

The use of chemical mass balance equations as a means of identifying all sources contributing to flow at a given outfall is appealing in theory. However, this research indicated that the amount of variation present within potential sources of dry-weather flow, as well as the likelihood of unexpected, and thus uncharacterized flows, especially in commercial areas, made this method less effective than desired. Possible additional modifications to the chemical mass balance program, such as allowing for the inclusion of more sources than unknowns (over-specification), variable weighting, and the linking of variables with relatively high correlation coefficients, could improve its effectiveness (Wilson 1958). However, these modifications would not compensate for the lack of information for certain specific (and previously unknown) source flows which will be encountered in some watersheds. The amount of time and effort required to adequately identify and characterize potential sources also decreases the economic advantage of this method over wide-scale dye testing or video camera surveying.

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

In summary, the following screening methodology is suggested for residential and commercial areas:

Characteristics of Local Source Waters--

- It is extremely important to determine the local characteristics of potential source waters. As a minimum, tracer parameters to be tested should include: fluoride, detergent (or fluorescence), ammonia, and potassium.

Outfall Surveys--

- All stormwater outfalls and direct discharge pipes should be located and evaluated.
- All dry-weather flows should be sampled, regardless of the size of the pipe or characteristics of the drainage area.

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• Physical characteristics of any flow and unusual characteristics surrounding the outfall must be noted to identify gross contamination and evidence of intermittent flows.

Outfall Sample Analyses and Interpretation—

• The flow chart method should be the primary method used to identify the contaminating flow sources and for prioritizing the level of contamination of the outfall flows.
• Outfall samples should be primarily tested for detergents (or fluorescence).
• If desired, outfall samples testing negative for detergents could be tested for fluoride, to identify flows from relatively clean tap water sources.
• Samples testing positive for detergents should be tested for ammonia and potassium. A high ammonia-to-potassium ratio indicates those outfalls most likely carrying flows from sanitary wastewater sources. These outfalls should receive the highest priority for source correction measures.

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Section 12
Emerging Technologies for the Detection and Elimination of Illicit Discharges

Introduction

This section describes several newly emerging technologies that may be useful for the identification of inappropriate ("illicit") discharges to storm drainage systems. This section also describes a series of tests where the original methods described previously in this report, along with selected new procedures, were examined using almost 700 stormwater samples collected from telecommunication manholes from throughout the U.S. About ten percent of the samples were estimated to be contaminated with sanitary sewage using these methods, similar to what is expected for most stormwater systems. The original methods are still recommended as the most useful procedure for identifying contamination of storm drainage systems, with the possible addition of specific tests for *E. coli* and enterococci and UV absorbance at 228 nm. Most of the newly emerging methods that have been published require exotic equipment and unusual expertise and are therefore not very available, especially at low cost and with fast turn-around times for the analyses. These emerging methods may therefore be more useful for special research projects than for routine screening of storm drainage systems.

Use of Bacteria as an Indicator of Sanitary Sewage Contamination

As previously mentioned in Section 5, bacteria has historically been used as an indicator of sanitary sewage contamination of stormwaters and receiving waters. This method has been beset with many analytical and interpretation problems. The following discussion is derived from: R. Pitt. *Stormwater Quality Management*, CRC Press, in preparation, and presents some historical background information concerning the likely sources of bacteria in urban areas that are not derived from sanitary sewage.

Several historical investigations have studied potential sources of bacteria and selected pathogens that are found in urban runoff. Some of these studies have examined surface sheet flows during rain induced and snowmelt induced runoff that would not likely be contaminated by human fecal matter. More commonly, many studies have examined runoff sampled at outfalls where the runoff may have been contaminated by inappropriate discharges to the storm drainage. The following discussion summarizes some of the observations from these studies.

Tests in Toronto examined sources of urban stormwater bacteria (Pitt and McLean 1986), as shown in Table 55. High bacteria populations were found in sidewalk, road, and some bare ground sheetflow samples (collected from locations where dogs would most likely be "walked"). Some of the Toronto sheetflow contributions were not sufficient to explain the concentrations of some constituents observed in runoff at the outfall. Most of the fecal coliform populations observed in sheetflows were significantly lower than those observed at the outfall, especially during snowmelt. It is expected that some sanitary sewage was entering the storm drainage system. Runoff from paved parking areas, streets, and landscaped areas generally had the highest observed bacteria densities, while runoff from roofs and freeways had low densities.

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Table 55. Source Area Bacteria Sheetflow Quality Summary (means)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets	Land-scaped	Un-developed	Freeway Paved Lane and Shoulders
Fecal Coliforms (#/100 mL)												
Residential:	85 (3) <2 (4) 1400 (5)	250,000 (5)	100 (5)		600 (5)			11,000 (5)	920 (4) 6,900 (5)	3300 (5)	5400 (3) 49 (4)	1500 (9)
Commercial	9 (4)	2900 (3) 350 (4) 210 (1) 480 (7) 23,000 (8)										
Industrial:	1600 (5)	8660 (8)	9200 (5)	18,000 (5)	66,000 (5)	300,000 (5)		55,000 (5)	100,000 (5)			
Fecal Strep (#/100 mL)												
Residential:	170 (3) 920 (4) 2200 (5)	190,000 (5)	<100 (5)		1900 (5)		1800 (5)		>2400 (4) 7300 (5)	43,000 (5)	16,500 (3) 920 (4)	2200 (9)
Commercial:	17 (3)	11,900 (3) >2400 (4) 770 (1) 1120 (7) 62,000 (8)										
Industrial:	690 (5)	7300 (5)	2070 (5)	8100 (5)	36,000 (5)	21,000 (5)		3600 (5)	45,000 (5)			
Pseudo. Aerug (#/100 mL)												
Residential:	30,000 (5) 50 (5)	1900 (5)	100 (5)		600 (5)		600 (5)		570 (5)	2100 (5)		
Industrial:		5800 (5)	5850 (5)	14,000 (5)	14,300 (5)	100 (5)		3600 (5)	6200 (5)			

References:
(1) Bannerman, *et al.* 1983 (Milwaukee, WI) (NURP)
(3) Pitt 1983 (Ottawa)

(4) Pitt and Bozeman 1982 (San Jose)
(5) Pitt and McLean 1986 (Toronto)
(7) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(8) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)
(9) Kobriger, *et al.* 1981 and Gupta, *et al.* 1977

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The Regional Municipality of Ottawa-Carleton (1972) studied the importance of rooftop, street surface, and field runoff in contributing bacteria contaminants to surface waters in the Ottawa area. Gore and Storrie/Proctor and Redfern (1981c) also investigated various urban bacteria sources affecting the Rideau River in Ottawa. They examined dry weather continuous coliform sources, the resuspension of contaminated river bottom sediments, exfiltration from sanitary sewers, and bird feces. These sources were all considered in an attempt to explain the relatively high dry weather coliform bacteria concentrations found in the river. They concluded, however, that stormwater runoff is the most probable source for the wet weather and continuing dry weather bacteria Rideau River concentrations. However, the slow travel time of the river water usually does not allow the river to recover completely from one rainstorm before another begins.

The Regional Municipality of Ottawa-Carleton (1972) summarized the early Ottawa activities in correcting stormwater and sanitary sewage cross-connections. Since that time, many combined sewer overflows have also been eliminated from the Rideau River. Loijens (1981) stated that as a result of sewer separation activities, only one overflow currently remained active (Clegg Street). During river surveys in 1978 and 1979 in the vicinity of this outfall, increased bacteria levels were not found. Gore and Storrie/Proctor and Redfern (1981c) stated that there was no evidence that combined sewer overflows were causing the elevated fecal coliform bacteria levels in the river. Environment Canada, (1980) however, stated that high, dry weather bacteria density levels, especially when considering the fecal coliform to fecal strep. ratio, constitutes presumptive evidence of low volume sporadic inputs of sanitary sewage from diverse sources into the downstream Rideau River sectors. The case study presented later examines some of these issues.

Street surfaces have been identified as potential major sources of urban runoff bacteria in many locations. Pitt and Bozeman (1982) found that parking lots, street surfaces, and sidewalks were the major contributors of indicator bacteria in the Coyote Creek watershed in California. Gupta, *et al.* (1981) found high concentrations of fecal coliforms at a highway runoff site in Milwaukee. This site was entirely impervious and located on an elevated bridge deck. The only likely sources of fecal coliforms at this site were bird droppings and possibly feces debris falling from livestock trucks or other vehicles.

Several studies have found that the bacteria in stormwater runoff in residential and light commercial areas were from predominantly nonhuman origins (Qureshi and Dutka 1979). They found that there may be an initial flush of animal feces when runoff first develops. However, the most important bacteria source for runoff is the feces bacteria that have been distributed generally in the soils and on the surfaces of the drainage area. Geldreich and Kenner (1969) stated that the fecal coliforms in stormwater are from dogs, cats, and rodents in city areas, and from farm animals and wildlife in rural areas. The most important source, however, may be feces bacteria that are distributed in the soil and not the fresh feces washing off the impervious surfaces.

Some studies have investigated vegetation sources of coliform bacteria. For example, Geldreich (1965) found that the washoff of bacteria from vegetation does not contribute significant bacteria to the runoff. They also found that most of the bacteria on vegetation is of insect origin. Geldreich, *et al.* (1980) found that recreation activities in water bodies also increase the fecal coliform and fecal strep. concentrations. These organisms of intestinal origin will concentrate in areas near the shore or in areas of stratification. Fennell, *et al.* (1974) found that open dumps containing domestic refuse can be a reservoir of Salmonella bacteria that can be spread to nearby water bodies by foraging animals and birds.

When a drainage basin has much of its surface paved, the urban runoff bacteria concentrations can be expected to peak near the beginning of the rainfall event and then decrease as the event continues. Initial high levels of bacteria may be associated with direct flushing of feces and small feces particles from paved surfaces. These feces are from dogs defecating on parking lots and street areas and from birds roosting on rooftops. When a drainage area has a lot of landscaped areas or open land, relatively high bacteria concentrations in the urban runoff may occur throughout the rain event.

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Bacteria Survival in Stormwater

The survival of urban runoff bacteria in receiving waters is an important issue. Very little direct consumption or contact of urban runoff usually occurs. However, when the runoff is discharged into a larger receiving water, consumption or contact may occur shortly after the rain event has ended. The Rideau River Stormwater Management Study (Ottawa, Ontario) examined the die-off of fecal coliform bacteria in the Rideau River (Droste and Gupgupoglu 1982; Environment Canada 1980; Gore and Storrie/Proctor and Redfern 1981b and 1981c). They found that the 90 percent die-off for Rideau River fecal coliforms was about two days. Because of the long travel time on the Rideau River and short interevent times of rains in the area, the effects of bacteria discharges from stormwater from one storm can affect the river concentrations during the next storm. The persistence of fecal coliforms and the slow river velocities cause downstream beach bacteria concentrations to seldom, if ever, regain true low background bacteria concentration levels. Environment Canada (1980) reported significant increase in coliform concentrations in recently excreted moist feces.

Seidler (1979) stated that the sources of Salmonella bacteria can determine their survival. This is probably true for most types of bacteria because the different bacteria sources usually determine the specific bacteria biotypes found in the feces. Different bacteria types can have quite different die-off rates.

Factors affecting urban runoff bacteria survival in stormwater have been found to be quite variable and site specific. Geldreich, *et al.* (1968) found that no significant differences in survival of urban runoff bacteria could be related to the chemical constituents present. Water temperature, however, did have a strong influence on urban runoff bacteria survival. Geldreich, *et al.* (1980) found in a Kentucky study that when copper sulfate was applied as an algicide in a reservoir, sharp declines in fecal coliform densities occurred. The standard plate count densities, however, sharply increased. They found that the survival of urban runoff bacteria was longer near the bottom of the reservoir than in shallower waters. They also found that reduced dissolved oxygen concentrations near the sediments was not detrimental to bacteria survival. Faust and Goff (1978) found that high clay concentrations in the Rhode River in the Chesapeake Bay area extended the survival of fecal coliform bacteria.

Many studies reported the effects of temperature on urban runoff bacteria die-off. Geldreich, *et al.* (1968), in a series of lab tests, found that stormwater bacteria persisted at higher concentrations under winter water temperature conditions (10°C) than they did for summer water temperature conditions (20°C). There were some differences in survival for the various specific types of stormwater bacteria, but this trend seemed typical. Van Donzel, *et al.* (1967) found that fecal strep. did not survive as long as fecal coliform bacteria during the summer months, while in the autumn there was little difference in their survival times. In the winter and spring, the fecal strep. survived much longer than the fecal coliforms. Seidler (1979) found that Salmonella survived for longer periods of time in colder water temperatures. McSwain (1977) reported that coliform bacteria were able to multiply in bottom sediments at a rate regulated by stream temperature. They reported another study that found significant enteric bacteria concentration increases at temperatures above 16°C, but that little or no growth occurred below 10°C. The conditions affecting bacteria survival in water appear to be site and bacteria specific. Many of the differences are probably associated with the specific bacteria biotype present and with the water temperature. Chemical constituent concentrations do not appear to be a factor, except when they are present at very low concentrations.

Table 56 summarizes reported 90 day die-off rates for different stormwater bacteria types. Fecal coliform die-off values varied from less than one day to about 13 days, but can be considered quite fast. Fecal strep. die-off values, however, were longer than the fecal coliform die-off rates. Some of the Streptococcus bacteria types had long survival rates, while others had short survival rates. The forms likely to be associated with agricultural activities (*S. bovis* and *S. equinus*) all are shown to have much shorter survival times than more common urban Streptococcus types (*S. faecalis*).

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Table 56. Survival of Stormwater Bacteria

Bacteria type	Location and conditions	Days survival before 90% dieoff	Reference
Fecal Coliforms	Rideau River – summer	2	Droste and Gupgupogula 1982
	Cincinnati – stormwater at 10°C	10	Geldreich, *et al.* 1968
	Cincinnati – stormwater at 20°C	2	Geldreich, *et al.* 1968
	Oakland, CA – bird feces into urban lake	Rapid	Pitt and Bozeman 1979
	Stormwater – summer	3	Van Donsel, *et al.* 1967
	Stormwater – autumn	13	Van Donsel, *et al.* 1967
Fecal Strep.	Oakland, CA – bird feces into urban lake	>30	Pitt and Bozeman 1979
	Stormwater – summer	3	Van Donsel, *et al.* 1967
	Stormwater – autumn	20	Van Donsel, *et al.* 1967
Streptococcus faecalis	Cincinnati – stormwater	>14	Geldreich, *et al.* 1968
S. faecalis var. *liquifaciens*	Cincinnati – stormwater at 10°C	>14	Geldreich, *et al.* 1968
	Cincinnati – stormwater at 20°C	6	Geldreich, *et al.* 1968
S. bovis	Cincinnati – stormwater at 10°C	<1	Geldreich, *et al.* 1968
	Cincinnati – stormwater at 20°C	1	Geldreich, *et al.* 1968
S. equinus	Cincinnati – stormwater	<1	Geldreich and Kenner 1969
Salmonella	Rural Oregon Creek	>6	Seidler 1979
S. typhirmrium	Cincinnati – stormwater at 10°C	7	Geldreich, *et al.* 1968
	Cincinnati – stormwater at 20°C	2	Geldreich, *et al.* 1968
Shigella flexneri	Baltimore – stormwater	>8	Field, *et al.* 1976
Enterbactor aerogenes	Cincinnati – stormwater at 10°C	5	Geldreich, *et al.* 1968
	Cincinnati – stormwater at 20°C	4	Geldreich, *et al.* 1968

Survival of Bacteria in Soil

Because of the importance of soil bacteria as a source of urban area bacteria, their survival in the soil after deposition is important. If an area has long interevent times between rain events, soil bacteria survival would have to be quite long in order for the soil to be a significant urban runoff bacteria source. However, in areas having frequent rains, soil bacteria survival is less important (assuming that it is greater than the interevent period). Many site conditions have been reported to influence soil bacteria survival. Van Donsel, *et al.* (1967) found that sunlight, temperatures, rainfall, soil moisture, pH, organic matter, and the presence of other microorganisms all affect the survival of total coliforms, fecal coliforms, and fecal strep. soil bacteria. They also reported that feces bacteria deposited on dry soils are relatively immobilized and subject to the specific site conditions. After-growth of soil bacteria (increasing populations without new deposition) may account for some of the seasonal variations in runoff bacteria counts. If the soil has not been recently contaminated, the runoff would have an immediate supply of microorganisms from the soil. Contamination of the receiving waters would be out of proportion to the true sanitary history of the area. They also stated that non-fecal coliforms reappeared after fecal organisms declined. They were also present in much higher concentrations after fecal bacteria die-off than before the soil was contaminated.

Both after-growth and decline of bacteria in soils have been reported. Soil coliforms exhibit after-growth following rainstorms and exhibit rapid declines during freezing weather. If very warm weather follows a rain, a very large increase in soil coliform bacteria was noted, while the increase was much less if cool weather followed a rain. They also found declining bacteria soil populations if the soil was dry. Alternate freezing and thawing at exposed winter sites caused significant morality of soil coliform bacteria. Evans and Owens (1972) reported that *E. Coli* and Enterococci showed 90 percent reductions after about two or three months in soils. Van Donzel, *et al.* (1967) reported prolonged persistence of other bacteria types. Various strains of Salmonella were found to exist for long periods of time (nine months for *S typhimurium*). It is not uncommon for soil bacteria to survive for up to 200 days after inoculation.

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Fecal Coliform to Fecal Strep. Bacteria Ratios

Geldreich (1965) found that the ratio of fecal coliform to fecal strep. bacteria concentrations may be indicative of the probable fecal source. In fresh human fecal material and domestic wastes, he found that the fecal coliform densities were more than four times the fecal strep. densities. However, this ratio for livestock, poultry, dogs, cats, and rodents was found to be less than 0.6. These ratios must be applied carefully, because of the effects of travel time and various chemical changes (especially pH) on the die-off rates of the component bacteria. As a generality, he stated that fecal coliform to fecal strep. ratios greater than four indicate that the bacteria pollution is from domestic wastes, which are composed mostly of human fecal material, laundry wastes, and food refuse. If the ratio is less than 0.6, the bacteria is probably from livestock or poultry in agricultural areas or from stormwater runoff in urban areas. He found that agricultural and stormwater runoff can be differentiated by studying the types of fecal strep. bacteria found in the water samples. Geldreich and Kenner (1969) further stressed the importance of carefully using this ratio. They stressed that samples must be taken at the wastewater outfalls. At these locations, domestic waste, meat packing wastes, stormwater discharges, and feedlot drainage contain large numbers of fecal organisms recently discharged from warm blooded animals. Once these organisms are diffused into the receiving stream, however, water temperature, organic nutrients, toxic metals, and adverse pH values may alter the relationship between the indicator organisms. This ratio should only be applied within 24 hours following the discharge of the bacteria.

Feachem (1975) examined how these ratios could be used with bacteria observations taken over a period of time. Because the fecal coliform and fecal strep. bacteria die-off rates are not the same, the ratio gradually changes with time. He found that bacteria is predominantly from human sources if the FC/FS ratios are initially high (greater than four) and then decrease with time. Non-human bacteria sources would result in initially low fecal coliform to fecal strep. ratios (less than 0.7) which then rise with time.

Table 57 summarizes the observed fecal coliform to fecal strep. bacteria population ratios in the Rideau River study area. These ratios are separated into source area sheetflow samples, Rideau River water samples and water samples collected at the swimming beaches. The source area sheetflow samples contain the most recent contamination, while the river segment and beach samples contain "older" bacteria. The initial source area samples all have ratios of less than 0.7. However, the river averages range from 0.5 to 1.2 and the beach samples (which may be "older" than the river samples) range from 1.7 to 2.8. These ratios are seen to start with values less than 0.7 and increase with time. Based on Feachem's (1975) work, this would indicate that the major bacteria sources in the Rideau River are from non-human sources. This substantiates the previous conclusions as presented in the Phase 1 Rideau River Stormwater Management Report. Periodic high bacteria ratios in the river and at the beaches could be caused by the greater die-off ratio of fecal strep. as compared to fecal coliform. The observed periodic high Rideau River FC/FS ratios (which can be greater than four) may therefore be from old, non-human fecal discharges and not from fresh human fecal discharges.

Table 57. Fecal Coliform to Fecal Strep. Bacteria Population Ratios in Study Area (Pitt 1983)

Source Areas	FC/FS ratio
Rooftop runoff	0.5
Vacant land sheetflow	0.3
Parking lot sheetflow	0.2
Gutter flows	0.2
Average of source area values	0.3
Rideau River Segment	
A	1.2
B	0.6
C	0.5
D	0.5
E	1.0
Average of river segment values	0.7

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River Swimming Beaches	
Strathcona	2.8
Brantwood	2.3
Brighton	2.1
Mooney's Bay	1.7
Average of swimming beach values	2.2

River and Lake Sediment Bacteria

Matson, *et al.* (1978) studied the effects of river and lake sediments as a source of bacteria to the water column in Connecticut. They found that resuspended sediments in shallow waters can elevate the water column bacteria concentrations significantly. They stated that the physical resuspension of shallow water sediments is increased by elevated river discharges, wind induced turbulence, dredging, motorboats, swimming, walking, and wading and normal activities of aquatic microorganisms. The magnitude of sediment resuspension varies with the intensity of the mechanisms involved, and the water depth to the sediment. They stated that during stable river flows, the water bacteria populations are relatively constant, but during periods of high flows, sediment organisms can be scoured from the benthic surfaces and mixed into the water column. After peak discharges, water borne microorganisms resettle downstream, which increases those sediment bacteria populations. Geldreich, *et al.* (1980) also studied bacteria interactions between sediment and water. They found that the sediment-water interface of a water body is an attractive habitat for a variety of different bacteria involved in different biochemical processes. Shallow bottom sediments attract a variable bacteria population because of the physical and chemical requirements that can be satisfied there, in contrast to the more limited conditions available in the water or buried in the sediments.
Davis (1979) stated that bacteria contamination of waterways during and following storm events is a function of the stream sediment bacteria concentrations, the concentrations of bacteria in soils adjacent to the stream (and source areas in an urban watershed), and the stream velocities. Davis further stated that stream sediments can contain greater densities of coliform bacteria on a number per unit weight or volume basis than the water body itself; the concentrations of bacteria in the top two inches of mud can be 100 to 1,000 times greater than the concentrations of the bacteria in the water. He reported fecal coliform sediment concentrations up to 100 organisms per gram of sediment and that the suspended sediments can be a major source of bacteria contamination. Geldreich, *et al.* (1980) stated that sediment bacteria concentrations can be as high as 3,000 to 15,000 organisms per square meter of particulate surface. Pitt and Bozeman (1979), in a study of an urban lake in Oakland, California, found fecal coliform sediment concentrations that ranged from one to 35,000 organisms per gram and averaged about 1,000. McSwain (1977) found that in a rural study in North Carolina, total and fecal coliform concentration increases were more related to bottom sediment disturbances than to stream bank flushing.

Soil Bacteria Sources

Van Donsel, *et al.* (1967) stated that soil bacteria pollution may occur from direct defecation by livestock, pets, and wild animals, by malfunctioning or overflowing septic tank systems or by flooding of sewerage systems. Much of the total coliform indicator bacteria organisms in urban areas, however, are not from these sources. Geldreich, *et al.* (1968) found that in a Cincinnati urban runoff study, direct fecal contamination accounted for less than 10 percent of the total coliform bacteria present in the stormwater. The remaining coliforms (which were non-fecal in origin) were assumed to be contributed from soil erosion. Therefore, soil can contain large numbers of both non-fecal and fecal coliform bacteria. Because rain water contains very small bacteria concentrations, urban runoff becomes contaminated with bacteria when the rain water contacts contaminated surfaces. In wilderness areas, runoff has very little fecal coliform bacteria, while runoff from agricultural areas or urban areas can have varying amounts of fecal coliform bacteria. Seidler (1979) found that the movement of fecal coliform bacteria in saturated soils were extremely rapid. Soil can add appreciable fecal and non-fecal coliform bacteria to rain runoff. Casserly and Davis (1979) found that coliform types in urban soils were the same as they found in urban runoff, indicating a strong interaction between polluted soils and contaminated urban runoff. Davis (1979) found that irrigated soils, with high humic content, can yield greater amounts of bacteria. Evans and Owens (1972) found that the concentrations of *E. Coli* and Enterococci in stormwater runoff were affected by the soil bacteria concentrations.

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Evans and Owens (1973) reported that bacteria was more likely to erode than the particulate matter in the soil. Davis (1979) found that the leaching action of rain on soil bacteria was quite erratic. The most important factors affecting bacteria concentrations in runoff were found to be the concentrations of the bacteria in soils. They reported total coliform concentrations in soils ranging from 200 to more than 500,000 total coliform organisms per gram. Fecal coliform soil concentrations ranged from less than 20 to about 300 organisms per gram and fecal strep. soil concentrations ranged from less than 20 to about 1,000 organisms per gram.

Wildlife Sources of Bacteria

Effects of Birds on Water Bacteria Concentrations

Several studies have been conducted which examined the effects of large migratory or permanent waterfowl populations on the bacteria quality of water bodies. A study at the Montezuma Bird Refuge in New York (Have 1973) found inconsistent relationships between the bird populations and the total coliform, fecal coliform, and fecal strep. counts. Peak populations of 70,000 geese and 100,000 ducks frequent this 1,000 acre refuge. In fact, they found that the concentrations of the non-pathogenic bacteria in the two major streams flowing into the refuge were greater than in the water flowing out of the refuge. The specific conductance of the inflowing water was also greater than the outflowing water. The effluent did have higher concentrations of phosphorous and nitrogen. They concluded that the settling effect of the quite waters in the refuge may help explain the improvement in the quality of water leaving the refuge.

Brierley, *et al.* (1975) studied the Rio Grande Refuge in New Mexico. This refuge supports bird populations of more than 10,000 Sandhill cranes, 2,000 Canada geese, more than 8,000 snow geese, and more than 25,000 ducks from October to early March along ten miles of river channel. The water flowing into this bird refuge area along the Rio Grande River has high concentrations of suspended sediments and bacteria. The bacteria concentrations seem to correlate directly with the high sediment concentrations. The presence of the large number of birds apparently does not affect the concentrations of the bacteria that were investigated (total heterotrophic bacteria, fecal and total coliforms, and Enterococci). Most of the birds use a single large pond at the end of their winter habitat. The draining of this pond at the end of their season did not seem to significantly change the bacteria population of the receiving channel water. The bird habitat pond, in fact, had decreased concentrations or bacteria during and following the period of maximum use. They concluded that the bacteria originated in upstream areas before it reached the refuge.

In a study at Lake Wingra in Wisconsin (Geldreich 1980), intermittent high fecal coliform counts during the late summer and early fall were found to be due to a combination of wastes from mallard ducks and the local weather. They reported that fecal coliforms in the sand due to duck defecation multiplied during the first week after deposition and then die-off occurred. Bacteria in these near-lake sands were transported into the water primarily by stormwater runoff erosion and by the foot traffic of bathers when going into the water.

Oplinger (1977) studied the effects of waterfowl populations on the water quality of a small creek park in Pennsylvania. They felt that increasing waterfowl populations and the declining water quality were related and threatened the health and welfare of both the waterfowl and the human watershed users.

Figley and Vandraff (1974), in a study of suburban parks in New York state, noted that mallard ducks are especially attracted to suburban lagoon developments. They felt that urban concentrations of semi-wild ducks may be detrimental, by serving as the focal points for outbreaks of infectious avian diseases and as a reservoir of diseases that could be transmitted to migrating wildfowl.

A study by Fennell, *et al.* (1974) examined the effects of about 500 roosting gulls on a one million cubic meter storage reservoir. Salmonella were usually found in the reservoir waters but never in the incoming water. They also found close correlations between the number of gulls and the degree of bacteria contamination. The sources of Salmonella appeared to be household and other refuse from dumps where the gulls were foraging. When the gulls left, after bird scaring fireworks were used, the Salmonella and other bacteria concentrations almost immediately decreased. The bacteria concentrations remained at low levels for a period of five weeks until the fireworks were stopped; the birds were allowed to return, and the bacteria concentrations in the reservoir immediately increased.

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It is evident that birds can have varying effects on the bacteria concentrations in waterbodies. Large refuges do not seem to be severely affected by the wildlife populations. In fact, the ponding of waters in refuges appears to improve the water quality through sedimentation. Waterfowl frequenting smaller bodies of water, especially creeks and small lagoons, appear to have the potential for substantially increasing the water bacteria concentrations.

Gore and Storrie/Proctor and Redfern, (1981a) summarized the results of studies made to determine the effects of birds roosting on bridges over the Rideau River on river bacteria concentrations. They found that the birds on the bridges could have a statistically significant impact on fecal coliform concentrations, especially during the low summer flows. Measured concentration increases of fecal coliform bacteria downstream from the Queensway Bridge was found to be about 300 fecal coliform organisma/100 mL.

Other Wildlife Bacteria Contributions

Certain biotypes are specific to certain forms of wildlife. The presence or absence of certain bacteria types in environmental samples can be a very important factor in identifying the bacteria sources (feces from which animals). As an example, *Streptococcus bovis* and *S. equinus* have not been found in human feces by several investigators. (These types, however, are the predominant fecal strep. type found in livestock feces.) Their absence in a sample indicates the probable absence of livestock feces contamination, however, their absence may only indicate die-off and not absence of fecal contamination. Geldreich and Kenner (1969) stated that the absence of fecal strep. bacteria indicates the absence of warm blooded animal fecal pollution. The presence of *Streptococcus faecalis* indicates human fecal contamination. *S. faecalis* far outnumbers *S. inulinaceus* in sewage and in sewage polluted waters, even though *S. inulinaceus* is in great abundance in fresh feces (Bartley and Slanetz 1960). *S. faecalis* var. *liquefaciens* is ubiquitous as it is present in almost all samples tested (Geldreich and Kenner 1969; Bartley and Slanetz 1960). *S. mitis* and *S. salivarious* are considered sensitive indicators of human pollution when they are found (Seidler 1979). *S. bovis* and *S. equinus* are nearly ideal non-human mammal fecal indicators (Seidler 1979). They have rapid die-off rates (much faster than fecal coliform die-offs) and are the most sensitive bacteria in the fecal strep. category. Their presence indicates recent livestock pollution (Feacham 1975; Geldreich 1976; Bartley and Slanetz 1960; Geldreich and Kenner 1969).

Drake, *et al.* (1961) found a wide variation in the coliform content of some wild and domestic animal feces. Coliform bacteria were present in small numbers or were absent for some feces, such as from rabbits, shrews, deer, elk, some squirrels, and many birds. They also found that coliform bacteria were not found in some carnivores (shrews) but were present in large number in the carnivores (coyotes and bears). They also found no significant differences in the fecal coliform content of different animals of the same species that were collected in different areas. However, feces from different species of animals collected in the same area could have large differences in their fecal coliform concentrations. They also noted that some mammals (coyote, bear, some gophers, and some squirrels) had coliform concentrations in the feces that were similar to human coliform concentrations. Animals with soft or moist feces (man and many domestic animals such as cows, dogs, and pigs) had very high numbers of coliform bacteria (many thousands to millions of coliform bacteria per gram). The feces of other animals, especially those with hard or dry feces, may contain few or no coliform bacteria.

Geldreich (1976) summarized a study that showed the variations in fecal strep. bacteria concentrations in human feces from different locations. Feces collected from humans living in Cincinnati had concentrations more than five times greater than samples collected from healthy people in Nagpur, India (13 million and 2 million fecal strep. organisms per gram, respectively). He also reported that fecal strep. densities in farm animal, cat, dog, mice, and chipmunk feces samples were in the order of millions of organisms per gram. Rabbit feces fecal strep. concentrations, however, may be several orders of magnitude lower than those found in other animals. The Ottawa waterbird feces samples were reported to have the largest total coliform, fecal coliform, and fecal strep. concentrations when compared to all other samples reported (except for the fecal strep. dog feces concentrations). Gull feces generally have the highest fecal coliform concentrations in their feces, followed by Ottawa pigeons, ducks, dogs, sheep, and humans. Other urban bird feces (pigeons, sparrows, robins, starlings, and blackbirds) were all reported to have much lower fecal coliform concentrations that were unusually high.

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Feces Discharges from Wildlife

Table 58 summarizes reported discharges of feces from different mammals and birds. These discharges are expressed in grams per animal per day and vary quite widely, depending on the study. Animals can deposit substantial quantities of feces in an urban area, depending upon the animal's population. Geldreich (1976) stated that major contributions of bacteria in urban communities are from fecal discharges from cats, dogs, and rodents. These feces are deposited on soil, asphalt, and cement. He stated that the one-half million dogs in New York City deposit about 150,000 pounds of feces on the streets, sidewalks, and park areas per day. Significant populations of rodents may also contribute large amounts of fecal material in urban areas. Fortunately, very little of this fecal bacteria enters receiving waters. Faust (1976), in an agricultural watershed in the Rhode River near Chesapeake Bay, found that only about one percent of the fecal coliform bacteria deposited by cattle in the watershed was washed into the receiving waters. Sometimes the yields (application rates) were higher, with high values around 5 percent and on one occasion reaching 25 percent. They concluded that fecal coliform discharges can be substantial from a watershed that has the equivalent of about one cow per two hectares. Evans and Owens (1973), from a study in Scotland, stated that most of the bacteria in the runoff water came from the soil. They found that the soil bacteria washoff yield was only about one-tenth of one percent of the estimated total soil bacteria population. They felt that the maximum annual discharge of bacteria from the contaminated soil would only be about 0.15 percent of the total soil bacteria population.

Table 58. Estimated Feces Discharges

Animal	Discharge[1] (grams/animal/day)	Reference
Mammals		
Humans	150	Geldreich 1976
Farm animals		
pig	680	Howe 1969
sheep	1,100	Howe 1969
cow	7,000	Howe 1969
horse	7,000	Howe 1969
Domestic pets		
cat	70	Howe 1969
dog	140	Howe 1969
	23 to 100	Marron and Senn 1974
Possible urban wildlife		
rabbit	550	Howe 1969
rat	35	Howe 1969
mouse	10	Howe 1969
Birds		
Farm birds		
chicken	55	Howe 1969
	180	Geldreich 1976
turkey	160	Howe 1969
	450	Geldreich 1976
Possible urban birds		
pigeon	25 to 50	Gore & Storrie/Proctor & Redfern 1981a
gulls	10 to 25	Gould and Fletcher 1978
duck	70	Howe 1969
	340	Geldreich 1976
goose	160	Howe 1969

[1] estimated application factors (fraction reaching urban receiving waters): 0.01 for land animals and 0.5 for waterfowl

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Case Study: Investigation of Urban Runoff Pathogen Sources in Ottawa, Ontario

The City of Ottawa, Ontario, sponsored several studies in the early 1980s investigating the sources of the high bacteria concentrations found in the Rideau River, and possible control procedures. The following discussion (from Pitt 1983) summarizes their findings, especially relating to the relative magnitude of urban bacteria sources.

Table 59 summarizes the bacteria concentrations observed for the different samples collected in the Ottawa urban area. Except for rooftop runoff, the catchment subarea sheetflow concentrations all approach the concentrations of the urban runoff. The urban runoff bacteria concentrations are slightly greater than the river concentrations below Mooney's Bay. The catchment area sheetflow fecal strep. concentrations, again except for rooftop runoff, are all substantially greater than the river concentrations.

Table 59. Typical Bacterial Population Densities in the Ottawa Area (Pitt 1983)

	Total Coliforms	Fecal Coliforms	Fecal Strep.
Water Samples (organisms/100 mL)			
Rideau River			
Below Mooney's Bay	7,000	1,000	500
Above Mooney's Bay	500	50	50
Urban runoff	na	10,000	na
Snowmelt	3,000	<2	2
Catchbasin sump water	na	50	300
Gutter flows	na	4,000	20,000
Parking area sheetflow	na	3,000	10,000
Vacant land and park sheetflow	na	6,000	20,000
Rooftop runoff	na	100	200
Sediment Samples (organisms/gram solids)			
Rideau river sediments (urban area)	na	20,000	na
Sewerage sediments	na	8,000	20,000
Catchbasin sump water	400	20	100
Street dirt	na	400	2,000

Estimated Unit Area Bacteria Yields

Five to eleven storms were completely monitored for fecal coliform concentrations at four test catchments from 1978 to 1981. Table 60 summarizes these observations for the 34 monitored storms. The resultant calculated catchment bacteria runoff yields expressed in millions of organisms per hectare per day are shown in Table 61. Approximately 1.5 x 10^8 fecal coliforms per hectare per year and about 3.7 x 10^8 fecal strep. organisms per hectare per year are the estimated bacteria yields for the Ottawa six month runoff season.

Table 60. Catchment Runoff Fecal Coliform Bacteria Observations in Ottawa area (Pitt 1983)

	Alta Vista	Chesterton	Leonard	St. Lauraent	Overall
Geometric mean* (#/100 mL)	14,100	12,300	21,700	4,580	10,200
Min. (#/100 mL)	5,900	720	11,500	540	540
Max. (#/100 mL)	38,000	96,600	64,100	31,400	96,600
Number of storms monitored	11	7	5	11	34
Study period	1980 and 1981	1978, 1979, and 1981	1980 and 1981	1980 and 1981	1978 through 1981

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* geometric mean of flow-weighted averaged concentrations for monitored storms

Table 61. Estimated Ottawa Catchment Bacteria Runoff Yields (10^6 organisms/ha/day) (Pitt 1983)

Catchment	Fecal Coliforms Mean (range)	Fecal Strep. Mean (range)
Alta Vista	0.5 (0.3 to 1.1)	1.3 (0.8 to 3)
Chestron	0.6 (0.4 to 1.5)	1.5 (1 to 4)
Leonard	1.4 (0.7 to 3)	3.5 (2 to 8)
St. Laurent	0.6 (0.3 to 1.4)	1.5 (0.8 to 4)
Average	$0.8x10^6$ FC org/ha/day	$2x10^6$ FS org/ha/day

In order to determine the importance of each of the catchment subareas in contributing urban runoff pollutants, a small sampling effort was conducted to collect sheetflow samples during two rain events. Table 62 summarizes the results of these analyses. The rooftop bacteria samples had substantially lower fecal coliform and fecal strep. bacteria concentrations than samples collected from vacant land and park sheetflows, parking lot sheetflows and street gutter flows. The rooftop samples, however, did have important bacteria concentrations, especially when compared to Rideau River bacteria concentrations above Mooney's Bay.

Table 62. Catchment Subarea Sheetflow Bacteria in Ottawa (August and September, 1981, observations) (Pitt 1983)

		Rooftop runoff	Vacant land and park sheetflow	Parking lot sheetflow	Gutter flow
Fecal coliforms	Geometric mean (#/100 mL)	85	5,600	2,900	3,500
	Min (#/100 mL)	10	360	200	500
	Max (#/100 mL)	400	79,000	19,000	10,000
	Number of observations	4	7	6	7
Fecal Strep.	Geometric mean (#/100 mL)	170	16,500	11,900	22,600
	Min (#/100 mL)	20	12,000	1,600	1,800
	Max (#/100 mL)	3,600	57,000	40,000	1,200,000
	Number of observations	4	7	6	7

The urban runoff fecal coliform unit area yield is more than a factor of ten greater than the snowmelt yield, and about a factor of ten greater than the sewerage and catchbasin sump yields. Therefore, snowmelt and sewerage accumulations probably do not appreciably affect the total annual yields, but they may significantly affect individual snowmelt and storm event concentrations and yields. The street surface particulate fecal coliform and fecal strep. accumulations are as much as one to two orders of magnitude greater than the total urban runoff bacteria discharges. Bacteria urban runoff yields do not appear to be source-limited in that substantial quantities of bacteria reside on the street surfaces that are not washed off by rain. A large quantity of bacteria is associated with particulates that are trapped in the street textures and may be subject to significant die-off during periods of dry weather. The many other sources of bacteria in the urban area would further increase this overabundance of bacteria sources for urban runoff.

These observed subarea bacteria concentrations were much greater than those observed in a similar sampling program in San Jose, California, (Pitt and Bozeman 1982). In San Jose, the observed fecal coliform gutter and parking lot sheetflow sample concentrations were much greater than elsewhere in the San Jose study areas, and were from several hundred to about 1000 organisms/100mL. Rooftop runoff and landscaped area runoff fecal coliform concentrations were less than ten and less than 50 organisms/100 mL., respectively. The San Jose sheetflow fecal strep. concentrations were closer to the observed Ottawa concentrations. An earlier Ottawa study reported by the

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Regional Municipality of Ottawa - Careleton (1972) measured rooftop runoff bacteria concentrations. The runoff from a roof at an experimental farm that was frequented by many birds had coliform concentrations greater than 10,000 organisms/100 mL. Street surface and parking lot runoff showed total coliform concentrations in the hundreds of thousand of organisms/100 mL.

The differences in bacteria yields from street surfaces when comparing large rains with small rains very large. The bacteria yields from the street surfaces decrease much more for the larger rains because of the high bacteria concentrations observed in non-street surface sheetflows. Even if all of the street surface bacteria was removed from the streets, a maximum reduction of about 60 to 70 percent in outfall bacteria yields would be achieved, and only for the runoff from residential areas and for the smallest rains. For the largest rains, and if all of the fecal coliform bacteria was removed from the streets, only about 10 to 25 percent bacteria reductions would be observed at the outfall. If sidewalks and driveways were cleaned, a greater fraction of the bacteria could be controlled. If the shopping center parking lots, along with the streets, were cleaned, then much of the bacteria in these areas could also be controlled and for almost all storms.

Mammal and Bird Populations and Bacteria Discharges in the Ottawa Urban Area

Table 63 summarizes the expected populations of mammals and birds in the lower Rideau River watershed. There are other domestic and wild animals in this watershed (such as other birds and rodents) but their population estimates are not available. It is estimated that about 16,000 dogs and the same numb er of cats live in this watershed, corresponding to approximately one dog or cat for every other house. The waterbird estimates are based upon actual population counts made along the river.

Table 63. Estimated Bird and Pet Populations in the Lower Rideau River Watershed (below Hogs Back) (Pitt 1983)

Animal	Population Density (animals/ha)	Total estimated animal population in the Lower Rideau River Watershed (4000 ha)
Dogs[1]	4	16,000
Cats[1]	4	16,000
Robins[2]	7	28,000
Pigeons (land)[1]	1	4,000
Pigeons (on bridges)[3]		600
Ducks (on river)[3]		100
Gulls (on river)[3]		150
Swans (on river)[3]		15
Other birds on river (sparrows and blackbirds)[3]		10

[1] estimated from Colt, *et al.* 1977
[2] estimated from Howard 1974
[3] Regional Municipality of Ottawa-Carleton 1980

The estimated total annual bacteria discharges from the mammals and birds in this watershed, based upon population estimates, fecal discharges, application factors, and bacteria concentrations in the feces is 2×10^{11} fecal coliforms per ha per year. This estimate is about two to three orders of magnitude greater than what is expected in the annual urban runoff bacteria yield. This large difference is likely associated with bacteria die-and sedimentation.

The major source of fecal coliforms in the Rideau River is expected to be pigeons (when using the high Ottawa pigeon fecal coliform values), followed by dogs and ducks. The other sources shown would all contribute less than a total of five percent. Dogs are expected to contribute almost half of the river total coliform organisms, while pigeons on the bridges and ducks on the river make up most of the remainder. Dogs are expected to contribute almost all of

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the river fecal strep. bacteria, with ducks on the river contributing to less than five percent. Pitt and Bozeman (1979) found that lake birds can contribute a significant amount of fecal strep. bacteria to a lake refuge in the middle of an urban area in Oakland, CA. However, urban runoff components contribute much more bacteria during wet weather conditions.

It is interesting to compare these calculated estimates of fecal coliform contributions with those reported elsewhere. Faust and Goff (1977) reported 10^9 to 10^{10} fecal coliforms discharged per hectare per year in the Chesapeake Bay area from cultivated lands, forests, and pastures. These values are about ten to 100 times the estimated urban area yields for the lower Rideau River watershed.

Summary of Ottawa Case Study

The limited assimilative capacity of the river and how the bacteria quality decreases as the river flows through Ottawa was previously described. The substantial bacteria density increases during wet weather indicate an urban runoff problem and the probable lengthy duration of adverse river conditions. The number of observations showing bacteria densities greater than the standards indicates that Strathcona, Brantwood, and Brighton Beaches exceed the fecal coliform criteria of 100 organisma/100 mL most of the time. Mooney's Bay Beach exceeds this criteria about ten percent of the time. A limited field program was conducted during this study that found the Rideau River bottom sediments to have substantial bacteria population densities.

An important phase in designing an urban runoff control program is to determine the sources of the problem pollutants in the watershed. An understanding of where they accumulate in the catchment is needed before appropriate controls may be selected. As an example, bacteria may accumulate almost everywhere in an urban area (on rooftops from birds, and on streets, parking lots, landscaped areas, and vacant land from dogs and other urban animals). Original sources therefore affect a variety of potential control areas. The Rideau River Stormwater Management Plan report identified urban runoff as the major source of the problem bacteria discharges. This special study summarized here included a limited field program which roughly identified the specific locations in the urban area where the bacteria originated. Feces from warm blooded animals are the only sources of fecal bacteria, while soils can contain some non-fecal bacteria. The ratio of fecal coliforms to fecal strep. bacteria population densities can be used to differentiate between human and non-human sources if the samples are obtained very close to the time of discharge. Otherwise, the different survival times of the fecal strep. biotypes can radically change this ratio with time. The periodic high ratios of these two bacteria indicator groups in the Rideau River may be explained by relatively old non-human discharges. If water bodies were small (creeks and small reservoirs), a relatively small number of birds (less than 100) were found to significantly increase various fecal bacteria biotypes in the water. However, if the water bodies were large (large bird refuges and large rivers), then large numbers of birds (as many as 100,000) did not significantly increase the bacteria population densities in the water. The water flowing from the bird refuges typically had better water quality than the inflowing water, possibly due to sedimentation in the refuge marshes. Dog feces are expected to contribute much of the fecal coliforms in urban runoff, while pigeons (on bridges) and ducks on the Rideau River may contribute most of the bacteria to the River. Polluted river sediments may also play an important role in contaminating river water.

Based on monitoring from the Rideau River Stormwater Management Study and other runoff bacteria studies, it is concluded that many potentially pathogenic bacteria biotypes can be present in the local urban runoff. Most of these pathogenic biotypes can cause health problems when ingested. Because of the low probability of ingestion of urban runoff, many of the potential human diseases associated with these biotypes are not likely to occur. The required infective doses of many of these biotypes and their relatively low concentrations in stormwater would require very large amounts of urban runoff to be ingested. As an example, Salmonella, when observed in Ottawa urban runoff and receiving waters, has been found in very low concentrations requiring the consumption of more than 20 liters of urban runoff for infections. Shigella, however, may be present in urban runoff and receiving waters and when ingested in low numbers can cause dysentery.

The pathogenic organisms of most importance in urban runoff are usually associated with skin infections and body contact. Body contact with urban runoff is not likely. However, the Rideau River retains many of the pathogenic

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biotypes originating from urban runoff for a long period of time after rains. The most important biotype causing skin infections is *Pseudomonas aeruginosa*. This biotype has been frequently detected in urban runoff at many locations in concentrations that may cause potential infections. However, there is little information relating increased infection hazards with increased *Pseudomonas* concentrations. *Staphylococci aureus* may also cause skin problems with body contact, but there is little information concerning the concentrations of this biotype in urban runoff. Various pathogenic yeasts and viruses may also be found in urban runoff, but their concentrations and infective pathways are not well enough known to establish criteria for urban runoff pollution. Therefore, the local bacteria concentration objectives based on fecal coliform concentrations may be unreasonable when actual potential health effects are considered.

Further studies also need to be made concerning populations of pathogenic bacteria (specifically *Pseudomonas aeruginosa, Staphylococci aureus* and Shigella) in the Rideau River. Population densities of these pathogens may be related to River location, storm type, and possibly indicator (fecal coliform) bacteria densities. If adverse levels of these pathogens can be predicted, or easily and quickly measured, then they should be used as the basis for beach closures in the River.

Emerging Tools for Identifying Sources of Discharges

Coprostanol and Other Fecal Sterol Compounds Utilized as Tracers of Contamination by Sanitary Sewage.

A more likely indicator of human wastes than fecal coliforms and other "indicator" bacteria may be the use of certain molecular markers, specifically the fecal sterols, such as coprostanol and epicoprostanol (Eaganhouse, *et al.* 1988). However, these compounds are also discharged by other carnivores in a drainage (especially dogs). A number of research projects have used these compounds to investigate the presence of sanitary sewage contamination. The most successful application may be associated with sediment analyses instead of water analyses. As an example, water analyses of coprostanol are difficult due to the typically very low concentrations found, although the concentrations in many sediments are quite high and much easier to quantify. Unfortunately, the long persistence of these compounds in the environment easily confuses recent contamination with historical or intermittent contamination.

Particulates and sediments collected from coastal areas in Spain and Cuba receiving municipal sewage loads were analyzed by Grimalt, *et al.* (1990) to determine the utility of coprostanol as a chemical marker of sewage contamination. Coprostanol can not by itself be attributed to fecal matter inputs. However, relative contributions of steroid components can be a useful indicator. When the relative concentrations of coprostanol and coprostanone are higher than their 5α epimers, or more realistically, other sterol components of background or natural occurrence, it can provide useful information.

Sediment cores from Santa Monica Basin, CA, and effluent from two local municipal wastewater discharges were analyzed by Venkatesan and Kaplan (1990) for coprostanol to determine the degree of sewage addition to sediment. Coprostanols were distributed throughout the basin sediments in association with fine particles. Some stations contained elevated levels, either due to their proximity to outfalls or because of preferential advection of fine-grained sediments. A noted decline of coprostanols relative to total sterols from outfalls seaward indicated dilution of sewage by biogenic sterols.

Other chemical compounds have been utilized for sewage tracer work. Saturated hydrocarbons with 16-18 carbons, and saturated hydrocarbons with 16-21 carbons, in addition to coprostanol, were chosen as markers for sewage in water, particulate, and sediment samples near the Cocoa, FL, domestic wastewater treatment plant (Holm, *et al.* 1990). The concentration of the markers was highest at points close to the outfall pipe and diminished with distance. However the concentration of C16-C21 compounds was high at a site 800 m from the outfall indicating that these compounds were unsuitable markers for locating areas exposed to the sewage plume. The concentrations for the other markers were very low at this station.

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The range of concentrations of coprostanol found in sediments and mussels of Venice, Italy, were reported by Sherwin, *et al.* (1993). Raw sewage is still discharged directly into the Venice lagoon. Coprostanol concentrations were determined in sediment and mussel samples from the lagoon using gas chromatography/mass spectroscopy. Samples were collected in interior canals and compared to open-bay concentrations. Sediment concentrations ranged from 0.2-41.0 μg/g (dry weight). Interior canal sediment samples averaged 16 μg/g compared to 2 μg/g found in open bay sediment samples. Total coprostanol concentrations in mussels ranged from 80 to 620 ng/g (wet weight). No mussels were found in the four most polluted interior canal sites.

Nichols, *et al.* (1996) also examined coprostanol in stormwater and the sea-surface microlayer to distinguish human versus nonhuman sources of contamination. Other steroid compounds in sewage effluent were investigated by Routledge, *et al.* (1998) and Desbrow, *et al.* (1998) who both examined estrogenic chemicals. The most common found were 17β-Estradiol and estrone which were detected at concentrations in the tens of nanograms per liter range. These were identified as estrogenic through a toxicity identification and evaluation approach, where sequential separations and analyses identified the sample fractions causing estrogenic activity using a yeast-based estrogen screen. GC/MS was then used to identify the specific compounds.

Estimating Potential Sanitary Sewage Discharges into Storm Drainage and Receiving Waters using Detergent Tracer Compounds. As described above, detergent measurements (using methylene blue active substance, MBAS, test methods) were the most successful individual tracer to indicate contaminated water in storm sewerage dry-weather flows. Unfortunately, the MBAS method uses hazardous chloroform for an extraction step. Different detergent components, especially linear alkylbenzene sulphonates (LAS) and linear alkylbenzenes (LAB), have also been tried to indicate sewage dispersal patterns in receiving waters. Boron, a major historical ingredient of laundry chemicals, can also potentially be used. Boron has the great advantage of being relatively easy to analyze using portable field test kits, while LAS requires chromatographic equipment. LAS can be measured using HPLC with fluorescent detection, after solid phase extraction, to very low levels. Fujita, *et al.* (1998) developed an efficient enzyme-linked immunosorbent assay (ELISA) for detecting LAS at levels from 20 to 500 mg/L.

LAS from synthetic surfactants (Terzic and Ahel 1993) which degrade rapidly, as well as nonionic detergents (Terzic and Ahel 1993) which do not degrade rapidly, have been utilized as sanitary sewage markers. LAS was quickly dispersed from wastewater outfalls except in areas where wind was calm. In these areas LAS concentrations increased in freshwater but were unaffected in saline water. After time, the lower alkyl groups were mostly found, possibly as a result of degradation or settling of longer alkyl chain compounds with sediments. Chung, *et al.* (1995) also describe the distribution and fate of LAS in an urban stream in Korea. They examined different LAS compounds having carbon ratios of C12 and C13 compared to C10 and C11, plus ratios of phosphates to MBAS and the internal to external isomer ratio (I/E) as part of their research. Gonález-Mazo, *et al.* (1998) examined LAS in the Bay of Cádiz off the southwest of Spain. They found that LAS degrades rapidly (Fujita, *et al.*, 1998, found that complete biodegradation of LAS requires several days), and is also strongly sorbed to particulates. In areas close to shore and near the untreated wastewater discharges, there as significant vertical stratification of LAS: the top 3 to 5 mm of water had LAS concentrations about 100 times greater than found at 0.5 m.

Zeng and Vista (1997) and Zeng, *et al.* (1997) describe a study off of San Diego where LAB was measured, along with polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons (AHs) to indicate the relative pollutant contributions of wastewater from sanitary sewage, nonpoint sources, and hydrocarbon combustion sources. They developed and tested several indicator ratios (alkyl homologue distributions and parent compound distributions) and examined the ratio of various PAHs (such as phenanthrene to anthracene, methylphenanthrene to phenanthrene, fluoranthene to pyrene, and benzo(a)anthracene to chrysene) as tools for distinguishing these sources. They concluded that LABs are useful tracers of domestic waste inputs to the environment due to their limited sources. They also describe the use of the internal to external isomer ratio (I/E) to indicate the amount of biodegradation that may have occurred to the LABs. They observed concentrations of total LABs in sewage effluent of about 3 mg/L, although previous researchers have seen concentrations of about 150 mg/L in sewage effluent from the same area.

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The fluorescent properties of detergents have also been used as a tracer by investigating the fluorescent whitening agents (FWAs), as described by Poiger, *et al.* (1996) and Kramer, *et al.* (1996). HPLC with fluorescence detection was used in these studies to quantify very low concentrations of FWAs. The two most frequently used FWAs in household detergents (DSBP and DAS 1) were found at 7 to 21 mg/L in primary sewage effluent and at 3 to 9 mg/L in secondary effluent. Raw sewage contains about 10 to 20 mg/L FWAs. The removal mechanisms in sewage treatment processes is by adsorption to activated sludge. The type of FWAs varies from laundry applications to textile finishing and paper production, making it possible to identify sewage sources. The FWAs were found in river water at 0.04 to 0.6 mg/L. The FWAs are not easily biodegradable but they are readily photodegraded. Photodegradation rates have been reported to be about 7% for DSBP and 71% for DAS 1 in river water exposed to natural sunlight, after one hour exposure. Subsequent photodegradation is quite slow.

Other Compounds Found in Sanitary Sewage that may be used for Identifying Contamination by Sewage. Halling-Sørensen, *et al.* (1998) detected numerous pharmaceutical substances in sewage effluents and in receiving waters. Their work addressed human health concerns of these low level compounds that can enter downstream drinking water supplies. However, the information can also be possibly used to help identify sewage contamination. Most of the research has focused on clofibric acid, a chemical used in cholesterol lowering drugs. It has been found in concentrations ranging from 10 to 165 ng/L in Berlin drinking water sampler. Other drugs commonly found include aspirin, caffeine, and ibuprofen. Current FDA guidance mandates that the maximum concentration of a substance or its active metabolites at the point of entry into the aquatic environment be less than 1 mg/L (Hun 1998).

Caffeine has been used as an indicator of sewage contamination by several investigators (Shuman and Strand 1996). The King County, WA, Water Quality Assessment Project is examining the impacts of CSOs on the Duwamish River and Elliott Bay. They are using both caffeine (representing dissolved CSO constituents) and coprostanol (representing particulate bound CSO constituents), in conjunction with heavy metals and conventional analyses, to help determine the contribution of CSOs to the river. The caffeine is unique to sewage, while coprostanol is from both humans and carnivorous animals and is therefore also in stormwater. They sampled upstream of all CSOs, but with some stormwater influences, 100 m upstream of the primary CSO discharge (but downstream of other CSOs), within the primary CSO discharge line, and 100 m downriver of the CSO discharge location. The relationship between caffeine and coprostanol was fairly consistent for the four sites (coprostanol was about 0.5 to 1.5 mg/L higher than caffeine). Similar patterns were found between the three metals, chromium was always the lowest and zinc was the highest. King Co. is also using clean transported mussels placed in the Duwamish River to measure the bioconcentration potential of metal and organic toxicants and the effects of the CSOs on mussel growth rates (after 6 week exposure periods). Paired reference locations are available near the areas of deployment, but outside the areas of immediate CSO influence. *US Water News* (1998) also described a study in Boston Harbor that found caffeine at levels of about 7 mg/L in the harbor water. The caffeine content of regular coffee is about 700 mg/L, in contrast.

DNA Profiling to Measure Impacts on Receiving Water Organisms and to Identify Sources of Micro organisms in Stormwater. This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. Kratch (1997) summarized several investigations on cataloging the DNA of *E. coli* to identify their source in water. This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. The procedure, developed at the Virginia Polytechnic Institute and State University, has been used in Chesapeake Bay. In one example, it was possible to identify a large wild animal population as the source of fecal coliform contamination of a shellfish bed, instead of suspected failing septic tanks. DNA patterns in fecal coliforms vary among animals and birds, and it is relatively easy to distinguish between human and non-human sources of the bacteria. However, some wild animals have DNA patterns that are not easily distinguishable. Some researchers question the value of *E. coli* DNA fingerprinting believing that there is little direct relationship between *E. coli* and human pathogens. However, this method should be useful to identify the presence of sewage contamination in stormwater or in a receiving water.

One application of the technique, as described by Krane, *et al.* (1999) of Wright State University, used randomly amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) generated profiles of naturally occurring crayfish. They found that changes in the underlying genetic diversity of these populations were significantly

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correlated with the extent to which they have been exposed to anthropogenic stressors. They concluded that this rapid and relatively simple technique can be used to develop a sensitive means of directly assessing the impact of stressors upon ecosystems. These Wright State University researchers have also used the RAPD-PCR techniques on populations of snails, pill bugs, violets, spiders, earthworms, herring, and some benthic macroinvertebrates, finding relatively few obstacles in its use for different organisms. As noted above, other researchers have used DNA profiling techniques to identify sources of *E. coli* bacteria found in coastal waterways. It is possible that these techniques can be expanded to enable rapid detection of many different types of pathogens in receiving waters, and the most likely sources of these pathogens.

Stable Isotope Methods for Identifying Sources of Water. Stable isotopes had been recommended as an efficient method to identify illicit connections to storm sewerage. A demonstration was conducted in Detroit as part of the Rouge River project to identify sources of dry weather flows in storm sewerage (Sangal, *et al.* 1996). Naturally occurring stable isotopes of oxygen and hydrogen can be used to identify waters originating from different geographical sources (especially along a north-south gradient). Ma and Spalding (1996) discuss this approach by using stable isotopes to investigate recharge of groundwaters by surface waters. During water vapor transport from equatorial source regions to higher latitudes, depletion of heavy isotopes occurs with rain. Deviation from a standard relationship between deuterium and ^{18}O for a specific area indicates that the water has undergone additional evaporation. The ratio is also affected by seasonal changes. As discussed by Ma and Spalding (1996), the Platte River water is normally derived in part from snowmelt from the Rocky Mountains, while the groundwater in parts of Nebraska is mainly contributed from the Gulf air stream. The origins of these waters are sufficiently different and allow good measurements of the recharge rate of the surface water to the groundwater. In Detroit, Sangal, *et al.* (1996) used differences in origin between the domestic water supply, local surface waters, and the local groundwater to identify potential sanitary sewage contributions to the separate storm sewerage. Rieley, *et al.* (1997) used stable isotopes of carbon in marine organisms to distinguish the primary source of carbon being consumed (sewage sludge vs. natural carbon sources) in two deep sea sewage sludge disposal areas.

Stable isotope analyses would not be able to distinguish between sanitary sewage, industrial discharges, washwaters, and domestic water, as they all have the same origin, nor would it be possible to distinguish sewage from local groundwaters if the domestic water supply was from the same local aquifer. This method works best for situations where the water supply is from a distant source and where separation of waters into separate flow components is not needed. It may be an excellent tool to study the effects of deep well injection of stormwater on deep aquifers having distant recharge sources (such as in the Phoenix area). Few laboratories can analyze for these stable isotopes, requiring shipping and a long wait for the analytical results. Sangal, *et al.* (1995) used Geochron Laboratories, in Cambridge, Massachusetts.

Dating of sediments using ^{137}Cs was described by Ma and Spalding (1996). Arsenic contaminated sediments in the Hylebos Waterway in Tacoma, WA, could have originated from numerous sources, including a pesticide manufacturing facility, a rock-wool plant, steel slags, powdered metal plant, shipbuilding facilities, marinas and arsenic boat paints, and the Tacoma Smelter. Dating the sediments, combined with knowing the history of potential discharges and conducting optical and electron microscopic studies of the sediments, was found to be a powerful tool to differentiate between the different metal sources to the sediments.

Summary of Emerging Techniques

In almost all cases, a suite of analyses is most suitable for effective identification of inappropriate discharges. A recent example was reported by Standley, *et al.* (2000), where fecal steroids (including coprostanol), caffeine, consumer product fragrance materials, and petroleum and combustion byproducts were used to identify wastewater treatment plant effluent, agricultural and feedlot runoff, urban runoff, and wildlife sources. They studied numerous individual sources of these wastes from throughout the US. A research grade mass sperctrophotometer was used for the majority of the analyses in order to achieve the needed sensitivities, although much variability was found when using the methods in actual receiving waters affected by wastewater effluent. This sophisticated suite of analyses

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did yield much useful information, but the analyses are difficult to conduct and costly and may be suitable for special situations, but not for routine survey work.

Another recent series of tests examined several of these potential emerging tracer parameters, in conjunction with the previously identified parameters, during a project characterizing stormwater that had collected in telecommunication manholes, funded by Tecordia (previously Bellcore), AT&T, and eight regional telephone companies throughout the country (Pitt and Clark 1999). Numerous conventional constituents, plus major ions, and toxicants were measured, along with candidate tracers to indicate sewage contamination of this water. Boron, caffeine, coprostanol, *E. coli*, enterococci, fluorescence (using specific wavelengths for detergents), and a simpler test for detergents were evaluated, along with the use of fluoride, ammonia, potassium, and obvious odors and color. About 700 water samples were evaluated for all of these parameters, with the exception of bacteria and boron (about 250 samples), and only infrequent samples were analyzed for fluorescence. Coprostanol was found in about 25 percent of the water samples (and in about 75% of the 350 sediment samples analyzed). Caffeine was only found in very few samples, while elevated *E. coli* and enterococci (using IDEXX tests) were observed in about 10% of the samples. Strong sewage odors in water and sediment samples were also detected in about 10% of the samples. Detergents and fluoride (at >0.3 mg/L) were found in about 40% of the samples and are expected to have been contaminated with industrial activities (lubricants and cleansers) and not sewerage. Overall, about 10% of the samples were therefore expected to have been contaminated with sanitary sewage, about the same rate previously estimated for stormwater systems.

Additional related laboratory tests, funded by the University of New Orleans and the EPA (Barbe', *et al.* 2000), were conducted using many sewage and laundry detergent samples and found that the boron test was a poor indicator of sewage, possibly due to changes in formulations in modern laundry detergents. Laboratory tests did find that fluorescence was an excellent indicator of sewage, especially when using specialized "detergent whitener" filter sets, but was not very repeatable. We also examined several UV absorbance wavelengths as sewage indicators and found excellent correlations with 228 nm, a wavelength having very little background absorbance in local spring waters, but with a strong response factor with increasing strengths of sewage.

Table 64 summarizes the different measurement parameters discussed above. We recommend that our originally developed and tested protocol, as reported by Pitt, *et al.* (1993), still be used as the most efficient routine indicator of sewage contamination of stormwater drainage systems, with the possible addition of specific *E. coli* and enterococci measurements and UV absorbance at 228 nm. The numerous exotic tests requiring specialized instrumentation and expertise do not appear to warrant their expense and long analytical turn-around times, except in specialized research situations, or when special confirmation is economically justified (such as when examining sewer replacement or major repair options).

Table 64. Comparison of Measurement Parameters used for Identifying Inappropriate Discharges into Storm Drainage

Parameter Group	Comments	Recommendation
Fecal coliform bacteria and/or use of fecal coliform to fecal strep. ratio	Commonly used to indicate presence of sanitary sewage.	Not very useful as many other sources of fecal coliforms are present, and ratio not accurate for old or mixed wastes.
Physical observations (odor, color, turbidity, floatables, deposits, stains, vegetation changes, damage to outfalls)	Commonly used to indicate presence of sanitary and industrial wastewater.	Recommended due to easy public understanding and easy to evaluate, but only indicative of gross contamination, with excessive false negatives (and some false positives). Use in conjunction with chemical tracers for greater sensitivity and accuracy.
Detergents presence (anionic surfactant extractions)	Used to indicate presence of wash waters and sanitary sewage.	Recommended, but care needed during hazardous analyses (only for well-trained personnel). Accurate indicator of contamination during field tests.
Fluoride, ammonia and potassium measurements	Used to identify and distinguish between wash	Recommended, especially in conjunction with detergent analyses. Accurate indicator of major contamination sources

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	waters and sanitary sewage.	and their relative contributions.
TV surveys and source investigations	Used to identify specific locations of inappropriate discharges, especially in industrial areas.	Recommended after outfall surveys indicate contamination in drainage system.
Coprostanol and other fecal sterol compounds	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analysis with GC/MSD. Not specific to human wastes or recent contamination. Most useful when analyzing particulate fractions of wastewaters or sediments.
Specific detergent compounds (LAS, fabric whiteners, and perfumes)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Fluorescence	Used to indicate presence of sanitary sewage and wash waters.	Likely useful, but expensive instrumentation. Rapid and easy analysis. Very sensitive.
Boron	Used to indicate presence of sanitary sewage and wash waters.	Not very useful. Easy and inexpensive analysis, but recent laundry formulations in US have minimal boron components.
Pharmaceuticals (colfibric acid, aspirin, ibuprofen, steroids, illegal drugs, etc.)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Caffeine	Used to indicate presence of sanitary sewage.	Not very useful. Expensive analyses with GC/MSD. Numerous false negatives, as typical analytical methods not suitably sensitive.
DNA profiling of microorganisms	Used to identify sources of microorganisms	Likely useful, but currently requires extensive background information on likely sources in drainage. Could be very useful if method can be simplified, but with less specific results.
UV absorbance at 228 nm	Used to identify presence of sanitary sewage.	Possibly useful, if UV spectrophotometer available. Simple and direct analyses. Sensitive to varying levels of sanitary sewage, but may not be useful with dilute solutions. Further testing needed to investigate sensitivity in field trials.
Stable isotopes of oxygen	Used to identify major sources of w ater.	May be useful in area having distant domestic water sources and distant groundwater recharge areas. Expensive and time consuming procedure. Can not distinguish between wastewaters if all have common source.
E. coli and enterococci bacteria	More specific indicators of sanitary sewage than coliform tests.	Recommended in conjunction with chemical tests. Relatively inexpensive and easy analyses, especially if using the simple IDEXX methods.

This project, a joint effort of the Center for Watershed Protection (CWP) and Dr. Robert Pitt with the University of Alabama is being conducted to complete a technical assessment of techniques and methods for identifying and correcting illicit and inappropriate discharges geared towards NPDES Phase II communities. The project has a three year duration. In the first half of the project, most of our effort will be directed to collecting data. The most cost effective and efficient techniques will be identified during this initial project period. In the second project half, the project team will develop draft guidance on methods and techniques to identify and correct illicit connections, test the efficacy of the draft guidance in four communities, complete a final "User's Manual for Identifying and Correcting Illicit and Inappropriate Discharges," and conduct training and dissemination.

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Appendix A
Field Equipment Summary

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS

Constituent	Method	Interferences
Acidity 1	titrimetric	not noted
Acidity 2	field titration kits	
Acidity 3	titrimetric	not noted
Alkalinity 1	pH - wet chemistry	
Alkalinity 2	titrimetric	not noted
Alkalinity 3	field titration kits	
Alkalinity 4	titrimetric	not noted
Alkalinity 5	titrimetric	standard interferences
Aluminum 1	comparative colorimetric	not noted
Aluminum 2	spectrophotometric	
Ammonia 1	comparative colorimetric	not noted
Ammonia 2	comparative colorimetric	standard interferences
Ammonia 3	comparative colorimetric	not noted
Ammonia 4	spectrophotometric	
Ammonia 5	Ion selective electrode	volatile amines
Ammonia 6	Ion selective electrode	volatile amines, Hg(+2)
Ammonia 7	comparative colorimetric	
Ammonium 1	indicator paper	not noted
Ammonium 2	titrimetric	standard interferences
Arsenic	spectrophotometric	
Bacteria, aerobic	dip strip/incubation	
Bacteria, anaerobic	dip strip/incubation	
Bacteria, total count 1	P/A color indicator	
Bacteria, total count 2	MF - Millipore samplers	
Bacteria, total count 3	membrane filtration	
Barium	spectrophotometric	
Benzotriazole	spectrophotometric	
Biochemical oxygen demand (rate)	manometric	
Boron	spectrophotometric	
Bromide 1	Ion selective electrode	I(-), CN(-), S(-2)
Bromide 2	Ion selective electrode	S(-2), I(-), CN(-), Cl(-), NH3
Bromine 1	comparative colorimetric	not noted
Bromine 2	comparative colorimetric	not noted
Bromine 3	spectrophotometric	
Cadmium 1	comparative colorimetric	not noted
Cadmium 2	spectrophotometric	
Cadmium 3	Ion selective electrode	Ag(+), Hg(+2), Cu(+2), Pb(+2), Fe(+2)
Calcium 1	Ion selective electrode	Zn(+2), Pb(+2), Fe(+2), Cu(+2)
Calcium 2	field titration kits	
Calcium 3	Ion selective electrode	None
Calcium 4	indicator paper	not noted
Calcium 5	titrimetric	standard interferences
Caprostanol	gas chromatography/mass spectrophotometry	
Carbon dioxide 1	titrimetric	not noted
Carbon dioxide 2	field titration kits	
Carbon dioxide 3	Ion selective electrode	volatile organic acids
Carbon dioxide 4	Ion selective electrode	volatile weak acids
Carbon dioxide 5	titrimetric	not noted
Carbon dioxide 6	titrimetric	standard interferences

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Chemical oxygen demand	spectrophotometric

(continued)

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Chloride 1	titrimetric	not noted
Chloride 2	field titration kits	
Chloride 3	Ion selective electrode	Br(-), I(-), CN(-), S(-2), OH(-)
Chloride 4	spectrophotometric	
Chloride 5	Ion selective electrode	standard interferences
Chloride 6	titrimetric	not noted
Chloride 7	Ion selective electrode	OH, S(-2), Br(-), I(-), CN(-)
Chloride 8	titrimetric	standard interferences
Chloride 9	indicator paper	not noted
Chlorine 1	comparative colorimetric	standard interferences
Chlorine 2	comparative colorimetric	not noted
Chlorine 3	comparative colorimetric	not noted
Chlorine 4	amperometric titrator	
Chlorine 5	ion selective electrode	strong oxidizing agents
Chlorine 6	spectrophotometric	
Chlorine 7	comparative colorimetric	
Chlorine 8	indicator paper	Br(-)
Chlorine 9	field titration kits	
Chlorine 10	titrimetric	not noted
Chlorine dioxide	spectrophotometric	
Chlorine/cyanide	indicator paper	not noted
Chromate 1	spectrophotometric	standard interferences
Chromate 2	comparative colorimetric	not noted
Chromate 3	indicator paper	not noted
Chromium 1	comparative colorimetric	not noted
Chromium 2	spectrophotometric	
Chromium 3	field titration kits	
Chromium (+3)	spectrophotometric	
Chromium (+6) 1	spectrophotometric	
Chromium (+6) 2	comparative colorimetric	
Cobalt	spectrophotometric	
Color 1	comparative colorimetric	not noted
Color 2	spectrophotometric	
Color 3	comparative colorimetric	
Conductivity 1	multi-meter, recording	
Conductivity 2	electrical conductance	
Conductivity 3	multi-meter, recording	
Conductivity 4	electrical resistance	
Copper 1	spectrophotometric	standard interferences
Copper 2	comparative calorimetric	not noted
Copper 3	spectrophotometric	
Copper 4	comparative calorimetric	
Copper 5	indicator paper	not noted
Copper (+2) 1	comparative colorimetric	standard interferences
Copper (+2) 2	ion selective electrode	Ag(+), Hg(+2), Cl(-), Br(-), Fe(+2)
Copper (+2) 3	ion selective electrode	S(-2), Ag(+), Hg(+2), Fe(+3), Cd(+2)
Cyanide 1	spectrophotometric	standard interferences
Cyanide 2	spectrophotometric	
Cyanide 3	comparative colorimetric	
Cyanide 4	ion selective electrode	I(-), S(-2)

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Cyanide 5	ion selective electrode	S(-2), I(-), Br(-), Cl(-)

(continued)

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Cyanuric acid	spectrophotometric	
Diethylhydroxylamine	spectrophotometric	
Diphenylamine	comparative colorimetric	standard interferences
E. Coli bacteria 1	ONPG/MUG colorimetric	
E. Coli bacteria 2	LT/MUG - MPN	
EDTA	field titration kits	
Erythorbic acid	spectrophotometric	
Fecal coliform bacteria	Membrane filtration	
Fecal streptococci bacteria	membrane filtration	
Fluoride 1	spectrophotometric	standard interferences
Fluoride 2	comparative colorimetric	not noted
Fluoride 3	Dedicated meter - ion selective	Al(+3), Fe(+3), La(+3), extreme pH
Fluoride 4	Ion selective electrode	Metal ions, pH<5 and pH>10
Fluoride 5	spectrophotometric	
Fluoride 6	Ion selective electrode	high pH
Fluoride 7	Dedicated meter - ion selective	
Fluorobromate	Ion selective electrode	many
Fluorescent dye tracer tablets		
Formaldehyde 1	spectrophotometric	standard interferences
Formaldehyde 2	titrimetric	not noted
Formaldehyde 3	spectrophotometric	
Formaldehyde 4	comparative colorimetric	
Formaldehyde 5	indicator paper	not noted
Fungi and yeast	dip strip/incubation	
Glycol 1	spectrophotometric	standard interferences
Glycol 2	comparative colorimetric	
Hardness 1	titrimetric	not noted
Hardness 2	Ion selective electrode	Ne(+)
Hardness 3	Ion selective electrode	Na(+), K(+)
Hardness 4	field titration kits	
Hardness 5	titrimetric	not noted
Hardness 6	indicator paper	not noted
Hardness 7	titrimetric	standard interferences
Hardness calcium	spectrophotometric	
Hardness magnesium	spectrophotometric	
Heavy metals 1	atomic adsorption spectrophotometry	
Heavy metals 2	titrimetric	not noted
Heavy metals 3	graphite furnace atomic adsorp. spectro.	
Heavy metals, particulates	Micro-chemical analyses	
Heavy metals, total	colorimetric	
Hydrazine 1	spectrophotometric	standard interferences
Hydrazine 2	comparative colorimetric	not noted
Hydrazine 3	spectrophotometric	
Hydrogen peroxide 1	spectrophotometric	standard interferences
Hydrogen peroxide 2	field titration kits	
Hydrogen sulfide	comparative colorimetric	
Hydroxide	titrimetric	not noted
Hypochtorite	comparative colorimetric	standard interferences
Iodine 1	comparative colorimetric	not noted
Iodine 2	comparative colorimetric	not noted

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Iodine 3	Ion selective electrode	S(-2), CN(-), NH3, S203(-2)
Iodine 4	spectrophotometric	
Iodine 5	comparative colorimetric	
Iodine 6	Ion selective electrode	CN(-), S(-2)

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Iron 1	comparative colorimetric	not noted
Iron 2	spectrophotometric	standard interferences
Iron 3	comparative colorimetric	not noted
Iron 4	comparative colorimetric	
Iron 5	spectrophotometric	
Iron 6	indicator paper	not noted
iron (+3)	spectrophotometric	
iron bacteria	Microscopic	
Lead 1	comparative colorimetric	not noted
Lead 2	comparative colorimetric	standard interferences
Lead 3	spectrophotometric	
Lead 4	spectrophotometric	standard interferences
Lead 5	ion selective electrode	Ag(+), Hg(+2), Cu(+2), Cd(+2), Fe(+2)
Lead 6	ion selective electrode	Fe(+3), Hg(+2), Ag(+), S(-2)
Manganese 1	comparative colorimetric	standard interferences
Manganese 2	comparative colorimetric	not noted
Manganese 3	spectrophotometric	
Manganese 4	comparative colorimetric	
Manganese 5	indicator paper	not noted
Mercaptobenzothiazole	titrimetric	standard interferences
Molybdate	comparative colorimetric	
Molybdenum/Molybdate	spectrophotometric	
Nickel 1	comparative colorimetric	not noted
Nickel 2	spectrophotometric	
Nitrate 1	spectrophotometric	standard interferences
Nitrate 2	comparative colorimetric	not noted
Nitrate 3	spectrophotometric	
Nitrate 4	comparative colorimetric	
Nitrate 5	Dedicated meter - ion selective	ClO4(-), I(-), Br(-), NO2(-), Cl(-), HCO3
Nitrate 6	ion selective electrode	many
Nitrate 7	Ion selective electrode	Cl(-), ClO4(-), I(-), Br(-)
Nitrate 8	indicator paper	not noted
Nitrite 1	spectrophotometric	standard interferences
Nitrite 2	comparative colorimetric	not noted
Nitrite 3	ion selective electrode	volatile organic acids
Nitrite 4	spectrophotometric	
Nitrite 5	comparative colorimetric	
Nitrogen dioxide	ion selective electrode	CO2, volatile weak acids
Nitrogen, Kjeldahl	spectrophotometric	
oil in water 1	UV photometer	
oil in water 2	spectrophotometric	
organic compounds 1	Portable gas chromatography	
organic compounds 2	Portable gas chromatography	
Oxygen 1	spectrophotometric	
Oxygen 2	membrane	
Oxygen 3	polarographic electrode meter	
Oxygen 4	field titration kits	
Oxygen 5	titrimetric	not noted
Oxygen 6	ion selective electrode	n/a

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Oxygen 7	spectrophotometric	standard interferences
Oxygen 8	comparative colorimetric	
Oxygen 9	comparative colorimetric	not noted
Oxygen 10	multi-meter, recording	
Oxygen 11	multi-meter, recording	
Oxygen 12	multi-meter, recording	
Oxygen 13	multi-meter, membrane	

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Ozone 1	spectrophotometric	
Ozone 2	comparative colorimetric	
Palladium	spectrophotometric	
Perchlorate	ion selective electrode	many
Permanganate	titrimetric	standard interferences
Peroxide	indicator paper	not noted
pH 1	pH electrode	Na(+)
pH 2	comparative colorimetric	standard interferences
pH 3	comparative colorimetric	
pH 4	comparative colorimetric	not noted
pH 5	pH probe	
pH 6	pH electrode	
pH 7	multi-meter, recording	
pH 8	litmus paper	
pH 9	multi-meter, recording	
Phenols 1	spectrophotometric	standard interferences
Phenols 2	comparative colorimetric	not noted
Phenols 3	spectrophotometric	
Phosphate 1	comparative colorimetric	not noted
Phosphate 2	comparative colorimetric	not noted
Phosphate 3	comparative colorimetric	
Phosphate (ortho)	spectrophotometric	standard interferences
Phosphonates	spectrophotometric	
Phosphorus 1	spectrophotometric	
Phosphorus 2	comparative colorimetric	
Plankton	microscopic	
Polyacrylic acid 1	spectrophotometric	
Polyacrylic acid 2	comparative colorimetric	
Potassium 1	dedicated meter - ion selective	low pH, NH4(+), Na(+)
Potassium 2	ion selective electrode	Cs(+), NH4(+4), low pH
Potassium 3	spectrophotometric	
Redox 1	ion selective electrode	
Redox 2	Ion selective electrode	
Redox 3	multi-meter, recording	
Redox 4	Ion selective electrode	
Residue, settleable	Imhoff cone	not noted
Salmonella bacteria 1	colorimetric	
Salmonella bacteria 2	membrane filtration	
Selenium	spectrophotometric	
Shigella bacteria	membrane filtration	
Silica 1	spectrophotometric	standard interferences

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Silica 2	comparative colorimetric	not noted
Silica 3	spectrophotometric	
Silica 4	comparative colorimetric	
Silver	spectrophotometric	
Silver/sulfide 1	ion selective electrode	Hg(+2)
Silver/sulfide 2	ion selective electrode	Hg(+2)
Sodium 1	dedicated meter - ion selective	Ag(+), low pH, K(+), NH4(+))
Sodium 2	ion selective electrode	other high level cations
Sodium 3	ion selective electrode	

(Continued)

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TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Sodium chromate	spectrophotometric	
Sulfate	spectrophotometric	
Sulfate	titrimetric	not noted
Sulfate	comparative colorimetric	
Sulfate	indicator paper	not noted
Sulfide	spectrophotometric	standard interferences
Sulfide	spectrophotometric	
Sulfide	comparative colorimetric	not noted
Sulfide	titrimetric	not noted
Sulfite	titrimetric	not noted
Sulfite	field titration kits	
Sulfite	titrimetric	standard interferences
Sulfite	indicator paper	not noted
Sulfur bacteria	microscopic	
Sulfur dioxide	ion selective electrode	volatile organic acids. C02. N02
Surfactants, anionic	spectrophotometric	
Surfactants	comparative colorimetric	
Surfactants	auto titration system	very few
Tannin and lignin	spectrophotometric	
Tannin and lignin	comparative colorimetric	
Temperature	multi-meter, recording	
Temperature	multi-meter, recording	
Temperature	multi-meter, recording	
Temperature	multi-meter	
Thiocyanate	ion selective electrode	many
Thiosutfate	titrimetric	standard interferences
Tolytriazole	spectrophotometric	
Total coliform bacteria	membrane filtration (MF)	
Total coliform bacteria	MF - portable water test kit	
Total coliform bacteria	MF - Millipore samplers	
Total coliform bacteria	membrane filtration	
Total coliform bacteria	ONPG/MUG colorimetric	
Toxicity	bacterial bioassay	
Toxicity	seed for SOD analyses	
Trihalomethanes (chloroform, etc.)	gas chromatography	
Turbidity	nephlemetry	standard interferences
Vapors	colorimetric	
Vapors	infrared absorbance	
Vapors	colorimetric	
Vapors, combustible	electrochemical cell	
Vapors, organic	photolonization	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Viruses	membrane filtration	
Volatile acid	spectrophotometric	
Yeast and mold	MF - Millipore samplers	
Yeast and mold	membrane filtration	
Zinc	spectrophotometric	standard interferences
Zinc	spectrophotometric	
Zinc	titrimetric	not noted

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Table A-2. Summary of Procedures and Detection Limits

Constituent	Possible Field Procedure		Laboratory Method		Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Acidity 1		X			<5,000	500
Acidity 2		X			100	160
Acidity 3		X			10,000	
Alkalinity 1	X				<1,000	225
Alkalinity 2		X			<3,000	300
Alkalinity 3		X			100	4,000
Alkalinity 4		X			10,000	
Alkalinity 5		X			100,000	10,000
Aluminum 1		X			<20	0.16
Aluminum 2		X			8	0.80
Ammonia 1		X			<100	2.70
Ammonia 2		X			<1,000	10,000
Ammonia 3		X			<250	2.50
Ammonia 4			X		5	2.50
Ammonia 5		X			8.5	17,000
Ammonia 6		X			10	17,000
Ammonia 7		X			100	3
Ammonium 1	X				10,000	400
Ammonium 2		X			100,000	10,000
Arsenic		X			2	0.20
Bacteria, aerobic			X			
Bacteria, anaerobic			X			
Bacteria, total count 1			X		qualitative only	
Bacteria, total count 2			X		qualitative only	
Bacteria, total count 3			X		qualitative only	
Barium		X			1,000	100
Benzotriazole		X			160	16
Biochemical oxygen demand (rate)			X		1,000	700
Boron		X			140	14
Bromide 1		X			40	80,000
Bromide 2		X			400	80,000
Bromine 1		X			<300	3
Bromine 2		X			<300	3
Bromine 3		X			45	4.50
Cadmium 1		X			<15	-1.2
Cadmium 2		X			0.8	0.08
Cadmium 3		X			10	11,000
Calcium 1		X			20	40,000
Calcium 2		X			200	4,000
Calcium 3		X			200	40,000
Calcium 4	X				25,000	250
Calcium 5		X			50,000	10,000
Caprostanol				X	1 to 10	
Carbon dioxide 1		X			<1,000	100
Carbon dioxide 2		X			200	1,000
Carbon dioxide 3		X			440	1,300

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Carbon dioxide 4	X		4,400	440
Carbon dioxide 5	X		5,000	
Carbon dioxide 6	X		10,000	10,000
Chemical oxygen demand		X	1,500	150

(continued)

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Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure		Laboratory Method		Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Chloride 1		X			<10,000	1,000
Chloride 2		X			100	10,000
Chloride 3		X			180	35,500
Chloride 4		X			200	20
Chloride 5		X			350	35,000
Chloride 6		X			500	
Chloride 7		X			1,800	35,500
Chloride 8		X			2,000	750,000
Chloride 9	X				60,000	3,600
Chlorine 1		X			<1,000	5,000
Chlorine 2		X			<250	3
Chlorine 3		X			<30	1
Chlorine 4			X		10	10
Chlorine 5		X			10	20
Chlorine 6		X			20	2
Chlorine 7		X			20	3.5
Chlorine 8	X				100	4
Chlorine 9		X			200	2,000
Chlorine 10		X			200	3
Chlorine dioxide		X			10	700
Chlorine/cyanide	X				4,000	120
Chromate 1		X			<1,000	10,000
Chromate 2		X			<10,000	100
Chromate 3	X				3,000	100
Chromium 1		X			<100	5
Chromium 2			X		6	0.6
Chromium 3		X			1,000	800
Chromium (+3)		X			0.20	20
Chromium (+6) 1		X			.6	0.6
Chromium (+6) 2		X			100	1,000
Cobalt		X			20	2
Color 1		X			<10 APHA units	200 APHA units
Color 2		X			5 color units	500 color units
Color 3		X			5 color units	500 color units
Conductivity 1	X					
Conductivity 2	X					
Conductivity 3	X					
Conductivity 4	X					
Copper 1		X			<1,000	10,000
Copper 2		X			<50	7
Copper 3		X			3	0.21
Copper 4		X			50	3
Copper 5	X				10,000	300
Copper (+2) 1		X			<100	10
Copper (+2) 2		X			0.06	6,300
Copper (+2) 3		X			30	63,000
Cyanide 1		X			<100	50

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Cyanide 2	X	2	0.2
Cyanide 3	X	10	0.3
Cyanide 4	X	13	260
Cyanide 5	X	200	260

(continued)

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Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure		Laboratory Method		Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Cyanuric acid		X			500	50
Diethylhydroxylamine		X			5	0.45
Diphenylamine		X			300,000	3,000
E. Coli bacteria 1			X		>1 org/100 mL qualitative	
E. Coli bacteria 2			X		>1 org/100 mL qualitative	
EDTA		X			10,000	200
Erythorbic acid		X			20	1.6
Fecal coliform bacteria			X			
Fecal streptococci bacteria			X			
Fluoride 1		X			<15	2
Fluoride 2		X			<150	2.7
Fluoride 3		X			2	saturation
Fluoride 4		X			9.5	19,000
Fluoride 5		X			20	2
Fluoride 6		X			20	saturation
Fluoride 7	X					
Fluorobromate		X			610	86,000
Fluorescent dye tracer tablets	X					
Formaldehyde 1		X			<1,000	5,000
Formaldehyde 2		X			<10,000	100,000
Formaldehyde 3		X			4	0.35
Formaldehyde 4		X			500	5
Formaldehyde 5	X				10,000	100
Fungi and yeast			X			
Glycol 1		X			<5,000	40
Glycol 2		X			qualitative only	
Hardness 1		X			<3,000	300
Hardness 2		X			80	40,000
Hardness 3		X			80	40,000
Hardness 4		X			100	4,000
Hardness 5		X			1,000	
Hardness 6	X				5,000	425,000
Hardness 7		X			50,000	100,000
Hardness calcium		X			40	4
Hardness magnesium		X			40	4
Heavy metals 1				X	low – many metals	
Heavy metals 2		X			qualitative test only	
Heavy metals 3				X	very low – many metals	
Heavy metals, particulates			X		qualitative – many compounds	
Heavy metals, total		X			<10,000	qualitative
Hydrazine 1		X			<100	500
Hydrazine 2		X			<30	0.3
Hydrazine 3		X			5	0.5
Hydrogen peroxide 1		X			<150	10,000
Hydrogen peroxide 2		X			200	10
Hydrogen sulfide		X			10	55

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Hydroxide	X	<100,000	10,000
Hypochtorite	X	0.3%	12%
Iodine 1	X	<100	1
Iodine 2	X	<250	2.5
Iodine 3	X	5	127,000
Iodine 4	X	70	7
Iodine 5	X	500	2.5
Iodine 6	X	640	130,000

(continued)

A0064448

Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure: Direct analysis	Possible Field Procedure: Prep. or field calibration needed	Laboratory Method: Normal	Laboratory Method: Advanced	Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
Iron 1		X			<100	10
Iron 2		X			<250	10,000
Iron 3		X			<500	5
Iron 4		X			2	10
Iron 5		X			15	3
Iron 6	X				3,000	500
iron (+3)		X			30	3
iron bacteria				X		
Lead 1		X			<15	1.20
Lead 2		X			<5	0.05
Lead 3		X			2	0.16
Lead 4		X			5	0.15
Lead 5		X			200	20,000
Lead 6		X			210	210,000
Manganese 1		X			<200	2,000
Manganese 2		X			<50	3
Manganese 3		X			10	20
Manganese 4		X			50	10
Manganese 5	X				5,000	500
Mercaptobenzothiazole		X			50,000	10,000
Molybdate		X			200	50
Molybdenum/Molybdate		X			30	35
Nickel 1		X			<50	6
Nickel 2		X			20	1.8
Nitrate 1		X			<200	250
Nitrate 2		X			<200	2
Nitrate 3		X			5	30
Nitrate 4		X			20	50
Nitrate 5		X			50	14,000
Nitrate 6		X			100	14,000
Nitrate 7		X			310	310,000
Nitrate 8	X				10,000	500
Nitrite 1		X			<100	2,000
Nitrite 2		X			<5	0.40
Nitrite 3		X			2	920
Nitrite 4		X			3	150
Nitrite 5		X			10	2,000
Nitrogen dioxide		X			180	230
Nitrogen, Kjeldahl			X		1,500	150
oil in water 1				X	100	10
oil in water 2		X			850	85
organic compounds 1		X			quantitative- many compounds	
organic compounds 2		X			quantitative- many compounds	
Oxygen 1		X			<1	13
Oxygen 2	X				<1,000	20
Oxygen 3	X				<1,000	20
Oxygen 4		X			<1,000	100

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Oxygen 5		X		<1,000	10
Oxygen 6		X		<1,000	14
Oxygen 7		X		1	10
Oxygen 8		X		1	20
Oxygen 9		X		200	
Oxygen 10	X				
Oxygen 11	X				
Oxygen 12	X				
Oxygen 13	X				

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure: Direct analysis	Possible Field Procedure: Prep. or field calibration needed	Laboratory Method: Normal	Laboratory Method: Advanced	Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
Ozone 1		X			14	1.4
Ozone 2		X			50	2.3
Palladium		X			2,500	250
Perchlorate		X			700	100,000
Permanganate		X			50,000	500
Peroxide	X				1,000	100
pH 1	X				0 pH units	14 pH units
pH 2		X			3 pH units	11 pH units
pH 3		X			3 pH units	11.6 pH units
pH 4		X			3 pH units	11 pH units
pH 5	X					
pH 6	X					
pH 7	X					
pH 8	X					
pH 9	X					
Phenols 1		X			<1,000	12,000
Phenols 2		X			<50	0.5
Phenols 3		X			2	0.2
Phosphate 1		X			<2,500	100
Phosphate 2		X			<500	5
Phosphate 3		X			100	50
Phosphate (ortho)		X			<400	10,000
Phosphonates		X			25	125
Phosphorus 1		X			25	45
Phosphorus 2		X			100	50
Plankton				X		
Polyacrylic acid 1		X			200	20
Polyacrylic acid 2		X			1,000	20
Potassium 1		X			8	39,000
Potassium 2		X			40	39,000
Potassium 3		X			70	7
Redox 1	X				-2,000 mv	+2,000 mv
Redox 2	X					

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Redox 3	X				
Redox 4	X				
Residue, settleable		X		n/a	
Salmonella bacteria 1			X		
Salmonella bacteria 2			X		
Selenium		X		10	1
Shigella bacteria			X		
Silica 1		X		<1,000	200
Silica 2		X		<1,000	10
Silica 3		X		16	100
Silica 4		X		20	800
Silver		X		6	0.6
Silver/sulfide 1		X		10	30,000
Silver/sulfide 2		X		15	>30,000
Sodium 1		X		2	saturation
Sodium 2		X		23	
Sodium 3	X			230	2,300

(continued)

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Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure: Direct analysis	Possible Field Procedure: Prep. or field calibration needed	Laboratory Method: Normal	Laboratory Method: Advanced	Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
Sodium chromate		X			10,000	1,100
Sulfate		X			650	65
Sulfate		X			25,000	
Sulfate		X			50,000	200
Sulfate	X				200,000	1,600
Sulfide		X			<150	10,000
Sulfide		X			6	0.60
Sulfide		X			500	1,000
Sulfide		X			2,000	
Sulfite		X			<2,000	200
Sulfite		X			1,000	1,600
Sulfite		X			2,000	600,000
Sulfite	X				10,000	500
Sulfur bacteria				X		
Sulfur dioxide		X			60	640
Surfactants, anionic		X			3	0.28
Surfactants		X			50	1
Surfactants			X			
Tannin and lignin		X			90	9
Tannin and lignin		X			500	150
Temperature	X					
Temperature	X					
Temperature	X					
Temperature	X					
Thiocyanate		X			290	58,000
Thiosulfate		X			5,000	1,000
Tolytriazole		X			160	16
Total coliform bacteria			X			
Total coliform bacteria		X				
Total coliform bacteria			X			
Total coliform bacteria			X			
Total coliform bacteria			X		>1 org/100 mL	qualitative
Toxicity				X		
Toxicity			X			
Trihalomethanes (chloroform, etc.)				X	<0.10000	
Turbidity		X			<1 NTU	90 NTU
Vapors		X			quantitative - many compounds	
Vapors	X				quantitative - many compounds	
Vapors		X			quantitative - many compounds	
Vapors, combustible	X				qualitative - hydrocarbons	
Vapors, organic	X				qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Viruses				X		
Volatile acid		X			28,000	2,800
Yeast and mold			X			

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Yeast and mold	X		
Zinc	X	<300	3
Zinc	X	20	2
Zinc	X	500	

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Acidity 1	25	none	low	Hanna (available from Cole-Parmer)
Acidity 2	small	low	moderate	Hach
Acidity 3	small	none	low	Taylor
Alkalinity 1	n/a	low	low	Orion
Alkalinity 2	15	none	low	Hanna (available from Cole-Parmer)
Alkalinity 3	small	low	moderate	Hach
Alkalinity 4	small	none	low	Taylor
Alkalinity 5	small	none	low	CHEMetrics
Aluminum 1	small	none	low	Taylor
Aluminum 2	small	low	low	Hach
Ammonia 1	small	none	low	Taylor
Ammonia 2	small	low	low	CHEMetrics
Ammonia 3	5	none	low	Hanna (available from Cole-Parmer)
Ammonia 4	small	low	low	Hach
Ammonia 5	1 L	moderate	moderate	HNU Systems
Ammonia 6	1 L	moderate	moderate	Orion
Ammonia 7	small	low	low	Hach
Ammonium 1	in-situ	none	low	EM (available from Markson)
Ammonium 2	small	none	low	CHEMetrics
Arsenic	small	low	low	Hach
Bacteria, aerobic	small	moderate	low	Easicult (available from Markson)
Bacteria, anaerobic	small	moderate	low	Easicult (available from Markson)
Bacteria, total count 1	small	moderate	moderate	Hach
Bacteria, total count 2	in-situ	moderate	moderate	Millipore
Bacteria, total count 3	small	moderate	moderate	Sanaline
Barium	small	low	low	Hach
Benzotriazole	small	low	low	Hach
Biochemical oxygen demand (rate)	2 L	low	moderate	Hach
Boron	small	low	low	Hach
Bromide 1	1 L	moderate	moderate	HNU Systems
Bromide 2	1 L	moderate	moderate	Orion
Bromine 1	25	none	low	Hanna (available from Cole-Parmer)
Bromine 2	small	none	low	Taylor
Bromine 3	small	low	low	Hach
Cadmium 1	small	none	low	Taylor
Cadmium 2	small	low	low	Hach
Cadmium 3	1 L	moderate	moderate	Orion
Calcium 1	1 L	moderate	moderate	Orion
Calcium 2	small	low	moderate	Hach
Calcium 3	1 L	moderate	moderate	HNU Systems
Calcium 4	in-situ	none	low	EM (available from Markson)
Calcium 5	small	none	low	CHEMetrics
Caprostanol	moderate	high	high	several sources
Carbon dioxide 1	50	none	low	Hanna (available from Cole-Parmer)
Carbon dioxide 2	small	low	moderate	Hach
Carbon dioxide 3	1 L	moderate	moderate	HNU Systems
Carbon dioxide 4	1 L	moderate	moderate	Orion
Carbon dioxide 5	small	none	low	Taylor

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Carbon dioxide 6	small	none	low	CHEMetrics
Chemical oxygen demand	small	low	low	Hach

(continued)

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Chloride 1	50	none	low	Hanna (available from Cole-Parmer)
Chloride 2	small	low	moderate	Hach
Chloride 3	1 L	moderate	moderate	HNU Systems
Chloride 4	small	low	low	Hach
Chloride 5	small	low	low	Hach
Chloride 6	small	none	low	Taylor
Chloride 7	1 L	moderate	moderate	Orion
Chloride 8	small	none	low	CHEMetrics
Chloride 9	in-situ	none	low	ETS (available from Markson)
Chlorine 1	small	low	low	CHEMetrics
Chlorine 2	5	none	low	Hanna (available from Cole-Parmer)
Chlorine 3	small	none	low	Taylor
Chlorine 4	1 L	low	moderate	Hach
Chlorine 5	1 L	moderate	moderate	Orion
Chlorine 6	small	low	low	Hach
Chlorine 7	small	low	low	Hach
Chlorine 8	in-situ	none	low	ETS (available from Markson)
Chlorine 9	small	low	moderate	Hach
Chlorine 10	small	none	low	Taylor
Chlorine dioxide	small	low	low	Hach
Chlorine/cyanide	in-situ	none	low	EM (available from Markson)
Chromate 1	small	low	low	CHEMetrics
Chromate 2	small	none	low	Taylor
Chromate 3	in-situ	none	low	EM (available from Markson)
Chromium 1	small	none	low	Taylor
Chromium 2	small	low	low	Hach
Chromium 3	small	low	moderate	Hach
Chromium (+3)	small	low	low	Hach
Chromium (+6) 1	small	low	low	Hach
Chromium (+6) 2	small	low	low	Hach
Cobalt	small	low	low	Hach
Color 1	small	none	low	Taylor
Color 2	small	low	low	Hach
Color 3	small	low	low	Hach
Conductivity 1	in-situ	moderate	low	Hydrolab
Conductivity 2	in-situ	low	low	Extech
Conductivity 3	in-situ	moderate	low	Solomat
Conductivity 4	in-situ	low	low	YSI
Copper 1	small	low	low	CHEMetrics
Copper 2	small	none	low	Taylor
Copper 3	small	low	low	Hach
Copper 4	small	low	low	Hach
Copper 5	in-situ	none	low	EM (available from Markson)
Copper (+2) 1	small	low	low	CHEMetrics
Copper (+2) 2	1 L	moderate	moderate	Orion
Copper (+2) 3	1 L	moderate	moderate	HNU Systems
Cyanide 1	small	low	low	CHEMetrics
Cyanide 2	small	low	low	Hach
Cyanide 3	small	low	low	Hach
Cyanide 4	1 L	moderate	moderate	HNU Systems

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Cyanide 5	1 L	moderate	moderate	Orion

(continued)

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Cyanuric acid	small	low	low	Hach
Diethylhydroxylamine	small	low	low	Hach
Diphenylamine	small	none	low	CHEMetrics
E. Coli bacteria 1	small	moderate	moderate	Colilert (from Access)
E. Coli bacteria 2	small	moderate	moderate	Hach
EDTA	small	low	moderate	Hach
Erythorbic acid	small	low	low	Hach
Fecal coliform bacteria	small	moderate	moderate	Sanaline
Fecal streptococci bacteria	small	moderate	moderate	Millipore
Fluoride 1	small	low	low	Hach
Fluoride 2	small	none	low	Taylor
Fluoride 3	small	low	moderate	Hach
Fluoride 4	1 L	moderate	moderate	HNU Systems
Fluoride 5	small	low	low	Hach
Fluoride 6	1 L	moderate	moderate	Orion
Fluoride 7	small	low/moderate	low	Orion
Fluorobromate	1 L	moderate	moderate	Orion
Fluorescent dye tracer tablets	n/a	low	low	many
Formaldehyde 1	small	low	low	CHEMetrics
Formaldehyde 2	5	none	low	Hanna (available from Cole-Parmer)
Formaldehyde 3	small	low	low	Hach
Formaldehyde 4	small	low	low	Hach
Formaldehyde 5	in-situ	none	low	EM.(available from Markson)
Fungi and yeast	small	moderate	low	Easicult (available from Markson)
Glycol 1	small	low	low	CHEMetrics
Glycol 2	small	low	low	Hach
Hardness 1	50	none	low	Hanna (available from Cole-Parmer)
Hardness 2	1 L	moderate	moderate	HNU Systems
Hardness 3	1 L	moderate	moderate	Orion
Hardness 4	small	low	moderate	Hach
Hardness 5	small	none	low	Taylor
Hardness 6	in-situ	none	low	ETS (available from Markson)
Hardness 7	small	none	low	CHEMetrics
Hardness calcium	small	low	low	Hach
Hardness magnesium	small	low	low	Hach
Heavy metals 1	moderate	moderate	moderate	several sources
Heavy metals 2	small	none	low	Taylor
Heavy metals 3	small	high	high	several sources
Heavy metals, particulates	small	moderate	high	PMN Labs
Heavy metals, total	small	low	low	Hach
Hydrazine 1	small	low	low	CHEMetrics
Hydrazine 2	small	none	low	Taylor
Hydrazine 3	small	low	low	Hach
Hydrogen peroxide 1	small	low	low	CHEMetrics
Hydrogen peroxide 2	small	low	moderate	Hach
Hydrogen sulfide	small	low	low	Hach
Hydroxide	50	none	low	Hanna (available from Cole-Parmer)
Hypochtorite	small	none	low	CHEMetrics
Iodine 1	small	none	low	Taylor

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Iodine 2	25	none	low	Hanna (available from Cole-Parmer)
Iodine 3	1 L	moderate	moderate	Orion
Iodine 4	small	low	low	Hach
Iodine 5	small	low	low	Hach
Iodine 6	1 L	moderate	moderate	HNU Systems

(continued)

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Iron 1	small	none	low	Taylor
Iron 2	small	low	low	CHEMetrics
Iron 3	5	none	low	Hanna (available from Cole-Parmer)
Iron 4	small	low	low	Hach
Iron 5	small	low	low	Hach
Iron 6	in-situ	none	low	EM (available from Markson)
iron (+3)	small	low	low	Hach
iron bacteria	small	moderate	high	Millipore
Lead 1	small	none	low	Taylor
Lead 2	small	none	low	CHEMetrics
Lead 3	small	low	low	Hach
Lead 4	small	low	low	Hach
Lead 5	1 L	moderate	moderate	Orion
Lead 6	1 L	moderate	moderate	HNU Systems
Manganese 1	small	none	low	CHEMetrics
Manganese 2	small	none	low	Taylor
Manganese 3	small	low	low	Hach
Manganese 4	small	low	low	Hach
Manganese 5	in-situ	none	low	EM (available from Markson)
Mercaptobenzothiazole	small	none	low	CHEMetrics
Molybdate	small	low	low	Hach
Molybdenum/Molybdate	small	low	low	Hach
Nickel 1	small	none	low	Taylor
Nickel 2	small	low	low	Hach
Nitrate 1	small	low	low	CHEMetrics
Nitrate 2	small	none	low	Taylor
Nitrate 3	small	low	low	Hach
Nitrate 4	small	low	low	Hach
Nitrate 5	small	low	moderate	Hach
Nitrate 6	1 L	moderate	moderate	Orion
Nitrate 7	1 L	moderate	moderate	HNU Systems
Nitrate 8	in-situ	none	low	EM (available from Markson)
Nitrite 1	small	low	low	CHEMetrics
Nitrite 2	small	none	low	Taylor
Nitrite 3	1 L	moderate	moderate	HNU Systems
Nitrite 4	small	low	low	Hach
Nitrite 5	small	low	low	Hach
Nitrogen dioxide	1 L	moderate	moderate	Orion
Nitrogen, Kjeldahl	small	low	low	Hach
oil in water 1	continuous	moderate	moderate	Teledyne
oil in water 2	small	low	low	Hach
organic compounds 1	moderate	high	high	HNU Systems
organic compounds 2	moderate	high	high	Sentex
Oxygen 1	small	low	low	Hach
Oxygen 2	in-situ	low	low	Extech
Oxygen 3	in-situ	low	low	Hach
Oxygen 4	small	low	moderate	Hach
Oxygen 5	10	none	low	Hanna (available from Cole-Parmer)
Oxygen 6	1 L	moderate	moderate	Orion

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Oxygen 7	small	low	low	CHEMetrics
Oxygen 8	small	low	low	Hach
Oxygen 9	small	none	low	Taylor
Oxygen 10	in-situ	moderate	low	Hydrolab
Oxygen 11	in-situ	moderate	low	Solomat
Oxygen 12	in-situ	moderate	low	YSI
Oxygen 13	in-situ	low	low	YSI

(continued)

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Ozone 1	small	low	low	Hach
Ozone 2	small	low	low	Hach
Palladium	small	low	low	Hach
Perchlorate	1 L	moderate	moderate	Orion
Permanganate	small	none	low	CHEMetrics
Peroxide	in-situ	none	low	EM (available from Markson)
pH 1	in-situ	low	low	Hach
pH 2	small	none	low	CHEMetrics
pH 3	small	low	low	Hach
pH 4	small	none	low	Taylor
pH 5	in-situ	low	low	Extech
pH 6	in-situ	low	low	HNU Systems
pH 7	in-situ	moderate	low	Hydrolab
pH 8	in-situ	low	low	many
pH 9	in-situ	moderate	low	Solomat
Phenols 1	small	low	low	CHEMetrics
Phenols 2	small	none	low	Taylor
Phenols 3	small	low	low	Hach
Phosphate 1	small	none	low	Taylor
Phosphate 2	5	none	low	Hanna (available from Cole-Parmer)
Phosphate 3	small	low	low	Hach
Phosphate (ortho)	small	low	low	CHEMetrics
Phosphonates	small	low	low	Hach
Phosphorus 1	small	low	low	Hach
Phosphorus 2	small	low	low	Hach
Plankton	moderate	moderate	high	Millipore
Polyacrylic acid 1	small	low	low	Hach
Polyacrylic acid 2	small	low	low	Hach
Potassium 1	small	low	moderate	Hach
Potassium 2	1 L	moderate	moderate	Orion
Potassium 3	small	low	low	Hach
Redox 1	in-situ	low	low	Hach
Redox 2	in-situ	moderate	low	HNU Systems
Redox 3	in-situ	moderate	low	Hydrolab
Redox 4	in-situ	moderate	low	Orion
Residue, settleable	small	none	low	Taylor
Salmonella bacteria 1	small	moderate	high	Dynatech
Salmonella bacteria 2	small	moderate	high	Millipore
Selenium	small	low	low	Hach
Shigella bacteria	small	moderate	high	Millipore
Silica 1	small	low	low	CHEMetrics
Silica 2	small	none	low	Taylor
Silica 3	small	low	low	Hach
Silica 4	small	low	low	Hach
Silver	small	low	low	Hach
Silver/sulfide 1	1 L	moderate	moderate	Orion
Silver/sulfide 2	1 L	moderate	moderate	HNU Systems
Sodium 1	small	low	moderate	Hach

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Sodium 2	1 L	moderate	moderate	HNU Systems
Sodium 3	in-situ	low	low	Extech

(continued)

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TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Sodium chromate	small	low	low	Hach
Sulfate	small	low	low	Hach
Sulfate	small	none	low	Taylor
Sulfate	small	low	low	Hach
Sulfate	in-situ	none	low	EM (available from Markson)
Sulfide	small	low	low	CHEMetrics
Sulfide	small	low	low	Hach
Sulfide	small	none	low	Sensidyne
Sulfide	small	none	low	Taylor
Sulfite	50	none	low	Hanna (available from Cole-Parmer)
Sulfite	small	low	moderate	Hach
Sulfite	small	none	low	CHEMetrics
Sulfite	in-situ	none	low	EM (available from Markson)
Sulfur bacteria	small	moderate	high	Millipore
Sulfur dioxide	1 L	moderate	moderate	HNU Systems
Surfactants, anionic	small	low	low	Hach
Surfactants	small	low	low	Hach
Surfactants	small	moderate	moderate	Orion
Tannin and lignin	small	low	low	Hach
Tannin and lignin	small	low	low	Hach
Temperature	in-situ	moderate	low	Hydrolab
Temperature	in-situ	moderate	low	Solomat
Temperature	in-situ	moderate	low	YSI
Temperature	in-situ	low	low	YSI
Thiocyanate	1 L	moderate	moderate	Orion
Thiosutfate	small	none	low	CHEMetrics
Tolytriazole	small	low	low	Hach
Total coliform bacteria	small	moderate	moderate	Hach
Total coliform bacteria	small	moderate	moderate	Millipore
Total coliform bacteria	in-situ	moderate	moderate	Millipore
Total coliform bacteria	small	moderate	moderate	Sanaline
Total coliform bacteria	small	moderate	moderate	Cotiert (from Access)
Toxicity	small	high	moderate	Microbics (Azur Environmental)
Toxicity	1 L	moderate	low	Polytox (available from Markson)
Trihalomethanes (chloroform, etc.)	etc.) moderate	high	high	several sources
Turbidity	small	low	low	Hach
Vapors	n/a	low	moderate	Draeger
Vapors	n/a	high	high	Foxboro
Vapors	n/a	low	moderate	Sensidyne
Vapors, combustible	n/a	moderate	low	Gas Tech
Vapors, organic	n/a	moderate	low	HNU Systems
Vapors, organic	n/a	high	high	Environmental Technologies
Vapors, organic	n/a	high	high	Foxboro
Vapors, organic	n/a	high	high	Microsensor Technology
Vapors, organic	n/a	high	high	Sentex
Vapors, organic	n/a	high	high	Thermal Environmental
Viruses	>100 gallons	moderate	high	Millipore
Volatile acid	small	low	low	Hach
Yeast and mold	in-situ	moderate	moderate	Millipore
Yeast and mold	small	moderate	moderate	Sanaline

A0064S4

Zinc	small	low	low	CHEMetrics
Zinc	small	low	low	Hach
Zinc	small	none	Low	Taylor

A006465

TABLE A-4. RESULTS FROM SEWAGE DILUTION STUDY

Parameter	% Sewage in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (µS/cm)												
expected	350	350.12	350.20	356	362	380	410	440	458	468.8	469.88	470
observed	350	.50	350	351	355	371	400	435	451	470	470	470
% error	0	0.03	0.06	1.40	1.93	2.11	2.44	1.14	1.53	0.26	2.03	0
Fluoride (mg/L)												
expected	0.06	0.06	0.07	0.10	0.14	0.27	0.48	0.69	0.82	0.89	0.90	0.90
observed	0.06	0.07	0.09	0.11	0.14	0.28	0.47	0.65	0.78	0.85	0.89	0.90
% error	0	-16.67	-28.57	-10.00	0	-3.70	2.08	5.80	4.88	4.67	10.2	0
Hardness (mg/L as $CaCO_3$)	227	226.89	225.94	221.7	216.4	200.5	174	147.5	131.6	122.06	121.11	121
expected	227	232	229	218	217	199	176	148	128	122	121	121
observed	0	-2.25	-1.35	1.66	-0.28	0.75	-1.15	-0.34	2.74	0.05	0.09	0
% error												
Detergent (mg/L)												
expected	0	0.01	0.07	0.33	0.66	1.65	3.3	4.95	5.94	6.54	6.59	6.6
observed	0	0	0.05	0.31	0.62	1.60	3.28	4.68	5.46	6	6.6	6.6
% error	0	100	28.57	6.06	6.06	3.03	6.06	5.45	8.08	8.26	-0.1	0
Fluorescence (% scale)												
expected	7	7.46	11.55	29.75	52.5	120.75	234.5	348.25	416.5	457.45	461.5	462
observed	7	7	10	28	50	114	224	335	390	448	462	462
% error	0	6.17	13.42	5.88	4.76	5.59	4.48	3.80	6.36	2.06	-.11	0

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TABLE A-4. (continued)

Parameter	% Sewage in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium (mg/L)												
expected	0.72	0.72	0.76	0.93	1.14	1.77	2.82	3.87	4.5	4.88	4.92	4.92
observed	0.72	0.73	0.78	0.95	1.18	1.79	2.85	3.96	4.62	5.02	4.96	4.92
% error	0	-1.39	-2.63	-2.15	-3.5	-1.13	-1.06	-2.33	-2.67	-2.66	-0.81	0
Ammonia (mg/L)												
expected	0.02	0.33	0.15	0.68	1.35	3.34	6.66	9.98	11.97	13.17	13.29	13.3
observed	0.02	0.04	0.13	0.687	1.42	3.52	7.11	10.19	11.67	13.06	13.16	13.3
% error	0	-20.19	14.92	0.58	-5.34	-5.39	-6.76	-2.10	2.5	0.81	0.95	0
Color (units)												
expected	0	0.03	0.3	1.5	3	7.5	15	22.5	27	29.7	29.97	30
observed	0	0	0	3	4	7	13	20	27	30	30	30
% error	0	100	100	-100	-25	6.67	13.33	11.11	0	-1.01	-1.01	0
pH (units)												
expected	7.02	7.02	7.02	7.03	7.04	7.07	7.12	7.17	7.20	7.22	7.22	7.22
observed	7.02	7.08	7.11	7.13	7.15	7.15	7.15	7.15	7.15	7.21	7.20	7.22
% error	0	0.9	1.3	1.4	1.6	1.1	0.4	-0.3	-0.7	-0.2	-0.3	0
Toxicity (% reduction)												
expected	0	0.08	0.82	4.09	8.17	20.43	40.85	61.28	73.53	80.90		81.7
observed	0	0	0	0	2.38	23.80	61.40	77.5	78.50	80.70	NA	81.7
% error	0	-100	-100	-100	-70.87	16.50	50.31	26.49	6.76	-0.25		0

NA: Data not available

A95497

TABLE A-5. RESULTS FROM SEPTAGE DILUTION STUDY

Parameter	% Septage in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (µS/cm)												
expected	340	340.58	345.85	369.25	398.5	486.25	632.5	778.75	866.5	919.15	924.42	925
observed	340	342	345	351	390	480	610	740	820	905	924	925
% error	0	-4.2	0.25	4.95	2.13	1.29	3.56	4.98	5.37	1.54	0.05	0
Fluoride (mg/L)												
expected	0.26	0.26	0.26	0.28	0.31	0.38	0.51	0.63	0.70	1.75	0.75	0.75
observed	0.26	0.27	0.27	0.29	0.30	0.36	0.49	0.60	0.69	0.73	0.73	0.75
% error	0	-3.85	-3.85	-3.57	3.23	5.26	3.92	4.76	1.43	2.66	2.66	0
Detergent (mg/L)												
expected	0	0.02	0.24	1.2	2.4	6	12	18	21.6	23.76	23.98	24
observed	0	0	0.25	1.2	2.5	5.80	12.6	18	21	24	24	24
% error	0	100	-4.17	0	-4.17	3.33	-5	0	2.78	-1.01	-0.08	0
Fluorescence (% scale)												
expected	7	8.64	2324	88.20	169.40	413	819	1225	1468.6	1614.76	1629.38	1631
observed	7	7.2	20	77.8	158.6	441.1	768.2	1194	1362.8	1492.6	1529.4	1631
% error	0	16.67	13.94	11.79	6.38	-6.8	6.2	6.61	7.2	7.56	6.14	0

(continued)

TABLE A-5. (Continued)

Parameter	% Septage in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium (mg/L)												
expected	1.2	1.22	1.39	2.17	2.95	6.03	10.85	15.68	18.57	20.31	20.48	20.5
observed	1.2	1.22	1.36	20.7	2.95	5.55	10.9	16	18.8	20	20.5	20.5
% error	0	0	2.16	4.61	0	7.96	-0.56	2.04	-1.24	1.53	0.10	0
Ammonia (mg/L)												
expected	0.08	0.14	0.64	2.90	5.72	14.19	28.30	42.40	50.87	55.95	56.45	56.51
observed	0.08	0.09	0.56	2.71	6	13.45	26.91	39.86	51.68	52.77	54.91	56.51
% error	0	34.03	13.08	6.60	-4.84	5.20	4.89	5.98	-1.60	5.68	2.73	0
Color (units)												
expected	0	1.04	10.4	52	104	260	520	780	936	1029.6	1039.0 1040	1040
observed	0	0	10	50	100	270	485	810	885	945	-0.10	1040
% error	0	100	3.85	3.85	3.85	-3.85	6.73	-3.85	5.45	8.22		0
pH (units)												
expected	7.30	7.30	7.30	7.31	7.32	7.36	7.42	7.48	7.52	7.54		7.54
observed	7.30	7.33	7.36	7.37	7.36	7.36	7.36	7.37	7.45	7.50	NA	7.54
% error	0	0.4	0.8	0.8	0.5	0	-0.8	-2.0	-0.9	-0.5		0
Toxicity (% reduction)												
expected	0	0.08	0.81	4.04	8.08	20.19	40.39	60.58	72.69	79.96	80.69	80.77
observed	0	0	0	0	12.33	36.43	50.03	68.57	72.70	74.13	79.73	80.77
% error	0	-100	-100	-100	52.60	80.43	23.87	13.19	0.01	-7.29	-1.20	0

NA: Data not available

69196

TABLE A-6. RESULTS FROM METAL PLATING BATH DILUTION STUDY

Parameter	% Metal Plating Bath Waste in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (µS/cm)												
expected	320	324.68	364.8	544	768	1440	2560	3680	4352	4755.2	4795.52	4800
observed	320	328	368	525	775	1500	2700	3850	4320	4750	4800	4800
% error	0	-1.08	-0.88	3.69	-0.91	-4.17	-5.47	-4.62	0.74	0.11	-0.09	0
Fluoride (mg/L)												
expected	0.10	0.10	0.12	0.19	0.28	0.54	0.98	1.42	1.68	1.84	1.86	1.86
observed	0.10	0.10	0.13	0.20	0.28	0.55	1.00	1.38	1.66	1.86	1.88	1.86
% error	0	0	-8.33	-5.26	0	-1.85	-2.04	2.81	1.19	-1.09	-1.08	1.86
Hardness (mg/L as $CaCO_3$)	222	228.56	227.53	249.65	277.3	360.25	498.5	636.75	719.7	769.47	774.95	775
expected	222	228	237	242	263	345	485	625	700	760	769	775
observed	0	-2.44	-4.16	3.06	5.16	4.23	2.71	1.84	2.74	1.23	0.70	0
% error												
Detergent (mg/L)												
expected	0	0.01	0.1	0.5	1	2.5	5	7.5	9	9.9	9.99	10
observed	0	0	0.09	0.48	1.06	2.4	4.65	7.6	9.2	9.68	9.79	10
% error	0	100	10.00	4.00	-6.00	4.00	7.00	-1.38	-2.22	2.22	2.00	0
Fluorescence (% scale)												
expected	6	6.10	7.04	11.2	16.4	32	58	84	99.6	108.96	109.90	110
observed	6	6	8	11	15	30	54	79	93	104	108	110
% error	0	1.64	-13.64	1.79	8.53	6.25	6.90	5.9	6.62	4.55	1.73	0

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TABLE A-6. (Continued)

Parameter	% Metal Plating Bath Waste in Springwater											
	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium (mg/L)												
expected	1.21	1.66	5.70	23.65	46.09	113.41	225.61	337.80	405.12	445.51	449	450
observed	1.21	1.99	6.32	25	48	117	230	350	420	442	444	450
% error	0	-19.88	-10.88	-5.71	-4.14	-3.17	-1.95	-3.61	-3.67	0.79	1.11	0
Ammonia (mg/L)												
expected	0	0	0.03	0.15	0.31	0.76	1.53	2.29	2.75	3.01	3.05	3.05
observed	0	0	0.02	0.16	0.29	0.74	1.62	2.29	2.75	3.01	3.05	3.05
% error	0	0	33.33	-6.67	6.45	2.63	-5.56	0	0	0	0	0
Color (units)												
expected	0	0.21	2.12	10.6	21.2	53	106	159	190.8	209.88	211.79	212
observed	0	0	3	10	20	55	110	162	194	216	212	212
% error	0	100	-41.5	5.67	5.67	-3.78	-3.78	-1.89	-1.68	-2.92	-0.01	0
pH (units)												
expected	7.90	7.90	7.91	7.93	7.96	8.05	8.20	8.35	8.44	8.49	8.50	8.50
observed	7.90	7.89	7.88	7.87	7.87	7.94	8.18	8.41	8.48	8.50	8.51	8.50
% error	0	-0.13	-0.38	-0.76	-1.13	-1.37	-0.24	0.72	0.47	0.12	0.12	0
Toxicity (% reduction)												
expected	0	0.1	1	5	10	25	50	75	90	99	99	100
observed	0	10.81	40.40	44.60	96.50	100	100	100	100	100	NA	100
% error	0	10710	3940	792	865	300	100	33.33	11.11	1.01		0

NA: Data not available

TABLE A-7. PROBABILITY VALUES FOR LOG-PROBABILITY DISTRIBUTIONS FOR LOW, MEDIUM, AND HIGH SAMPLE VARIATIONS

	Low Sample Variability	Medium Sample Variability	High Sample Variability
COV (σ/x):	0.16	0.83	1.67
Range Ratio (x_{90}/x_{10}):	1.5	10	100
Probability that conc. will be greater than shown		Relative Concentrations:	
99	0.70	0.12	0.014
98	0.73	0.16	0.23
95	0.78	0.23	0.05
90 (x_{90})	0.80	0.32	0.1
80	0.88	0.48	0.22
70	0.92	0.63	0.39
60	0.96	0.81	0.64
50 (median)	1.0	1.0	1.0
40	1.04	1.3	1.6
30	1.08	1.6	2.6
20	1.12	2.2	4.5
10 (x_{10})	1.20	3.2	10
5	1.29	4.5	19
2	1.34	6.5	42
1	1.41	8.3	70

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Appendix B
Statistical Plots for Equipment Selection

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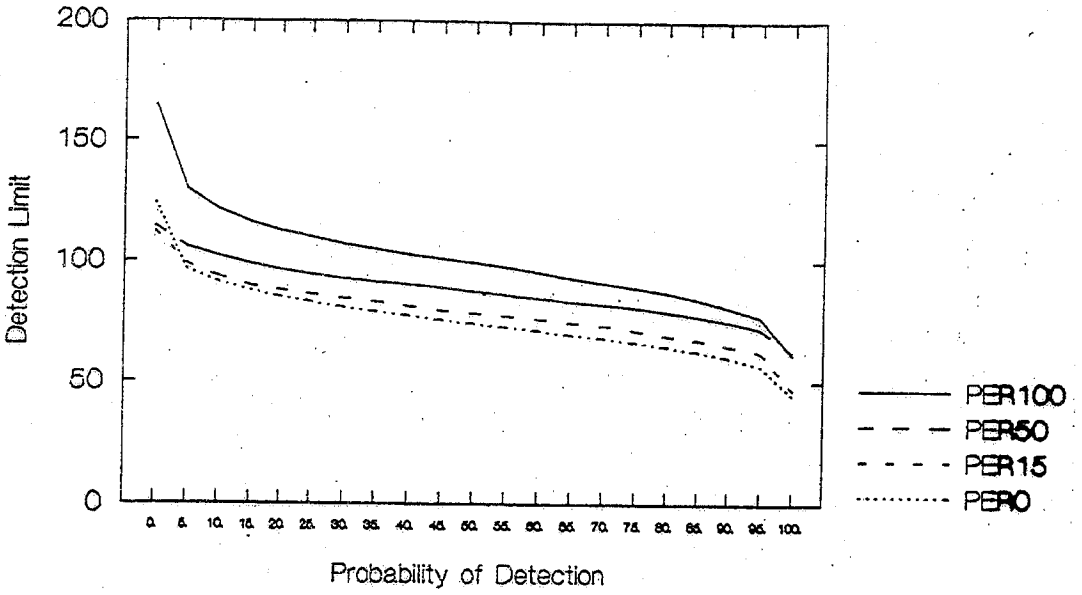

Figure B-1. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 1.33 (75L-100L).

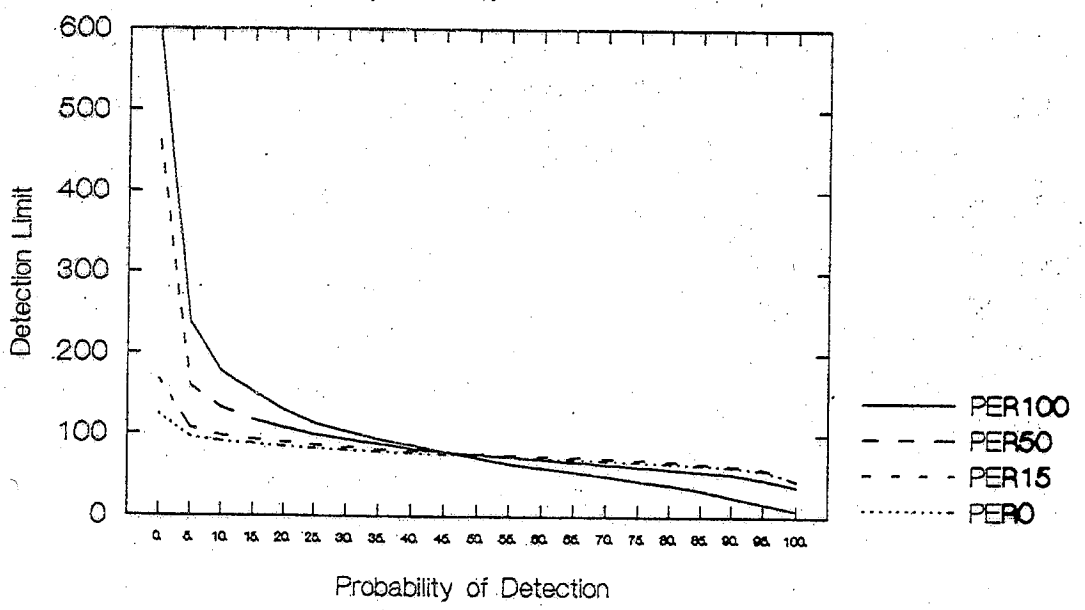

Figure B-2. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 1.33 (75L-100M).

A006475

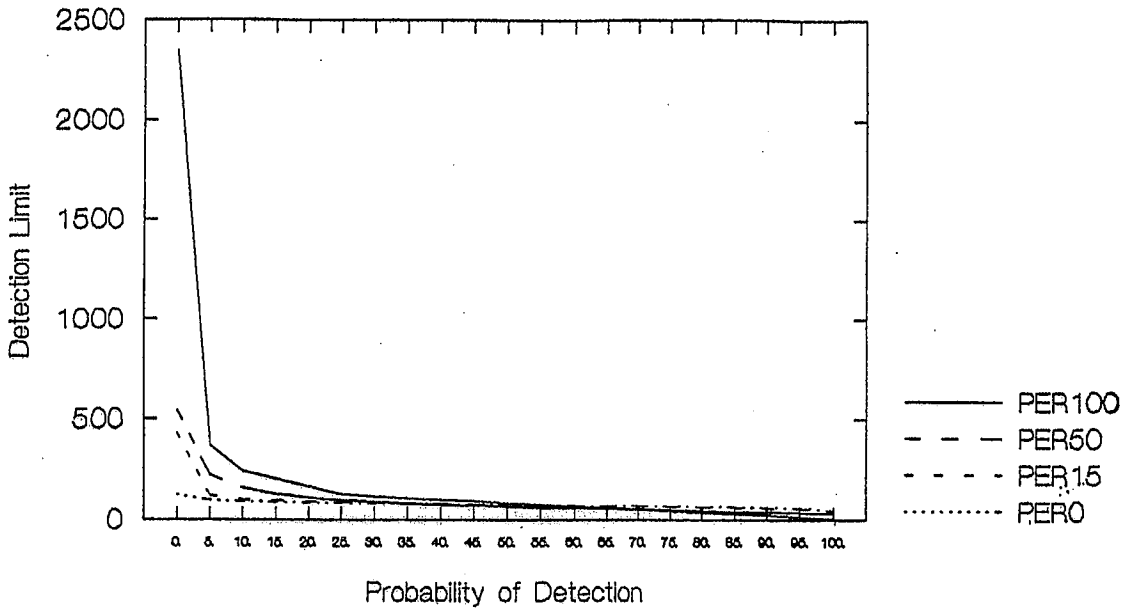

Figure B-3. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 1.33 (75L-100H).

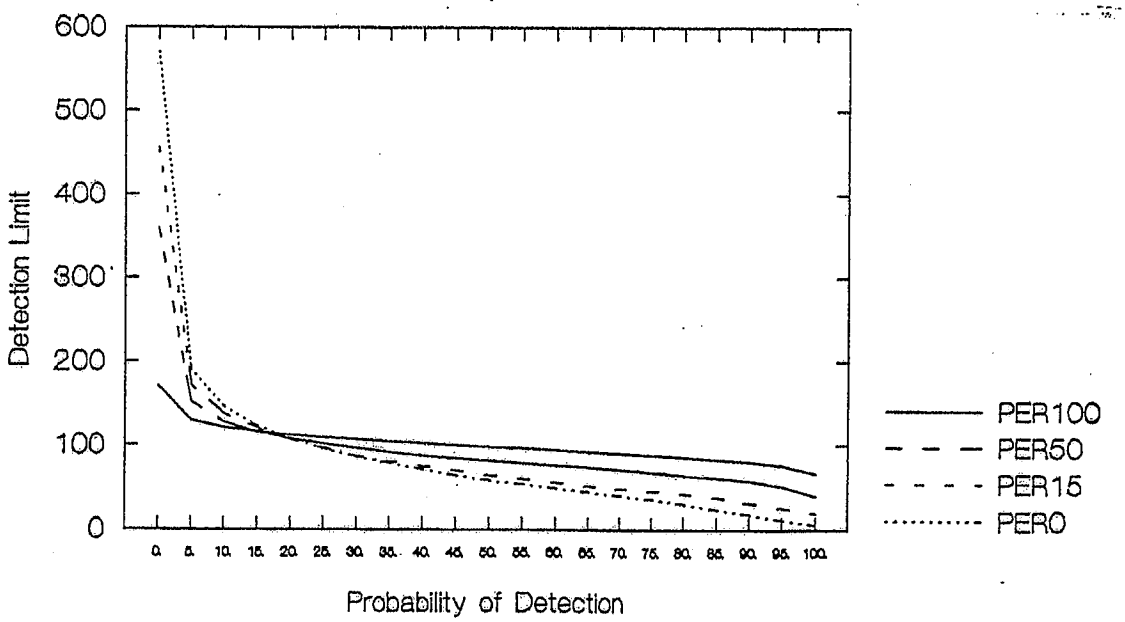

Figure B-4. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 1.33 (75M-100L).

A0006476

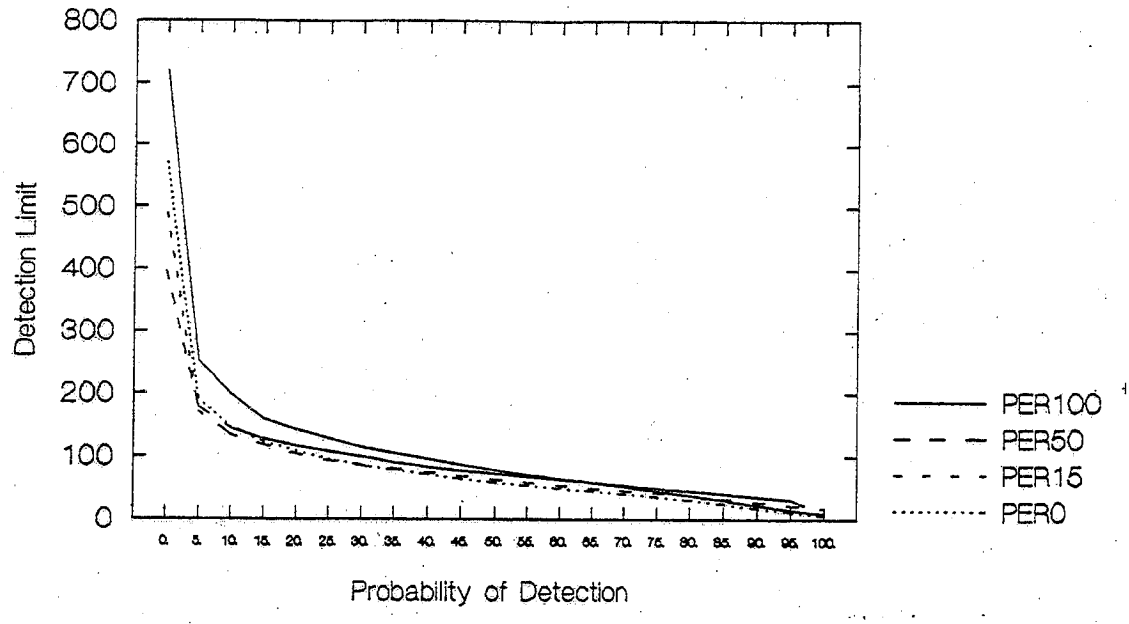

Figure B-5. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 1.33 (75M-100M).

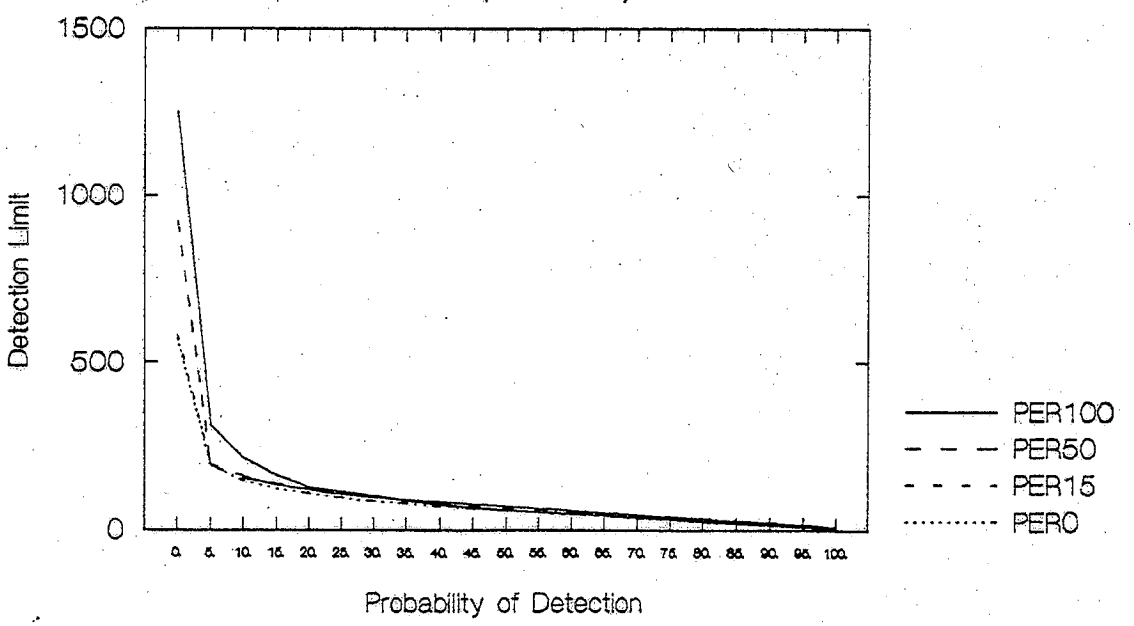

Figure B-6. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 1.33 (75M-100H).

A0066477

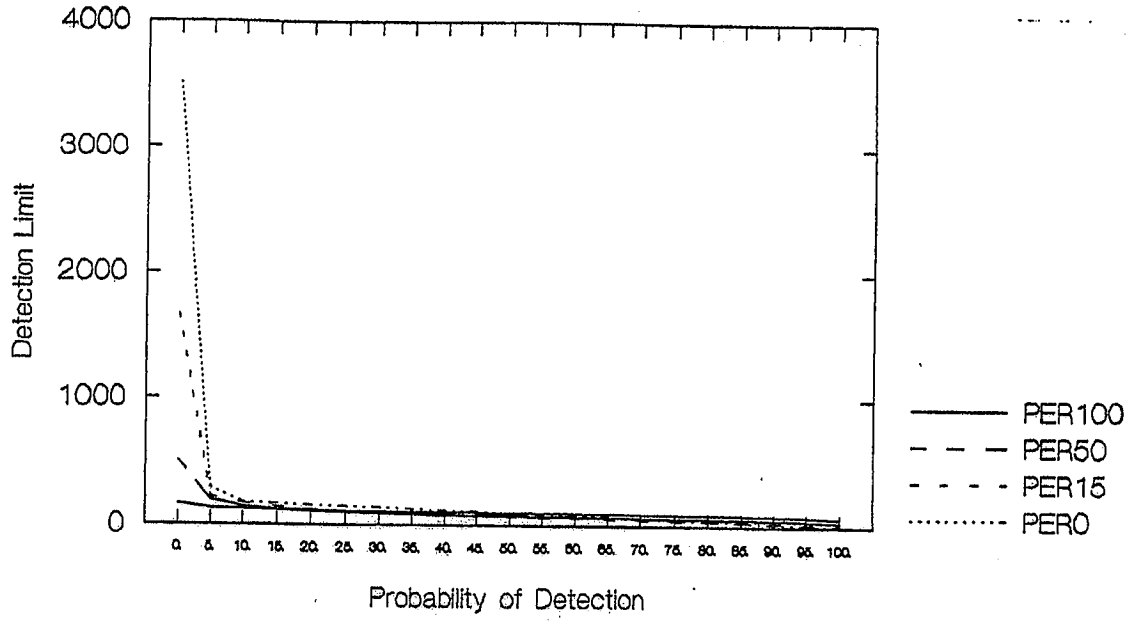

Figure B-7. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 1.33 (75H-100L).

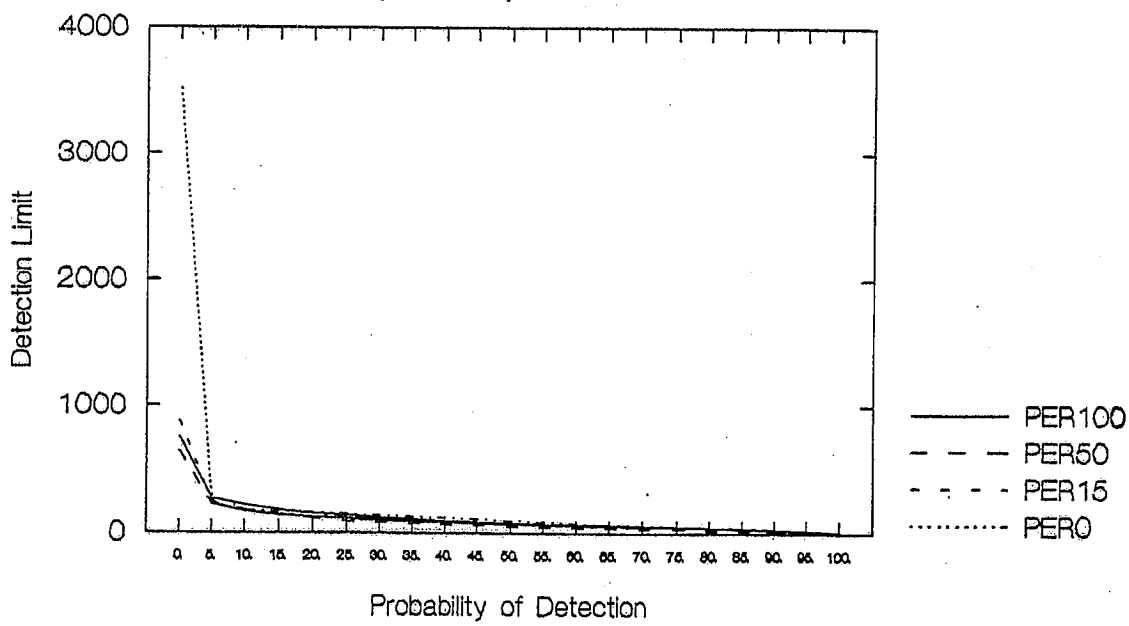

Figure B-8. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 1.33 (75H-100M).

A006478

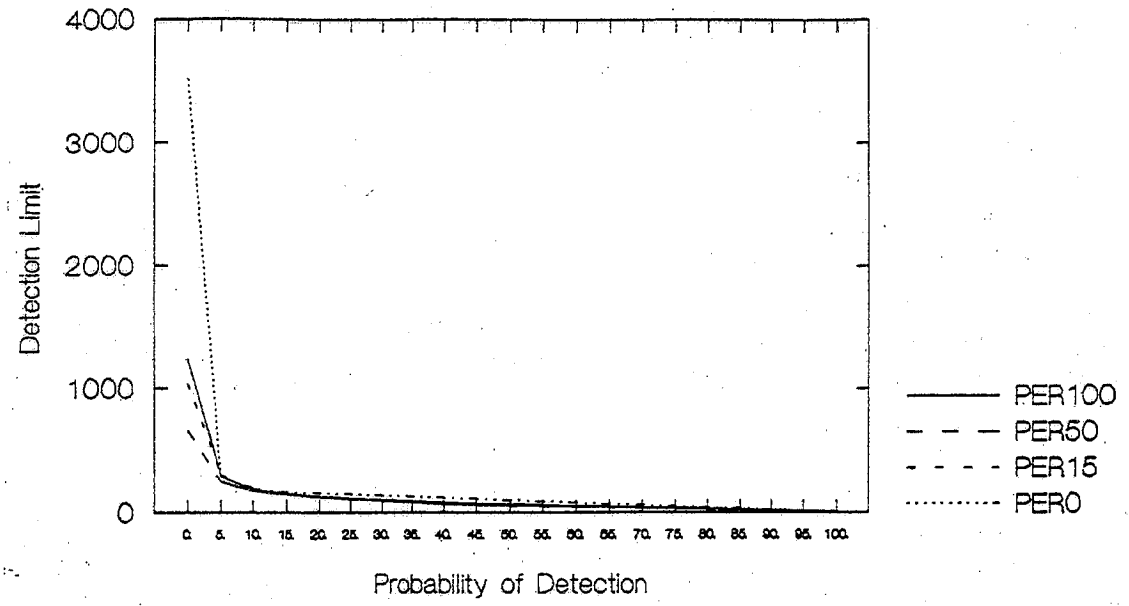

Figure B-9. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 1.33 (75H-100H).

A006479

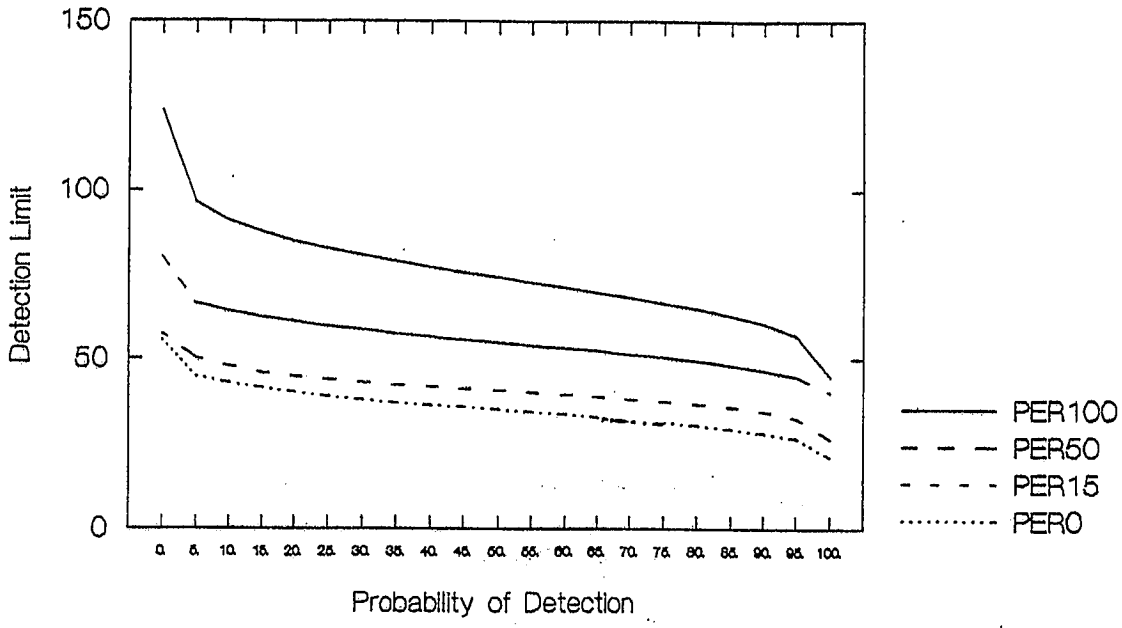

Figure B-10. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 2.14 (35L-75L).

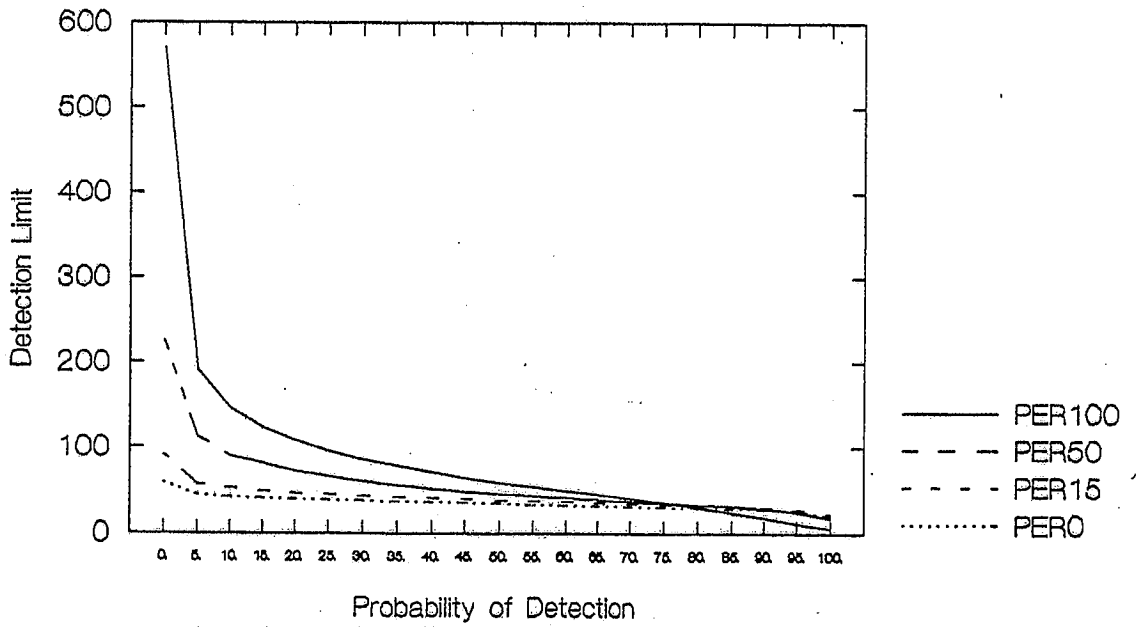

Figure B-11. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 2.14 (35L-75M).

A006480

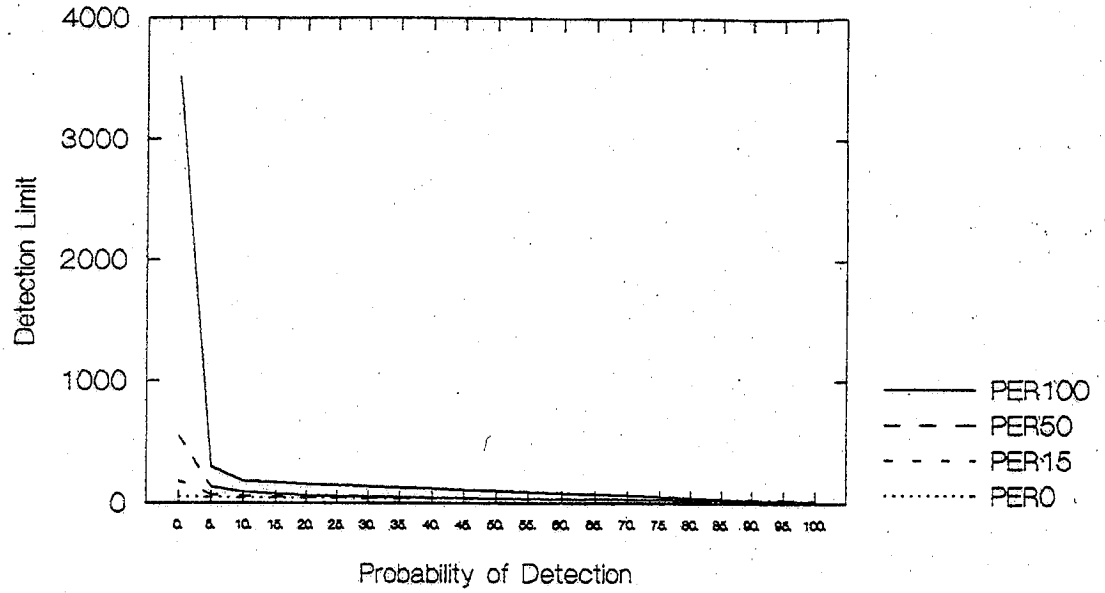

Figure B-12. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 2.14 (35L-75H).

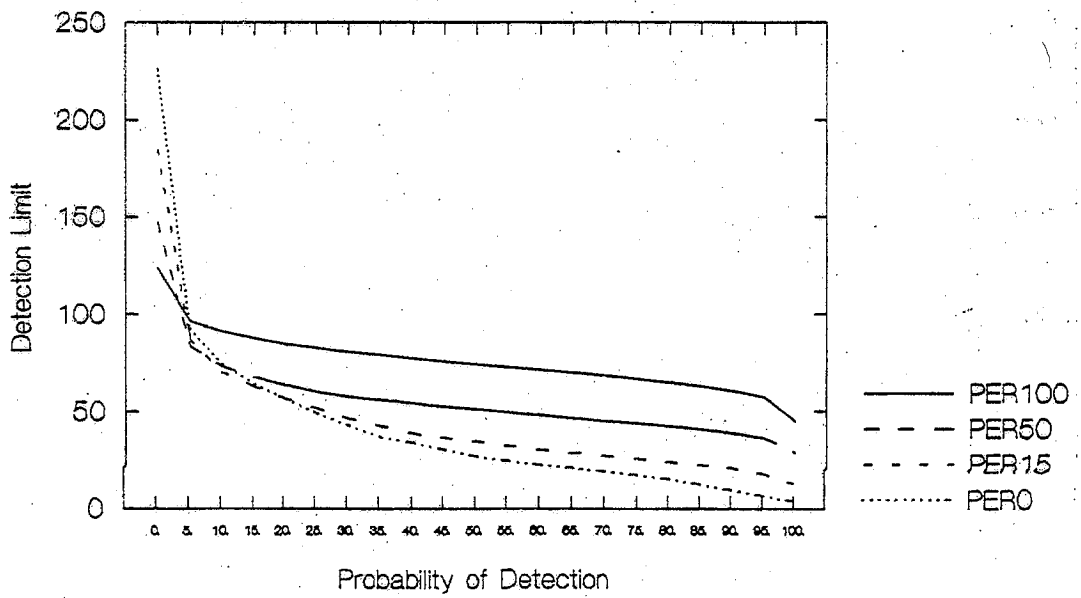

Figure B-13. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 2.14 (35M-75L).

A006481

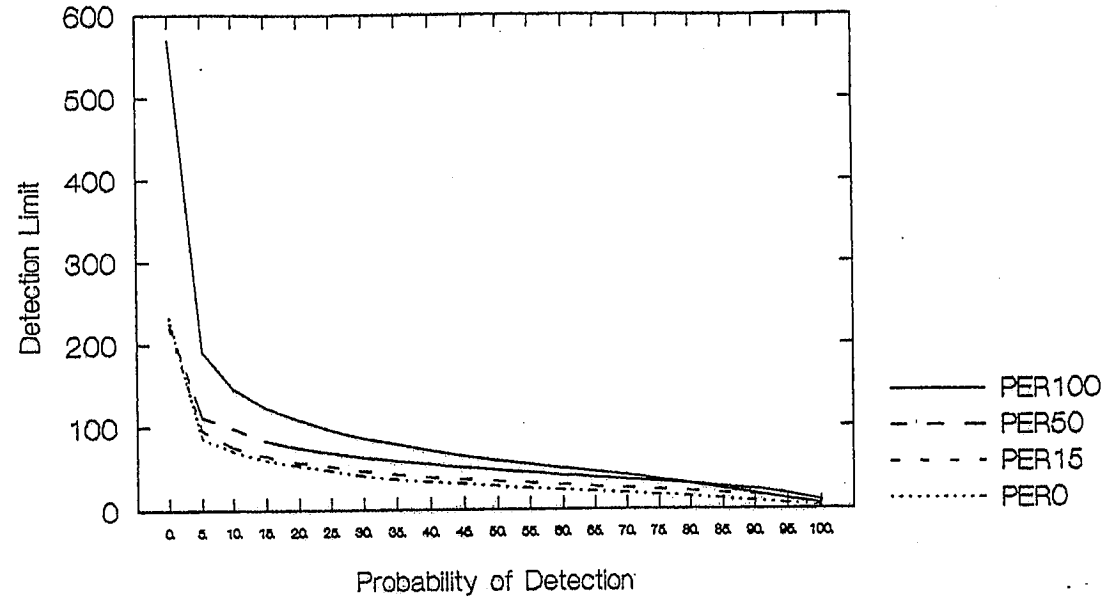

Figure B-14. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 2.14 (35M-75M).

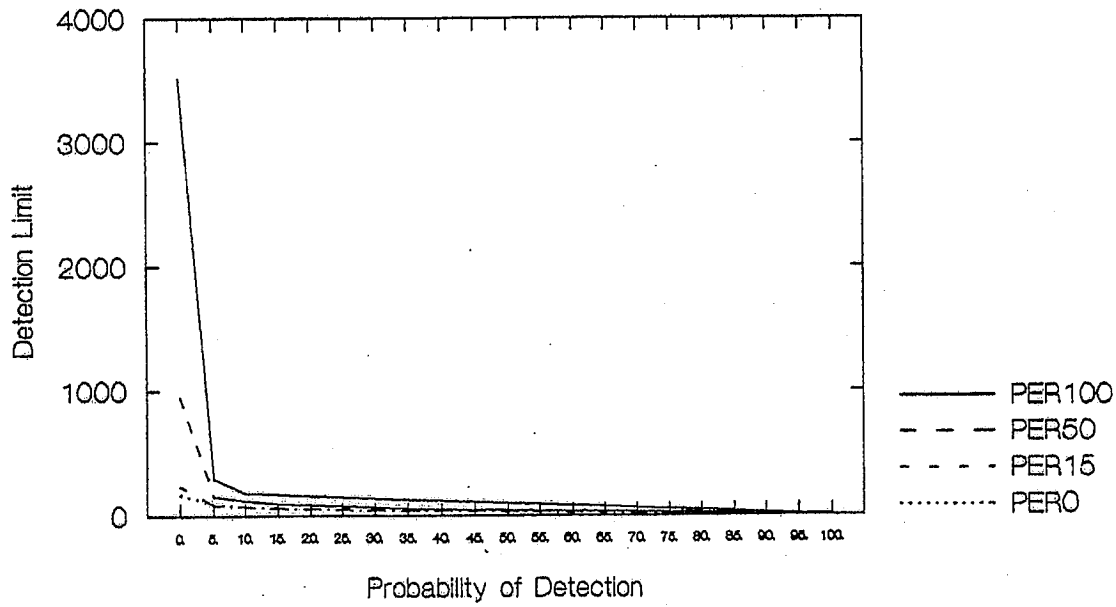

Figure B-15. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 2.14 (35M-75H).

A006482

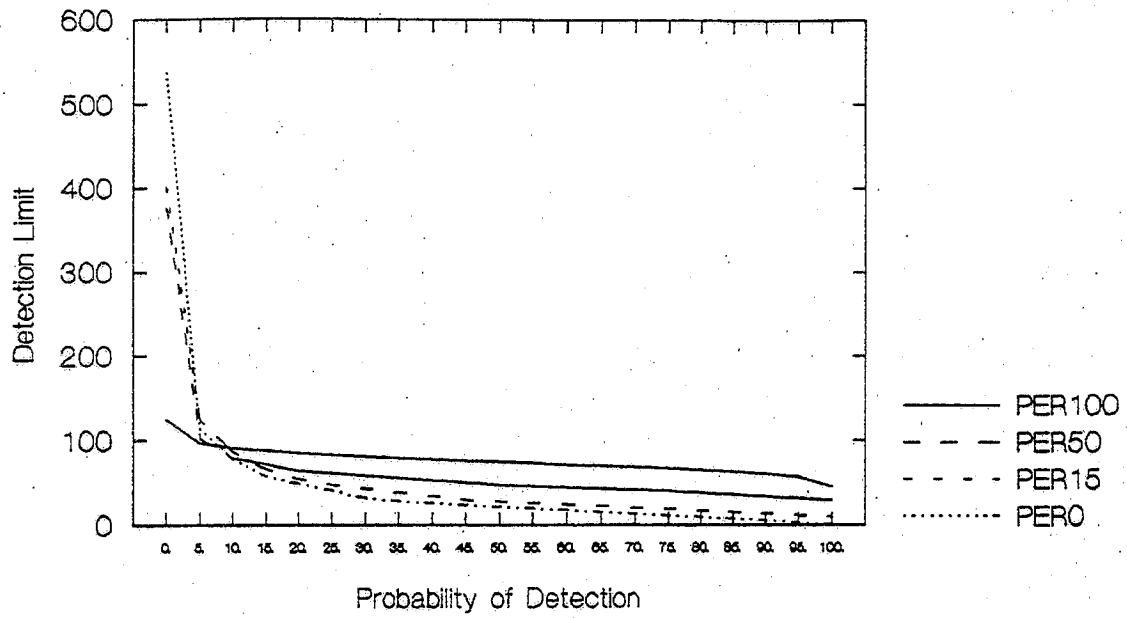

Figure B-16. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 2.14 (35H-75L).

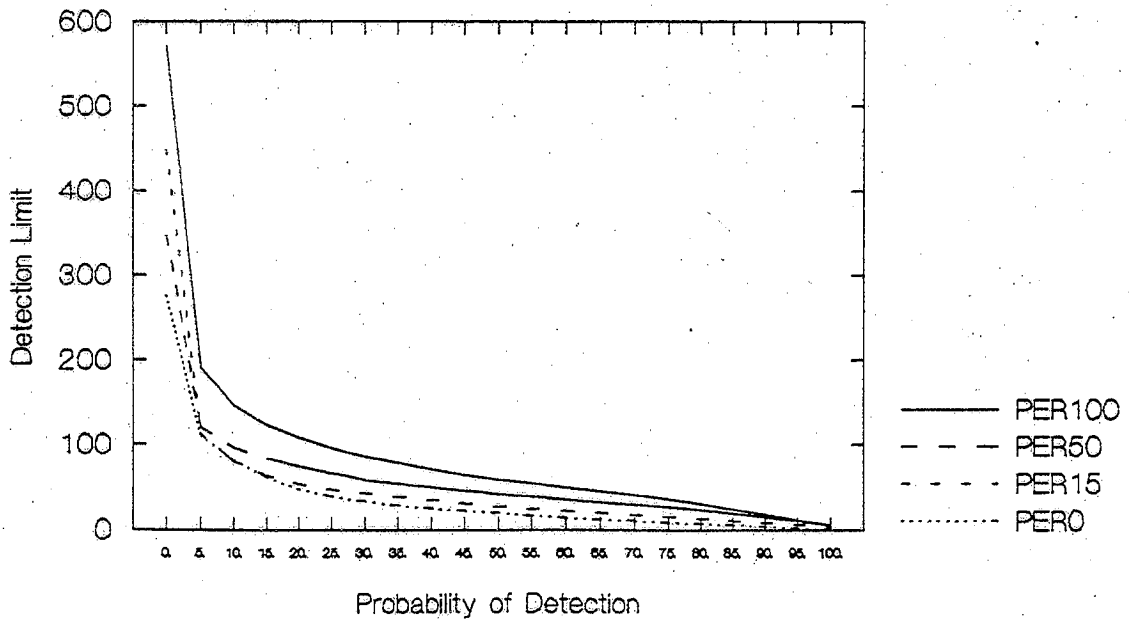

Figure B-17. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 2.14 (35H-75M).

A006483

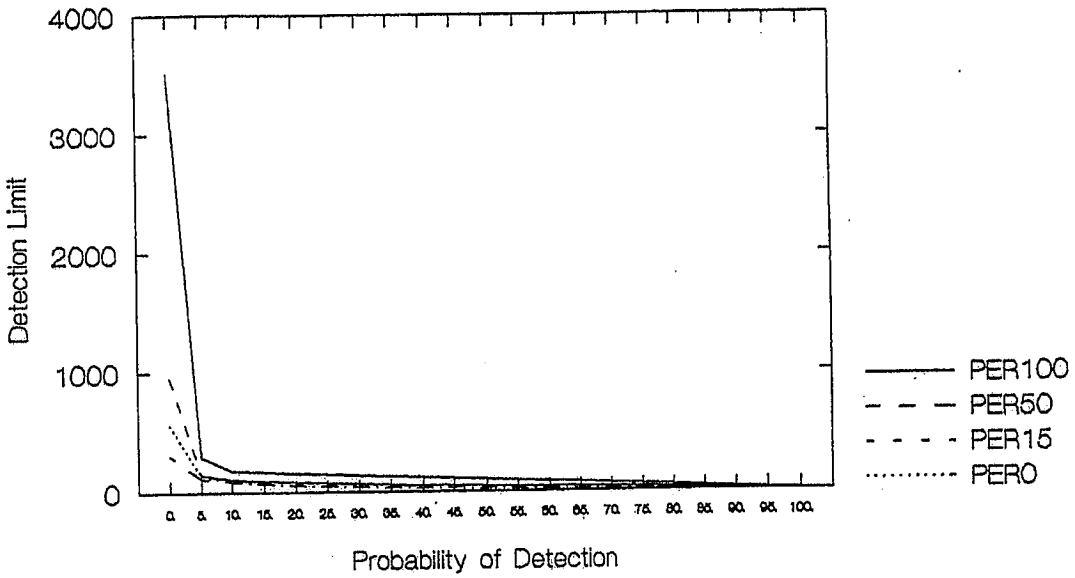

Figure B-18. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 2.14 (35H-75H).

A006484

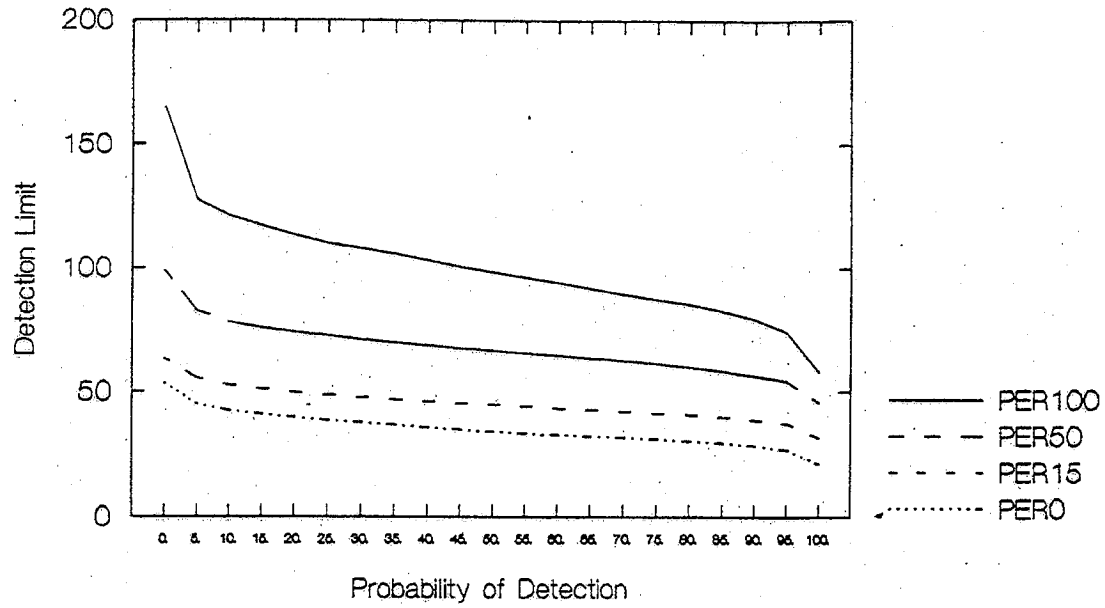

Figure B-19. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 2.86 (35L-100L).

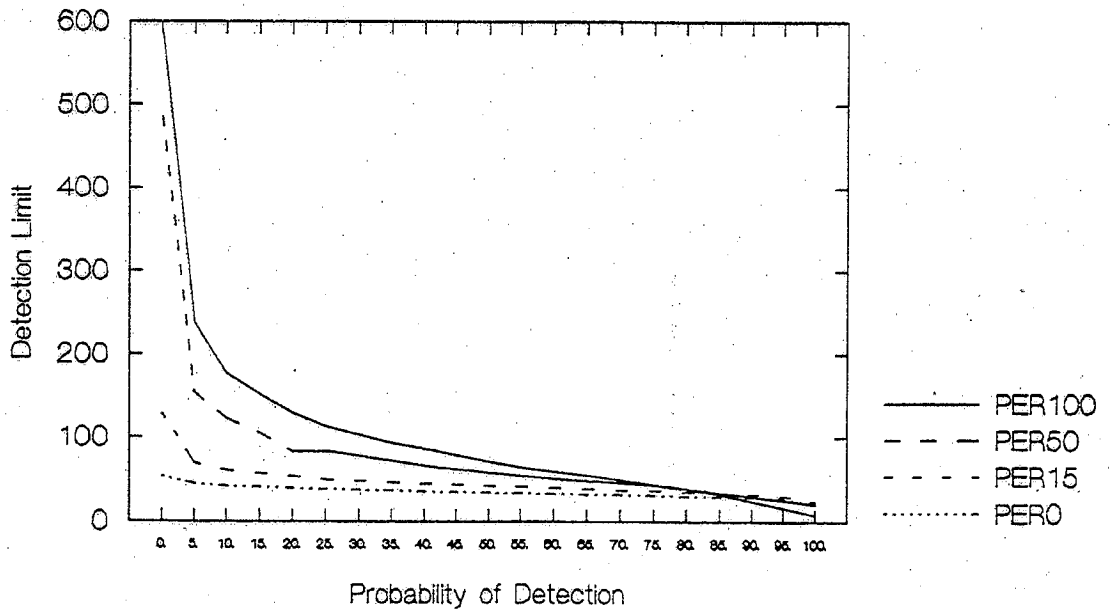

Figure B-20. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 2.86 (35L-100M).

A006485

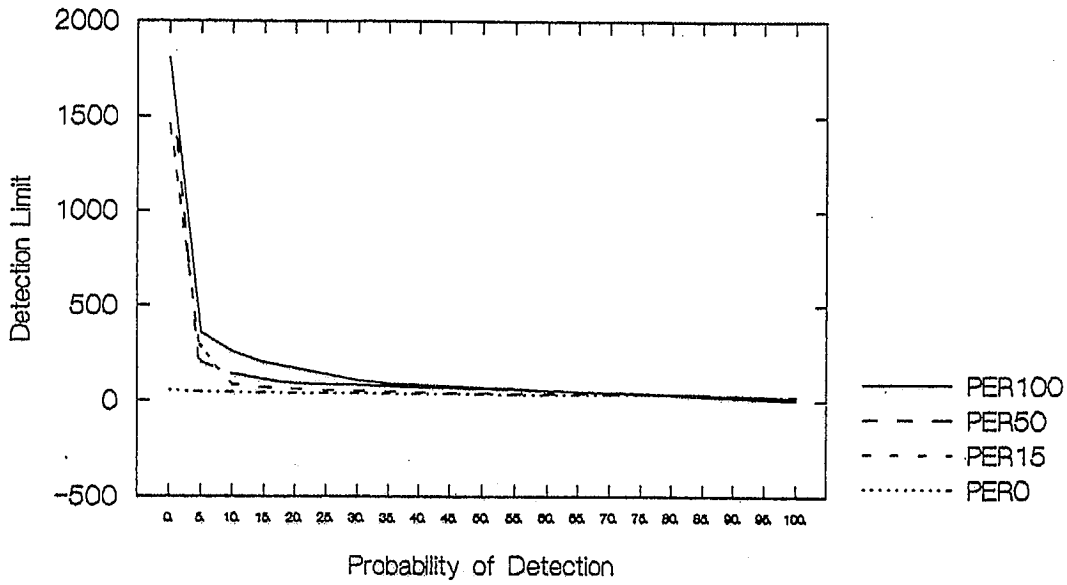

Figure B-21. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 2.86 (35L-100H).

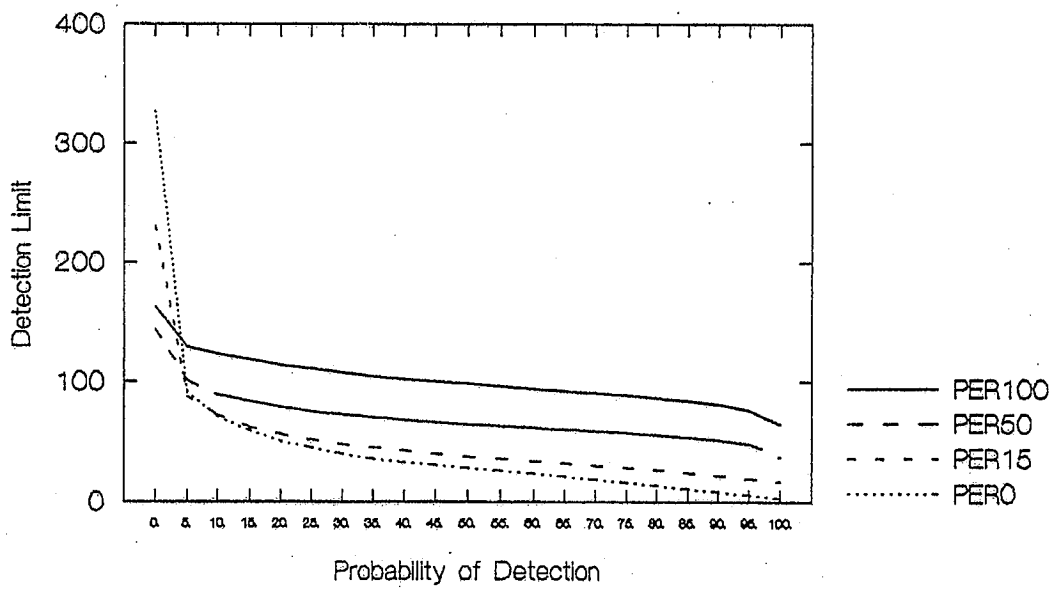

Figure B-22. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 2.86 (35M-100L).

A006486

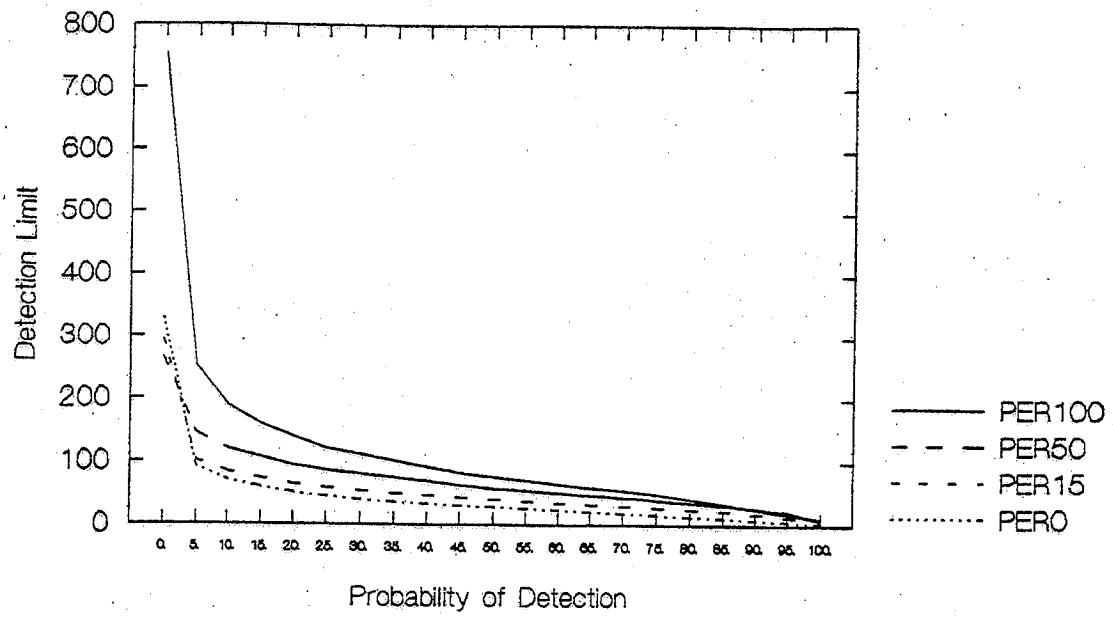

Figure B-23. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 2.86 (35M-100M).

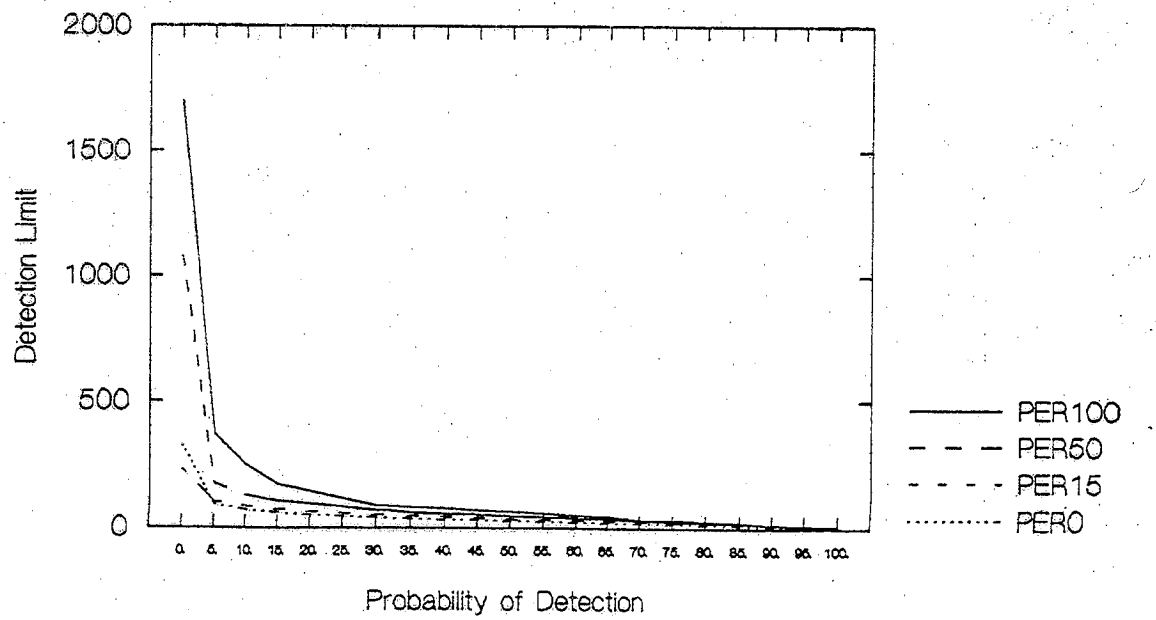

Figure B-24. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 2.86 (35M-100H).

A006487

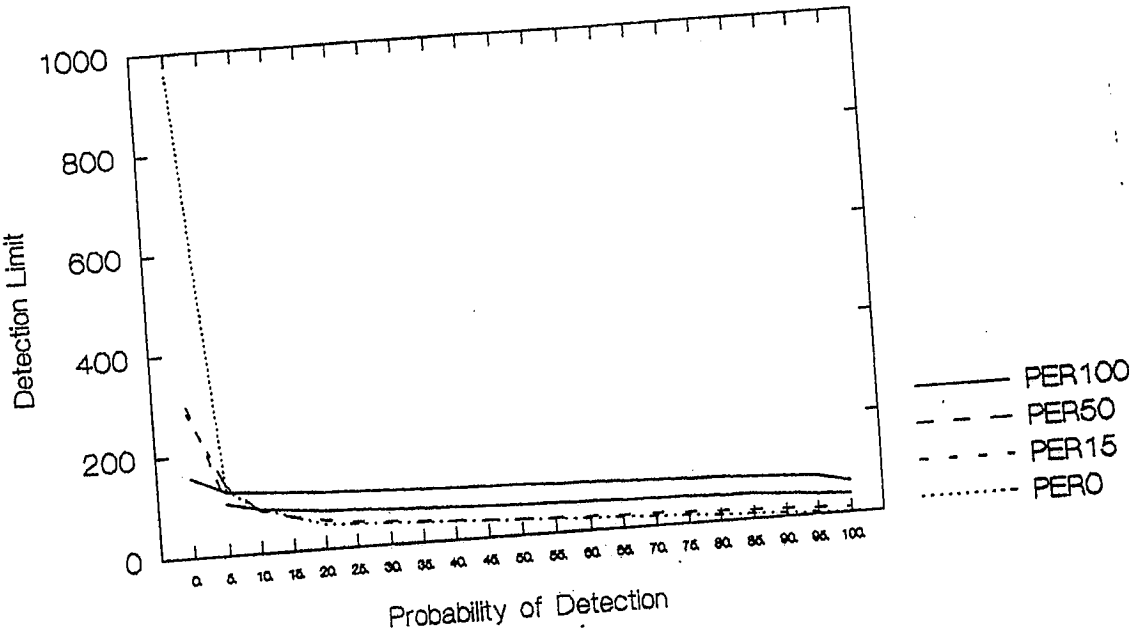

Figure B-25. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 2.86 (35H-100L).

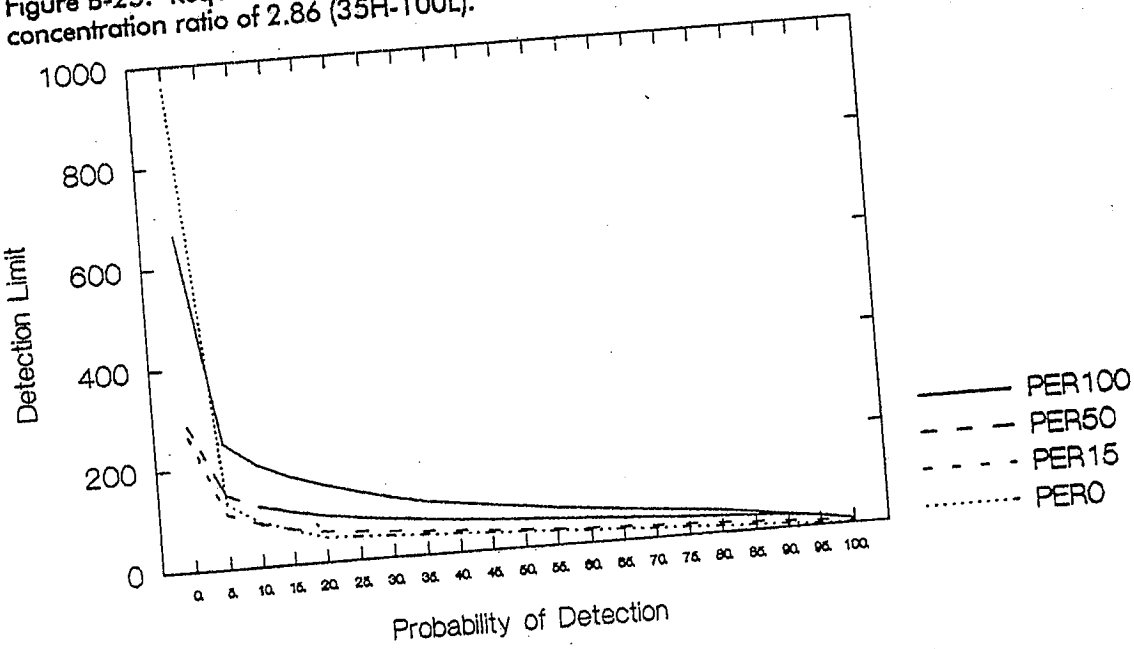

Figure B-26. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 2.86 (35H-100M).

A006488

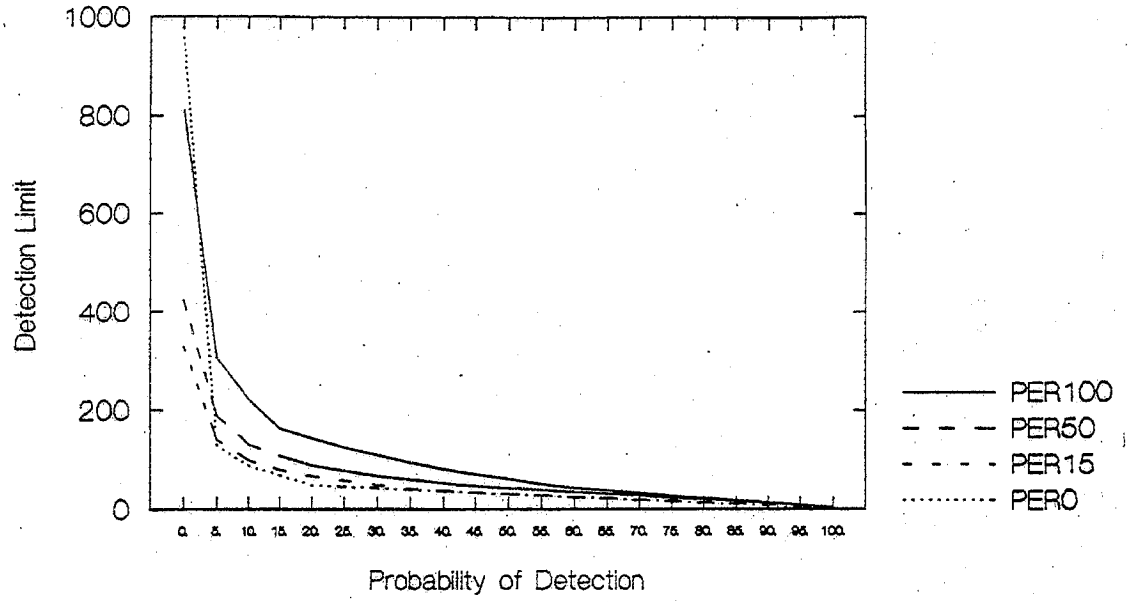

Figure B-27. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 2.86 (35H-100H).

A006489

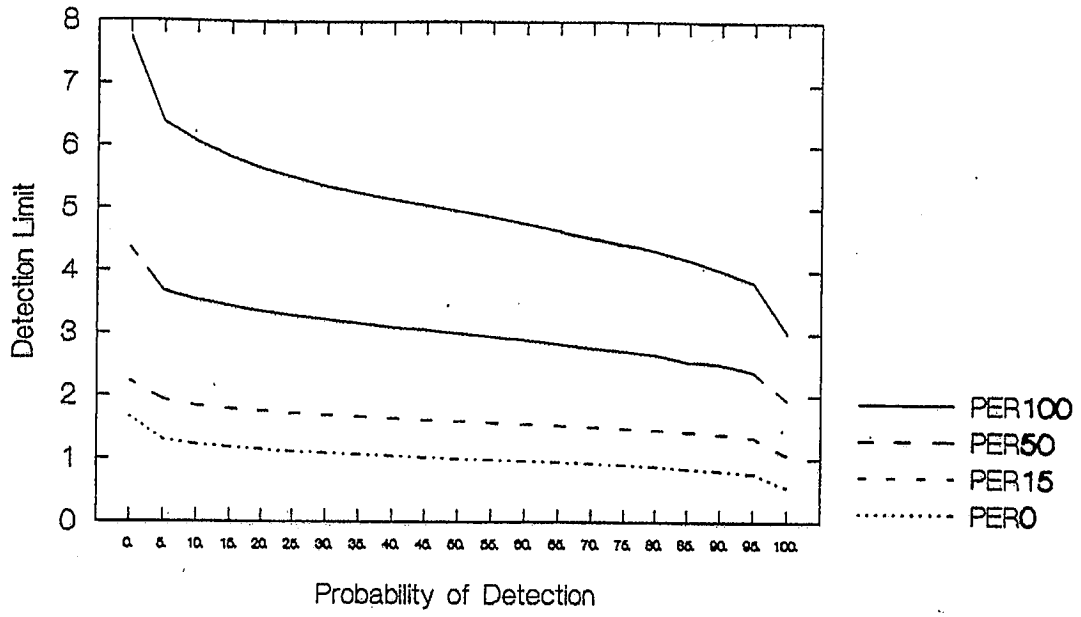

Figure B-28. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 5 (1L-5L).

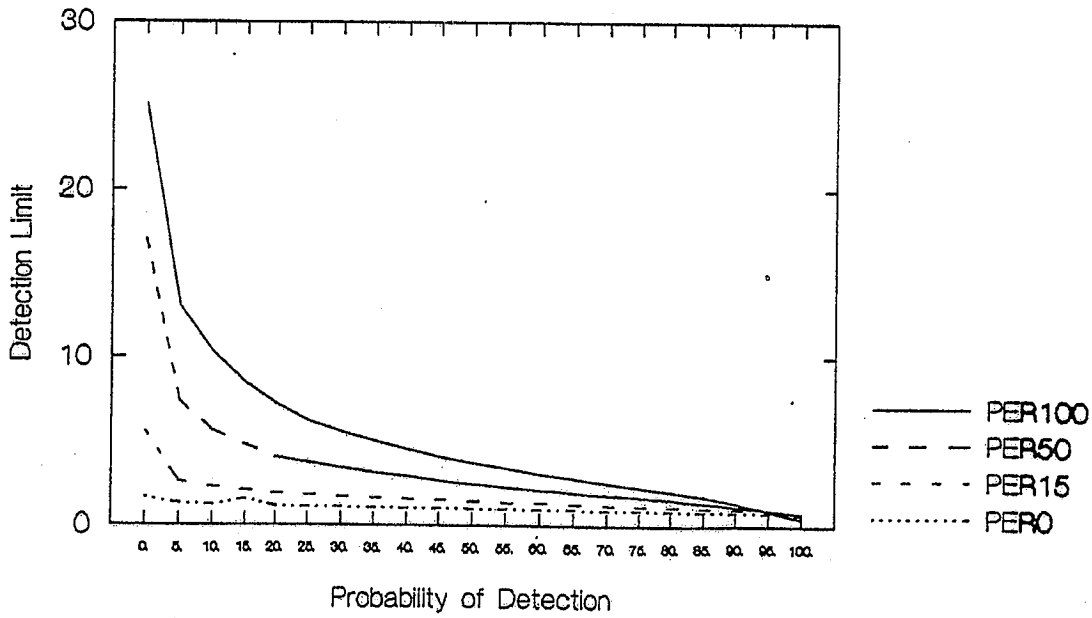

Figure B-29. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 5 (1L-5M).

A0065490

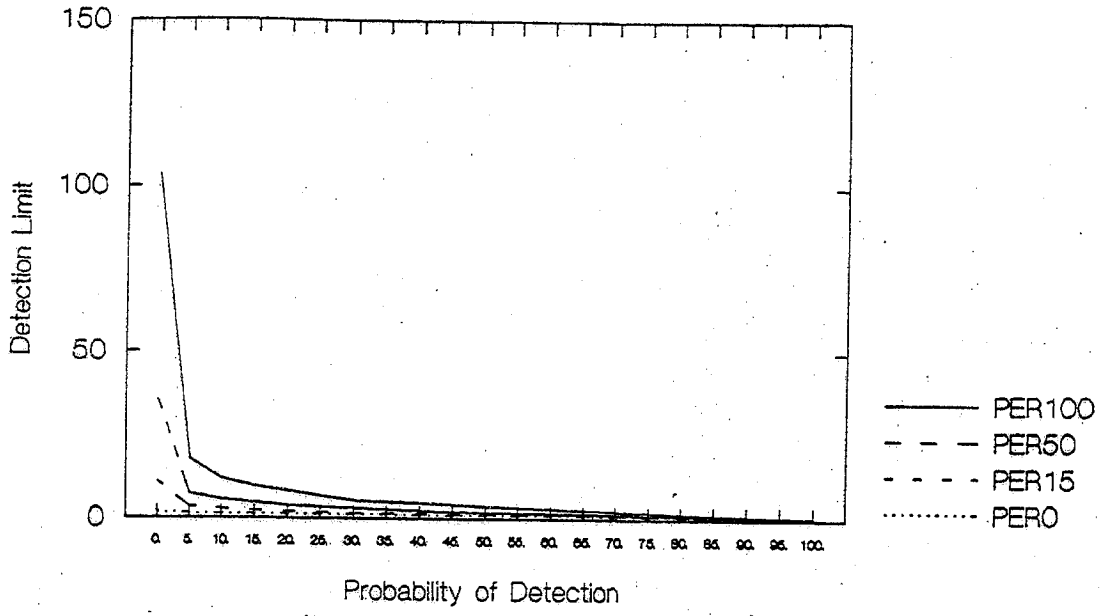

Figure B-30. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 5 (1L-5H).

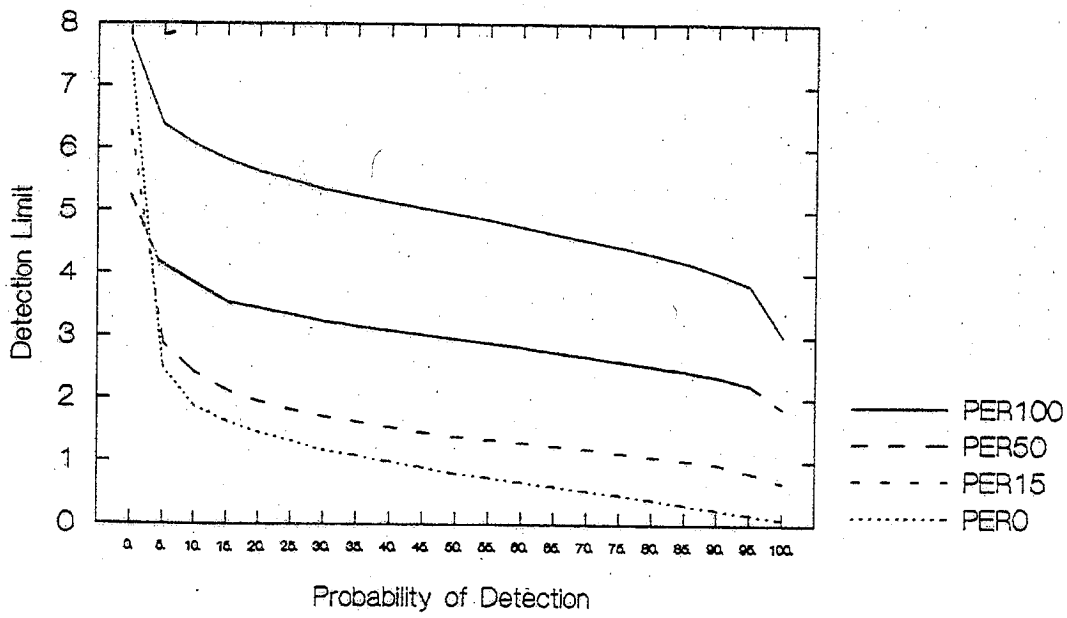

Figure B-31. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 5 (1M-5L).

A006491

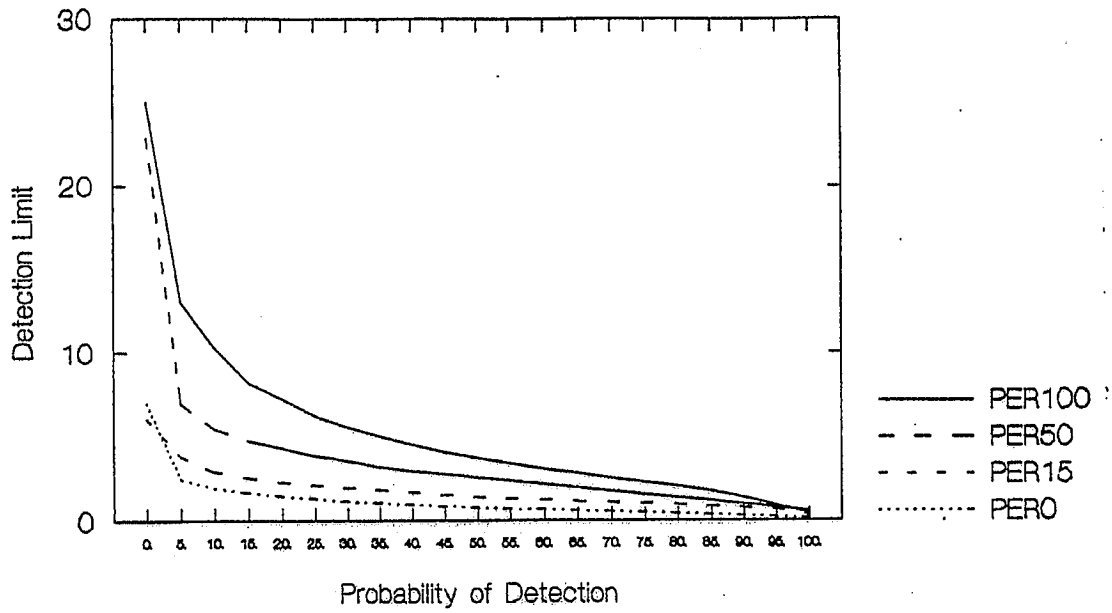

Figure B-32. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 5 (1M-5M).

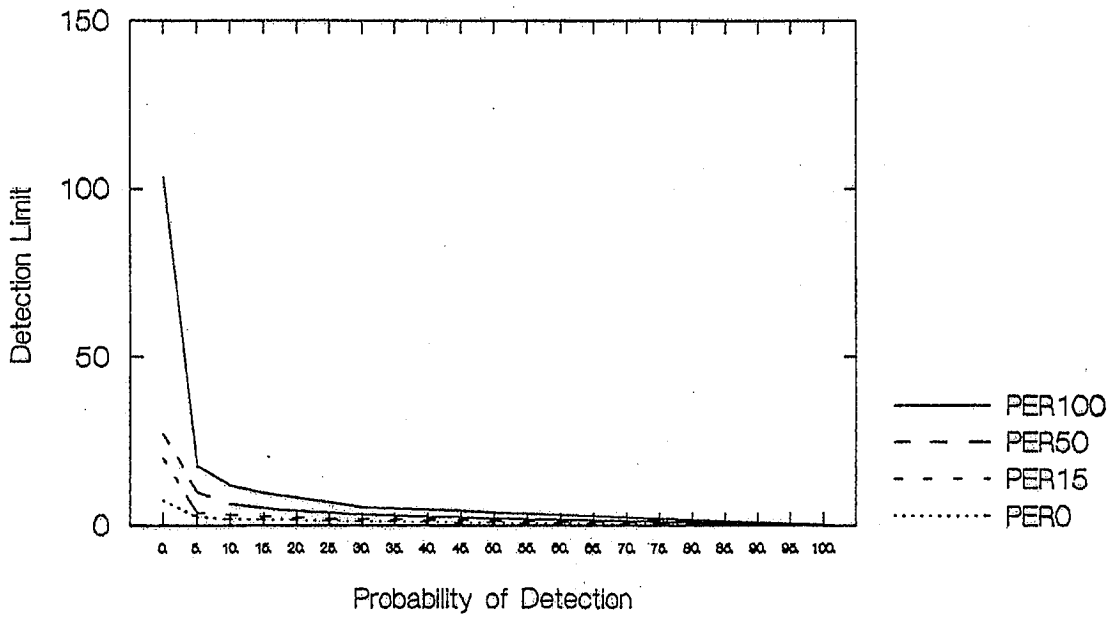

Figure B-33. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 5 (1M-5H).

A006492

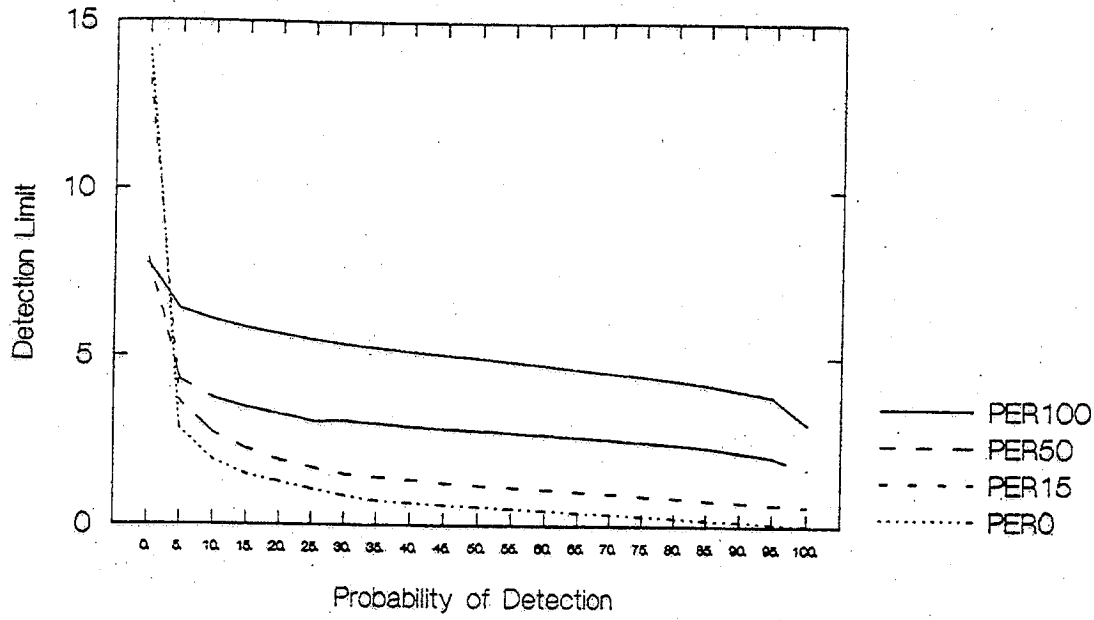

Figure B-34. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 5 (1H-5L).

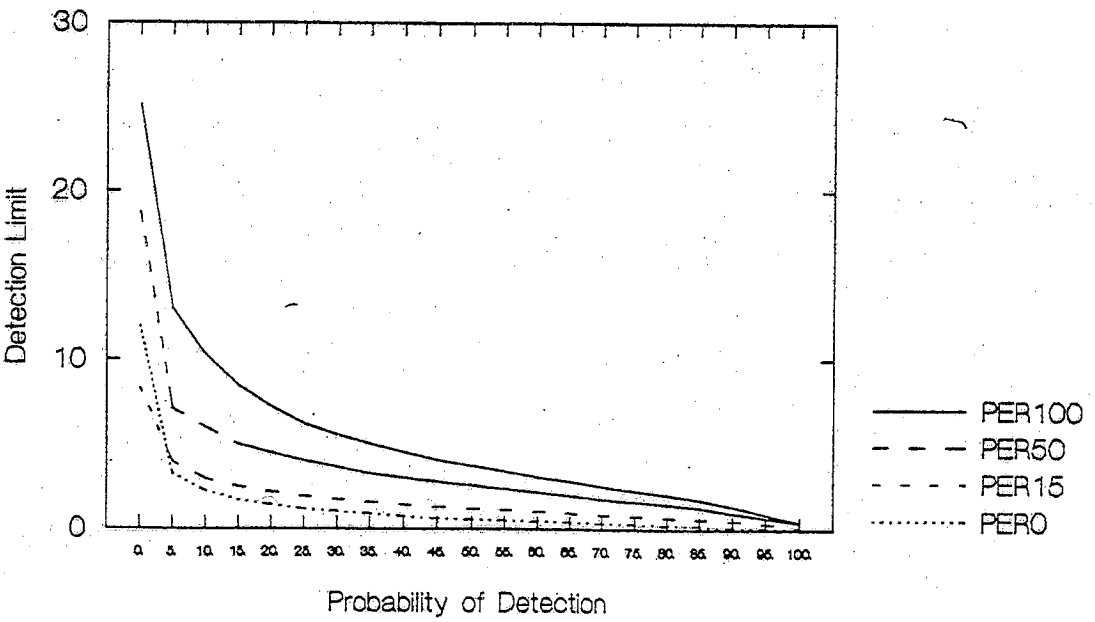

Figure B-35. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 5 (1H-5M).

A006493

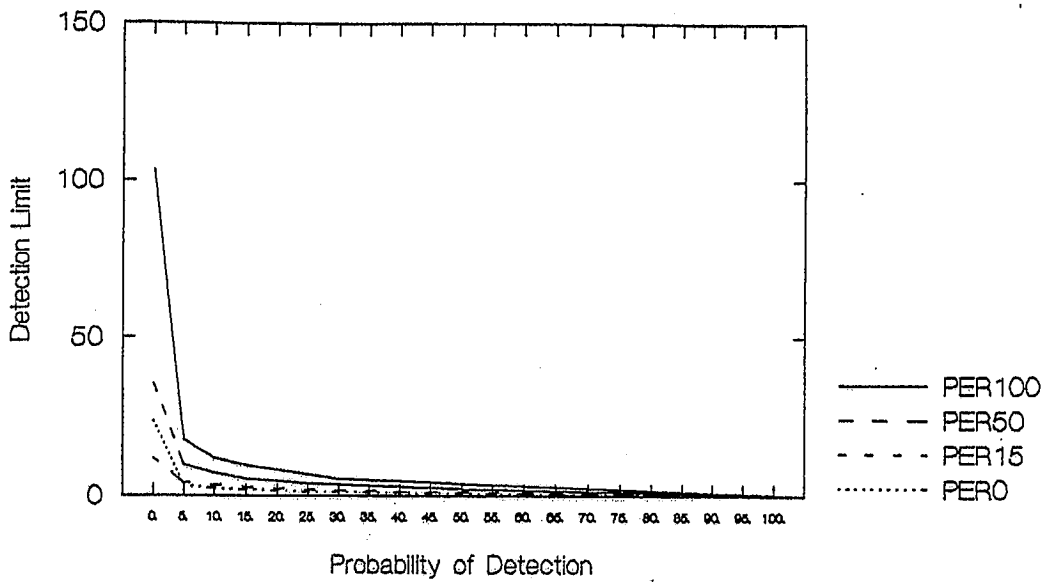

Figure B-36. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 5 (1H-5H).

A0006494

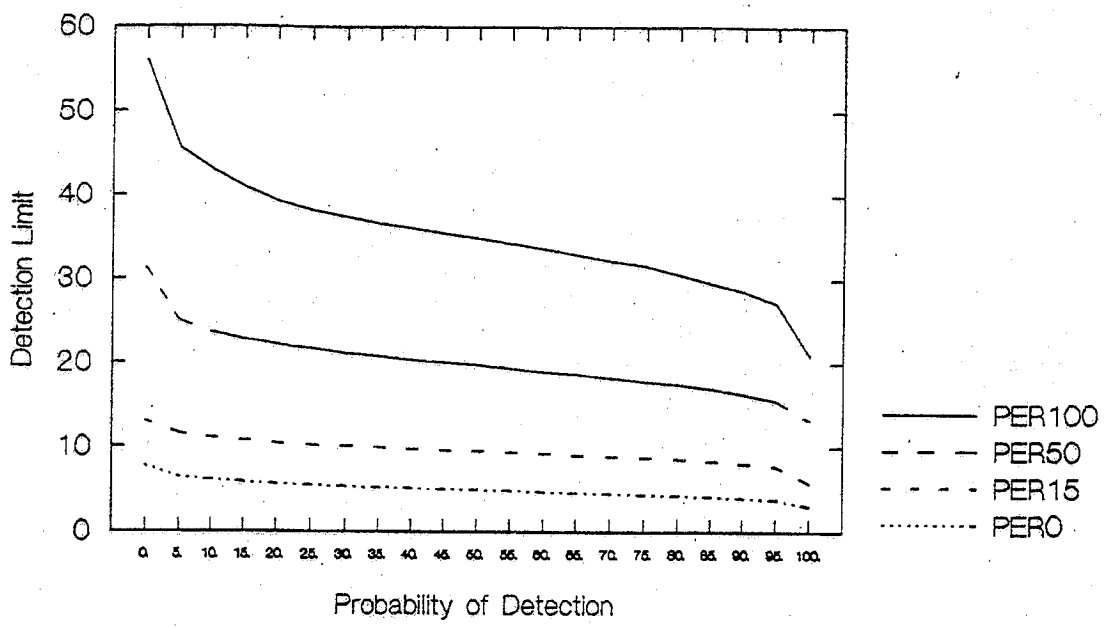

Figure B-37. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 7 (5L-35L).

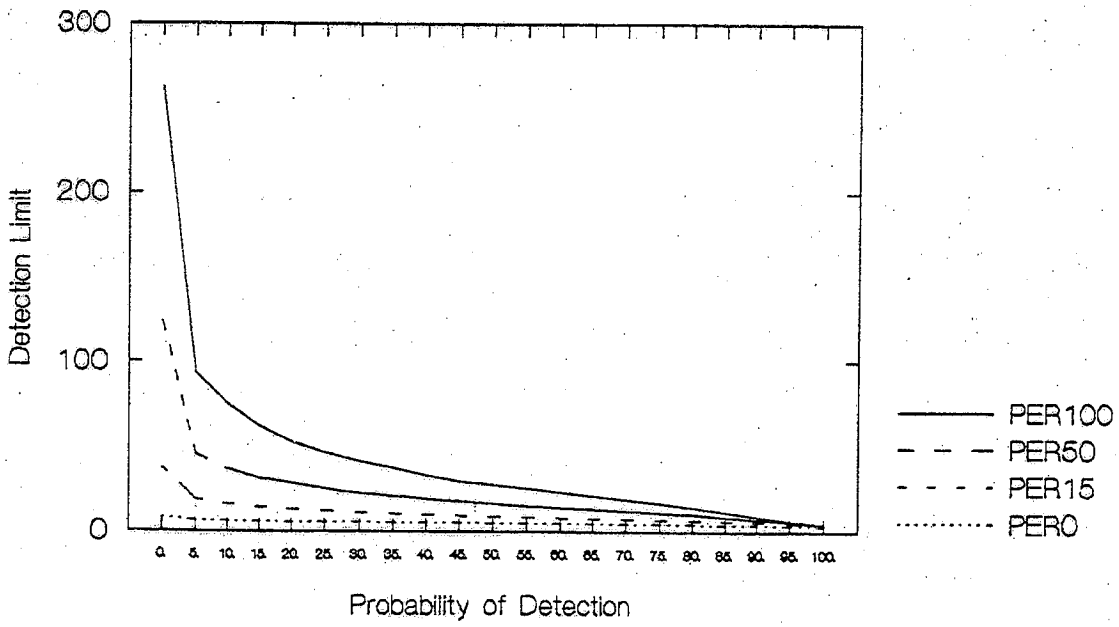

Figure B-38. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 7 (5L-35M).

A006495

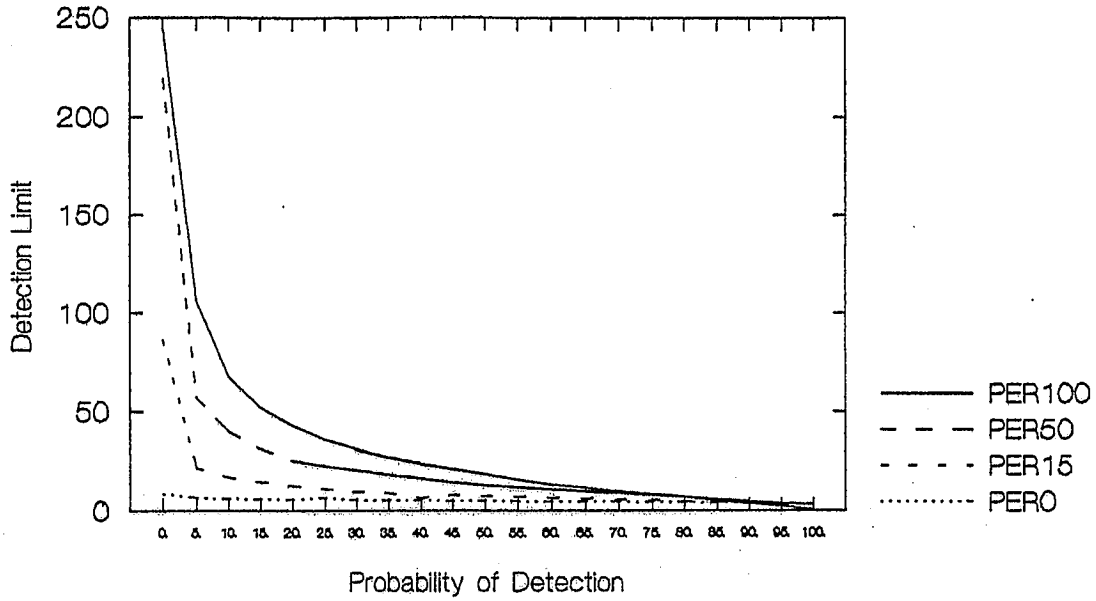

Figure B-39. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 7 (5L-35H).

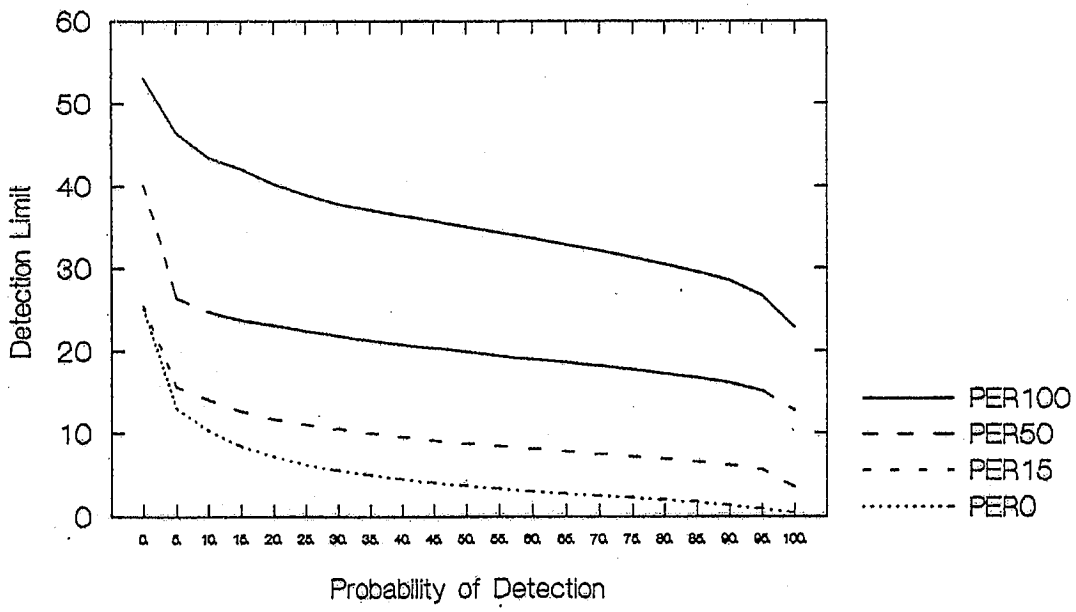

Figure B-40. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 7 (5M-35L).

A006496

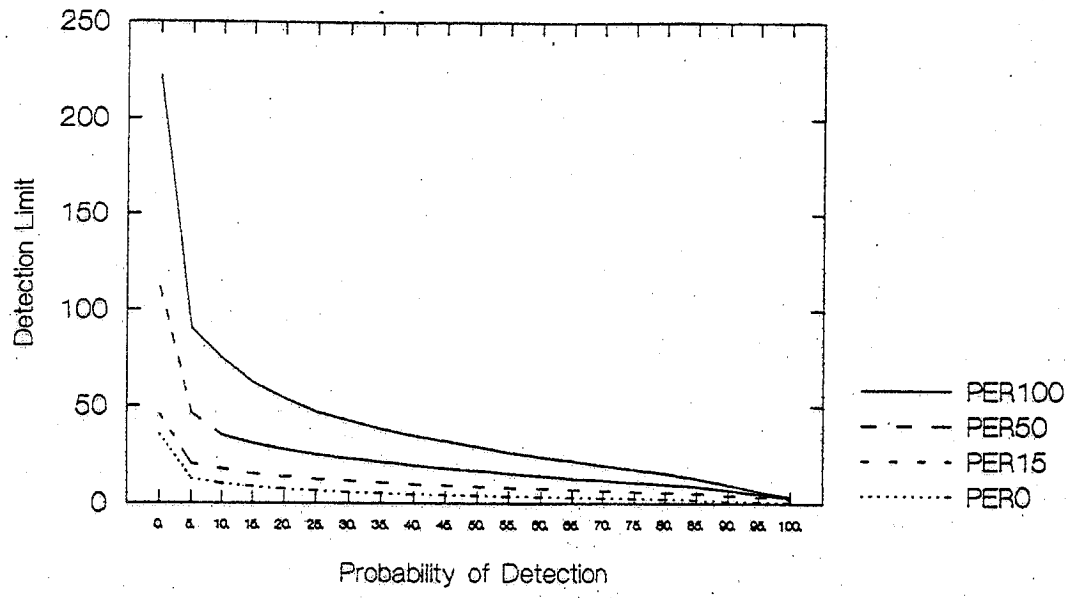

Figure B-41. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 7 (5M-35M).

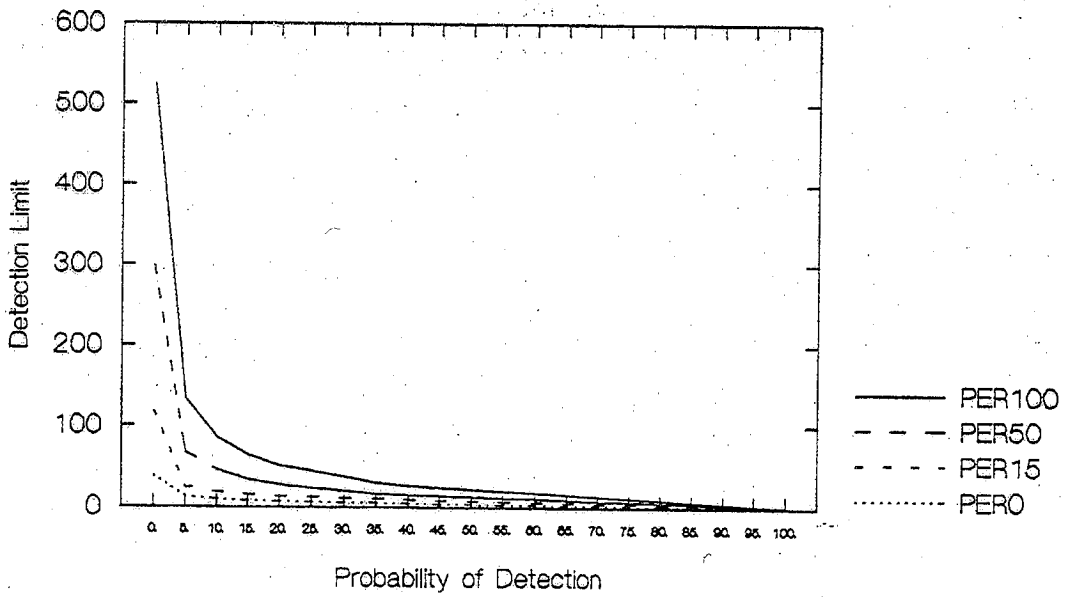

Figure B-42. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 7 (5M-35H).

A006497

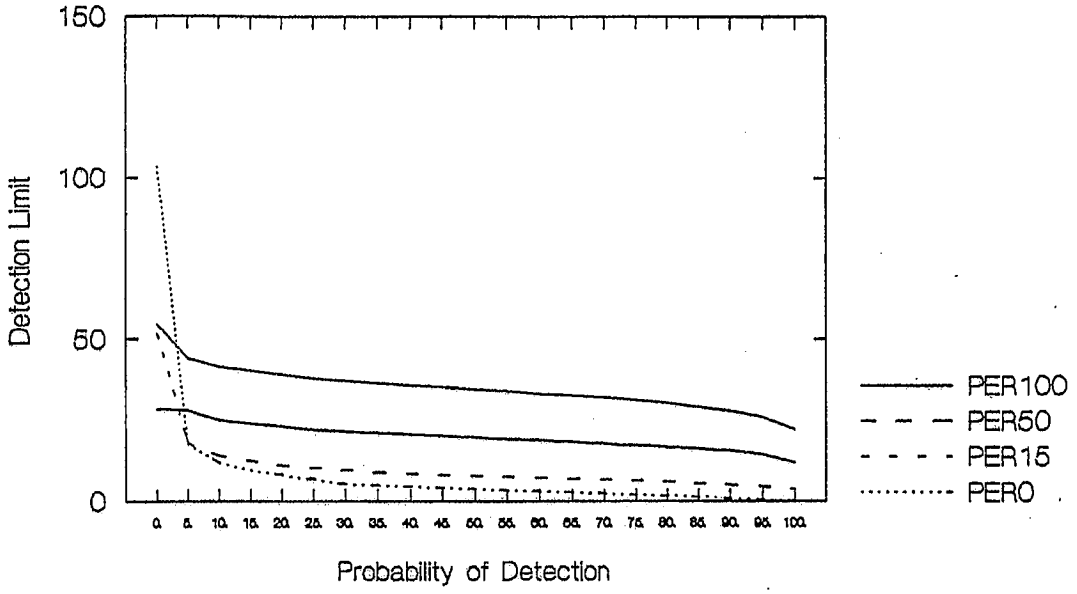

Figure B-43. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 7 (5H-35L).

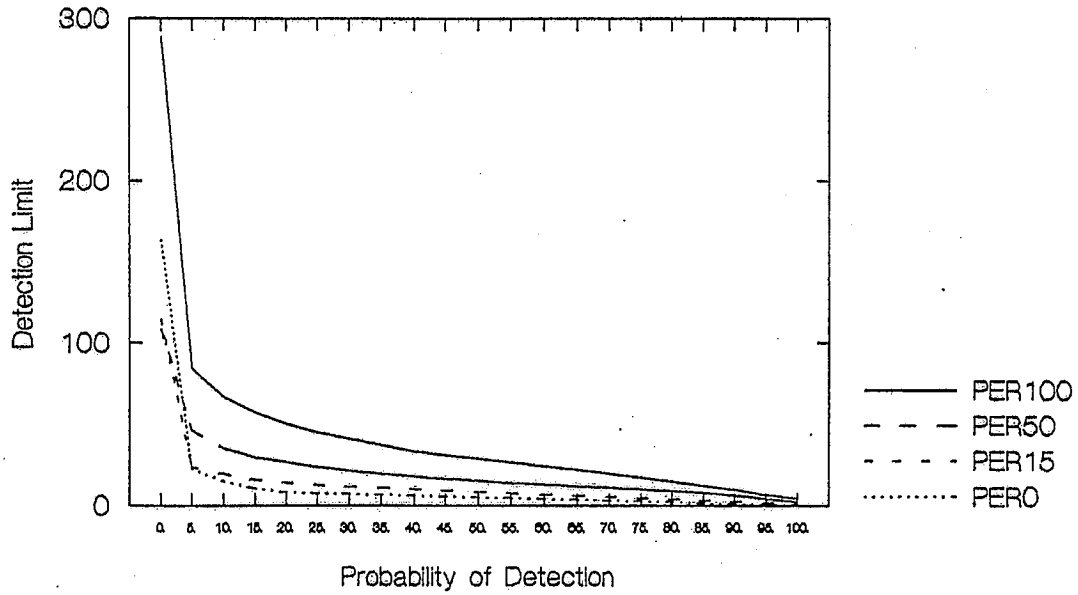

Figure B-44. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 7 (5H-35M).

A006498

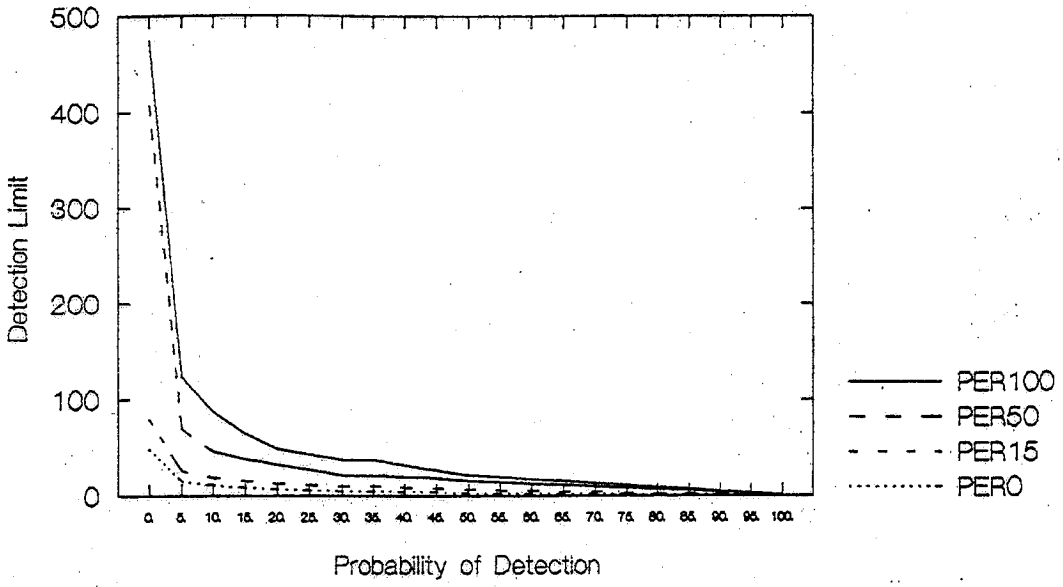

Figure B-45. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 7 (5H-35H).

A006499

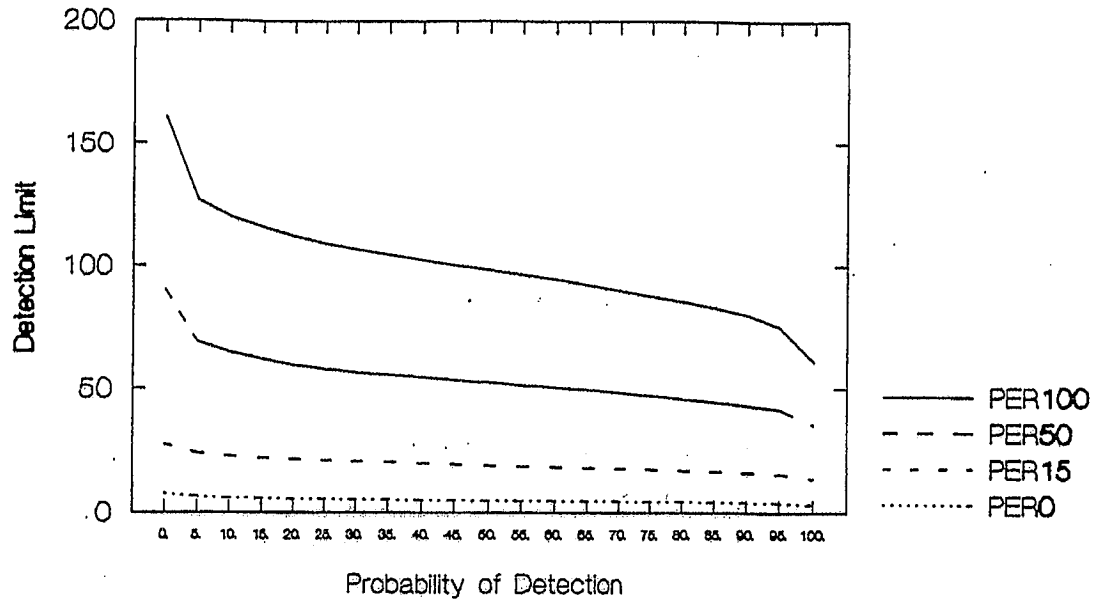

Figure B-46. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 20 (5L-100L).

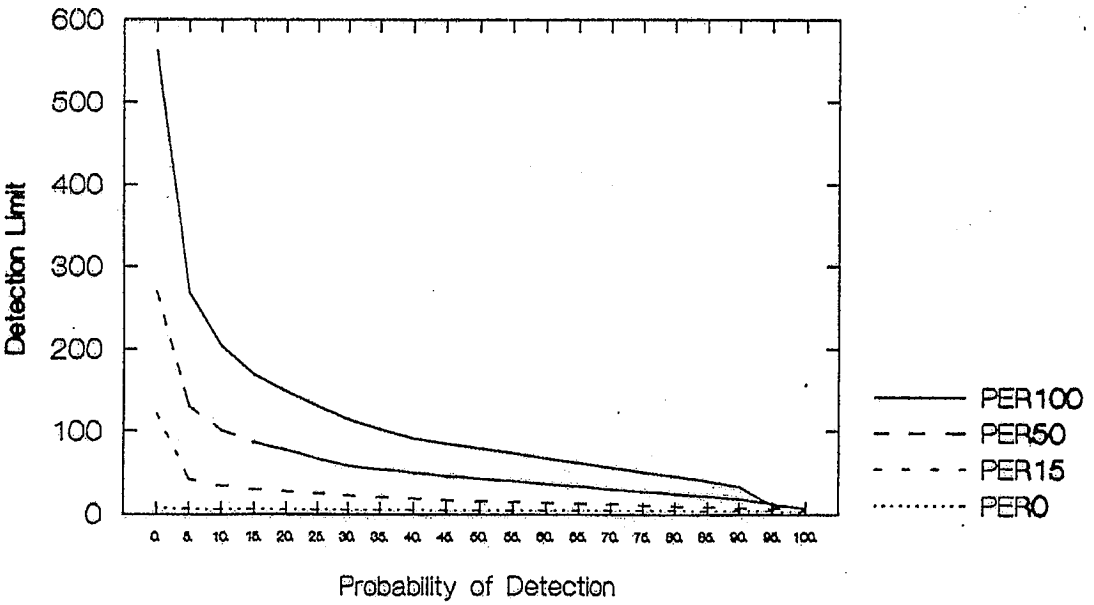

Figure B-47. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 20 (5L-100M).

A206500

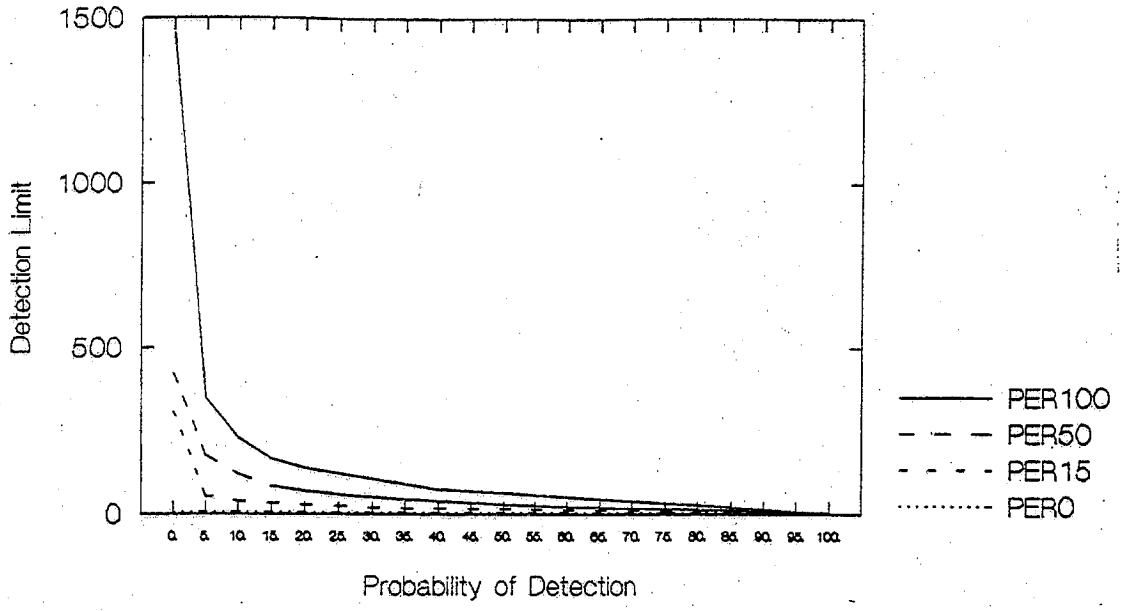

Figure B-48. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 20 (5L-100H).

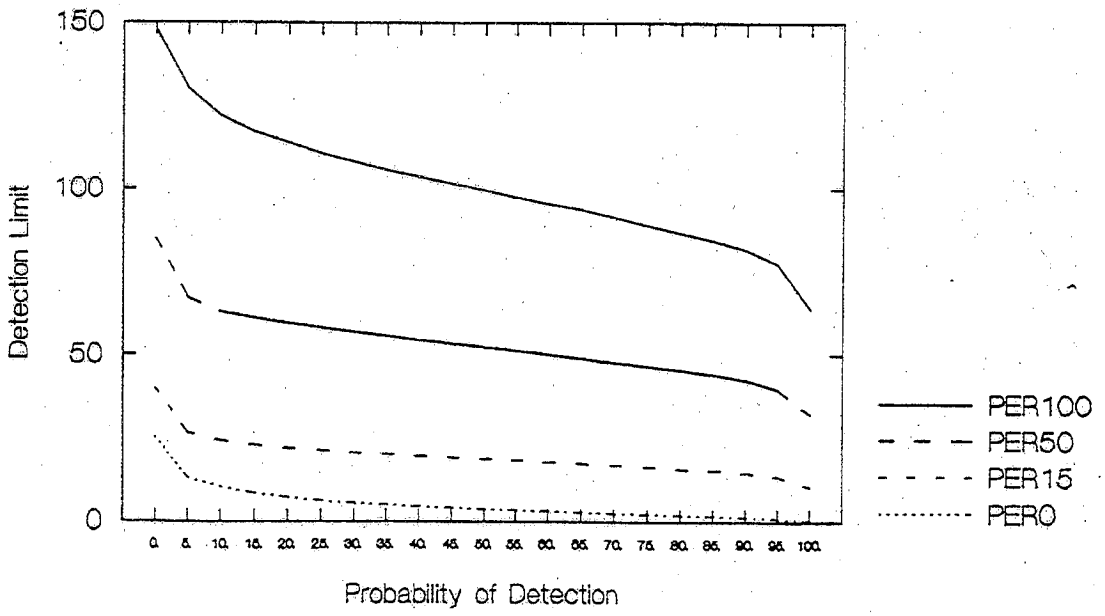

Figure B-49. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 20 (5M-100L).

A006501

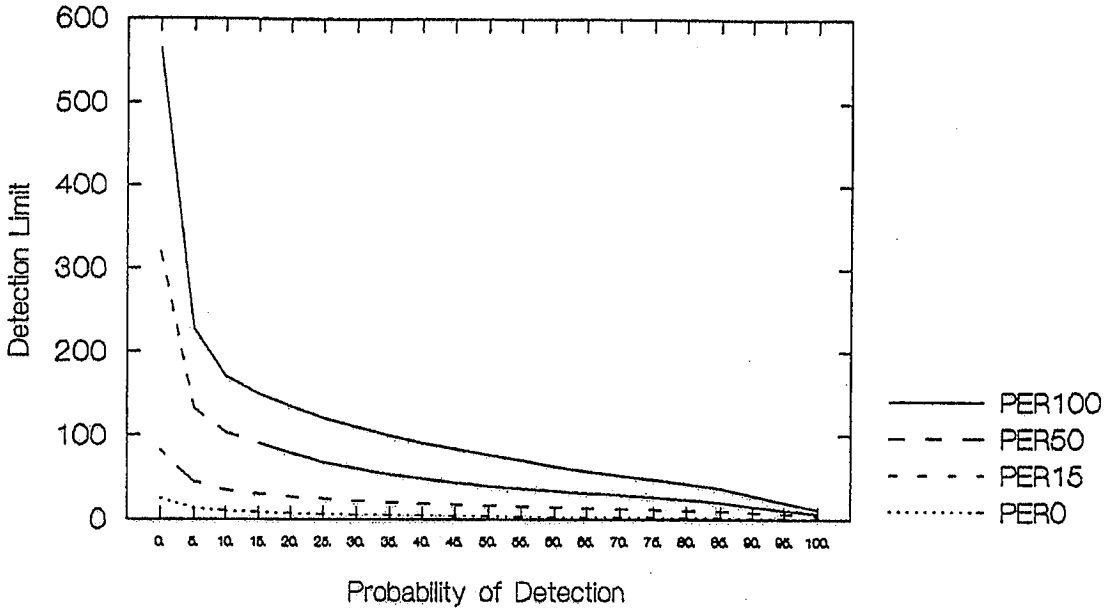

Figure B-50. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 20 (5M-100M).

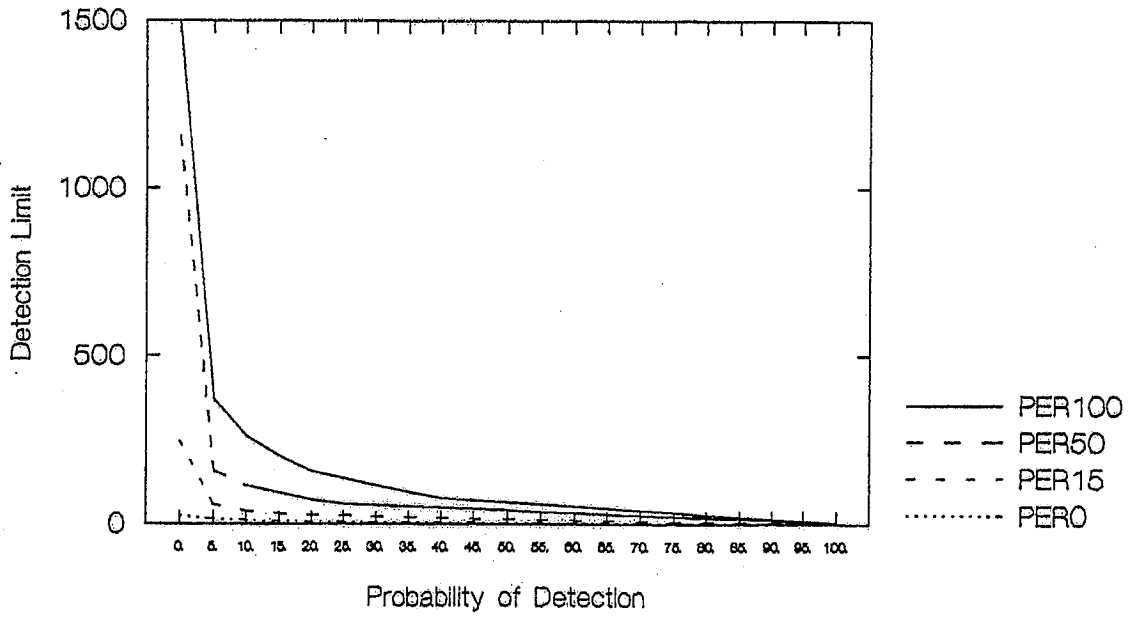

Figure B-51. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 20 (5M-100H).

A006502

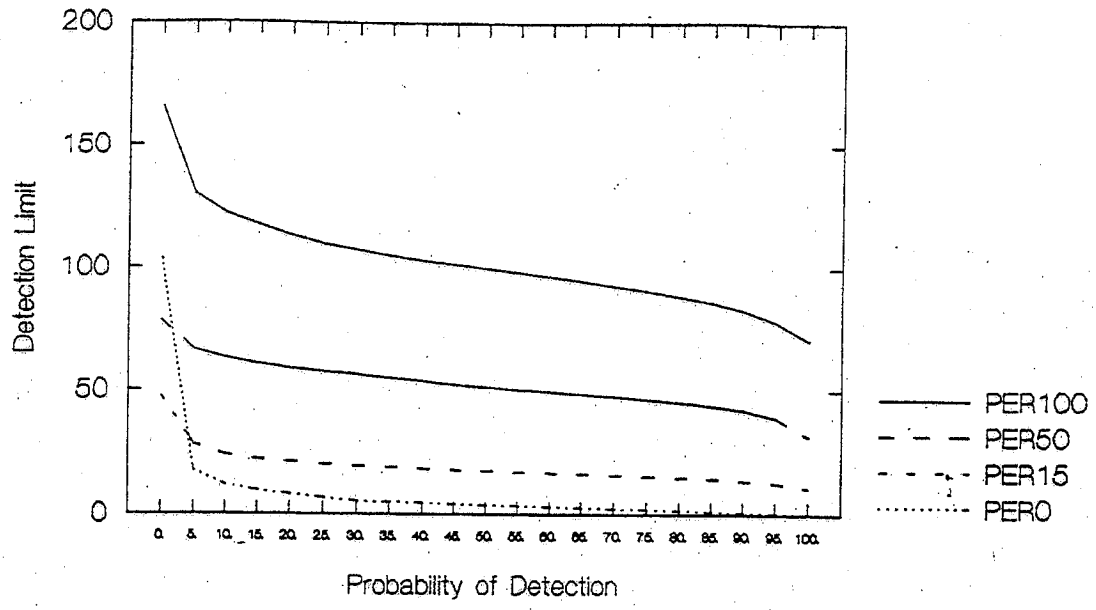

Figure B-52. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 20 (5H-100L).

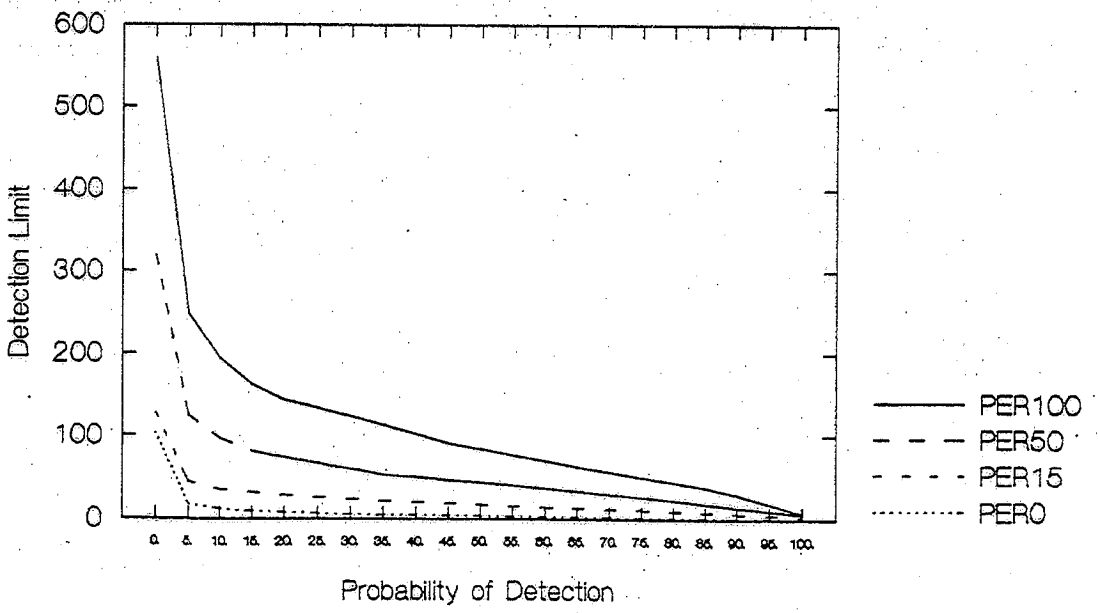

Figure B-53. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 20 (5H-100M).

A006503

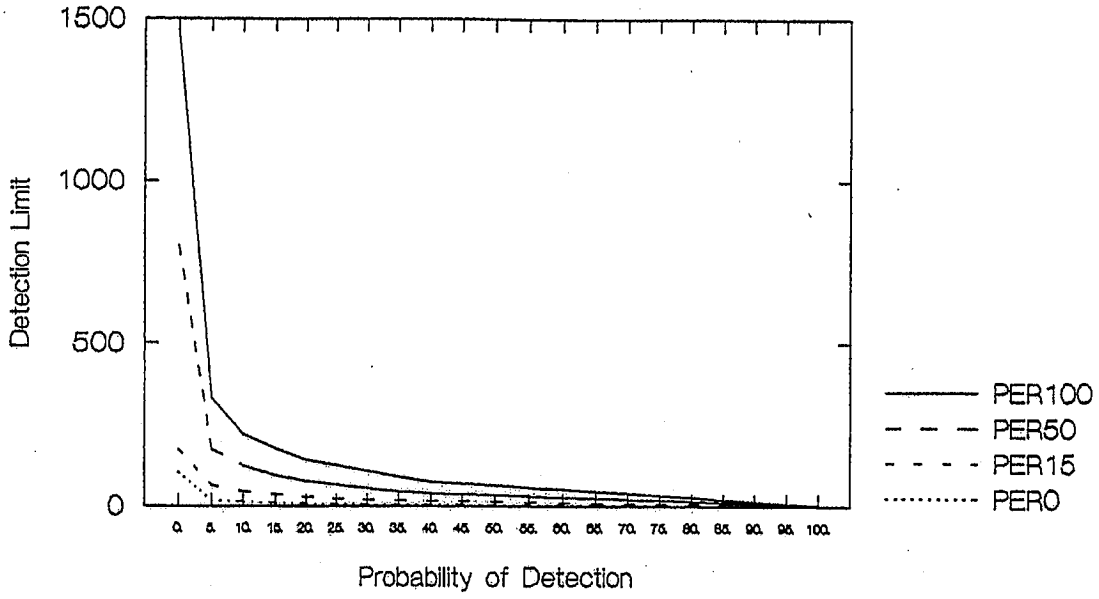

Figure B-54. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 20 (5H-100H).

A0065Ø4

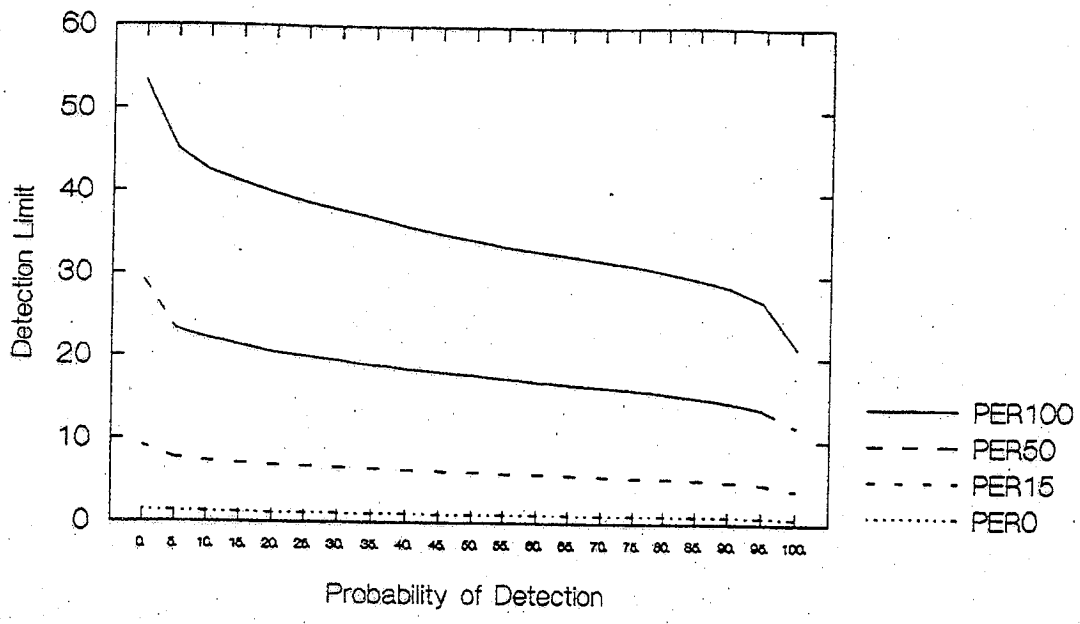

Figure B-55. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 35 (1L-35L).

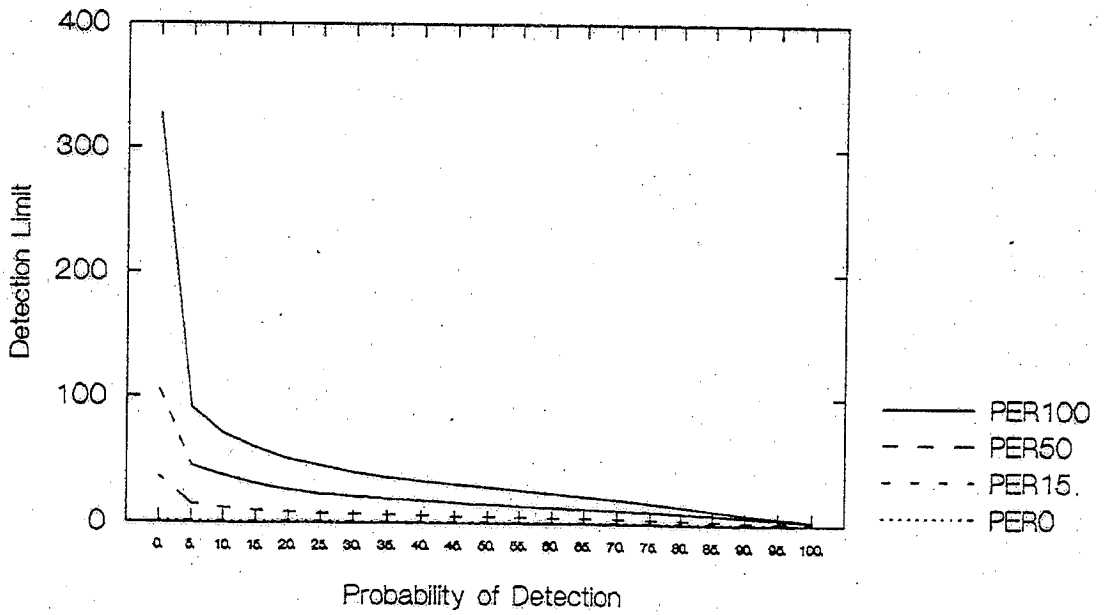

Figure B-56. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 35 (1L-35M).

A006505

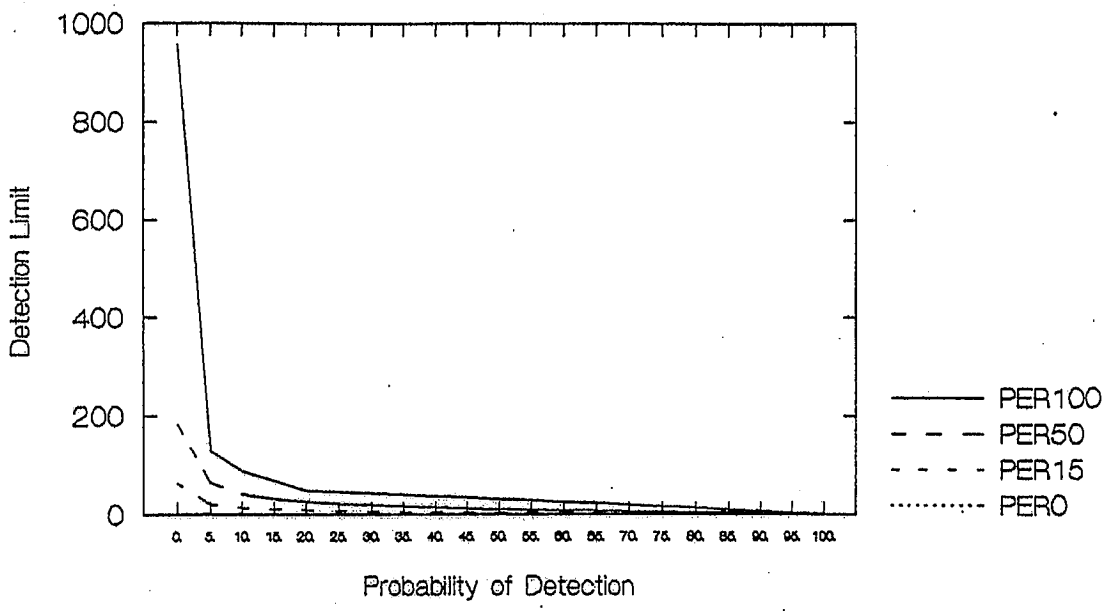

Figure B-57. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 35 (1L-35H).

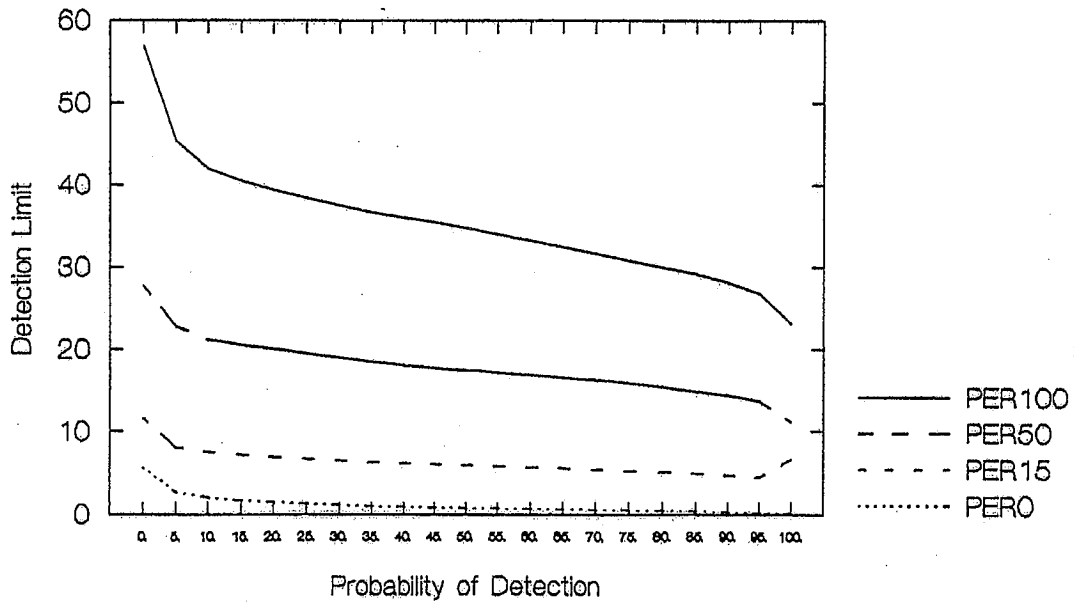

Figure B-58. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 35 (1M-35L).

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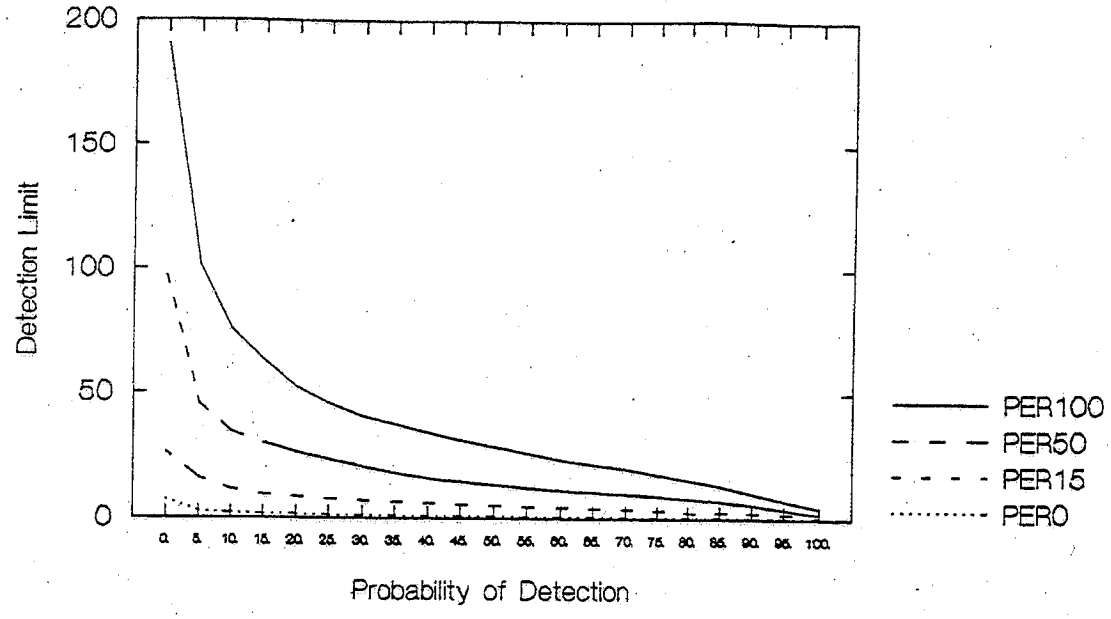

Figure B-59. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 35 (1M-35M).

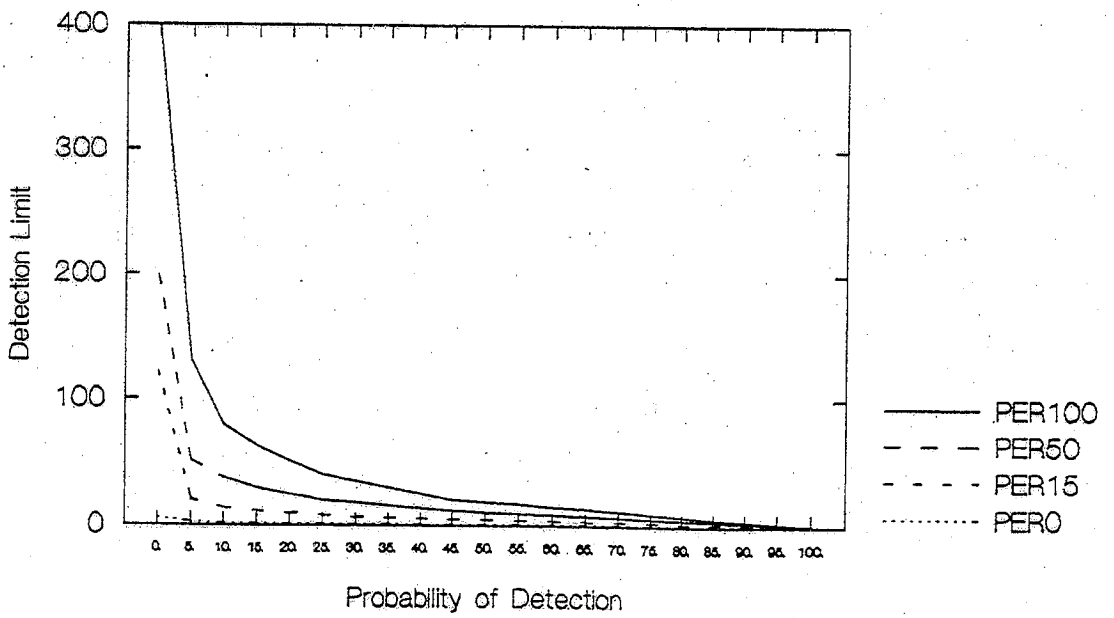

Figure B-60. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 35 (1M-35H).

A006507

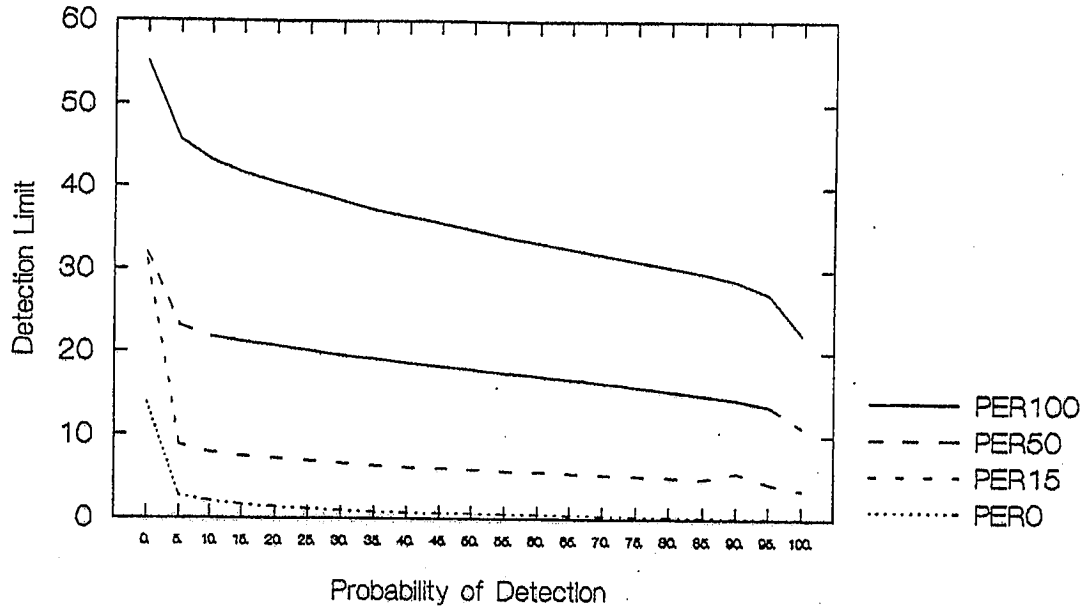

Figure B-61. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 35 (1H-35L).

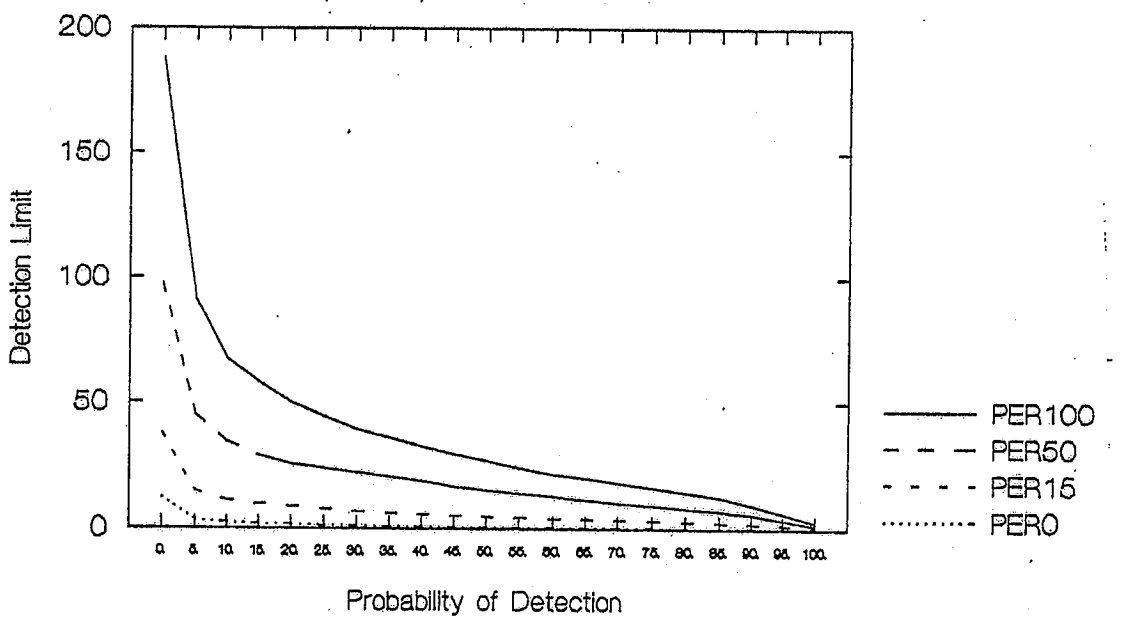

Figure B-62. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 35 (1H-35M).

A006508

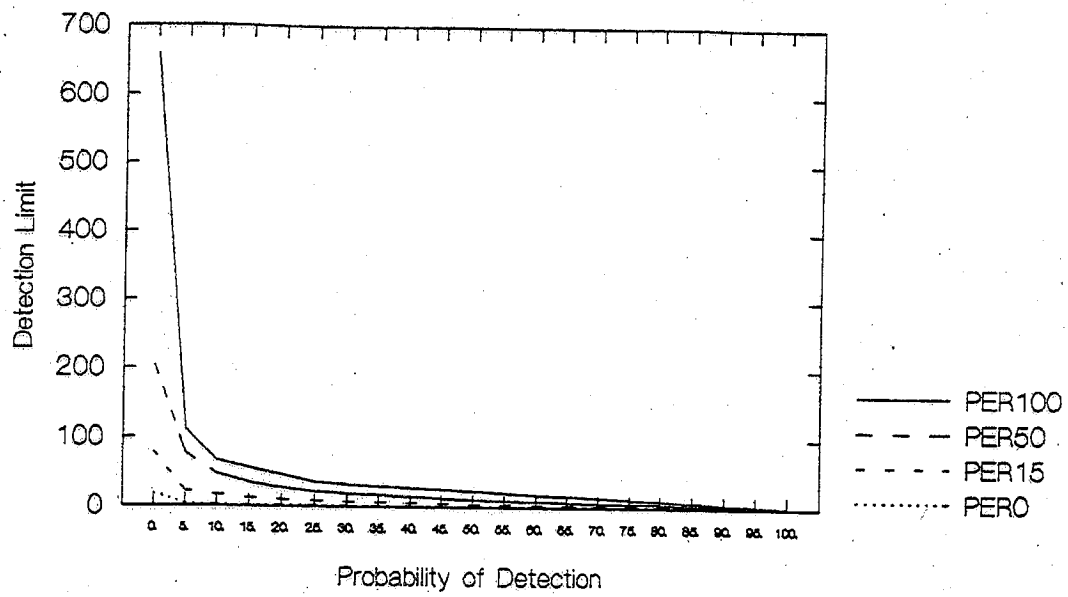

Figure B-63. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 35 (1H-35H).

A006509

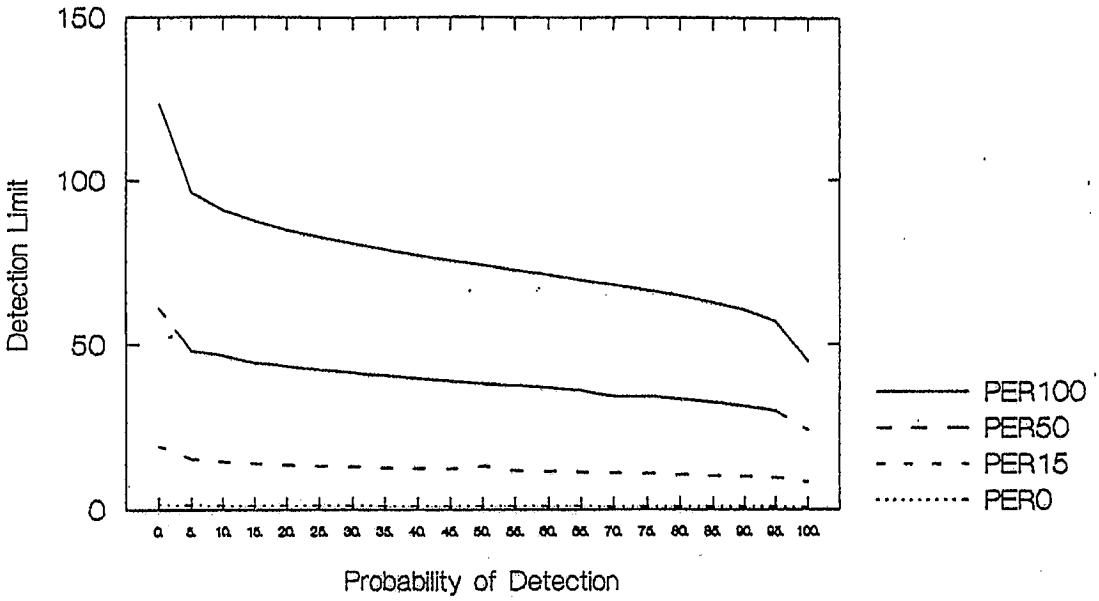

Figure B-64. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 75 (1L-75L).

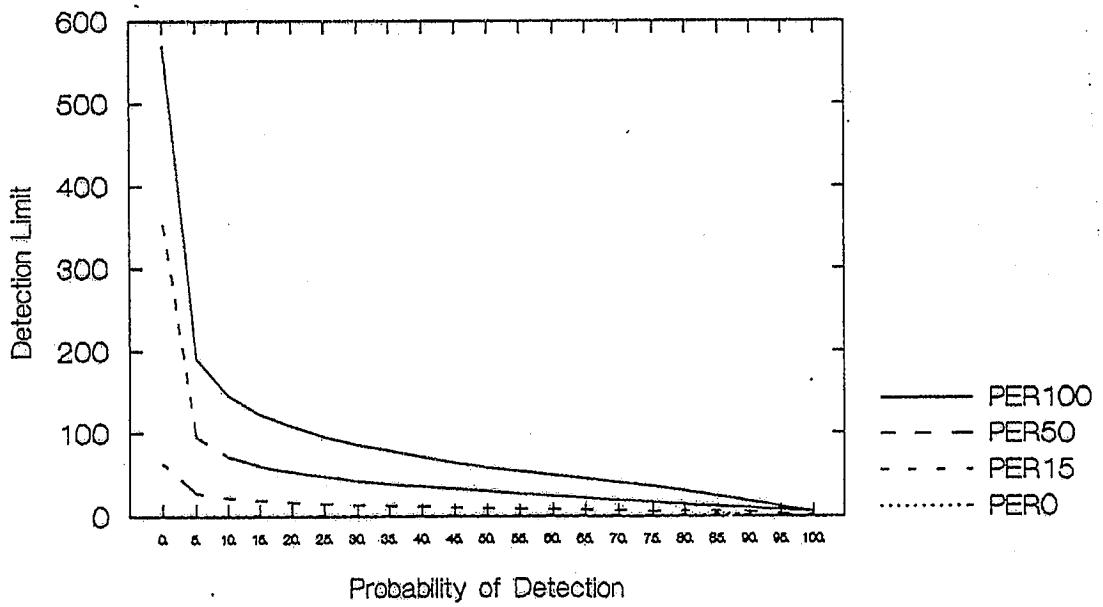

Figure B-65. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 75 (1L-75M).

A006510

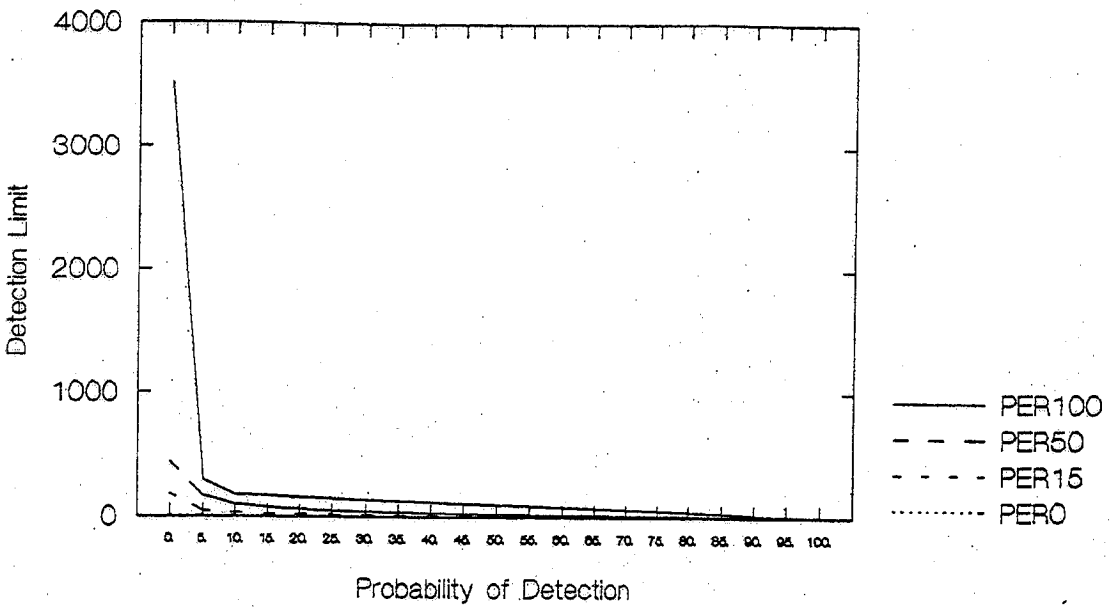

Figure B-66. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 75 (1L-75H).

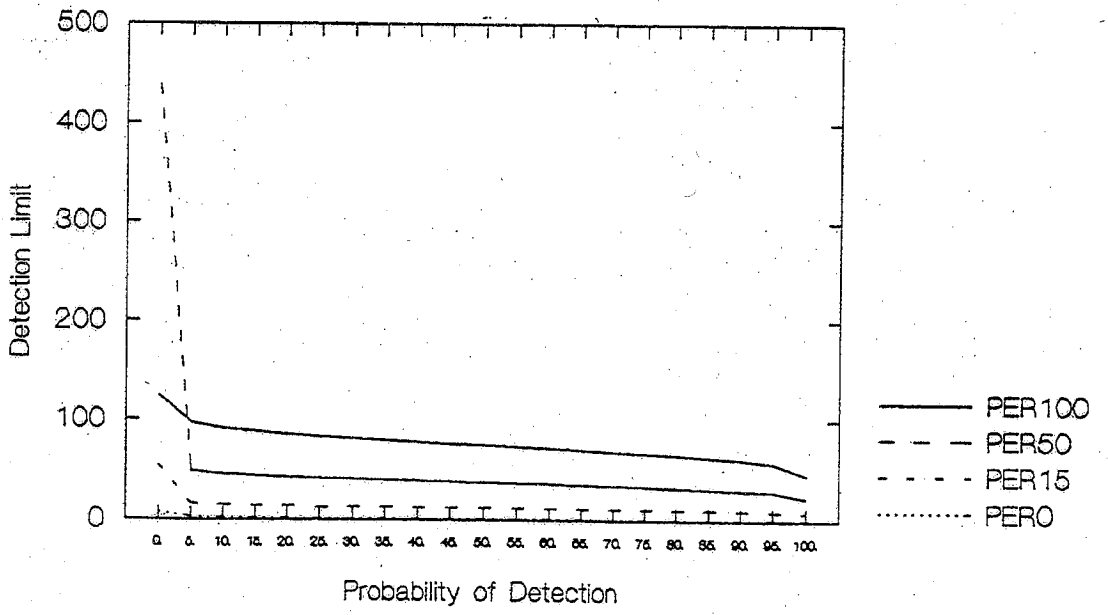

Figure B-67. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 75 (1M-75L).

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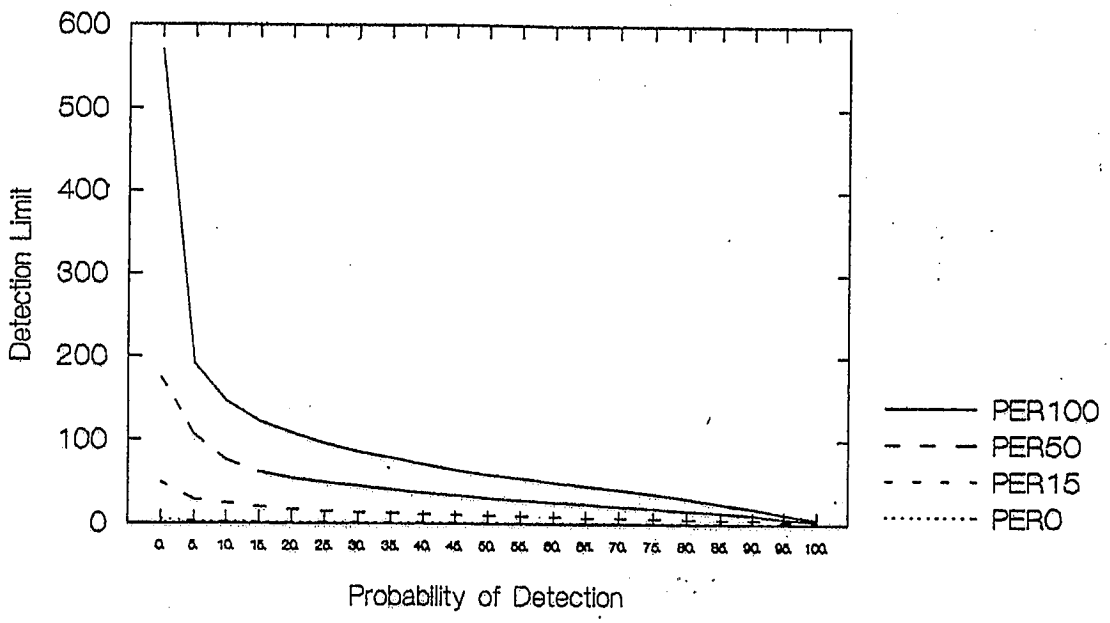

Figure B-68. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 75 (1M-75M).

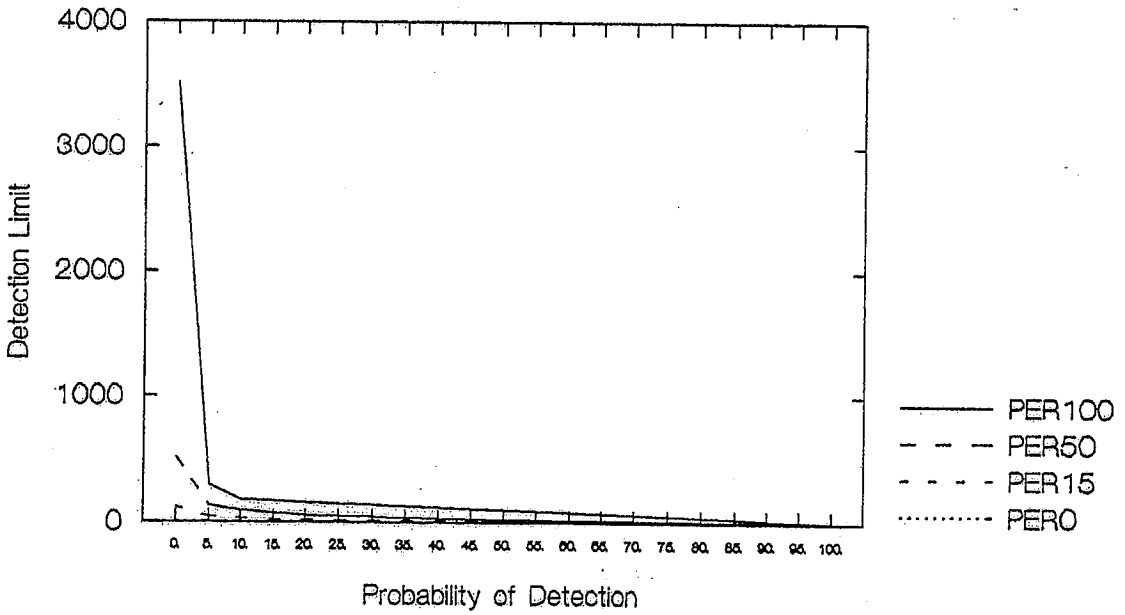

Figure B-69. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 75 (1M-75H).

A006512

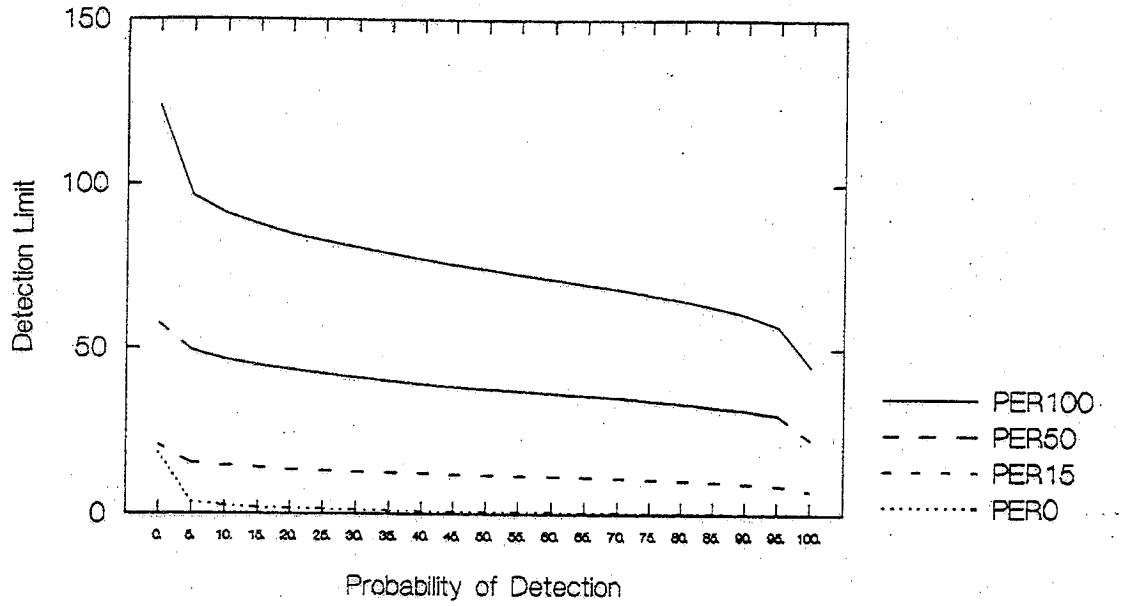

Figure B-70. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 75 (1H-75L).

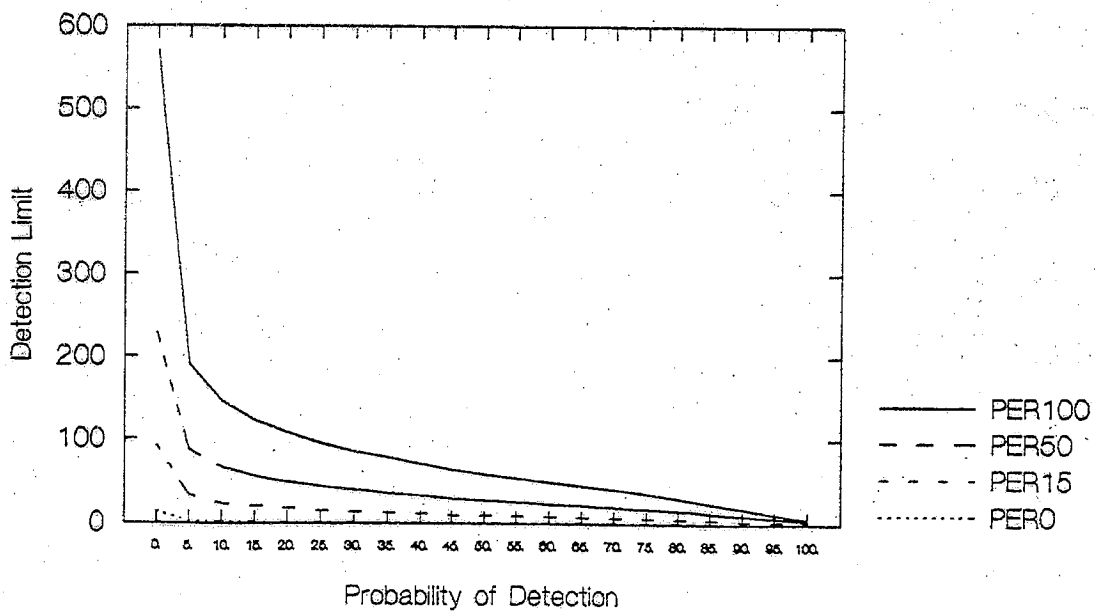

Figure B-71. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 75 (1H-75M).

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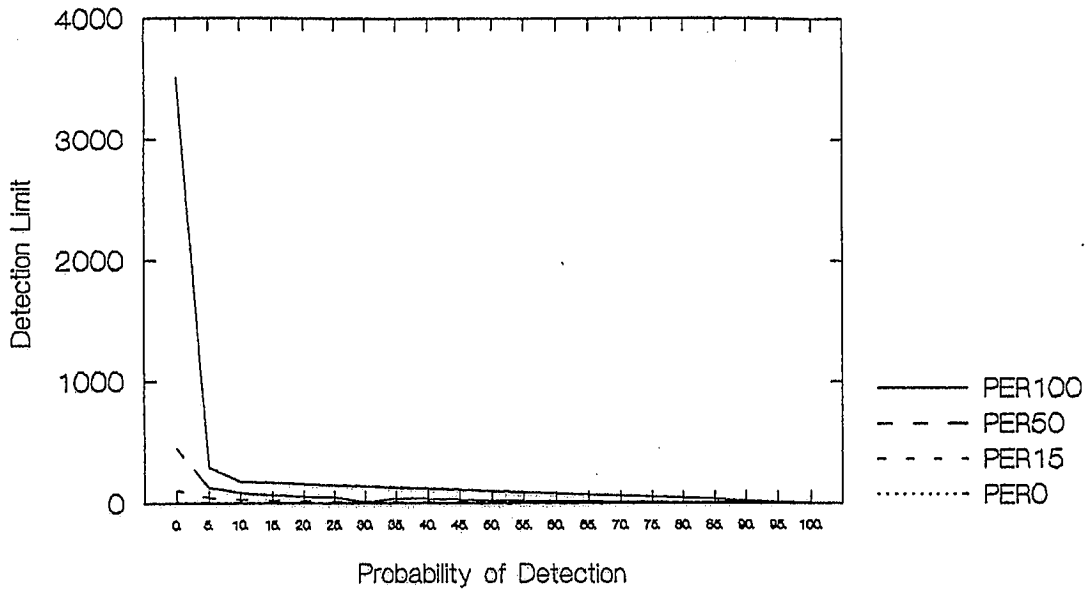

Figure B-72. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 75 (1H-75H).

A006514

Appendix C
Case Studies of Non-Stormwater Discharges into Separate Storm Sewer Systems

Introduction

Many different local and regional units of government have investigated local problems associated with non-stormwater discharges into storm drainage systems. This appendix summarizes several case studies that have been conducted in various locations in North America. This information has been very useful in developing the strategy presented earlier in this report. Other local studies were also reviewed, and referenced, during the development of this report.

Allen Creek Drain, Ann Arbor, Michigan

Agency

Washtenaw County Health Department, Washtenaw County Drain Commissioner. Director of Environmental Health, P.O. Box 8647, Ann Arbor, Michigan, 48107.

Initial Alert to Problem

Several surveys, beginning as early as 1963, identified bacterial and chemical contamination of the Allen Creek storm drainage system. Studies in 1963, 1978 and 1979 found that discharges from the Allen Creek storm drain contained significant quantities of fecal coliform and fecal streptococci. The 1979 study also documented high pollutant loads of solids, nitrates and metals.

Nature of Non-Stormwater Contamination

A large number of inappropriate storm drain connections originating from businesses were found, especially within automobile related facilities. Chemical pollutants, such as detergents, oil, grease, radiator wastes and solvents were causing potential problems. Sanitary sewage was not found to be as large of a problem as originally thought.

Procedures Employed to Identify Contaminant Sources

A four phase plan was developed to identify sources of contamination resulting from inappropriate storm sewer connections.

Phase 1: Comprehensive Drain Survey--

The main stem and accessible lateral branches of the storm drainage system were surveyed by County personnel. This survey was to identify the origin of suspicious connections to the storm drain that were causing the continuous dry-weather discharges found by consultants during the 1970's. The resulting list of suspicious connections provided target areas for future investigations.

Phase 2: Intensive Bacteriological Study--

The main stem, major lateral branches and the outfall of the storm drainage system were sampled weekly over a nine month period for fecal coliform and fecal streptococci bacteria in an effort to locate areas where the expected sanitary

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sewage was entering the storm drain. A large number of sampling locations were used in order to better isolate individual source locations and to minimize the effects of dilution on bacteria concentrations.

Phase 3: Priority I Business Survey and Dye-Testing Program--
Priority I businesses were designated as those directly involved with the storage and/or use of petroleum products. A letter explaining the pollution control project was mailed to each business owner/manager (see Attachment C-1). County personnel then visited each individual business in an effort to determine the type, use, storage and disposal of petroleum products and other hazardous chemicals and whether plumbing fixtures and floor drains showed any signs of chemicals being discharged into storm drains. A standardized survey form was used to record this information and a rough sketch of the facility was also made (See Attachment C-2).

Survey results formed the basis for dye-testing priorities. Liquid or powdered fluorescent tracing dyes were used for the dye-tests so that wastewater would be brightly colored and easily distinguished. Observers located at the closest accessible storm drain and sanitary sewer manholes recorded the destination of the colored wastewater from each individual floor drain and plumbing fixture.

Phase 4: Priority II Business Survey and Dye-Testing Program--
Businesses designated as Priority II were those indirectly involved with the use of petroleum products or directly involved with other types of potentially hazardous chemicals. Following the completion of Phase 3, Priority II businesses were surveyed and dye-tested in the manner described above.

Corrective Action
Letters describing the survey findings was sent to owners where storm drain connections were found, after the dye-testing of the businesses in priority groups I and II. The letter described the problem and identified the appropriate official to be consulted with regard to corrective action. As a follow-up, site meetings were held with business owners and inspections of corrections were performed as they were completed.

Of the 160 businesses dye-tested, 61 (38%) were found to have improper storm drain connections, very few of which were sanitary sewage. Ninety-two percent of these improper connections were corrected as of December 31, 1986. The elimination of these storm drain connections prevented thousands of gallons of contaminated water from entering the Huron River from the Allen Creek storm drainage system annually. Eight sampling locations along the main stem and major lateral branches of the storm drainage system were established and monitored for 37 chemicals during rain events. From 1984 to 1986, 32 (86%) of these chemicals showed a decrease in concentrations while only 2 (5%) showed an increase. In spite of this improvement, chemical concentrations in wastewater at the Allen Creek outfall were still greater than those from the control station much of the time.

Discussion
Due in part to information obtained during this project, the Huron River Pollution Abatement District was established on January 1, 1987. This effort enlists the support of Ann Arbor and Ypsilanti as well as all of Washtenaw County in a five year program (The Huron River Pollution Abatement Program) to limit the impact of non-point source pollution on the district's water quality.

References
Schmidt, Stacy D. and Douglas R. Spencer. "The Magnitude of Improper Waste Discharges in an Urban Stormwater System", *Journal Water Pollution Control Federation*, July 1986.
Washtenaw County Drain Commissioner and Washtenaw County Health Department. *Allen Creek Drain Water Quality Survey* - Status Report. September 1984.
Washtenaw County Statutory Drainage Board. *Huron River Pollution Abatement Program.* September 1987.

A006515

WASHTENAW COUNTY HEALTH DEPARTMENT
2355 West Stadium Boulevard P.O. Box 8645 Ann Arbor, Michigan 48107-8645

ENVIRONMENTAL HEALTH
PUBLIC HEALTH ENGINEER
Barry Johnson, P.E., M.S.
(313) 994-2492

DIRECTOR
John B. Atwater, M.D., Dr. P.H.

May 4, 1984

Dear Business Owner/Operator:

Since 1982, the Washtenaw County Heath Department and the Washtenaw County Drain Commissioner's Office have been working toward eliminating pollution flowing into the Huron River from the Allen Creek Drain. Significant improvements in water quality have already been made by detecting and removing several sources of contamination to the Allen Creek storm drain system. However, an important aspect of the pollution control program remains to be performed. Non-residential premises within the Allen Creek drainage basin need to be evaluated in order to determine: (1) Whether floor drains and other plumbing fixtures in these premises are properly connected to the sanitary sewer, and (2) What type of chemicals that may be discharged to the sewer are in use at each of these premises.

As your business is located in the Allen Creek drainage basin, your cooperation in this pollution control program is essential. In the near future, a representative from the Health Department will call on you at your establishment to further discuss the program, answer any questions you might have, and perform a short survey on the type, use, and storage of petroleum products and other chemicals at your business. An additional visit by the Health Department representative will be necessary to examine and dye-test plumbing fixtures and floor drains.

Your participation in this program is essential if pollution to the Allen Creek Drain and the Huron River is to be successfully eliminated. Please feel free to call the Washtenaw County Health Department at 994-2492 if you have any questions concerning this program.

Sincerely,

Douglas R. Spencer, Coordinator
Water Pollution Program

Attachment C-1. Letter from Washtenaw Co. Health Department to business operators explaining program.

A006517

Establishment: GOODYEAR TIRE & SERVICE CENTER

Address : 2260 W. Stadium Blvd.

Contact Person: Fred Hillquist, Store Manager

Telephone: 994-5100

General Comments:

- LARGE VOLUME OF CAR SERVICE WORK DONE (IN EIGHT SERVICE BAYS)

- HAVE FAIR AMOUNT OF SPILLAGE WHEN TRANSFERRING SPENT OIL INTO HOLDING TANK VIA 2" DIAMETER PIPE OUTSIDE BUILDING - SPILLED OIL RUNS DOWN PARKING LOT INTO TRENCH DRAIN IN DRIVEWAY ON STADIUM BLVD.

Chemical Substances (types, uses, storage):

Spent Oil? stored in 500 gal underground tank - drained from shop collectors once a day - picked up every two weeks by ABC Oil

Oil Separator ? unknown

Radiator Wastes? flushed down trench drain with water

Solvents: Floor? biodegradable soap used once a week (Saturday)
Parts/Tools? self-contained Safety-Kleen machine, aerosol solvents

Batteries? stored in cool,dry place - retrieved by used battery dealer from Flat Rock

Others? fresh oil stored in 250 gal tank (not close to any drains)

Floor Drain/Plumbing Fixture Survey:

- small floor drains in each of seven regular service bays
- eighth bay has pit with sump pump
- employee restroom has large utility sink, fixtures, and floor drain
- two customer restrooms have fixtures and floor drain
- small floor drain in storage area for discharging compressor condensates
- floor drain in area near employee's restroom for removing bluing from tires (area very dirty)
- drinking fountain in service area
- outdoor trench near sidewalk at western driveway - pavement blackened due to oil spillages that eventually drain into trench

SURVEYED: 5/15/84 SS

DYE-TESTED: 6/20/84 SS
SA
RB

- all plumbing fixtures and floor drains inside building ----- sanitary
- trench drain in driveway that receives oily runoff ----- storm

Attachment C-2. Example on-site survey form used in Allen Creek project.

A006518

Fort Worth, Texas

Agency

Fort Worth Health Department, Storm Drain Team. 1800 University Drive, Fort Worth, Texas, 76107.

Initial Alert to Problem

The Texas Water Code required all cities with more than 5000 inhabitants to plan abatement of pollution from generalized sources, such as from storm sewers. Because the public, especially children, had easy access to the City's storm drainage system, the Fort Worth Health Department developed this program to evaluate, maintain and/or improve the water quality within these drainages.

Nature of Non-Stormwater Contamination

This program has been underway since June of 1985. Investigations to date indicate few direct connections from industries to storm drains. Illegal dumping, storm runoff, accidental spills and direct discharges into the street or adjacent creeks seem to account for the majority of industrial pollution entering the storm drainage system.

Major additional problems stemmed from septic tanks, self-management of liquid wastes by industry and construction of municipal overflow bypasses from the sanitary sewer to the storm drains. Figure C-1 provides information on some of the major sources of drainage system contamination which were identified and addressed during this period. Metals were found in receiving water sediments, but not in dry weather discharges.

Procedures Employed to Identify Contaminant Sources

Problem Detection--

Approximately 200 stormwater outfalls discharge into the Trinity River within the city of Fort Worth. Citizen referrals, helicopter surveillance flights, patrols by city personnel and an innovative city wide-water quality assessment program were used to target the most contaminated outfalls.

The Fort Worth Water Quality Assessment Program for Storm Drainages was based on the premise that poor water quality can be detected by the careful observation of aquatic environmental features and the use of simplified versions of conventional chemical and physical tests. It was designed to be inexpensive and require minimal training of the personnel involved. Stormwater outfalls with dry-weather flows were located and evaluated on rainless days using the special target-area survey report (See Attachment C-3). Public accessibility of the candidate sites, and their proximity to the drinking water supply, was also noted.

Based on this information, 24 target sites were selected for the initial phase of the program. A control site was located upstream from industrial and residential activity. All target and control sites were surveyed monthly and results were recorded on a Target Area Tabulation Sheet (See Attachment C-4). Sediment samples were collected annually and analyzed for cadmium, lead, chromium, nickel, copper and zinc.

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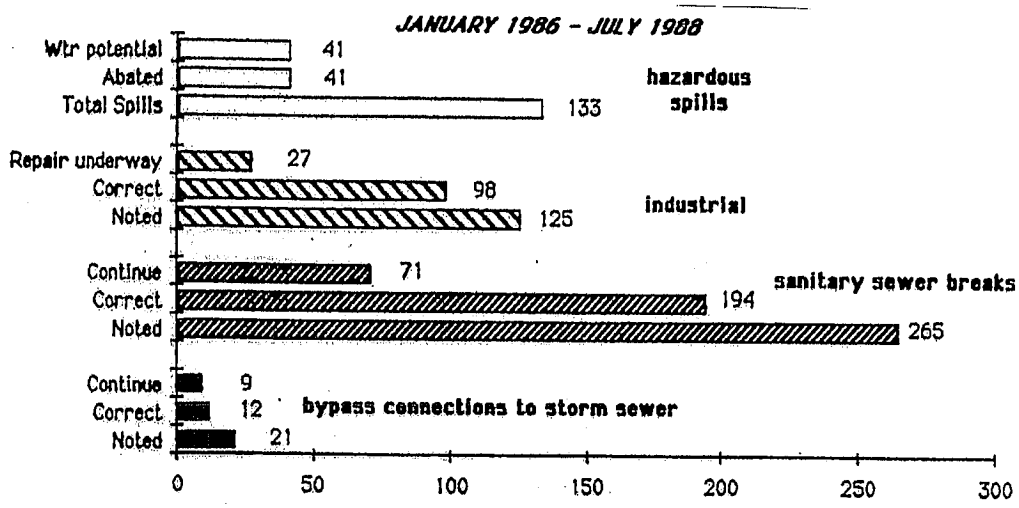

Figure C-1. Fort Worth, TX, drainage way contamination.

A006520

ATTACHMENT C-3. TARGET AREA SURVEY REPORT USED IN FORT WORTH PROJECT

(+) UNDESIREABLE (/) PRESENT (-) NOT NOTED

SITE _____ DATE _____ DAY _____ TIME _____ WEATHER _____

LOCATION _____

_____

BIOLOGICAL

MAMMALS _____ ALGAE _____ AQUATIC INSECTS _____

FISH _____ * SEWAGE BACTERIA _____ * MOSQUITOES _____

TURTLES _____ CATTAIL _____ TUBIFEX WORMS _____

BIRDS _____ OTHER _____ SNAILS _____

FROGS/TADPOLES _____ EUTROPHICATION _____ CRAWFISH _____

OTHER _____ OTHER _____ * FISH KILL _____

OTHER _____

REMARKS _____

_____

_____

PHYSICAL

WATER TEMP _____ AIR TEMP _____ WATER FLOW _____

* COLOR _____ * HYDROCARBONS _____ TRASH _____

* ODOR _____ * SCUM (TYPE) _____ OTHER _____

* CLARITY _____ SEWAGE _____

REMARKS _____

_____

_____

CHEMICAL

* pH _____ CHLORINE _____ OTHER _____

* NESSLER _____

SAMPLE #_____ #_____

REMARKS _____

_____

_____

*-UNDESIREABLE FREATURES FOR PROFILES OBSERVER _____

A006521

ATTACHMENT C-4. TARGET AREA TABULATION SHEET OF UNDESIREABLE CHARACTERISTICS AS USED IN FORT WORTH

Date:

		SITE #																			
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
O	Septic																				
D	Hydrocarbon																				
O	Other																				
R																					
P	Color																				
H	Clarity																				
Y	Scum																				
S	Hydrocarbon																				
	Trash																				
	Other																				
	Turtles																				
	Fish																				
	Frogs																				
	Tadpoles																				
	Mammals																				
B	Birds																				
I	Other																				
O																					
L	Mosquitoes																				
O	Tube worms																				
G	Crayfish																				
I	Snails																				
C	Other																				
A																					
L	Cattail																				
	Algae																				
	Sewage bact.																				
	Other																				
	Eutrophy																				
	FISH KILLS																				
	Other																				
C	pH																				
H	Nessler																				
E	Chlorine																				
M	Other																				
A	Fecal Coli																				
N	Sample #																				
A	Bioassay																				
L	Other																				

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Source Identification--
Following the detection of a storm drainage pollution problem, the source of the problem was investigated. Field testing equipment was used in conjunction with laboratory analyses for determining specific chemical constituents. On-site biotoxicity tests were carried out when warranted. A storm drainage survey was also conducted, when necessary, followed by smoke and dye testing where appropriate. Pollutants in open channels could sometimes be physically traced upstream to their source.

Corrective Action
Responsible parties were notified of code violations and necessary clean-up and/or repair actions. Follow-up checks were made to insure that appropriate action had been taken. In cases where the responsible party was unwilling to make necessary corrections, the news media was notified.

The success of this program was judged by a decline in the number of undesirable features at the target outfalls. An average of 44 undesirable observations per month were made in 1986 (522 total), compared to an average of 21 undesirable observations per month in 1988. Figure C-2 compares the number of undesirable features observed at the 24 target sites each month from 1986 to 1988.

Discussion
The Fort Worth drainage water pollution control program was developed and implemented by the Fort Worth Public Health Department and is on-going. The program is being carried out at an annual cost of approximately $7000 (excluding salaries) and utilizes only 2-3 persons.

References
Falkenbury, John. *Water Quality Standard Operating Procedures*. City of Fort Worth Public Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1987.

Falkenbury, John. *City Of Fort Worth Water Pollution Control Program Overview*. Fort Worth Public Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1988.

Moore, A.H. and Dena Hoffpauir. *Biotoxicity Testing*. Fort Worth Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1988.

Toronto, Ontario

Agency
Ontario Ministry of the Environment, Toronto, Ontario, Canada.

Initial Alert to Problem
Recent studies conducted by the Ministry of the Environment showed that tributary watersheds within Metropolitan Toronto had a high impact on water quality along the Lake Ontario waterfront. The Humber River and Tributary Dry-Weather Outfall Study was initiated to identify and sample all stormwater outfalls having dry-weather flows in the Humber River Basin of Metropolitan Toronto.

Nature of Non-Stormwater Contamination
Stormwater outfalls contributing significant quantities of nutrients, phenols and metals, as well as fecal coliforms, were discovered. Industrial and sanitary sewer cross-connections were suspected, as well as contaminated runoff from facilities such as meat packing plants.

A006524

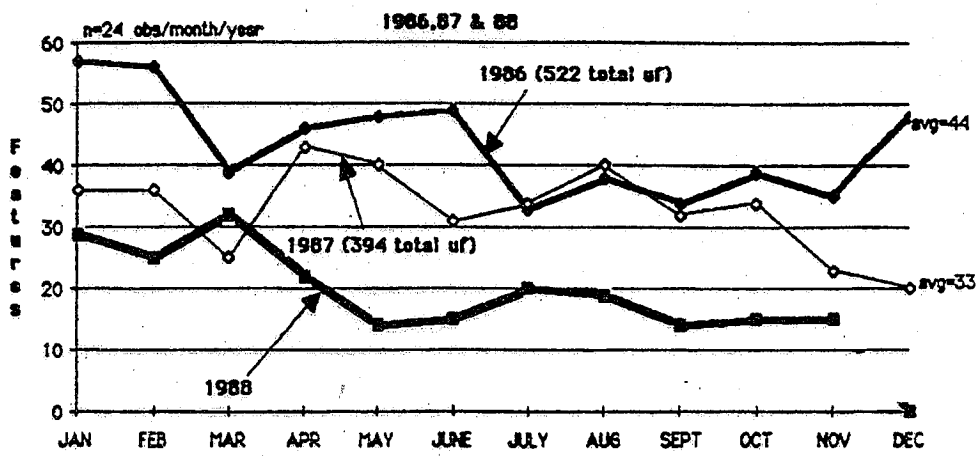

Figure C-2. Fort Worth, TX, undesirable features for 24 target areas.

Procedures Employed to Identify Contaminant Sources

Two two-person field crews carried out mapping and outfall sampling screening surveys. As the study progressed, outfalls were prioritized based on chemical loadings and bacteria levels. Only the most contaminated outfalls were extensively sampled.

First Screening--

Crews proceeded upstream within each stream tributary reach and located, photographed and described as many outfalls as possible. An identification number was assigned to each outfall. During this initial survey, 432 outfalls were mapped, of which 157 had dry-weather flows. Samples were collected from outfalls having dry-weather flows. Flow rates were recorded and field tests were also made (See Attachment C-5). Samples were tested in the lab for many contaminants and outfalls with effluents exceeding preliminary guidelines (See Table C-1) were designated "contaminated" and were further studied.

Second Screening--

Crews re-sampled effluent from contaminated stormwater outfalls. Municipal maps and lists, and information from earlier studies, were also used to locate any outfalls which had been overlooked during the first screening. These outfalls were then located, described and sampled. By the end of the second screening, a total of 624 outfalls had been mapped, 366 (59%) had dry-weather flows. After all samples were tested, the results were compared to a second set of "high threshold" contamination guidelines (See Table C-2) and the most contaminated outfalls were identified for extensive sampling.

Extensive Sampling--

A total of 84 outfalls identified during the second screening were sampled on three occasions during dry-weather in November and December. Samples were taken only for the parameters which exceeded the high threshold guidelines (BOD, COD, and bacteria was treated as one test group to facilitate basin-wide analysis). A total of 60 outfalls were assigned priority for future investigations, based on the fact that they each contributed more than 1% of the total dry-weather load for at least one chemical, while 29 outfalls were identified as significant sources of fecal coliform and fecal streptococci.

Corrective Action

This study terminated with the identification of significant outfalls. Investigations to locate actual sources of the contaminants were to be undertaken by the respective municipalities.

A006525

References

Gartner Lee and Assoc. *Toronto Area Watershed Management Strategy Study - Humber River and Tributary Dry Weather Outfall Study*. Technical Report #1. Ontario Ministry of the Environment. Toronto, Ontario. 1983.

Huron River, Washtenaw County, Michigan

Agency

Washtenaw County Drainage Board, James E. Murray, Chairman. Huron River Pollution Abatement Program Project Coordinator, Washtenaw County Environmental Health Bureau, P.O. Box 8645, Ann Arbor, Michigan, 48107-8645.

Initial Alert to Problem

The impact of urban stormwater on the Huron River had been well documented. In 1966, University of Michigan researchers concluded that illegal connections into storm drains had a significant impact on the water quality of the Huron River. Subsequent studies yielded similar conclusions, especially with regard to high fecal coliform counts. During the early 1980's, studies conducted by the towns of Ann Arbor (The Allen Creek Drain Water Quality Survey, described previously) and Ypsilanti identified chemical contamination as well.

A006526

ATTACHMENT C-5. FIELD DATA SHEET USED IN TORONTO'S HUMBER RIVER OUTFALL STUDY

FIELD DATA SHEET
Humber River Outfall Study

Outfall # _____ Date :_____/_____/_____ Time: _____ Crew:

_____

Weather: Today:

_____

Yesterday:

_____

River: Humber Main Black Creek Humber West Other: _____

Reach: A B C D E F Borough: Etobicoke Toronto

G H I J K L York North York

M N O P Q

Location:

_____

(sketch on back of sheet)

Outfall Description: Size: _____ Diameter W X H: _____

Material: _____ Shape: _____

Active: Y/N Photographed: Y/N # _____

Samples Collected: Bacteria Routine Chemical

Metals Organics

Other: _____

Flow Rate: Velocity: _____

Depth: _____

Sketch cross-section shape (on back of sheet)

Field Tests: D.O. _____mg/L Air Temp: _____°C

pH _____ Water Temp: _____°C

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conductivity: _____ µmhos
Observations: Color Odour Erosion Impacts Land Use Other **Accessibility:** Easy Difficult Road Manhole Boat Only Is the outfall otherwise mapped? Map: _____ # _____

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TABLE C-1. GUIDELINES USED IN TORONTO TO SELECT OUTFALLS FOR SAMPLING DURING SECOND SCREENING (LOW THRESHOLD)

Parameter	Outfall Re-Sampled If Concentration Exceeded (mg/L)
BOD_5	20
COD	25
TKN	5
NH_3	1
Tot-P	1
Sol-P	1
Fe, Cu, Zn, Pb, Cr	1
Suspended Solids	15

TABLE C-2. GUIDELINES USED IN TORONTO TO SELECT OUTFALLS FOR SAMPLING (HIGH THRESHOLD)

Parameter	Outfall Effluent Intensively-Sampled of Levels Exceeded (mg/L)
BOD_5	50
COD	50
TKN	5
NH_3	1
Tot-P	1
Sol-P	1
Fe,	5
Cu, Zn, Pb, Cr	1
Suspended Solids	100
Phenols	5 µg/L
Fecal Streptococci	10,000/100 ml
Fecal Coliforms	50,000/100 ml

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Nature or Non-Stormwater Contamination

This on-going, five year study is investigating sanitary as well as chemical contamination from the more than 60 storm drain outfalls found discharging into the Huron River in Washtenaw County. Information from the sampling program to date indicates very elevated levels of nitrate, ammonia nitrogen, total phosphorus, and fecal coliform bacteria at the storm drain outfalls and in the river, as compared to the control station.

Procedures Employed to Identify Contaminant Sources

Methods used to identify sources of contamination include sampling the storm sewer systems and the river, and surveying buildings (including dye-testing).

Sampling-- Sampling efforts include permanent sampling stations, grab samples from the river and storm drain systems and soil samples. Permanent sampling stations are located at the outfalls of the three major storm drain systems in the area, the Allen Creek Drain in Ann Arbor; the Owen Drain in Ypsilanti; and the Beyer Drain in Ypsilanti Township. These stations have 24-hour composite samplers and flow meters. Chemical constituents were selected to cover a wide range of water quality indicators. Weekly composite samples are taken for primary analyses and samples are analyzed biweekly for a secondary list of constituents (See Table C-3). Grab samples from four stations on the Huron River (including one upstream control station) are collected and analyzed biweekly for the primary and secondary constituents as well as dissolved oxygen. All storm drain manholes are checked for improper connections and water quality problems. Grab samples collected from storm sewers are used for locating industrial discharges, and isolating residential neighborhoods that have sanitary wastewater discharges into the storm sewer. Grab samples from storm sewers are also used for complaint investigations. Soil samples are collected from industrial areas which have discharged to septic tank drainfields in the past.

Survey/Dye Test-- Commercial, industrial, and other buildings are surveyed to determine use, storage and disposal practices of chemicals and hazardous materials. An outline of the building's plumbing scheme is also obtained. Where applicable, a company's small quantity generator number, Pollution Incident Prevention Plan, National Pollutant Discharge Elimination System permit and Material Safety Data Sheets are examined. A dye-test is then made of each plumbing fixture and floor drain. Businesses having improper storm sewer connections are notified and given correction alternatives.

Corrective Action

As of January 1, 1989, dye testing had been completed at 1067 establishments. A total of 154 (14%) improper connections were discovered, including connections in restaurants, dormitories, car washes and several auto repair facilities. Only 29 (19%) of these problems had been corrected by the end of the year. County personnel have reported a marked reduction in the number of complaint calls related to oil slick discharges from the Allen Creek drain. This was thought to be a result of locating and correcting discharges from automotive service stations along the Creek corridor.

Discussion

Since federal and state funds were not available, a new approach was used to generate local money to fund this project. A special assessment district was established along the Huron River. Property owners within this district will have an assessment added to their property tax bill for the next five years. Assessment rates are based on use and size of the property, and range from $4.50 a year for the typical home owner, to $200.00 per year for large commercial enterprises. The money generated by the district is utilized to cover all costs of the inspection program including personnel, consulting fees, lab services, administration, equipment purchases, etc.

References

Washtenaw County Statutory Drainage Board. *Huron River Pollution Abatement Program.* September 1987.

Murray, James E. Washtenaw County Drain Commissioner. *Statement To The Board Of Commissioners.* December 1985.

Office of the Washtenaw County Drain Commissioner. *Huron River Pollution Abatement Project 1988 Summary.* 1988.

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TABLE C-3. CONSTITUENTS ANALYZED DURING HURON RIVER INVESTIGATIONS

Drain Samples:

Group I	Group II
Oil and grease	Nitrate
Total Suspended Solids	Ammonia
Total Phosphorus	Toxicity
Total Organic Carbon	Zinc
Cadmium	Chloride
Chromium	
Lead	
Fecal Coliform	
pH	
Conductivity	

River Samples:

Group I	Group II
Oil and grease	Nitrate
Total Suspended solids	Ammonia
Total Phosphorus	Toxicity
Total Organic Carbon	Zinc
Cadmium	Chloride
Chromium	BOD_5
Lead	Turbidity
Fecal Coliform	Total Dissolved Solids
pH	
Conductivity	

Soil/Sediment Samples:

- Volatile organics
- Base/neutral/acid organics
- Metals
- Cyanide
- Phenolics

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Rideau River, Ottawa, Ontario

A study of the lower Rideau River in the Regional Municipality of Ottawa-Carleton was conducted to establish the causes of bacteriological water quality degradation in the urbanized reach of the river and to analyze the impacts of future urbanization. Earlier programs had identified and corrected many cross-connections between sanitary sewers and stormwater sewers. Bacteriological water quality improved, but swimming standards at beaches were still not obtained.

Pollution from combined sewer overflows, urban stormwater runoff and feces from birds on bridges was known to occur but was largely unquantified. This study quantified these sources and identified additional sources along the lower Rideau River. The sources of bacteriological pollution were investigated under dry-weather conditions and during rainfall events.

A pollution abatement plan for the fully urbanized reach within the City of Ottawa was recommended. This plan initially focused on correcting local dry weather sources of pollution, including pigeon control, repairing leaks from sanitary sewers, and eliminating cross-connections between storm and sanitary sewers. It was recommended that stormwater quality controls be included in all new urban developments to control runoff pollution.

Reference
Ontario Ministry of the Environment. *Rideau River Stormwater Management Study*. Toronto, Ontario. 1983.

Sacramento, California

The City of Sacramento is currently undertaking a project to identify pollutant discharges and illegal connections into the stormwater drainage system. Recent studies identified potentially toxic substances associated with urban runoff in concentrations that could potentially impair beneficial uses of the Lower American River in the City and County of Sacramento. Bioassays by Foe (1987) demonstrated acute toxicity in some stormwater. In a 1984-85 study, Montoya (1987) found that slightly less than half the water discharged from Sacramento's stormwater drainage system was not directly attributable to precipitation. High concentrations of copper, lead, zinc, cadmium, chromium, arsenic and nickel were documented. Mass loading estimates of copper, lead and zinc from Sacramento urban runoff discharges were several times higher than similar estimates computed for the Sacramento Regional Treatment Plant secondary effluent.

The proposed study will characterize storm drainage discharge quality, evaluate its toxicity by bioassay, identify remedial measures to improve quality, and recommend actions to reduce water quality impairments in the river. Initially, testing for a broad range of pollutants will be carried out at four locations which are representative of the various land use categories found in the project area. Sufficient sampling and analysis will be conducted to establish water quality conditions during dry weather, first storm of season, and major storm events. Monitoring is planned to continue for a two year period.

References
Montoya, Barry L. *Urban Runoff Discharges From Sacramento, California*. Submitted to California Regional Water Quality Control Board, Central Valley Region, CVRWQCB Report Number 87-1SPSS. 1987.
Johnson, Melvin H. and Douglas M. Fraleigh. *Workplan for Federal Clean Water Act Section 205 (j) (2) Grant*. Submitted by the City of Sacramento, Flood Control and Sewer Division, in cooperation with the County of Sacramento, Division of Water Resources. 1988.

Inner Grays Harbor, Washington

Investigations into persistent water quality problems at Grays Harbor were initiated as early as the 1930's. Current investigations focus primarily on survival of coho salmon, however, a variety of water quality problems are of

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concern, including low dissolved oxygen, bacterial contamination and potentially toxic industrial discharges (Beyer 1979).

During a dry-weather survey in July of 1987, the lower reaches of the Chehalis, Wishkah, and Hoquiam Rivers, as well as inner Grays Harbor, were inspected and approximately 90 urban storm drains were located and mapped. The 29 drains having dry-weather flows at the time were sampled for a variety of pollutants, including fecal coliforms, ammonia, nitrate and nitrite, total phosphorus, total solids, total non-volatile solids, total suspended solids, non-volatile suspended solids, and turbidity. Visual observations and field measurements of temperature, pH and specific conductance were also made. Results were compared to pollutant levels expected in typical urban runoff, as characterized by the EPA NURP report (1983). Nineteen of the drains sampled exhibited anomalous pollutant levels (at least one parameter outside approximate 95 percent distribution interval for typical urban runoff). Eight drains were suspect, based on visual characteristics. Six drains were included in both categories. The outfalls were then prioritized for further study. At least one drain was later found to receive a residential sanitary sewage connection which has since been corrected. This drain exhibited no unusual visual characteristics, but was found to have atypical pH and total suspended solids levels. Notably, fecal coliform levels were within the typical range.

References

Beyer, D.L., P.A. Kingsbury, and J.E. Butts. *History and Current Status of Water Quality and Aquatic Ecology Studies in the Lower Chehalis River and Grays Harbor, Washington*. Prepared for Washington Public Power Supply System. 1979.

Pelletier, G.J. and T.A. Determan. *Urban Storm Drain Inventory, Inner Gray Harbor*. Prepared for Washington State Department of Ecology, Water Quality Investigations Section, Olympia, Washington. 1988.

Boston, Massachusetts

A flow and quality monitoring study was carried out in Boston in 1993 and 1994 by Metcalf and Eddy (1994) using the draft procedures presented in the User's Guide (Pitt, *et al.* 1993) prepared as part of this research. A field screening program was conducted to determine the relative levels of contamination at various locations in the Stony Brook drainage system. This information provided insight as to whether water quality impacts in the vicinity of the outfall discharge location were due to dry weather contamination sources, CSOs, or stormwater discharges. Field screening activities took place during dry weather, and emphasized characterization of base flows in the brooks and overflow conduits that comprised the system. This screening program consisted of field inspection and utilization of test kits to determine relative levels of contamination. Grab samples were collected from various structures within the Stoney Brook system and field test kits were used to measure color, fluoride, ammonia nitrogen, and detergents.

Inspection forms (Attachment C-6) were filled out for each inspection activity noting obvious outflow conditions, photograph information, and water quality conditions. During eight days of dry-weather sampling, numerous inappropriate discharges of sanitary sewage into the drainage system were identified using these procedures and a modified flow chart approach. Differences in tracer concentrations in Boston source waters required that the numeric values presented in the User's Guide (Pitt, *et al.* 1993) be slightly changed.

Reference

Metcalf & Eddy. *Draft 1993 Flow and Quality Monitoring Program and Results*. Prepared for the Massachusetts Water Resources Authority. Boston, Massachusetts. March 1994.

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Structure No.: MH-36 **BWSC Sheet No.** 11E **Location:** In front of 216 Belgrade Ave.

Date: 11/24/93 **Time:** 10:15 A.M.

Inspected/Analysis by: G.S., P.T.

Weather: Dry X Rain ____ Snow ____ **Comments:** P. Sunny 50's

Days Since Last Rain: 5 (11/19/93) **Amount** 0.30 in.

Photographs:

Photo No.	Description
17	Inside MH-36
18	Area of MH-36

PHYSICAL OBSERVATIONS: 9.2' deep

Flow Characteristics: (estimates) Depth ½ in. Velocity ≈ 2 fps Steady X
Intermittent ____ Turbulent ____ Other ____
Comments: Can hear trickle of flow into pipe upstream

Odor: None ___ Sewage ___ Sulfide ___ Petroleum ___ Gas ___ Rancid/sour X Other X
Comments: slightly sour / musty

Color: Clear ___ Yellow ___ Brown X Green ___ Red ___ Gray ___ Other ____
Comments: Light color

Turbidity: Clear ___ Cloudy X Opaque ___

Floatables: None ___ Petroleum sheen ___ Sewage ___ Other X (collect sample)
Comments: sediment / sand

Deposits/stains: None ___ Sediment ___ Oily ___ Other X (collect sample)
Comments: stain at invert (gray color)

Vegetation conditions: Normal ___ Excessive growth ___ Inhibited growth ___ None X
Comments: ____

Structure:
Material Cast iron cover, cast iron steps, brick manhole
Damage: None X Concrete cracking ___ Concrete spalling ___ Rebar exposed ___
Other damage: ____
Comments: ____

SAMPLE ANALYSES:

Parameter	Filtered	Time	Results
Color:	X	3:05 P.M.	25 Units
Fluoride:	X	3:05 P.M.	1.20 mg/L
Detergents:	X	3:10 P.M.	>1.0 mg/L
Ammonia:	X	3:10 P.M.	>3.0 mg/L as N

Attachment C-6. Massachusetts Water Resources Authority (MWRA) Stony Brook system (Boston) investigation field screening inspection form.

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Appendix D
Village Creek Mapping Demonstration Project Activities

This appendix describes the mapping activities that were associated with the Birmingham demonstration project. It includes specific information sources that were utilized and presents the final drainage area maps and summary tables. This appendix supplements the information presented in Section 11.

To properly document inappropriate pollutant entries into a storm drainage system, a substantial amount of mapping activities must be carried out, as previously summarized in Section 3. This information is listed below:

1. High quality topographic maps of the receiving water's drainage area.
2. Location, size, type, and drainage area of each stormwater outfall in the study area.
3. Land use and zoning maps of the entire drainage area.
4. Location and description of commercial, industrial, agricultural, and residential activities in the study area, with attention drawn to illicit storm drain connections.

An investigation of a storm drainage system should incorporate mapping and preliminary drainage area evaluation in the early stages. A complete picture of the drainage area can be developed using detailed topographic maps in combination with the corresponding land use and zoning maps. Evaluation of the maps will reveal areas and outfalls of concern within the drainage area. Storm drain outfalls which have in their drainage area commercial or industrial operations which are likely to produce non-stormwater entries into the storm drainage system can be investigated for evidence of these discharges.

The first step in mapping is to obtain good quality topographic maps of the drainage area. While United States Geological Survey (USGS) 7-½ minute quadrangle maps are important to use for these activities, the course contour interval (20 foot for the Birmingham area) will present problems when trying to identify individual outfall drainage areas. For most areas, a contour interval of 1 to 5 feet will expedite the mapping by increasing the accuracy of the final drainage area boundaries. The City of Birmingham engineering department had maps with 1-foot contour intervals which were especially helpful. One problem with obtaining topographic maps from a municipal source is that the maps usually end at the city limit.

It will be helpful to make two copies of each map, one to work with, and another to keep as a master copy. Vellum copies seem to be the best choice for maps with small contour intervals because of the contrast between the vellum and the contour lines. If the contour intervals are greater, blueline reproductions will save some money. If USGS maps are all that are available, they will need to be enlarged to several times their original size. Obviously this will not increase the accuracy of the maps, but it will provide room to draw drainage areas and label storm outfalls without crowding. Even if more detailed maps are available, the enlarged USGS maps are helpful as they will provide a complete picture of the drainage area and adjacent receiving waters in a relatively small space. It will also be helpful to ask the city engineers for storm drainage maps and a listing of known outfalls. At this point, the drainage area for the receiving water as a whole should be drawn on the maps. This is not a complex step, but care should be taken as it is important.

While this mapping is being completed, a field team needs to investigate the receiving waters for the specific locations of stormwater outfalls. It is important to locate as many outfalls as possible and to take accurate notes as to

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their location, size, and type. Locating outfalls is not trivial. For this reason, the field team needs to examine the banks of the receiving water every time samples are being taken to find outfalls that have been overlooked on previous trips. Once a list of outfalls and their locations has been completed, this information can be transferred to the maps. Each outfall should be labeled clearly on the maps using the same numbering system that has been developed by the field team.

The maps should now show the total drainage area of the receiving water and every outfall as reported by the field team. The next step is to detail the drainage area of each outfall. Identifying the individual outfall drainage areas is the most daunting map work that will be done. Several factors contribute to the difficulty of the task. The first problem is that the drainage areas will have to be developed mostly using topographic maps. While this is the logical method, it must be understood that there is an inherent error associated with assuming that storm drainage pipes flow in the same direction as surface flow. Certainly it is standard practice to follow the topography, but it is not uncommon for a drainage pipe to cross a drainage divide. On the reach of Village Creek selected in this study, for example, the only National Pollutant Discharge Elimination System (NPDES) permit issued is to an industry that, based upon the topographic maps, is not even physically located in the Village Creek drainage area. To complicate matters further, municipal storm drainage maps, when available, typically show only the relatively new outfalls associated with new developments and do not accurately show the older outfalls.

Another problem with using surface topography to define storm drainage areas is that it is impractical to draw drainage divides reflecting grading and small drainage patterns on individual lots. The best decision may be to draw the drainage divides by following the surface topography. Thus, if the surface topography indicates a drainage divide crosses the roof of a building, it is assumed that there is a drainage divide on the roof. In most situations this will not be a realistic assumption, but it is impractical, if not impossible, to visit each rooftop and parking lot to determine detailed flow directions. A similar problem can arise when an outfall is actually an illicit process discharge from a commercial or industrial operation rather than a storm drain. In these cases the outfall is not dependent upon the topography at all.

There may be outfalls where a drainage area cannot be easily determined because of a lack of information about the storm sewer There is a general lack of accurate information about the location of storm sewer pipes. It is important to obtain as much storm drainage system information from the city engineers as possible. However, the information should not be blindly accepted. In several cases, the city in this study had plans which did not correspond to actual pipe locations. Given this, it is sometimes up to the field team to attempt to follow a pipe to its inlet in order to identify the actual drainage area. This is difficult at best because of interconnections between pipes which cannot be seen from the surface. Detailed storm drainage surveys are time consuming and costly. It is therefore recommended that basic drainage divides be based on surface topography and available drainage maps. However, detailed surveys need to be conducted for outfalls that are determined to be a problem based upon the physical and chemical outfall surveys.

When the field team is locating and identifying the outfalls, clues to the purpose of the outfall can often be found. This information is often very helpful in determining a drainage area for individual outfalls. Air conditioner drain pipes, for example, are often small p.v.c. pipes. In a similar fashion, the field team may be able to identify sanitary sewer relief pipes and obvious discharges from nearby commercial or industrial operations. In each of these cases, the outfall can be very important, although there is no actual "storm" drainage area.

Regular sampling can begin as soon as the field team feels confident that the great majority of the outfalls have been located. The field team should develop two field sheets (Tables D-1 and D-2) while taking samples at the outfalls. Table D-1 is a listing of the outfalls for this study. The Village Creek outfall listing was revised on almost every trip, which is an indicator of the difficulty of locating all of the outfalls. As predicted, there were several instances in which the University of Alabama at Birmingham field team could not relate an outfall to the city of Birmingham's "official" list.

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Table D-2 is the Village Creek non-stormwater flow evaluation field sheet which shows the observations that should be recorded as each sample is taken. As the sample is taken, one member of the field team can survey the outfall for signs of non-stormwater discharges, as described in Section 7

The maps should detail the total drainage area, each outfall, and the drainage area for each outfall. The next addition to the maps is land use within the drainage area. The city land use and zoning maps should be very accurate and useful indicators. Because tax revenue varies with land use, municipalities keep good records of current land use. The drainage area should be divided into at least three main land use categories: residential, commercial, and industrial (Agricultural can be added if applicable). Other important land use information such as areas served by septic tanks, abandoned land fills, and old industrial areas should also be drawn on the maps. The different land use categories should be drawn on the same maps that have the drainage areas. The city will probably not allow the zoning maps to be taken out of the office. However, as only a simplified version of the city's zoning maps is needed, the work goes fairly quickly and, with permission, can be completed efficiently done in their office.

Once the commercial and industrial land uses have been mapped, the rest of the drainage area will most likely be residential, with some open space and institutional areas. Except for poorly maintained septic tanks and sewage leak problems, the majority of pollutant entries from residential areas are of a very short duration. Landscaping, vehicle maintenance, and car washing are typical problems that can be detected at an outfall, but not easily traced to a specific source. As the majority of "shade tree" mechanics operate on the week-ends, these are the times when the field team should drive through these areas. Depending on the area, there may also be some agricultural zones within the drainage area which would obviously be of importance. The "agricultural" zoning laws may allow a great variety of land uses, and each agricultural activity that may be suspect should be documented.

After the drainage area has been divided into the main land use areas, it is necessary to determine the specific critical activities within these areas. All industrial activities need to be noted and described, but only selected commercial activities likely pose a significant water quality threat during dry weather. The commercial operations of most interest are: laundry and dry cleaning stores (including hotels and hospitals which have similar facilities); vehicle service businesses (including parts stores, auto repair shops, new and used car dealers, body shops, car washes, wrecker services and gas stations), restaurants; and any other commercial operation which may be suspect. Common sense can dictate whether or not a business is suspect. Contractor yards containing construction materials are an example of a business which will not be encountered often, but nonetheless are important.

To properly locate the critical land use activities in the drainage area, it is necessary to drive throughout the drainage area. Using the maps, a field team can visit each commercial and industrial area to locate and describe businesses that are present. At each location that contains a business of concern, the name should be recorded and the business should be numbered. A field sheet, such as Table D-3, should be completed for each site. A quick survey of each site will reveal any obvious problems. A direct process connection will most likely be visible only in those situations where the facility lies adjacent to the receiving water. Physical and chemical testing of the dry-weather flow at the appropriate outfall will reveal any sub-surface connection to the storm sewer. Indirect discharge can be observed as surface flow from the facility. Stains or discoloring of the pavement can be the result of intermittent surface flow. Often these stains follow a path from the facility to a storm drain. Though septic system failure is visible only in some cases, any sign of such a failure should also be noted. The location should also be highlighted on the topographic maps. If the business lies near a drainage divide, the lot can be examined and the divide can be re-drawn to reflect the true drainage pattern.

The discharge from each critical activity has distinct characteristics. In the Village Creek study, there were two instances when restaurants seemed to be a culprit. In both cases, the smell of the restaurant from the storm drain outfall was unmistakable. In one case, a fish kill seemed to coincide with a distinct smell of doughnuts. Peering over the bank of the creek revealed a doughnut shop across the street. In the second, case a yellow-orange sludge lined the bottom of the storm drain pipe. The smell was familiar, but could not be identified until a look over the bank revealed a Mexican restaurant not far away. Another smell connected the two, and identified the sludge as cheese. For reasons similar to these, restaurants and food processors are included on the list of "suspect" businesses as

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frequent offenders. There are several car washes in the Village Creek drainage area. While most of these retain the wash water in a pit for discharge to the sanitary waste water system, one of the car washes used manual washing methods outside. A considerable amount of wash water was directed to a nearby storm drain. This problem can be expected on a more sporadic basis as schools and other organizations hold fund raising car washes in parking lots.

Auto body shops, auto repair shops and car dealers have the potential to be the most flagrant offenders. Filthy auto repair shops not only cause wet weather runoff problems, but if the parking lot is rinsed, or cars are washed or drained outside, there is a dry-weather runoff problem as well. Body shops use paints and solvents, while repair shops have parts baths which require an expensive method of disposal. All too often the disposal is into a nearby body of water via a nearby storm drain. These offenses can be long term, flagrant, and shamelessly obvious. There is one offender of this nature in the Village Creek drainage area. It is a used car dealer which does repair and body work in-house. Village Creek lies about 10 or 15 feet behind the building and several cast iron pipes run directly from the building to the creek bank. The grass on the creek bank is matted down and blackened from the frequent discharges. The discharges consist of a base flow which is a steady drip, and fairly regular slug flows lasting 2 or 3 minutes. From the analysis of the flow, it seems to be the parts solvent being drained. During other studies, small plating businesses have also been found to be frequent illicit dischargers, and outfalls associated with these activities should be checked frequently. Laundries and dry cleaners have also been found to be frequent offenders. In some cases, operators store the screens from the dry cleaning machines in the yard behind the building. There, the screens are either hosed off or rained upon. In other cases the runoff is more direct. One hotel in the Village Creek study seems to dispose of laundry wash water directly into the storm drain. When confronted, the problem abated for a time and then resumed.

Table D-4 contains the actual Village Creek critical land uses, while Table D-5 lists the outfalls containing industrial and commercial operations in their drainage areas. In the Village Creek drainage area that was studied, two of the outfalls had very large drainage areas and contained the majority of the industrial and commercial operations. The majority of the outfalls had small drainage areas with little or no activity of interest.

Also given in this appendix are copies of watershed drainage maps locating each of the specific industrial and commercial activities noted in these tables, the major land uses, drainage areas, and outfall locations.

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TABLE D-1. VILLAGE CREEK OUTFALL DESCRIPTIONS

Outfall #	History of Flow	Pipe Size and Type	Location
1		6'x6' conc.	Robison Drive
2		30" conc.	left - between Laurel Dr. and Robison Dr.
3(abcde)		e) 36"conc.	under Annie Laurel Dr
4(ab)		24" conc.	under Dalton Rd.
5		6" steel	left - from house (Downstream Dalton)
6		16" conc.	left - road drain (Downstream Dalton)
7(abc)		a) 6'x10'	crossing to North Roebuck elementary
		b) 36" conc.	
		c) 12" conc.	
8		16" conc.	right - drains ball park (60'down from 7)
9		open ditch	right - downstream ball park behind houses
10(abc)		a) 16" conc.	under Redlane Road
		b) 18"x36"	
		c) gutter in	
10z			right
Dry Branch			left - large
11		2" steel	lying in creek bed
12		6" pvc	crossed creek - sewage leaking
13		3'x8' open ditch	left just upstream of golf course
14	Y	3" pvc	right - golf course
14z	Y	open ditch	right - golf course
15		10" conc.	left - golf course
16	Y	3" pvc	left - golf course
spring runs in			
16z		12" conc.	right - golf course
16zz		10" conc.	left - golf course
17		18" clay	right - corner of West Blvd & 1st Ave
18(ab)		a) 18" clay	under 86th street
		b) 2' conc.	
19(ab)		4" irons	left - behind East Lake Auto Sales (ELA)
20	Y	3'x4' stone	left - behind ELA
21	Y	6" iron	left - behind ELA
22	Y	4"	left - behind ELA, buried in grass
23		4" iron	left - behind ELA
24		2" plastic	left - behind ELA
25		4" with vinyl sleeve	left - behind ELA
26	Y	48" conc.	right - between ELA and Big Ed's
27		18" conc.	right – above 85th St. crossing
28		16"	left - just above85th St. crossing
29		several	under 85th street
29z	Y	5'x12' stone	left - immediately below 85th St. crossing
30		12" conc.	left - below 85th
31(ab)	Y	16" conc.	left - behind hotel
32			left - above 84th
33		48" brick	under 84th st.
34		16" clay	right - below 84th
35		16" clay	right - below 84th
36		6" steel	.right - below 84th
37		submerged	right - in creek overflow cap - just above #38
38	Y	36" aluminum	right - below 84th

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39	Y	12" steel	right - below 84th
40	Y	open ditch	left - just above overhead pipe crossing
40z	Y		
41		14" clay	left - below park bridge
42	Y	36" conc.	left - below park bridge
43		18" conc.	left - back and above creek

(continued)

TABLE D-1. VILLAGE CREEK OUTFALL DESCRIPTIONS (continued)

Outfall #	History of Flow	Pipe Size and Type	Location
44		spillway	East Lake Spillway
45	Y	4'x6' conc.	left - just below spillway
46		6" plastic	located with #45
47		18" conc.	left - back and above creek - just above a pipe crossing
48	Y	36" conc.	left - just above 80th St. crossing
49			right - look for small stone wall
50		9" iron	under 80th St.
51			below 80th St.
52	Y	42" conc.	left - below 80th St.
53	Y	6'x6'	left - above Oporto-Madrid crossing
54		12" clay	above Oporto-Madrid
55		30" conc.	left - above Oporto-Madrid crossing
56		21" iron	left - above Oporto-Madrid crossing
57		18" conc.	left - above Oporto-Madrid crossing
58		24" conc.	right - downstream Oporto-Madrid
59		21" conc.	left - downstream Oporto-Madrid
60	Y	48" conc.	left - downstream Oporto-Madrid
60a	Y	36" conc.	right - back from creek
61(abcd)		16" clay	left - at 75th St. crossing
62		open ditch	left - downstream75th St.
63		48" conc.	right - downstream75th St.
64	Y	open ditch	left - about 200 ft. above airport underground
65	Y	open ditch	right - just above airport underground

A006540

TABLE D-2. SAMPLE OUTFALL EVALUATION SHEET

Sample #19
Outfall # 65 Photograph # 21 Date: 11/14/91

Location: last outfall above enclosed reach

Weather: Air temp: 58°F Rain: Y (N) Sunny (Cloudy)

Outfall Flow Estimate: 5 L/sec

Industrial or commercial activity in drainage area? (Y) N
Describe: airport maintenance

PHYSICAL OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other ___

Color: clear yellow brown green red (gray) other ___
HACH color = 30 units

Turbidity: clear cloudy (opaque)

Floatables: (none) oil sheen sewage other ___

Deposits/Stains: (none) sediment oily describe ___

Vegetation Conditions/growth: (normal) excessive inhibited

Damage to outfall structure:
(none) cracking spalling peeling corrosion
other ___
identify structure ___
extent ___

ANALYSES:			**EQUIPMENT USED:**
Specific conductivity:	225	µS/cm	YSI 33
Temperature:	13	°C	YSI 33
Flouride:	0.87	mg/L	Accu-vac
Hardness:	137	mg/L	digital titrator
Surfactants:	0	mg/L	extraction & color.
Flourescence:	52	% of scale	Turner III
Potassium:	2.3	mg/L	HACH DR/2000
Ammonia:	BDL	mg/L as N	DR/2000 direct Nessler
pH:	7.74		Fisher Accumet
chlorine:	0.01	mg/L	Accu-vac

A006541

TABLE D-3. POTENTIAL DISCHARGER EVALUATION SHEET

Name of facility: _____

Description: _____

Location: _____

Outfall # _____ Photograph:_____ ID#_____

Zoning: Agricultural Residential Industrial Commercial

Evidence of direct process connection? Y N

Describe: _____

_____

_____

Evidence of indirect discharge? Y N

Describe: _____

_____

_____

Equipment or material stored outside? Y N

Describe: _____

_____

_____

Evidence of septic system failure? Y N

Describe: _____

_____

_____

Notes: _____

_____

_____

_____

_____

A006542

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA

Site #	Business	Description
1	The Dobbins Co.	N.A.
2	?	Looks like auto shop, may be out of business
3	American Legion	N.A.
4	Hill Crest Hospital	Laundry
5	Southtrust Processing	N.A.
6	Food Fair	N.A.
7	Security Training	N.A.
8	Chevron	Gas station
9	Handy TV	N.A.
10	Fullilove Automotive	Auto repair (large and dingy looking)
11	STS Auto Clinic	Auto repair
12	Birmingham Corvette	Sales (repair ?)
13	Metro Yamaha	Sales and service
14	Citgo	Gas station
15	Select Car Corner	Auto sales
16	Auto Zone	Auto parts
17	Bo's Home Improvement	Car sales
18	McCay Tire Co.	Auto service
19	Harley-Davidson	Sales and service
20	Jebs Auto Sales	Auto sales
21	Showcase Cars	Auto sales
22	East Lake Auto Clinic	Auto repair
23	Trammel Auto Sales	Auto sales
24	Axiom Auto Sales	Auto sales
25	J & J Auto Brokers	Auto sales
26	Byrd's Tire and Auto Service	Auto repair
27	Motors Auto Sales	Auto sales
28	MTO Motors Auto Sales	Auto sales
29	Gallery of Cars Inc.	Auto sales and service
30	NAPA Auto Parts	Auto parts
31	Payless Used Tires	Auto service and car wash (dingy). Wash cars outside (direct runoff)
32	Chevron	Gas and car wash
33	Don Bland Body Shop	Auto repair
34	Bama Motel	Laundry
35	Exxon	Gas and car wash
36	Airport Service St.	Gas station
37	Dandy RV Sales	Sales and service
38	Magic City Kawasaki	Sales
39	Ellis Wrecker Service	Next to and seems to work with #40
40	Herren's Paint and Body Shop	Auto repair
41	Jim Crocker Auto	Auto sales
42	Exxon	Gas station
43	Tony's Auto Sales	Auto sales
44	East Lake Auto Parts	Auto parts and machine shop
45	Gene's Auto Service	Auto repair
46	El Rancho Motel	Laundry
47	Anchor Motel	Laundry
48	Tucker Paint and Body Shop	Large auto repair (several buildings)
49	Allens Auto Sales	Auto sales
50	East Lake Auto Sales	Sales and service
51	Easy Food Mart	Gas station

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52	Plaza Motel	Laundry
53	Mild to Wild Van Conversions	Sales and service
54	Phillips 66	Gas station
55	85th St. Laundry	Laundry and dry cleaning
56	Highlander Laundry	Laundry and dry cleaning
R1	East Lake Grill	Restaurant

(continued)

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA (continued)

Site #	Business	Description
57	Marty's Transmissions	Auto repair
58	Southeastern Dry Cleaners	Parts and service for laundries
59	Car Care 2000	Auto Repair
60	C & R Laundry	Laundry and dry cleaning
61	Regal Cleaners	Laundry and dry cleaning
62	Express Oil Change	Auto service
63	Phillips 66	Gas only
R2	Egg-A-Day	Restaurant
64	Burch and Sons Refrigeration Systems	Keeps ammonia and freon in-house (water coming from bay door)
65	Self Serve Car Wash	6 bays
66	Conoco Gas Station	Gas only
67	Shell Gas Station	Gas and auto service
68	Allens Auto Sales	Sales and repair
69	Chevron Gas Station	Gas only
70	Phillips 66 Car Wash	Big tunnel type
71	Roebuck Chrysler	New car dealer
R3	Catfish Cabin	Restaurant
72	Lake Highland Gas St.	Looks closed
73	Dave Smith Auto Trim	Vinyl tops
R4	Arby's	Restaurant
74	Roebuck Mazda	New car dealer
75	World Sales Used Cars	Used cars
76	Magic City Auto Bro.	Used cars
77	? Used Cars	Used cars
R5	Pasquales Pizza	Restaurant
78	? Cleaners	Laundry and dry cleaning
R6	El-Gringo	Restaurant
R7	Shoney's	Restaurant
R8	Pizza Hut	Restaurant
79	Safelite Auto Glass	Installation
80	Unocal 76 Gas St.	Gas and auto repair
81	BP Gas Station	Gas only
82	House Of Cars	Used cars (closed)
R9	Krystal	Restaurant
R10	Pioneer Cafeteria	Restaurant
83	Metro Transmission	Auto repair
R11	Baskin-Robbins	Restaurant
R12	Subway Sandwiches	Restaurant
R13	Waffle House	Restaurant
84	Parkway Inn	Laundry
R14	Milo's	Restaurant
R15	Denny's	Restaurant
85	Shell Gas Station	Gas only
86	Dan Tucker Auto Sales	Used cars

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87	Chevron Gas Station	Gas and auto repair
R16	McDonald's	Restaurant
R17	Arlie's	Restaurant
88	Royal Honda	New car dealer
89	National Tire Wholesale	Tires and auto repair
R18	Blimpie's	Restaurant
R19	Chucke-Cheese	Restaurant
R20	Mrs. Winners	Restaurant
R21	Chick-Fil-A	Restaurant
90	Eastern Glass	Auto glass and trim
91	Gray's Auto Service	Auto repair
R22	Spud's Pub	Restaurant
92	Quality Cleaners	Laundry & dry cleaning

(continued)

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA (continued)

Site #	Business	Description
93	McNuts Radiator	Auto repair
94	Shop-A-Snak	Gas
95	Goodyear	Tires and auto repair
96	Automotive Service Group	Auto repair
R23	Pork Palace	Restaurant
97	Bob's Laundry	Laundry and dry cleaning
98	K-Mart Auto	Auto repair
99	Union 76	Gas only
R24	Steak and Ale	Restaurant
100	Exxon	Gas and repair
101	Gargus Pontiac	New car dealer
102	Chevron	Gas only
103	Sam's Used Cars	Used car dealer
104	Firestone	Auto repair and tires
R25	Taco Bell	Restaurant
105	Dun Rite Cleaners	Laundry and dry cleaning
106	Bel Aire Cleaners	Laundry and dry cleaning
107	Berthons Cleaners	Very big (main store?)
R26	Rally's Hamburgers	Restaurant
108	PTL Auto & Tire	Auto repair and tires
109	Mr. Transmission	Auto repair-signs of very dirty runoff
110	Serra Hyundai	New car dealer
111	Champion Lincoln	New car dealer
112	Jiffy Lube	Oil change
R27	Sadies Buffet	Restaurant
R28	Burger King	Restaurant
R29	Giovanni's	Restaurant
113	Bussey Metal Co.	Metal (tin) shop
114	Anderson Construction Materials	Metal and wood
115	Villa Construction	Materials (rolls of insulation) outside
R30	Kelly's Hamburgers	Restaurant
R31	Contri Brother's	Restaurant
R32	Huddle House	Restaurant
R33	Bobbie's	Restaurant
R34	Burger King	Restaurant
R35	Andrews BBQ	Restaurant

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R36	Taco Bell	Restaurant
R37	Church's Chicken	Restaurant
R38	Rally's Hamburgers	Restaurant
R39	Joe and Debs	Restaurant
R40	Subway	Restaurant
116	L & L Auto	Used cars
117	Beasley Auto Repair	Auto repair
R41	Southeastern Meats	Butcher
R42	Fran's Famous	Restaurant
R43	El Palacio	Restaurant
R44	Big East Grill	Restaurant
118	Curry's Auto Paint	Paint and body shop
R45	Krispy Kreme	Restaurant
119	N' and Out	Gas station
R46	Big Bull and Red Place	Restaurant
120	Coin Op Laundry	Laundry

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TABLE D-5. OUTFALLS CONTAINING FACILITIES OF CONCERN IN THEIR DRAINAGE AREA

Outfall #			Gas Stations with:							
UAB	B'ham	# of activities	Gas only	Gas and service	Car wash	Wash and service	Auto repair	Auto parts	Wrecker service	Body shop
Dry Branch	BD1-BD6	43	3	3			8			1
20	B182	3	1							
26	B177	2			1					
28	B175	4								1
29(z)	B174	2								1
40	B163	7	2						1	1
60(a)	B146	1					1			
	B138	1		1						
62	B137	2					1			
64	B133	33	2		1	1	5	1		1
65	B132	1								
Drainage areas with no known commercial or industrial activity of concern: 1, 2, 3a, 3b, 3c, 3d, 3e, 4a, 4b, 5, 7a, 7b, 7c, 8, 9, 10a, l0b, l0c, l0z, B198, 11, 12, 13, 14, 14z, 15, 16, 16z, B190, 16zz, B188, B187, 17, 18a, 18b, 19ab, 21, 22, 23, 24, 25, 27, 29, B173, 30, 31ab, 32, 33, 34, 35, 36, 37, 38, 39, B162, 40z, 41, B159, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51,B, 51, B154, 52, 53, 54, 55, 56, 57, 58, 59, 60, B144, 61a, 61b, 61c, 61d, B139, 63, B135, and 65										

Outfall #		Used car dealer	New car dealer	Metal shop	Construction	Laundry/Dry cleaner	Restaurant
UAB	B'ham						
Dry Branch	BD1-BD6	5	2			4	17
20	B182					1	1
26	B177		1				
28	B175	1					2
29(z)	B174					1	
40	B163	3					
60(a)	B146						
	B138						
62	B137	1					
64	B133	10	2	1	2	3	4
65	B132						

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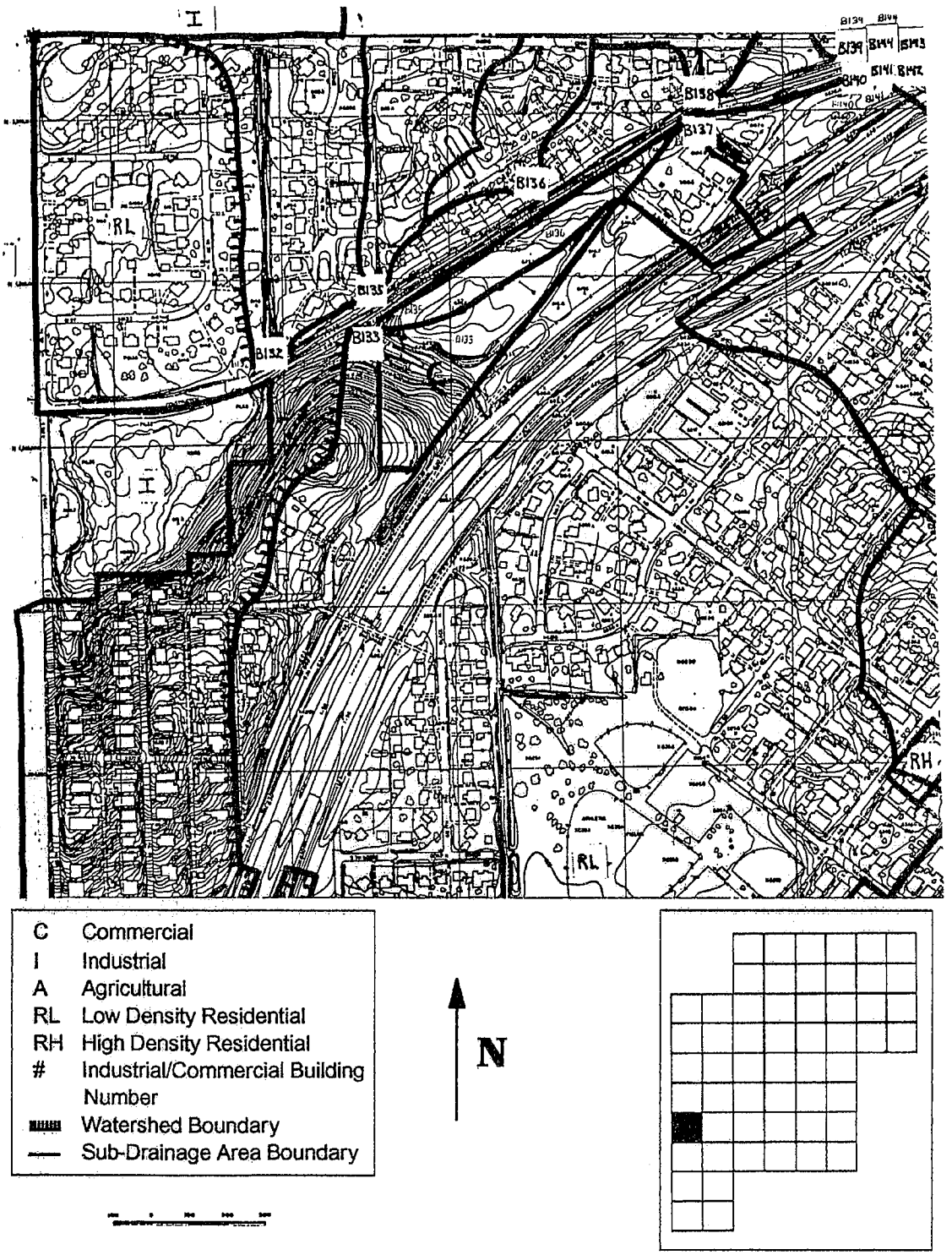

Figure D-1. 72nd Street and 4th Ave. example area showing outfall numbers along Village Creek and associated drainage areas.

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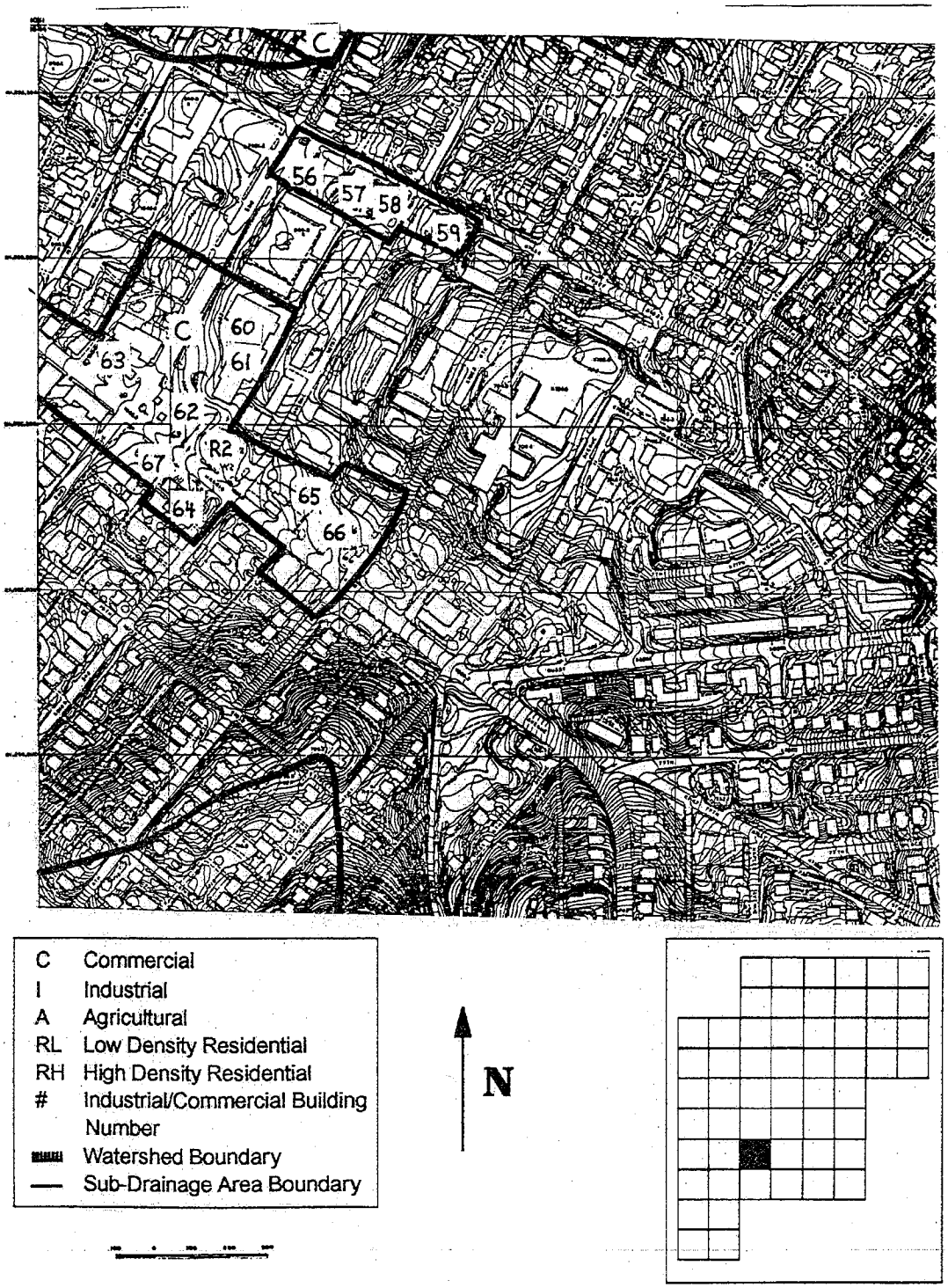

Figure D-2. Oporto-Madrid Ave. and Rugby Ave. example area showing specific commercial establishments in drainage areas.

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Appendix E
Source Area Statistical Tests for Birmingham Demonstration Project

A006550

TABLE E-1. SPRING WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25 % reduc.)	Copper (mg/L)	Phenols (mg/L)
1	310	0.09	231	0	11	0.83	0.02	6.92	0	0.00	0	NA	NA
2	288	0.01	239	0	4	0.76	0.00	6.89	0	0.00	0	NA	NA
3	327	0.01	255	0	5	0.69	0.01	7.01	0	0.00	0	NA	NA
4	310	0.03	248	0	5	0.72	0.05	6.98	0	0.01	0	0	0
5	301	0.05	240	0	10	0.74	0.00	7.00	0	0.01	0	0	0
6	295	0.00	243	0	2	0.73	0.00	6.87	0	0.00	0	0	0
7	298	0.03	241	0	6	0.56	0.00	6.99	0	0.00	0	0	0
8	290	0.03	229	0	8	0.72	0.00	6.95	0	0.00	0	0	0
9	295	0.05	233	0	10	0.76	0.00	6.99	0	0.01	0	0	0
10	298	0.01	239	0	7	0.77	0.01	7.01	0	0.00	0	0	0
mean	301	0.03	240	0	7	0.73	0.01	6.96	0	0.00	0	0	0
st. dev.	11.6	0.03	7.83	0	2.9	0.07	0.02	0.05	0	0.00	0	0	0
95%conf limits (mean +/-)	6.87	0.02	4.63	0	1.7	0.04	0.01	0.03	0	0.00	0	0	0
median	298	0.03	240	0	7	0.74	0.00	6.99	0	0.00	0	0	0
COV	0.04	1.00	0.03	--	0.43	0.10	2.00	0.01	--	--	--	--	--
distribution	normal	normal	normal	uniform	normal	normal	l-norm	normal	uniform	uniform	uniform	uniform	uniform

NA: Data not available

TABLE E-2. SHALLOW GROUND WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25 % reduc.)	Copper (mg/L)	Phenols (mg/L)
1	5	0.08	5	0	7	NA	NA	NA	5	0.04	0	0.01	0
2	5	0.03	22	0	12	NA	NA	NA	20	0.00	0	0.01	0
3	32	0.14	18	0	160	NA	NA	7.8	35	0.08	0	0.00	0
4	128	0.07	41	0	34	1.70	0.38	6.2	0	0.02	0	0.00	0
5	119	0.05	38	0	22	2.15	0.89	5.4	0	0.00	0	0.00	0
6	77	0.04	29	0	15	0.81	0.08	6.4	10	0.01	0	0.00	0
7	31	0.05	32	0	8	0.91	0.05	6.5	5	0.00	0	0.00	0
8	43	0.06	35	0	11	0.89	0.09	6.7	0	0.00	0	0.00	0
9	46	0.04	27	0	17	1.01	0.13	6.4	5	0.01	0	0.00	0
10	28	0.07	26	0	13	0.83	0.08	6.3	0	0.00	0	0.00	0
mean	51	0.06	27	0	30	1.19	0.24	6.46	8	0.02	0	0.00	0
st. dev.	43.3	0.03	10.5	0	46.4	0.53	0.31	0.66	11.4	0.03	0	0.00	0
95%conf limits (mean +/-)	34.6	0.03	8.48	0	37.1	0.42	0.25	0.53	9	0.02	0	0.00	0
median	38	0.06	28	0	14	0.91	0.09	6.40	5	0.01	0	0.00	0
COV	0.84	0.50	0.39	--	1.55	0.44	1.26	0.10	1.42	1.50	--	--	--
distribution	normal	l-normal	normal	uniform	l-normal	normal	normal	normal	l-normal	normal	uniform	uniform	uniform

NA: Data not available

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TABLE E-3. SAMPLES FROM IRRIGATION OF LANDSCAPED AREAS

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	109	0.98	42.3	0	132.1	6.46	0.28	6.88	5	0.03	0.0	0.00	0.00
2	119	0.93	39.0	0	218.6	9.42	0.24	6.90	15	0.05	0.0	0.00	0.00
3	92	1.65	41.4	0	267.6	3.21	0.55	7.09	15	0.08	0.0	0.00	0.00
4	98	1.94	40.4	0	199.9	6.32	0.40	7.04	10	0.02	0.0	0.00	0.00
5	107	0.97	39.4	0	231.6	5.44	0.41	6.90	10	0.03	0.0	0.00	0.00
6	110	0.81	38.0	0	242.0	6.71	0.37	7.02	13	0.00	0.0	0.00	0.00
7	100	0.93	39.0	0	212.4	6.49	0.31	7.01	10	0.03	0.0	0.00	0.00
8	102	0.89	41.0	0	201.2	4.98	0.48	6.89	7	0.01	0.0	0.00	0.00
9	106	0.91	42.0	0	223.6	5.79	0.35	6.91	5	0.00	0.0	0.00	0.00
10	107	0.98	39.0	0	215.0	6.01	0.32	6.98	10	0.00	0.0	0.00	0.00
mean	105	0.90	40.2	0	214.4	6.08	0.37	6.96	10	0.03	0.0	0.00	0.00
st. dev.	7.28	0.10	1.47	0	35.20	1.56	0.09	0.08	3.62	0.03	0.00	0.00	0.00
95%conf. limits (mean +/-)	5.83	0.08	1.18	0	28.17	1.25	0.07	0.06	2.90	0.02	0.00	0.00	0.00
median	106	0.93	39.9	0	216.80	6.17	0.36	6.95	10	0.03	0.0	0.00	0.00
COV	0.07	0.11	0.04	--	0.16	0.26	0.25	0.01	0.36	1.00	--	--	--
distribution	normal	normal	normal	uniform	normal	normal	normal	bi-modal	normal	normal	uniform	uniform	uniform

NA: Data not available

TABLE E-4. RESIDENTIAL/COMMERCIAL SANITARY SEWAGE SAMPLES

Sample #	Collection Date	Collection Time	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)
1	1-Aug	10 p.m.	265	0.90	149	0.96	240	5.25
2	2-Aug	12 a.m.	320	0.72	161	3.80	200	4.79
3	2-Aiug	2 a.m.	360	0.46	172	0.58	170	3.44
4	2-Aug	4 a.m.	350	0.58	181	0.54	155	3.09
5	2-Aug	6 a.m.	410	0.74	167	0.54	205	4.51
6	2-Aug	8 a.m.	435	0.87	154	0.99	265	5.88
7	2-Aug	10 a.m.	410	1.08	150	0.48	265	5.99
8	2-Aug	12 p.m.	400	0.77	145	3.60	270	5.70
9	2-Aug	2 p.m.	410	0.83	149	0.54	280	7.50
10	2-Aug	4 p.m.	460	0.93	151	0.95	265	7.20
11	2-Aug	6 p.m.	410	0.88	156	0.98	265	6.78
12	2-Aug	8 p.m.	430	0.88	158	0.96	300	7.56
13	4-Aug	6 p.m.	550	0.69	145	4.20	280	7.00
14	4-Aug	8 p.m.	460	0.64	133	4.40	280	6.73
15	4-Aug	10 p.m.	500	0.74	123	0.97	265	6.05
16	5-Aug	12 a.m.	420	0.60	142	0.99	227	4.03
17	5-Aug	2 a.m.	360	0.54	148	0.65	175	3.55
18	5-Aug	4 a.m.	365	0.43	158	0.64	120	4.94
19	5-Aug	6 a.m.	390	0.60	142	0.62	230	7.47
20	5-Aug	8 a.m.	500	1.04	126	0.65	310	7.13
21	5-Aug	10 a.m.	450	0.80	125	0.96	315	6.87
22	5-Aug	12 p.m.	430	0.97	126	0.98	310	6.88
23	5-Aug	2 p.m.	420	0.85	126	0.90	300	7.07
24	5-Aug	4 p.m.	460	0.83	122	0.94	290	7.55
25	6-Aug	6 p.m.	440	0.81	127	2.40	280	7.14
26	6-Aug	8 p.m.	435	0.66	123	1.60	290	6.75
27	6-Aug	10 p.m.	400	0.77	120	0.97	265	6.12
28	7-Aug	12 a.m.	390	0.67	133	0.96	210	5.06
29	7-Aug	2 a.m.	340	0.44	149	0.89	175	3.59
30	7-Aug	4 a.m.	400	0.43	141	0.76	170	3.57
31	7-Aug	6 a.m.	420	0.68	138	0.98	300	6.65
32	7-Aug	8 a.m.	465	1.04	136	0.95	260	5.68
33	7-Aug	10 a.m.	460	0.94	141	3.00	280	6.69
34	7-Aug	12 p.m.	460	0.89	138	3.60	285	6.93
35	7-Aug	2 p.m.	490	0.85	135	4.00	265	7.11
36	7-Aug	4 p.m.	450	0.83	155	2.00	270	6.69
mean			420	0.76	143	1.50	251	5.97
st.dev.			55.14	0.17	15.04	1.22	49.88	1.36
95% conf. limits (mean +/-)			18.01	0.06	4.91	0.40	16.33	0.45
median			420	0.79	142	0.96	265	6.67
COV			0.13	0.23	0.11	0.82	0.20	0.23
distribution			normal	normal	normal	normal	normal	normal

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(continued)

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TABLE E-4. (continued)

Sample #	Collection Date	Collection Time	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	1-Aug	10 p.m.	8.59	7.35	42	0.01	23.8	0.01	0.00
2	2-Aug	12 a.m.	7.25	7.23	10	0.03	29.2	0.00	0.00
3	2-Aiug	2 a.m.	5.02	7.33	12	0.03	30.3	0.00	0.00
4	2-Aug	4 a.m.	5.22	7.24	8	0.01	26.0	0.00	0.00
5	2-Aug	6 a.m.	13.04	7.35	11	0.02	16.3	0.00	0.00
6	2-Aug	8 a.m.	14.23	7.30	12	0.00	23.8	0.00	0.00
7	2-Aug	10 a.m.	13.03	7.17	15	0.01	20.6	0.01	0.00
8	2-Aug	12 p.m.	9.67	6.97	31	0.00	21.7	0.02	0.00
9	2-Aug	2 p.m.	8.00	6.98	28	0.00	15.3	0.00	0.00
10	2-Aug	4 p.m.	8.81	7.12	22	0.00	11.0	0.00	0.00
11	2-Aug	6 p.m.	7.82	7.03	23	0.00	17.4	0.00	0.00
12	2-Aug	8 p.m.	7.32	7.09	21	0.05	19.5	0.01	0.00
13	4-Aug	6 p.m.	10.03	7.21	75	0.00	43.3	NA	NA
14	4-Aug	8 p.m.	9.18	6.94	61	0.03	47.2	NA	NA
15	4-Aug	10 p.m.	11.82	7.10	45	0.00	41.7	NA	NA
16	5-Aug	12 a.m.	11.04	6.89	49	0.00	41.1	NA	NA
17	5-Aug	2 a.m.	6.38	7.10	26	0.02	46.7	NA	NA
18	5-Aug	4 a.m.	6.00	7.05	19	0.01	49.6	NA	NA
19	5-Aug	6 a.m.	12.83	7.16	22	0.00	52.2	NA	NA
20	5-Aug	8 a.m.	19.49	7.06	50	0.01	52.8	NA	NA
21	5-Aug	10 a.m.	12.34	6.88	60	0.00	37.8	NA	NA
22	5-Aug	12 p.m.	10.67	7.00	64	0.00	48.9	NA	NA
23	5-Aug	2 p.m.	8.57	6.98	54	0.01	47.8	NA	NA
24	5-Aug	4 p.m.	9.25	7.06	48	0.00	53.3	NA	NA
25	6-Aug	6 p.m.	11.00	7.03	62	0.02	65.4	NA	NA
26	6-Aug	8 p.m.	9.99	6.98	48	0.04	99.6	NA	NA
27	6-Aug	10 p.m.	10.66	7.01	43	0.10	99.4	NA	NA
28	7-Aug	12 a.m.	8.29	7.06	15	0.03	40.5	NA	NA
29	7-Aug	2 a.m.	5.53	7.13	16	0.00	4.2	NA	NA
30	7-Aug	4 a.m.	5.84	7.13	18	0.01	3.1	NA	NA
31	7-Aug	6 a.m.	17.28	7.16	42	0.02	54.0	NA	NA
32	7-Aug	8 a.m.	15.74	7.18	68	0.00	98.3	NA	NA
33	7-Aug	10 a.m.	10.99	7.03	80	0.00	68.6	NA	NA
34	7-Aug	12 p.m.	10.03	7.08	54	0.00	71.9	NA	NA
35	7-Aug	2 p.m.	7.43	6.86	52	0.01	69.7	NA	NA
36	7-Aug	4 p.m.	8.58	7.11	58	0.03	71.9	NA	NA
mean			9.92	7.09	38	0.01	43.4	0.00	0.00
st.dev.			3.33	0.13	20.95	0.02	25.47	0.01	0.00
95% conf. limits (mean +/-)			1.09	0.04	6.84	0.01	8.32	0.00	0.00
median			9.46	7.09	42	0.01	42.5	0.00	0.00
COV			0.34	0.02	0.55	2.00	0.59	--	--
distribution			L-normal	normal	normal	L-normal	normal	uniform	uniform

NA: Data not available

A006556

TABLE E-5. RESIDENTIAL SEPTIC TANK DISCHARGE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	82	0.75	252	0.03	511	30.06	117.80	7.23	38	0.03	100	NA	NA
2	108	0.70	186	0.00	547	32.06	124.60	7.38	38	0.01	100	NA	NA
3	56	0.62	186	0.00	536	27.26	114.40	7.16	18	0.00	100	NA	NA
4	397	1.19	36	10.00	266	8.16	26.07	6.61	68	0.01	100	NA	NA
5	482	0.70	29	5.00	321	8.83	135.75	6.53	87	0.03	100	NA	NA
6	362	1.12	36	12.00	351	8.16	26.77	6.67	77	0.00	100	NA	NA
7	812	0.92	80	0.50	466	20.85	89.60	6.63	54	0.00	100	NA	NA
8	812	1.55	84	0.15	431	23.25	91.60	6.59	64	0.01	100	NA	NA
9	762	1.26	82	0.57	471	22.25	86.10	6.54	91	0.03	100	NA	NA
10	432	0.61	45	2.50	455	24.51	95.90	7.39	55	0.20	100	0.00	0.00
11	297	0.42	53	1.00	253	18.66	107.80	6.19	10	0.00	100	0.00	0.00
12	236	0.56	61	0.50	463	21.73	99.30	6.59	100	0.19	100	0.40	0.00
13	327	0.87	63	0.45	339	31.81	113.20	6.72	100	0.20	100	0.35	0.00
mean	502	0.93	57	3.27	382	18.82	87.21	6.65	70.60	0.07	100	0.19	0.00
st. dev.	209.87	0.36	20.52	4.35	84.95	7.97	35.11	0.30	27.28	0.09	0.00	0.22	0.00
95%conf. limits (mean +/-)	114.09	0.20	11.16	2.37	46.18	4.33	19.09	0.16	14.83	0.05	0.00	0.12	0.00
median	414	0.90	57	0.79	391	21.29	93.75	6.60	72.50	0.02	100	0.18	0.00
COV	0.42	0.39	0.36	1.33	0.22	0.42	0.40	0.04	0.39	1.28	0.00	1.16	--
distribution	normal	normal	log-normal	log-normal	normal	normal	normal	normal	normal	normal	uniform	bi-modal	uniform

NA: Data not available

TABLE E-6. COMMERCIAL CARWASH SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	448	16.5	145	50.4	1325	22.00	0.28	6.49	380	0.00	100	0.00	0.00
2	450	11.5	149	52.2	1350	22.00	0.32	6.46	340	0.00	100	0.00	0.00
3	550	12.5	152	52.5	1400	78.40	0.20	7.11	190	0.00	100	0.00	0.00
4	490	15.5	150	49.0	1100	40.70	0.23	6.90	190	0.01	100	0.00	0.00
5	495	12.5	158	56.7	1075	47.70	0.19	6.84	190	0.00	100	0.00	0.00
6	470	8.0	160	50.3	1095	35.40	0.14	6.77	240	0.02	100	0.00	0.00
7	480	10.2	172	38.0	1005	48.20	0.23	6.76	200	0.08	100	NA	NA
8	473	11.8	165	49.0	1155	46.20	0.25	6.67	175	0.23	100	NA	NA
9	492	12.3	159	43.5	1190	16.70	0.19	6.40	160	0.12	100	0.00	0.00
10	505	12.2	155	48.0	1205	39.60	0.36	6.80	150	0.15	100	0.00	0.00
mean	485	12.3	157	49.0	1190	42.69	0.24	6.72	222	0.07	100	0.00	0.00
st. dev.	9.41	2.40	8.07	5.14	130.79	15.92	0.07	0.22	77.46	0.08	0.00	0.00	0.00
95%conf. limits (mean +/-)	8.23	1.49	5.00	3.19	81.06	9.87	0.04	0.14	48.01	0.05	0.00	0.00	0.00
median	485	12.3	157	49.7	1173	43.45	0.23	6.77	190	0.05	100	0.00	0.00
COV	0.06	0.19	0.05	0.10	0.11	0.37	0.28	0.03	0.35	1.14	0.00	--	--
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	bi-modal	uniform	uniform	uniform

NA: Data not available

496559

TABLE E-7. COMMERCIAL LAUNDRY SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	752	15.89	32	37.0	1169.6	3.47	0.94	9.37	25	0.57	100	NA	NA
2	462	23.98	40	21.5	1144.6	3.97	0.96	9.40	59	0.51	100	NA	NA
3	422	54.48	38	17.0	844.6	3.37	0.62	8.37	61	0.44	100	NA	NA
4	589	42.48	36	32.5	819.6	3.67	0.70	8.60	43	0.38	100	NA	NA
5	657	48.98	34	35.0	1169.6	3.57	0.84	9.10	49	0.21	100	NA	NA
6	565	31.48	37	31.0	1094.6	3.27	0.91	9.20	30	0.33	100	NA	NA
7	485	22.48	38	20.0	994.6	3.77	0.78	9.41	55	0.42	100	NA	NA
8	715	26.98	33	25.0	1019.6	2.57	0.88	9.05	38	0.47	100	0.00	0.00
9	545	35.98	32	24.0	1019.6	3.67	0.69	9.36	57	0.33	100	0.00	0.00
10	437	25.48	37	26.0	969.9	3.47	0.84	9.12	50	0.35	100	0.00	0.00
mean	563	32.82	36	26.9	1024.6	3.48	0.82	9.10	47	0.40	100	0.00	0.00
st. dev.	115.81	12.45	2.78	6.69	124.61	0.38	0.12	0.35	12.41	0.10	0.00	0.00	0.00
95%conf. limits (mean +/-)	68.44	7.36	1.64	3.96	73.64	0.22	0.07	0.21	7.33	0.06	0.00	0.00	0.00
median	555	29.23	37	25.5	1019.6	3.52	0.84	9.16	50	0.40	100	0.00	0.00
COV	0.21	0.38	0.08	0.25	0.12	0.11	0.14	0.04	0.27	0.26	0.00	--	--
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	normal	uniform	uniform	uniform

NA: Data not available

TABLE E-8. RADIATOR WASTE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	4250	136.5	0	17.4	20850	3230	16.9	6.95	2933	0.04	100	NA	NA
2	3350	177.0	0	13.8	24000	2446	32.4	6.99	3000	0.02	100	NA	NA
3	4200	172.5	32	14.7	20500	3473	21.0	6.25	3066	0.06	100	NA	NA
4	3321	133.3	12	14.2	21940	2694	18.1	7.01	3000	0.03	100	NA	NA
5	3289	129.8	0	15.1	22210	2902	22.3	6.85	3000	0.04	100	NA	NA
6	3510	121.5	12	18.3	22240	2907	12.2	6.50	3000	0.00	100	NA	NA
7	1900	183.0	0	13.5	22650	2282	8.9	7.61	2933	0.03	100	NA	NA
8	2510	124.5	0	13.5	22250	2364	90.1	7.38	3000	0.03	100	NA	NA
9	2987	170.1	0	14.6	21920	2899	23.8	6.98	3066	0.02	100	NA	NA
10	3466	145.0	0	15.3	21900	2821	17.5	7.11	3000	0.03	100	NA	NA
mean	3278	149.3	5.6	15.04	22046	2801	26.3	6.96	3000	0.03	100	NA	NA
st. dev.	704.32	23.76	10.53	1.62	952.08	374.89	23.32	0.39	44.33	0.02	0.00	NA	NA
95%conf. limits (mean +/-)	436.54	14.73	6.53	1.00	590.10	323.36	14.45	0.24	27.48	0.01	0.00	NA	NA
median	3335	140.8	0	14.65	22075	2864	24.5	6.99	3000	0.03	100	NA	NA
COV	0.21	0.16	1.88	0.11	0.04	0.13	0.89	0.06	0.01	0.52	0.00	NA	NA
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	normal	uniform	NA	NA

NA: Data not available

TABLE E-9. PLATING BATH WASTE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	16200	9.00	1408	15.0	640.0	774	105.00	1.78	60	0.12	100	0.27	0
2	3620	1.68	950	1.8	505.0	552	74.20	4.82	90	0.27	100	0.00	0
3	8500	1.86	775	10.0	77.5	1730	3.05	5.20	368	0.01	89.4	0.00	0
4	9700	6.00	1452	9.0	225.0	186	139.37	6.15	70	0.08	100	0.21	0
5	10200	5.52	1476	11.4	390.0	220	29.33	3.36	90	0.00	100	0.32	0
6	7000	5.85	1818	1.5	88.0	490	76.00	8.60	50	0.04	68.4	0.07	0
7	8000	6.00	2433	1.6	75.0	356	58.60	7.60	50	0.03	90.5	0.05	0
8	12500	7.95	1484	6.9	510.5	380	60.90	3.10	75	0.02	100	0.35	0
9	8100	4.20	1398	3.9	147.5	1100	101.00	2.50	110	0.00	100	0.48	0
10	19700	3.20	1091	7.0	275.0	4300	9.05	6.20	75	0.19	100	0.00	0
mean	10352	5.13	1429	6.8	293.4	1009	65.65	4.93	104	0.08	94.8	0.18	0.00
st. dev.	4681.35	2.41	464.03	4.63	206.61	1247.85	43.37	2.25	94.71	0.09	10.15	0.17	0.00
95%conf. limits (mean +/-)	2901.53	1.49	287.61	2.87	128.06	773.42	26.88	1.39	58.70	0.06	6.29	0.11	0.00
median	9100	5.69	1430	6.9	250.0	521	67.55	5.01	75	0.04	100	0.14	0.00
COV	0.45	0.47	0.32	0.68	0.70	1.24	0.66	0.46	0.91	1.20	0.11	0.94	--
distribution	normal	normal	normal	normal	normal	log-normal	normal	normal	normal	normal	bi-modal	uniform	uniform

165351

TABLE E-10. MANN-WHITNEY U TEST ALPHA VALUES FOR CONDUCTIVITY

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0002	0.0000	0.0002	0.0002	0.0002	0.0036	0.0257	0.0002
RADIATOR			0.0002	0.0000	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003
SPRING				0.0000	0.0012	0.0002	0.0002	0.0002	0.0002	0.0001
SEWAGE					0.9894	0.0002	0.0004	0.0001	0.0001	0.0000
SEPTAGE						0.2413	0.2730	0.0014	0.0014	0.0002
LAUNDRY							0.2413	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0233	0.0014
SHALLOW GROUND										0.0014
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

A065562

TABLE E-11. MANN-WHITNEY U TEST ALPHA VALUES FOR FLUORIDE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0001	0.4727	0.0002	0.0002	0.1289	0.0014	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0348	0.0001
SEWAGE					0.2308	0.0000	0.0000	0.0094	0.0001	0.0000
SEPTAGE						0.0002	0.0002	0.8501	0.0014	0.0002
LAUNDRY							0.0002	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0051	0.0014
SHALLOW GROUND										0.0014
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-12. MANN-WHITNEY U TEST ALPHA VALUES FOR HARDNESS

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0000	0.4727	0.0001	0.0002	0.0002	0.0002	0.0002
RADIATOR			0.0002	0.0000	0.0002	0.0001	0.0002	0.0002	0.0019	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0002	0.0011	0.0127
SEWAGE					0.0000	0.0000	0.0046	0.0000	0.0000	0.0000
SEPTAGE						0.0265	0.0002	0.1405	0.0022	0.0002
LAUNDRY							0.0001	0.0008	0.0346	0.0001
CARWASH								0.0002	0.0002	0.0002
IRRIGATION									0.0013	0.0002
SHALLOW GROUND										0.0002
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

A066561

TABLE E-13. MANN-WHITNEY U TEST ALPHA VALUES FOR DETERGENT

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0001	1.0000	0.0000	0.0001	0.0001	0.0001	0.8919	0.8919	0.0001
RADIATOR			0.0001	0.0000	0.0002	0.0003	0.0002	0.0008	0.0008	0.001
SPRING				0.0000	0.0001	0.0001	0.0001	0.8919	0.8919	0.0001
SEWAGE					0.7798	0.0000	0.0000	0.0000	0.0000	0.0001
SEPTAGE						0.0002	0.0002	0.0008	0.0008	0.0494
LAUNDRY							0.0002	0.0008	0.0008	0.0002
CARWASH								0.0008	0.0008	0.0002
IRRIGATION									1.0000	0.0008
SHALLOW GROUND										0.0008
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

A95951

TABLE E-14. MANN-WHITNEY U TEST ALPHA VALUES FOR FLUORESCENCE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0290	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0057	0.0001
SEWAGE					0.0002	0.0000	0.0000	0.0813	0.0001	0.9257
SEPTAGE						0.0002	0.0002	0.0029	0.0014	0.3447
LAUNDRY							0.0173	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0082	0.7042
SHALLOW GROUND										0.0057
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-15. MANN-WHITNEY U TEST ALPHA VALUES FOR POTASSIUM

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0000	0.0002	0.0002	0.0002	0.0002	0.1571	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0002	0.0142	0.0028
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0293	0.0001
SEWAGE						0.0001	0.0000	0.5314	0.0048	0.0000
SEPTAGE						0.0002	0.0017	0.0040	0.0008	0.0002
LAUNDRY							0.0002	0.0262	0.0142	0.0002
CARWASH								0.0014	0.0282	0.0002
IRRIGATION									0.0008	0.0014
SHALLOW GROUND										0.0008
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-16. MANN-WHITNEY U TEST ALPHA VALUES FOR AMMONIA

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0025	0.0000	0.0002	0.0002	0.0002	0.0002	0.0008	0.0002
RADIATOR			0.0001	0.0001	0.0010	0.0002	0.0002	0.0002	0.0008	0.0640
SPRING				0.0000	0.0001	0.0001	0.0001	0.0001	0.0007	0.0001
SEWAGE					0.0000	0.0000	0.0000	0.0000	0.0000	0.0010
SEPTAGE						0.0002	0.0002	0.0002	0.0008	0.2413
LAUNDRY							0.0002	0.0002	0.2049	0.0002
CARWASH								0.0125	0.4469	0.0002
IRRIGATION									1.0000	0.0014
SHALLOW GROUND										0.0142
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

A99558

TABLE E-17. MANN-WHITNEY U TEST ALPHA VALUES FOR pH

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.5708	1.0000	0.0007	0.0211	0.0002	0.0211	0.7863	0.2888	0.0376
RADIATOR			0.7513	0.1224	0.0640	0.0002	0.0494	1.0000	0.2293	0.0211
SPRING				0.0008	0.0022	0.0001	0.0035	0.6511	0.1704	0.0221
SEWAGE					0.0001	0.0000	0.0000	0.0355	0.1095	0.0042
SEPTAGE						0.0002	0.2899	0.0108	0.2888	0.0312
LAUNDRY							0.0002	0.0014	0.0058	0.0003
CARWASH								0.0197	0.2031	0.0257
IRRIGATION									0.2410	0.0577
SHALLOW GROUND										0.1573
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-18. MANN-WHITNEY U TEST ALPHA VALUES FOR CHLORINE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0008	0.0001	0.0000	0.0025	0.2730	0.0013	0.0040	0.0029	0.0022
RADIATOR			0.0008	0.0058	0.6501	0.0002	0.7913	0.9136	0.4159	0.6232
SPRING				0.0648	0.0317	0.0001	0.0620	0.0014	0.0875	0.0060
SEWAGE					0.1621	0.0000	0.1359	0.0441	0.4291	0.0184
SEPTAGE						0.0002	0.9699	0.8283	0.7042	0.6501
LAUNDRY							0.0002	0.0014	0.0014	0.0002
CARWASH								0.7863	0.4808	0.7624
IRRIGATION									0.4712	0.7042
SHALLOW GROUND										0.3028
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

A006570

TABLE E-19. MANN-WHITNEY U TEST ALPHA VALUES FOR TOXICITY

	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING	NEUTRALIZED TAP
TAPWATER	0.0002	0.0001	0.5314	0.0002	0.0002	0.0002	0.0014	0.0014	0.002	0.0058
RADIATOR		0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.3787	0.0001
SPRING			0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0001	0.0001
SEWAGE				0.0000	0.0000	0.2716	0.0000	0.0000	0.0000	0.0535
SEPTAGE					1.0000	0.2696	0.0000	0.0000	0.3787	0.0001
LAUNDRY						0.7989	0.0000	0.0000	0.3787	0.0001
CARWASH							0.0000	0.0000	0.3787	0.0001
IRRIGATION								1.0000	0.0008	0.0008
SHALLOW GROUND									0.0008	0.0008
PLATING										0.0002

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-20. MANN-WHITNEY U TEST ALPHA VALUES FOR COPPER

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		*	0.2696	0.8501	0.665	0.4705	1.0000	0.3374	0.594	0.1376
RADIATOR			*	*	*	*	*	*	*	*
SPRING				0.2716	0.2696	0.7341	1.0000	0.8973	0.4777	0.0209
SEWAGE					0.5083	0.5083	0.2716	0.3531	0.7210	0.0570
SEPTAGE						0.4706	0.2696	0.3374	0.4555	1.0000
LAUNDRY							0.7989	0.9151	0.7491	0.0897
CARWASH								0.9485	0.4777	0.0209
IRRIGATION									0.5752	0.0393
SHALLOW GROUND										0.0577
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference
* = unknown

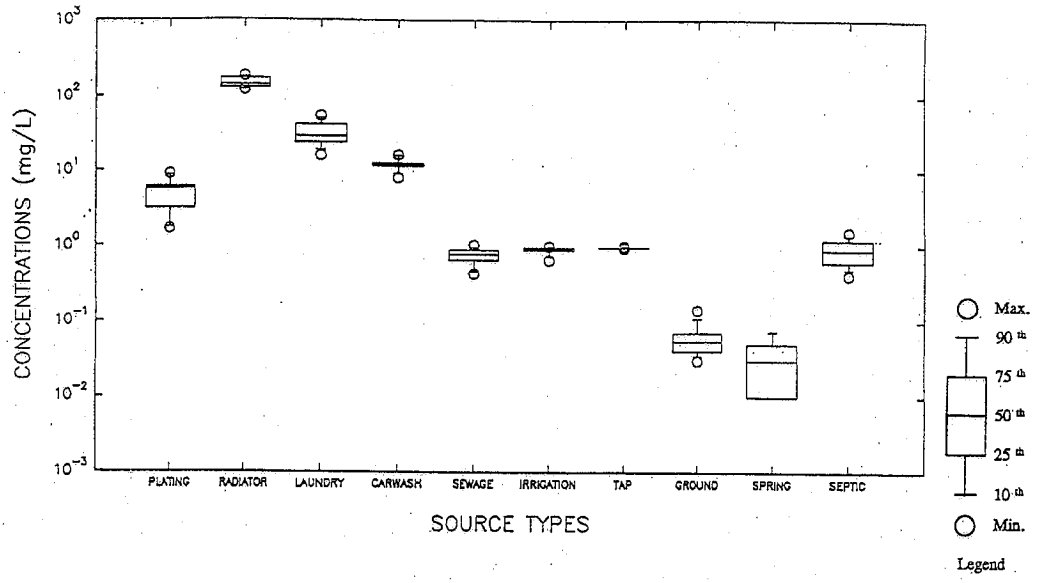

Figure E-1. Fluoride comparisons for different source area flows.

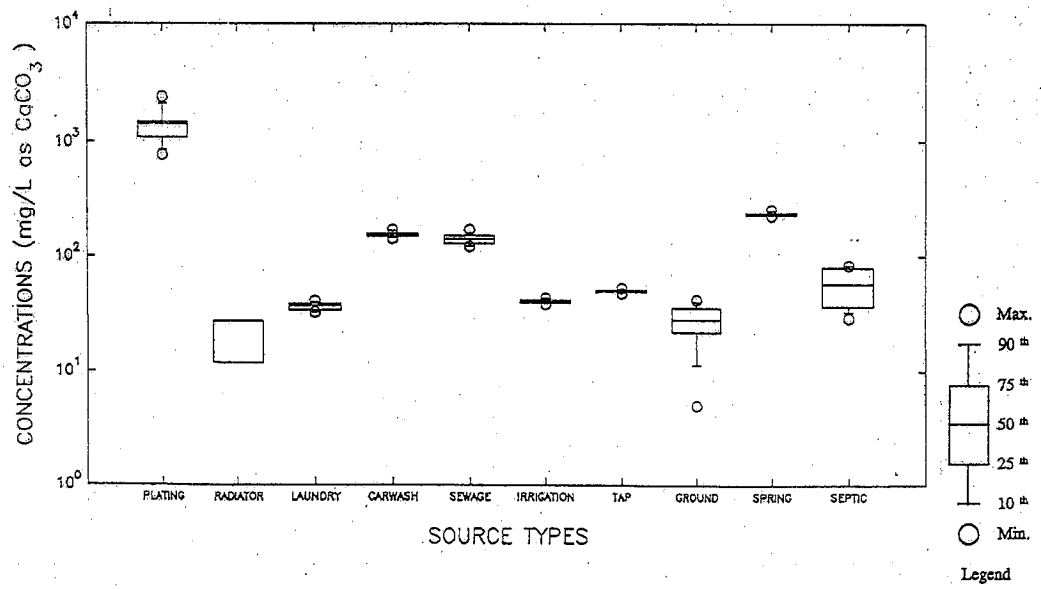

Figure E-2. Hardness comparisons for different source area flows.

A006573

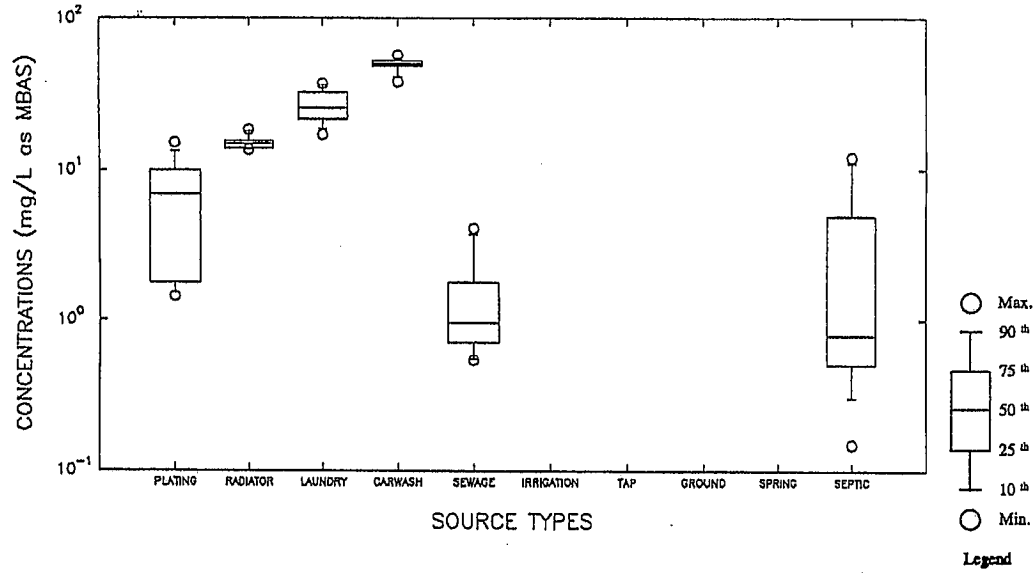

Figure E-3. Detergent comparisons for different source area flows.

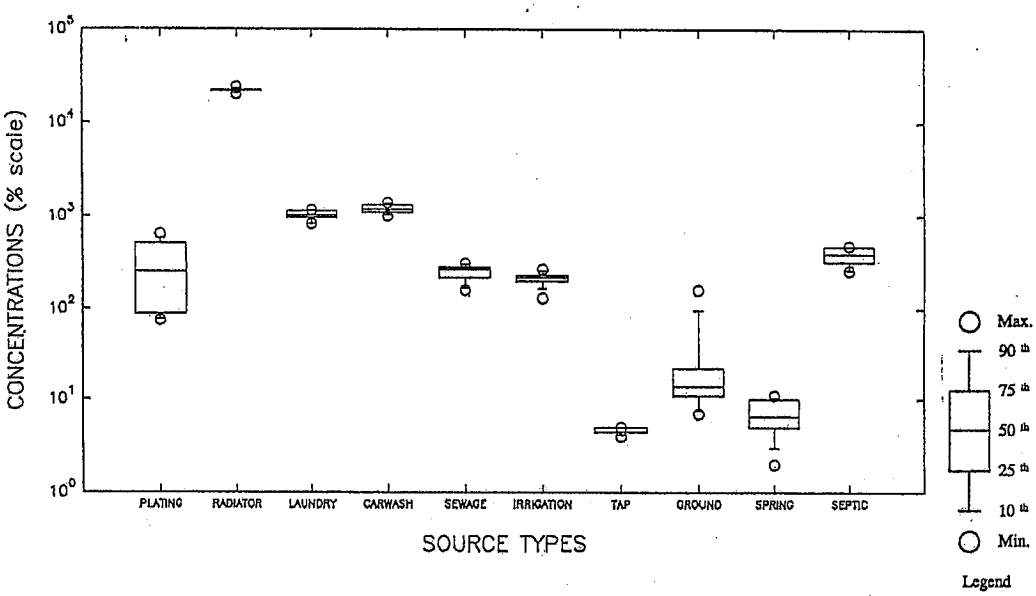

Figure E-4. Fluorescence comparisons for different source area flows.

A006574

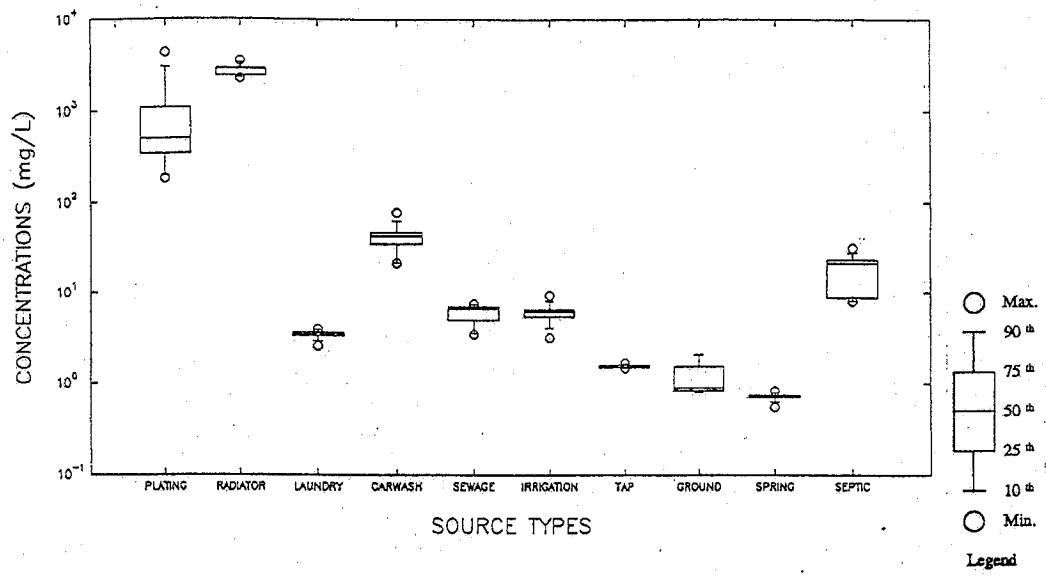

Figure E-5. Potassium comparisons for different source area flows.

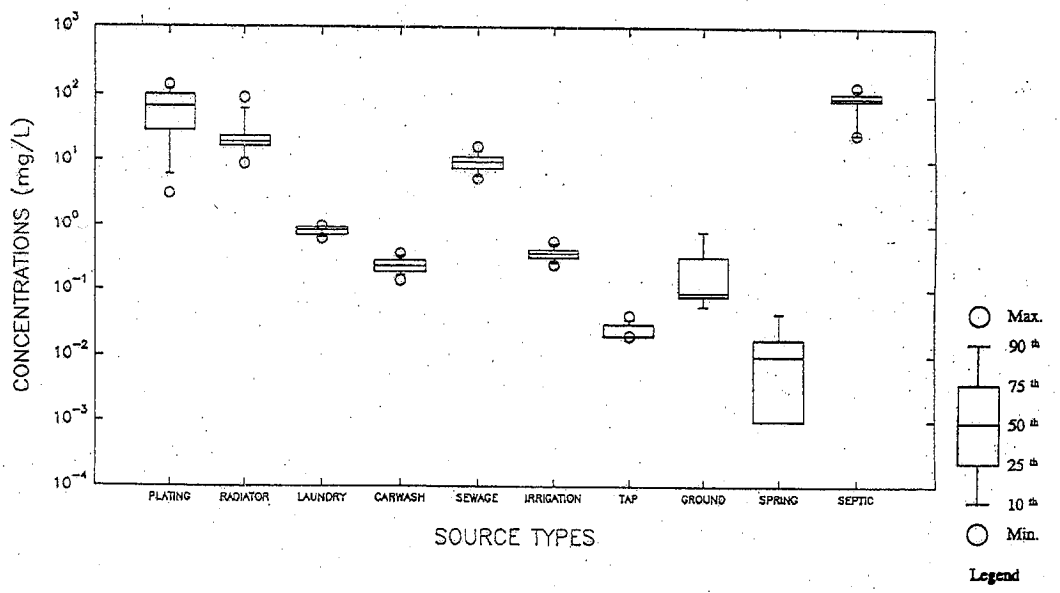

Figure E-6. Ammonia comparisons for different source area flows.

A005575

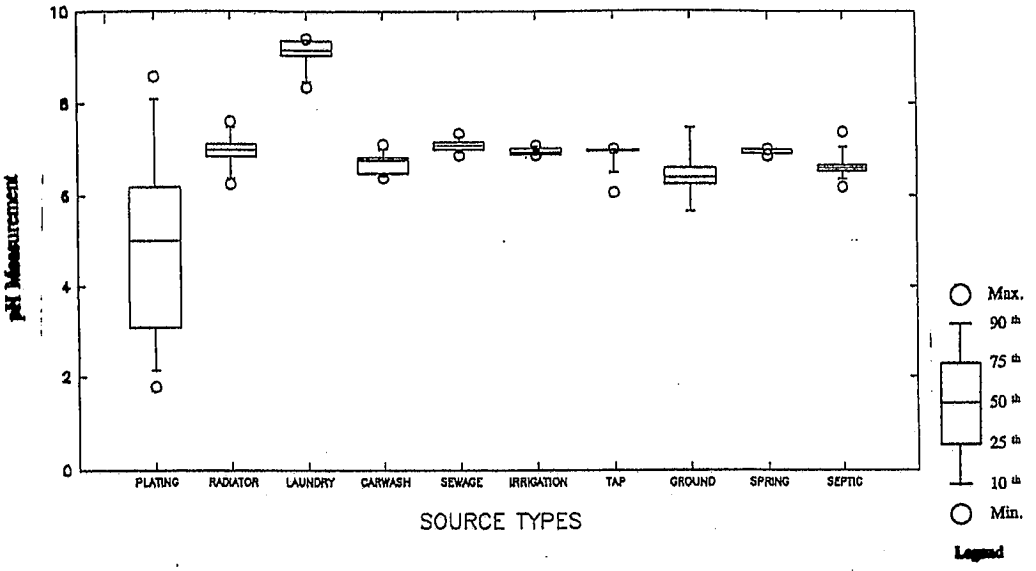

Figure E-7. pH comparisons for different source area flows.

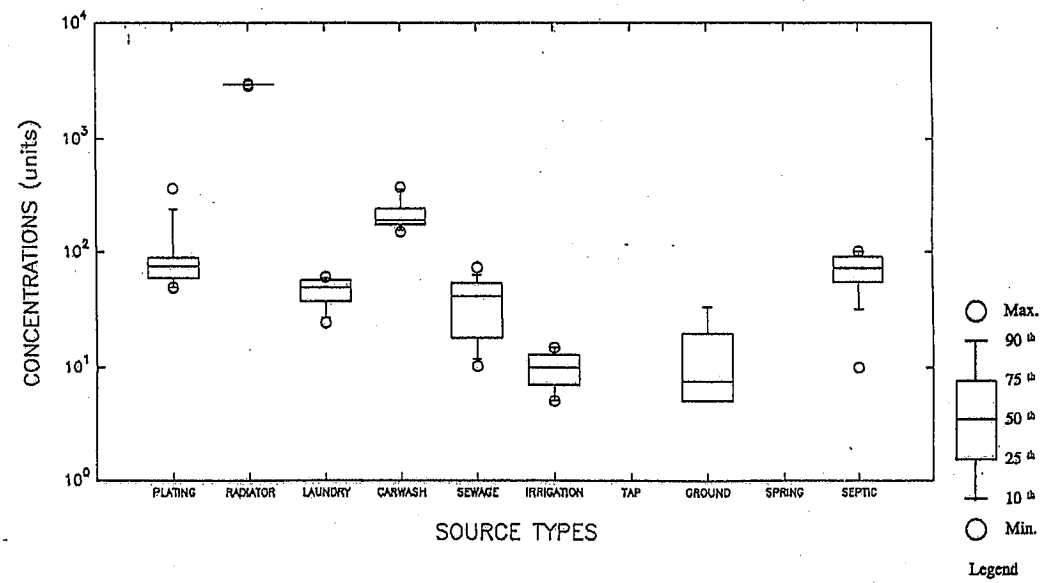

Figure E-8. Color comparisons for different source area flows.

A006576

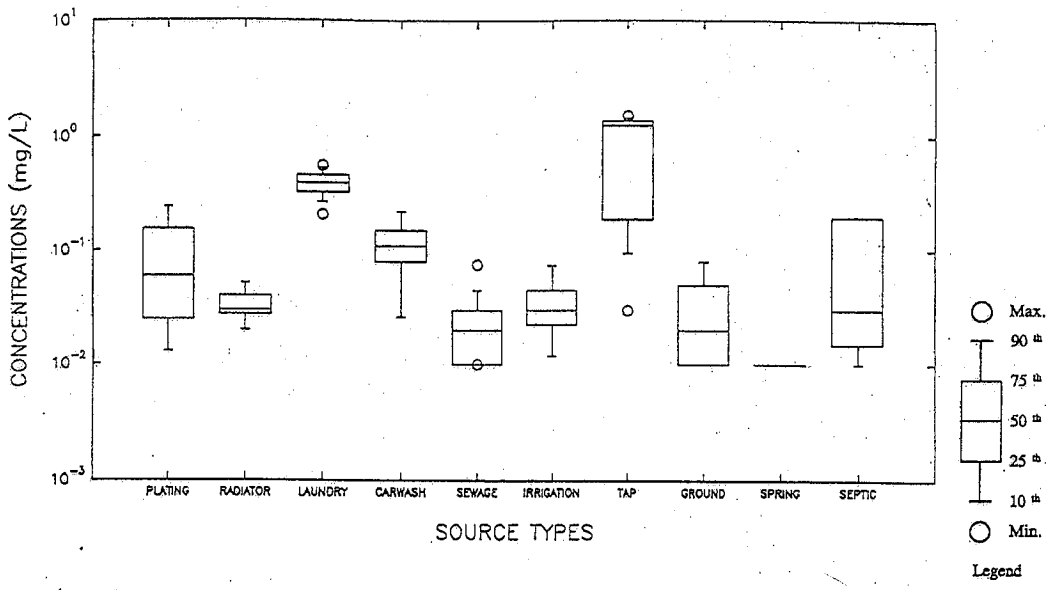

Figure E-9. Chlorine comparisons for different source area flows.

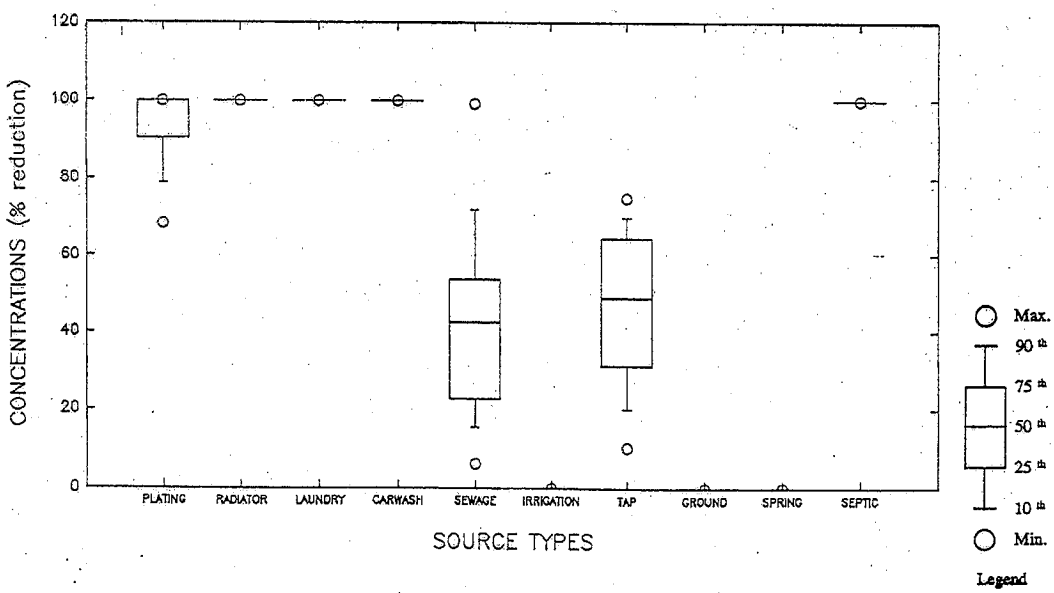

Figure E-10. Microtox comparisons for different source area flows.

A006577

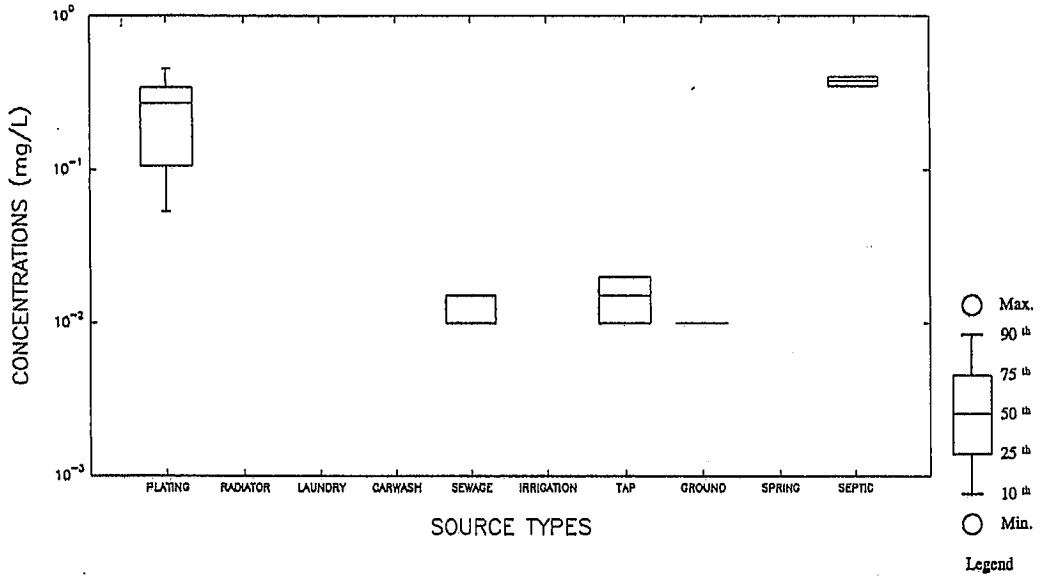

Figure E-11. Copper comparisons for different source area flows.

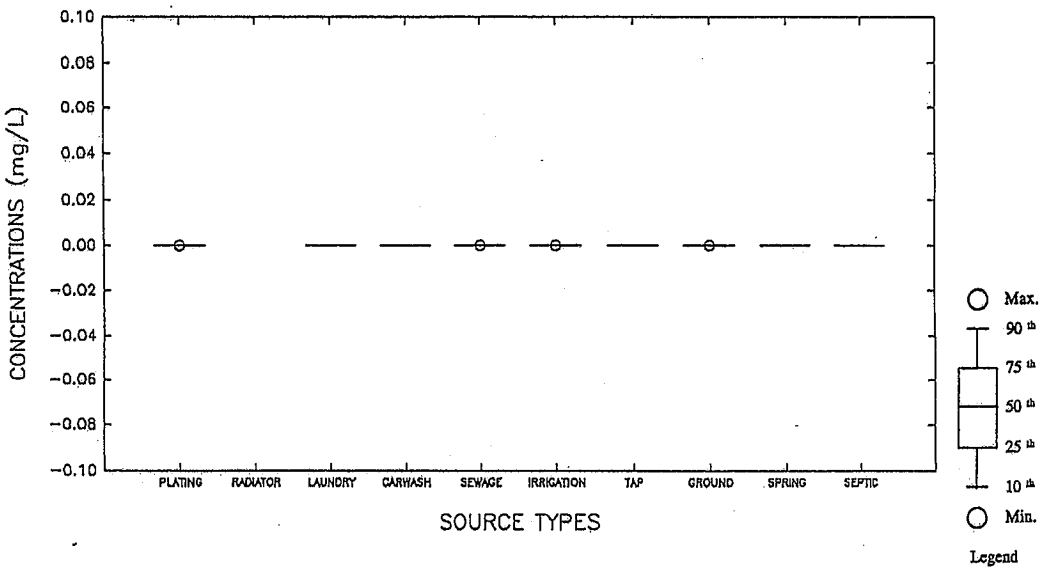

Figure E-12. Phenol comparisons for different source area flows.

A006578

Appendix F
Outfall Sample Analytical Results for Birmingham, AL, Verification Tests

A006579

Table F-1. Analysis Results for Outfall Samples

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
14	9/18/90	0.22	375	0.07	195	0	12	0.65	0	7.07	0	0	0		
	1/15/91	0.35	325	0.05	250	0	7	0.6	0	6.98	0	0			
	3/26/91	drip	372	0.07	208	0	13	0.67	0	7.1	0	0			
	4/17/91	drip													
	6/18/91	drip													
	7/25/91	drip													
	10/15/91	drip													
	9/15/92	drip													
*	3/3/93	drip	327	0.04	240	0	9	0.69	0	7.01	0	0	0	0	0
14z	9/18/90	ND													
	1/15/91	ND													
	3/26/91	ND													
	4/17/91	ND													
	6/18/91	18.7	255	0.26	205	0	10	0.86	0	8.16	0	0.01	28.1	0	0
	7/25/91	none													
	10/15/91	none													
	9/15/92	none													
16	9/18/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	0.1	329	0.05	245	0	8	0.58	0	6.96	0	0	0	0	0
	7/25/91	none													
	10/25/91	none													
	9/15/92	none													

A95599

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
20	9/24/90	11.7	175	0.92	83	0	38	2.48	0.01	7.55	0	0.01	0		
	1/15/91	12.4	160	0.8	79	0.02	25	2.1	0.12	7.29	0	0			
	3/26/91	18.7	180	0.83	90	0	32	2.68	0.01	7.48	0	0			
	4/17/91	26	240	0.73	111	0	30	2.02	0.14	7.34	0	0.02	5.2		
	6/18/91	70.1	330	0.69	165	0	12	2.7	0.1	7.59	0	0.01			
	7/25/91	74.8	335	0.66	180	0	10	2.86	0.07	7.67	0	0.04			
	10/15/91	10.1	164	0.84	81	0	27	2.05	0.03	7.33	0	0	4.1		
	9/15/92	33	200	0.67	115	0	57	2.15	0.01	7.39	0	0.01		0	0
*	3/3/93	21.4	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	2.4	0	0
21	9/24/90	2.3	305	2.39	38*	9.5	262	3.46	0.06	7.24	65	0.02	72.4		
	1/15/91	3	310	2.5	int	10.1	300	3.75	0.08	7.18	60	0			
	3/26/91	3.1	285	2.3	int	9.7	295	4.02	0.03	7.2	60	0.01			
	4/17/91	drip													
	6/18/91	none													
	7/25/91	none													
	10/15/91	2.9	415	3	int	15.7	350	4.98	0.13	7.19	100	0.07	99.9	0.03	0.04
*	9/15/92	3.5	480	2.8	85	20	491	5.08	0.11	7.04	120	0.09	99.9	0.04	0.03
22	9/24/90	1	175	2.73	58*	9.5	89	1.74	0.04	6.95	25	0.27	89		
	1/15/91	1	213	2.61	int	10	97	2.98	0.07	6.91	22	0.21			
	3/26/91	1	195	2.5	int	9.7	80	3.26	0.06	7.01	20	0.2			
	4/17/91	drip													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/15/92	3	130	1.69	63	14	99	3.79	0.07	6.99	22	0.25	99.9	0.03	0
24	9/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/15/92	0.1	190	0	59	0	160				180			0	0

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Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
26	9/24/90	112.2	380	0.08	243	0	9	0.74	0.01	7.8	0	0	0		
	1/15/91	120	385	0.07	240	0	9.5	0.71	0	7.78	0	0			
	3/26/91	84.2	360	0.07	245	0	7	0.8	0	7.8	0	0			
	4/17/91	74.8	350	0.09	231	0	10	0.75	0.01	7.71	0	0.01			
	6/18/91	94.6	382	0.09	238	0	9.5	0.8	0	7.82	0	0.01			
	7/25/91	105.2	385	0.1	222	0	9	0.86	0	7.92	0	0			
	10/15/91	150	341	0.03	235	0	11	0.79	0	7.75	0	0.01	0		
	9/15/92	185	321	0	216	0	14	0.81	0	7.72	0	0	0	0	0
*	3/3/93	142	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0	0
28	9/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	none													
	7/25/91	15.6	490	0.81	242	0.43	128	5.64	2.6	7.48	26	0.04			
	10/15/91	none													
*	9/15/92	9.35	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	5.9	0	0
29z	9/24/90	ND													
	1/15/91	4.5	130	0.52	50	0	9	1.88	0.02	7.55	0	0.05			
	3/26/91	4.2	153	0.61	52	0	12	1.61	0.01	7.44	0	0.12			
	4/17/91	3.1	140	0.36	45	0	11.5	1.76	0.01	7.36	0	0.16			
	6/18/91	5.2	139	0.98	58	0	8	1.87	0.02	7.81	0	0.06			
	7/25/91	6.23	135	1.04	46	0	10	1.94	0.02	7.97	0	0.08			
	10/15/91	6.5	142	0.98	49	0	12	1.88	0.03	7.83	0	0.1			
	9/17/92	6	138	0.97	47	0	9	1.65	0.02	7.77	0	0.09			

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Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
31	9/24/90	1.6	130	1.34	56	0	23	2.49	0.01	8.04	5	0	0		
	1/15/91	5.8	207	0.98	132	1	25	1.52	0.05	7.91	0	0.03			
*	3/26/91	4.2	165	1.13	34	18	235	2.96	0.24	8.34	25	0.19			
	4/17/91	6.2	210	1.03	103	0.05	14	1.45	0.03	7.8	0	0.01			
	6/18/91	drip													
	7/25/91	-	185	1.2	75	0.11	25	4.18	0.04	7.74	10	0.02			
	10/15/91	drip													
	9/17/92	0.05	213	1	168	0.95	23	3.01	0.21	7.98	15	0.14		0.04	0
38	10/24/90	0.1	293	0.12	185	0	32	1.4	0.01	7.91	0	0	0		
	1/15/91	'0.4	301	0.09	221	0	40	1.62	0.02	7.89	0	0			
	3/26/91	0.3	295	0.15	178	0	42	1.52	0.03	7.87	0	0			
	4/17/91	0.3	320	0.3	220	0	39.5	2.3	0.02	8.02	0	0.01			
	6/18/91	1.2	307	0.21	219	0	34.5	1.4	0.01	7.91	0	0.02			
	7/25/91	1.6	310	0.2	188	0	37	3.7	0.03	7.82	0	0			
	10/15/91	0.3	313	0.14	197	0	36	1.69	0.02	7.87	0	0			
	9/17/92	0.2	299	0.17	214	0	39	1.97	0.01	7.93	0	0			
39	10/24/90	0.05	255	0.33	188	0	20.5	0.99	0.02	8.1	40	0.01	0		
	1/15/91	0.08	273	0.19	162	0	20	0.87	0.07	8.08	25	0			
	3/26/91	0.02	340	0.18	177	0	18.5	0.98	0.03	8.14	20	0.01			
	4/17/91	none													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/17/92	none													
40	10/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	16.6	326	0.21	158	0	59.5	1.76	0.2	7.96	10	0.01			
	6/18/91	4.1	299	0.32	163	0.2	87.5	3.98	0.39	7.74	40	0.01			
	7/25/91	4.7	345	0.34	167	0.23	102.4	4.07	0.47	7.76	46	0.01			
	10/15/91	none													
	9/17/92	4.6	370	0.12	220	0.35	86	2.91	0.15	7.81	45	0.01		0	0

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (%scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
40z	10/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
*	6/18/91	1	340	0.12	184	0.2	26.5	0.94	0.87	7.42	20	0			
	7/25/91	none													
	10/15/91	none													
	9/17/92	none													
42	10/24/90	149.6	390	0.22	220	0	14	1.6	0.01	7.9	10	0.01	0		
	1/15/91	149.6	387	0.16	217	0	12	1.59	0	7.87	0	0			
	3/26/91	74.8	365	0.14	205	0	9	1.65	0	7.82	0	0			
	4/17/91	74.8	380	0.14	195	0	10	1.46	0	7.87	0	0.01			
	6/18/91	149.6	372	0.13	211	0	10	1.49	0	7.85	0	0			
	7/25/91	56.1	395	0.15	226	0	11	1.47	0	7.79	0	0			
	10/15/91	-	352	0.1	233	0	11	0.9	0	7.71	0	0	0		
	9/17/92	49.9	375	0.06	230	0	8	0.73	0	7.68	0	0.01		0	0
*	3/5/93	60.2	361	0.07	228	0	6	0.81	0	7.72	0	0			
45	10/24/90	none													
	1/15/91	none													
	3/26/91	0.2	312	0.12	184	0	6.8	1	0	7.72	0	0			
	4/17/91	2.1	300	0.13	176	0	5.5	1.07	0.01	7.56	0	0			
	6/18/91	2.9	220	0.07	98	0	18	0.82	0.04	7.24	0	0			
	7/25/91	2.3	330	0.13	186	0	7.1	1.19	0	7.8	0	0			
	10/15/91	none													
	9/17/92	none													

F95564

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (%scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
48	10/24/90	146.8	340	0.12	192	0	12	1.07	0.01	8	12	0	0		
	1/15/91	152	345	0.08	193	0	11	0.99	0	7.83	0	0			
	3/26/91	146.4	348	0.07	187	0	9	0.86	0	7.91	0	0			
	4/17/91	168.3	345	0.01	173	0	7.2	0.84	0	7.82	0	0			
	6/18/91	146.4	351	0.09	189	0	9	0.98	0	7.87	0	0			
	7/25/91	280.5	410	0.53	161	3.2	163.5	4.4	5.62	7.54	15	0.01			
*	8/2/91	301	482	0.53	162	5	245		10.46	7.33	32	0			
	10/15/91	320	469	0.48	158	3.6	225		5.27	7.27	27	0.01			
	9/17/92	146.4	339	0.08	196	0	10	0.98	0	7.8	0	0	0	0	0
52	10/31/90	62.3	355	0.16	216	0.3	25	1.9	1.1	7.63	0	0.01	0		
	1/15/91	37.4	368	0.18	210	0.4	28	1.68	0.31	7.78	0	0			
	3/26/91	37.4	362	0.16	213	0.2	21	1.62	0.3	7.82	0	0			
	4/17/91	28.1	400	0.15	209	0.3	17.5	1.58	0.35	7.96	0	0.01			
	6/18/91	37.4	372	0.16	217	0.33	27.5	1.66	0.37	7.81	0	0			
	7/25/91	112.2	420	0.06	233	0.18	lost	lost	lost	7.84	5	0			
	10/15/91	37.4	358	0,07	221	0	21	1.64	0.32	7.78	0	0			
	9/21/92	56.1	335	0.1	233	0	25	1.59	0.28	7.83	5	0.01		0	0
53	10/31/90	sub	230	0.84	115	0.1	25	2.04	0.73	7.79	0	0.51	93.6		
	1/15/91	sub													
	3/26/91	sub													
	4/17/91	sub	301	0.18	1.39	0.1	21.5	1.54	0.32	8.05	0	0.15			
	6/18/91	sub													
	7/25/91	28.1	330	0.23	167	2		1.57	0.19	7.94	5	0.02			
	10/15/91	sub													
	9/21/92	sub													
60	10/31/90	18.7	497	0.28	327	0	72.5	1.9	0.01	8.16	0	0.01	0		
	1/15/91	12.2	352	0.1	278	0	43	0.93	0.01	7.89	0	0			
	3/26/91	37.4	360	0.07	282	0	46	0.86	0.01	7.86	0	0			
	4/17/91	56.1	415	1.13	188	1.3	51.5	0.89	0.02	7.91	0	0.01			
	6/18/91	78.6	382	0.67	182	0.8	53	0.91	0.01	7.69	0	0			
	7/25/91	34	359	0.14	211	0.5	58	1.35	0	8.3	0	0.02			
	10/15/91	15.6	361	0.09	247	0	48	0.81	0	7.72	0	0			
	9/21/92	19.8	305	0.12	211	0	67	0.84	0	7.85	15	0		0.02	0

999585

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
60a	10/31/90	ND													
	1/15/91	none													
	3/26/91	none													
*	4/17/91	2.7	197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0	0
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/21/92	1.5	280	0.61	175	0	97	2.99	0.31	7.28	10	0	0	0.03	0
64	11/14/90	84.2	335	0.16	234	0	41	1.62	0.01	7.86	20	0.01	0		
	1/15/91	58	310	0.09	210	0	15	0.99	0	7.35	0	0			
	3/26/91	168.3	295	0.1	172	0	37	1.35	0	7.28	0	0			
	4/17/91	326.6	210	0.16	192	0	22	1.4	0.01	7.2	0	0.01			
	6/18/91	450	250	0.04	101	0	41	1.03	0.08	7.01	5	0			
	7/25/91	74.8	350	0.07	228	0	9	0.87	0	7.22	5	0.01			
	10/15/91	35	298	0.05	239	0	11	0.76	0.01	7.12	0	0			
	9/21/92	30	312	0.11	213	0	17	0.89	0.02	7.25	5	0		0	0
65	11/14/90	62.3	225	0.87	137	0	52	2.26	0.01	7.74	30	0.01	22		
	1/15/91	60		0.39	121	0	62	2.69	0	7.98	20	0.01			
	3/26/91	187	290	0.42	118	0	59	1.71	0	8.23	25	0.02			
	4/17/91	598.4	330	0.34	122	0	53	1.5	0.01	8.25	5	0.02			
	6/18/91	620		0.28	138	0	43	1.3	0	7.92	0	0.01			
	7/25/91	124.7	375	0.37	174	0	61	1.63	0	8.12	20	0.02			
	10/15/91	65		0.38	110	0	72	1.81	0.02	8.28	25	0.02			
	9/21/92	60	330	0.18	119	0	68	1.72	0.01	8.31	25	0.02		0	0

Notes: * in outfall column marks sample collected when source of flow was confirmed
ND in flow column mean not detected at that time
"sub" refers to a submerged outfall

A005536

Examination of All Village Creek, Birmingham, AL, Outfall Data Using Alternative Evaluation Tools

Introduction

An evaluation of all of the Birmingham Village Creek data was conducted by Kimberly Brown, a UAB graduate student, and summarized in the following discussion. The purpose of the work described here was to (1) determine the consistency of the three main methods in identifying non-stormwater pollutants at outfalls, (2) determine the variability of flow among outfalls and the variability of non-stormwater pollutants indicated by the three methods among outfalls, (3) examine the relationship of rainfall history to non-stormwater pollutants indicated at outfalls, and (4) determine the sampling frequency needed for an adequate inappropriate discharge screening program.

A data analysis of dry-weather storm drainage outfalls was done to identify problem outfalls (outfalls affected by non-stormwater entries) and correlate them with potential sources and to identify which outfalls need further analyses and investigations. Several methods of data analyses were used, such as, physical indicators of contamination, detergents as indicators of contamination, a simple checklist for major flow component identification, a flow chart method for most significant flow component identification, flow-weighted mixing calculations, matrix algebra solutions of simultaneous equations, and matrix algebra solutions considering uncertainty using Monte Carlo simulation, alldescribed in Section 7 of this report.

During the Birmingham demonstration project, samples were collected from potential dry-weather flow sources to establish background data. The background data contained measured parameters specific to certain potential dry-weather sources. It was determined that the background data collected was sufficient to allow contaminated source types to be distinguished from non-contaminated source types and that the measured parameters identified would be sufficient to distinguish among all of the potential commercial/residential sources of dry-weather flows.

A 3-mile section of Village Creek was selected for the field investigation to test the methods of analyses for identifying problem outfalls and potential sources of contamination. Stormwater outfalls and direct discharges were identified by walking the creek. A total of 73 outfalls were located. These outfalls were described in Appendix D of this report.

Dry-weather outfall data was obtained from September 1990 to March 1993. Each outfall was visited 8 or 9 times during this 30 month period. Visits were conducted during different months of the year, wet seasons (i.e., spring and summer) and dry seasons (i.e., fall and winter) in Birmingham. This appendix earlier presented the complete analysis results from all outfall samples collected during this demonstration project.

Lalor (1993) selected 10 outfalls (14, 20, 21, 26, 28, 31, 40z, 42, 48, and 60a) from the 73 in the study area for confirmation of the problem prediction methods. She used five evaluation methods: physical indicators of contamination, detergents as indicators of contamination, a flow chart method to identify the most significant flow components, matrix algebra solutions of simultaneous equations, and matrix algebra solutions considering uncertainty using Monte Carlo simulation. Section 11 of this report presents the results of problem outfall identification and flow source confirmation for the 10 outfalls.

Evaluation of Three Methods for Identifying Problem Outfalls and Outfall Variability

The three simple methods were further evaluated for each outfall visit and presented in this appendix, in order to evaluate the consitency of the methods over an extended period of time:

(1) physical indicators of contamination,
(2) detergents as indicators of contamination, and
(3) a flow chart method for most significant flow component identification.

Twenty-four of the 73 outfalls had observed dry-weather flows during at least one of the field visits. A total of 124 occurrences of dry-weather flows were observed during the 8 or 9 visits to these outfalls.

A006587

Variability of Flow Among Outfalls

Even though the outfalls were visited for sample collection 8 or 9 times over a 30-month period during the demonstration project, flows were not consistently found during each visit at each outfall. The percentage of flowing outfalls that were sampled during outfall visits is shown in Table F-2 and Figure F-1. Most of the outfalls (49 of the 73) never had any observed dry-weather flows, and 9 had flows at every visit. Fifteen outfalls had flows from about 10 to 90 percent of the time.

Consistency of the Three Methods in Identifying Problem Outfalls

Application of the outfall data to the physical indicators of contamination method resulted in 18 observations of problems during 54 visits to the 24 outfalls that had observed dry-weather flow at least once during all visits. Field sheets were filled out for each outfall and the presence of odor, color, turbidity, floatables, deposits/stains, vegetation growth at the outfall, and structural damage were noted. If any of the above physical indicators was noted as being present on the field sheet, the outfall was termed a problem outfall. The results of the evaluation of outfalls using physical indicators of contamination are shown in Table F-3.

A006588

Table F-2. Variability of Flow Among Outfalls

Outfall Number	Number of Collection Dates	Percentage of Samples Collected with Flow Present
14	9	44
14z	8	12.5
16	8	12.5
20	9	100
21	8	62.5
22	8	50
24	8	12.5
26	9	100
28	8	25
29z	8	87.5
31	8	75
38	8	100
39	8	37.5
40	8	50
40z	8	12.5
42	9	100
45	8	50
48	9	100
52	8	100
53	8	37.5
60	8	100
60a	8	25
64	8	100
65	8	100

A006589

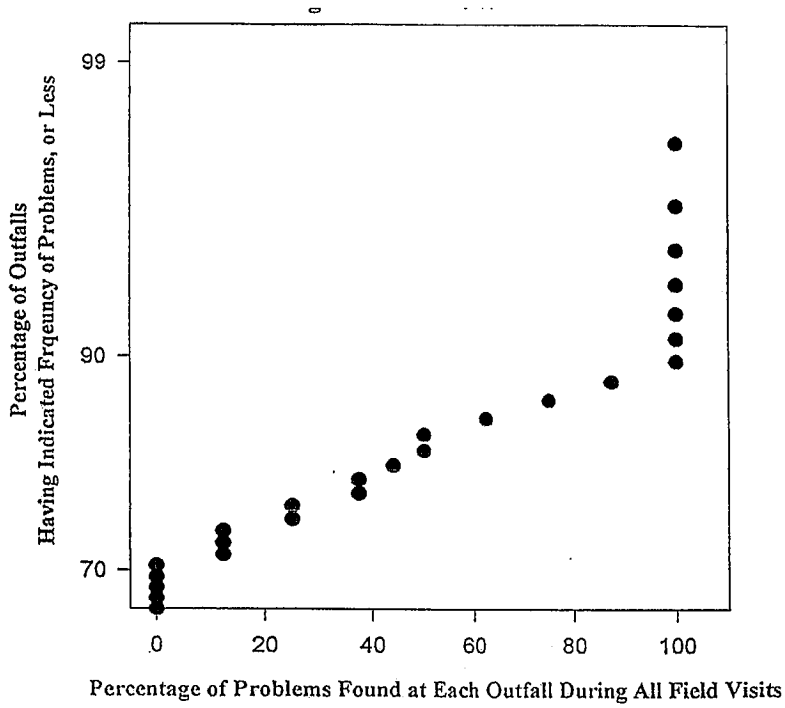

Figure F-1. Percentage of problem outfalls identified during all visits.

The outfall data was applied to the detergent method as an indicator of contamination and resulted in 10 problem outfalls that periodically had problems. These problems were found during 34 of the 124 total visits to the 24 outfalls that had observed dry-weather flow at least once. An outfall was termed a problem outfall if detergent was present at a concentration greater than 0.06 mg/L. The 0.06 mg/L concentration limit translates to the lower limit of detection (3 times the standard deviation from replicate analysis) for the HACH detergent test kit. Table F-4 summarizes the results of the application of the detergent method.

The flow chart method to identify the most significant flow component was also evaluated. This method also resulted in 10 outfalls that had periodic problems. These problems were also found during 34 of the 124 visits to the 24 outfalls that had observed dry-weather flow at least once. An outfall was termed a problem outfall by the flow chart method if the resulting source was likely washwater or sanitary wastewater. The results of the evaluation using the flow chart method are summarized in Table F-5.

Table F-6 summarizes the consistency of the three methods for determining problem outfalls. All three methods consistently identified the same occurence of problems at 15 of the 24 outfalls (63%) (outfalls 14z, 16, 20, 21, 22, 24, 26, 29z, 38, 39, 40, 42, 45, 53, and 60a). However, the three methods were not consistent in identifying problems at 9 of the 24 outfalls (outfalls 14, 28, 31, 40z, 48, 52, 60, 64, and 65). Fifteen outfall visits (at the 9 outfalls) out of the 124 total outfall visits resulted in inconsistent conclusions. Thirteen of these (at 8 outfalls) were associated with problems with the physical indicator method (7 false positives and 6 false negatives). Two visits at outfall number 31 resulted in opposite evaluations using the other two methods. However, 123 of the 125 evaluations were identical using the detergent and flow chart methods. The results of variability among problems indicated by the three methods are summarized in Table F-7 and Figure F-2.

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Table F-3. Physical Indicators of Contamination

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
14	9/18/90	No	No	No	No	Yes (white chalky)	Normal	No	Yes
14	3/26/91	No	Yes (grey)	No	No	Yes (grey sediment)	Normal	No	Yes
14z	6/18/91	No	No	No	No	No	Normal	No	No
20	9/24/90	No	No	No	No	No	Normal	No	No
20	3/26/91	No	No	No	No	No	Normal	No	No
20	4/17/91	No	No	No	No	No	Normal	No	No
20	7/25/91	No	No	No	No	No	Normal	No	No
21	9/24/90	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
21	3/26/91	Yes (sewage)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
22	9/24/90	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
22	3/26/91	Yes (oil)	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
26	9/24/90	No	No	No	No	No	Normal	No	No
26	3/26/91	No	No	No	No	No	Normal	No	No
26	4/17/91	No	No	No	No	No	Normal	No	No
26	7/25/91	No	No	No	No	No	Normal	No	No
28	7/25/91	No	No	No	No	No	Normal	No	No
29z	4/17/91	No	No	No	No	No	Normal	No	No
29z	7/25/91	No	No	No	No	No	Normal	No	No
31	9/24/90	No	No	No	No	No	Normal	No	No
31	7/25/91	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
38	10/24/90	No	No	No	No	No	Normal	No	No
38	3/26/91	No	No	No	No	No	Normal	No	No
38	4/17/91	No	No	No	No	No	Normal	No	No
38	7/25/91	No	No	No	No	No	Normal	No	No

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Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
39	10/24/90	No	No	No	No	No	Normal	No	No
40z	4/17/91	No	No	No	No	No	Normal	No	No

(continued)

Table F-3. Physical Indicators of Contamination (continued)

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
42	10/24/90	No	No	No	No	No	Normal	No	No
42	3/26/91	No	No	No	No	No	Normal	No	No
42	7/25/91	No	No	No	No	No	Normal	No	No
45	3/26/91	No	No	No	No	No	Normal	No	No
45	7/25/91	No	No	No	No	No	Normal	No	No
48	10/24/91	No	No	No	No	No	Normal	No	No
48	4/17/91	No	No	No	No	No	Normal	No	No
48	7/25/91	Yes (sewage)	Yes (grey)	Yes (cloudy)	No	Yes (sediment)	Normal	No	Yes
52	10/31/90	Yes (sewage)	No	No	No	No	Excessive Growth (algae)	No	Yes
52	3/26/91	No	No	No	No	No	Normal	No	No
52	4/17/91	Yes (sewage)	No	No	No	No	Normal	No	Yes
52	7/25/91	No	No	No	No	No	Normal	No	No
53	10/31/90	Yes (dead fish)	No	No	Yes (oil sheen)	Yes (clayey)	Normal	No	Yes
53	4/17/91	Yes (sewage)	No	No	No	No	Normal	No	Yes
53	7/25/91	Yes	Yes (grey)	Yes (cloudy)	No	Yes (sediment)	Normal	No	Yes
60	10/31/90	No	No	No	No	No	Normal	No	No
60	3/26/91	No	No	No	No	No	Normal	No	No

A006592

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
60	4/17/91	Yes (oil)	No	No	Yes (oil sheen)	No	Normal	No	Yes
60	7/25/91	No	No	No	No	No	Normal	No	No

(continued)

Table F-3. Physical Indicators of Contamination (continued)

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
60a	4/17/91	No	No	No	No	No	Normal	No	No
64	11/14/90	No	No	No	Yes (methane bubble)	No	Normal	No	Yes
64	3/26/91	No	No	No	No	No	Normal	No	No
64	4/17/91	No	No	No	No	No	Normal	No	No
64	7/25/91	No	No	No	No	No	Normal	No	No
65	11/14/90	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
65	3/26/91	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
65	4/17/91	No	No	No	No	No	Normal	No	No
65	7/25/91	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes

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Table F-4. Detergent Method as an Indicator of Contamination

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
14	9/18/90	0	No	No
14	1/15/91	0	No	No
14	3/26/91	0	No	No
14	3/3/93	0	No	No
14z	6/18/91	0	No	No
16	6/18/91	0	No	No
20	9/24/90	0	No	No
20	1/15/91	0.02	No	No
20	3/26/91	0	No	No
20	4/17/91	0	No	No
20	6/18/91	0	No	No
20	7/25/91	0	No	No
20	10/15/91	0	No	No
20	9/15/92	0	No	No
20	3/3/93	0	No	No
21	9/24/90	9.5	Yes	Yes
21	1/15/91	10.1	Yes	Yes
21	3/26/91	9.7	Yes	Yes
21	10/15/91	15.7	Yes	Yes
21	9/15/92	20	Yes	Yes
22	9/24/90	9.5	Yes	Yes
22	1/15/91	10	Yes	Yes
22	3/26/91	9.7	Yes	Yes
22	9/15/92	14	Yes	Yes
24	9/15/92	0	No	No
26	9/24/90	0	No	No
26	1/15/91	0	No	No
26	3/26/91	0	No	No
26	4/17/91	0	No	No
26	6/18/91	0	No	No
26	7/25/91	0	No	No

A006594

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
26	10/15/91	0	No	No
26	9/15/92	0	No	No
26	3/3/93	0	No	No

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
28	7/25/91	0.43	Yes	Yes
28	9/15/92	0.23	Yes	Yes
29z	1/15/91	0	No	No
29z	3/26/91	0	No	No
29z	4/17/91	0	No	No
29z	6/18/91	0	No	No
29z	7/25/91	0	No	No
29z	10/15/91	0	No	No
29z	9/17/92	0	No	No
31	9/24/90	0	No	No
31	1/15/91	1	Yes	Yes
31	3/26/91	18	Yes	Yes
31	4/17/91	0.05	No	No
31	7/25/91	0.11	Yes	Yes
31	9/17/92	0.95	Yes	Yes
38	10/24/90	0	No	No
38	1/15/91	0	No	No
38	3/26/91	0	No	No
38	4/17/91	0	No	No
38	6/18/91	0	No	No
38	7/25/91	0	No	No
38	10/15/91	0	No	No
38	9/17/92	0	No	No
39	10/24/90	0	No	No
39	1/15/91	0	No	No

A006595

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
39	3/26/91	0	No	No
40	4/17/91	0	No	No
40	6/18/91	0.2	Yes	Yes
40	7/25/91	0.23	Yes	Yes
40	9/17/92	0.35	Yes	Yes
40z	6/18/91	0.2	Yes	Yes

(continued)

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
42	10/24/90	0	No	No
42	1/15/91	0	No	No
42	3/26/91	0	No	No
42	4/17/91	0	No	No
42	6/18/91	0	No	No
42	7/25/91	0	No	No
42	10/15/91	0	No	No
42	9/17/92	0	No	No
42	3/5/93	0	No	No
45	3/26/91	0	No	No
45	4/17/91	0	No	No
45	6/18/91	0	No	No
45	7/25/91	0	No	No
48	10/24/90	0	No	No
48	1/15/91	0	No	No
48	3/26/91	0	No	No
48	4/17/91	0	No	No
48	6/18/91	0	No	No
48	7/25/91	3.2	Yes	Yes
48	8/2/91	5	Yes	Yes

A006596

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
48	10/15/91	3.6	Yes	Yes
48	9/17/92	0	No	No
52	10/31/90	0.3	Yes	Yes
52	1/15/91	0.4	Yes	Yes
52	3/26/91	0.2	Yes	Yes
52	4/17/91	0.3	Yes	Yes
52	6/18/91	0.33	Yes	Yes
52	7/25/91	0.18	Yes	Yes
52	10/15/91	0	No	No
52	9/21/92	0	No	No
53	10/31/90	0.1	Yes	Yes
53	4/17/91	0.1	Yes	Yes
53	7/25/91	2	Yes	Yes

(continued)

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
60	10/31/90	0	No	No
60	1/15/91	0	No	No
60	3/26/91	0	No	No
60	4/17/91	1.3	Yes	Yes
60	6/18/91	0.8	Yes	Yes
60	7/25/91	0.5	Yes	Yes
60	10/15/91	0	No	No
60	9/21/92	0	No	No
60a	4/17/91	0	No	No
60a	9/21/92	0	No	No
64	11/14/90	0	No	No
64	1/15/91	0	No	No
64	3/26/91	0	No	No
64	4/17/91	0	No	No
64	6/18/91	0	No	No

A006597

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
64	7/25/91	0	No	No
64	10/15/91	0	No	No
64	9/21/92	0	No	No
65	11/14/90	0	No	No
65	1/15/91	0	No	No
65	3/26/91	0	No	No
65	4/17/91	0	No	No
65	6/18/91	0	No	No
65	7/25/91	0	No	No
65	10/15/91	0	No	No
65	7/25/91	0	No	No

A006598

Table F-5. Flow Chart Method for Identifying Most Significant Flow Component

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
14	9/18/90, 1/15/91, 3/26/91, 3/3/93	Yes	No	No	NA	Natural Water	No
14z	6/18/91	Yes	No	Yes	NA	Tap Water	No
16	6/18/91	Yes	No	No	NA	Natural Water	No
20	9/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/15/92, 3/3/93	Yes	No	Yes	NA	Tap Water	No
21	9/24/90, 1/15/91, 3/26/91, 10/15/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
22	9/24/90, 1/15/91, 3/26/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
24	9/15/92	Yes	No	No	NA	Natural Water	No
26	9/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/15/92, 3/3/93	Yes	No	No	NA	Natural Water	No
28	7/25/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
29z	1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/17/92	Yes	No	Yes	Yes	Tap Water	No
31	1/15/91, 3/26/91, 7/25/91, 9/17/92	Yes	Yes	NA	No	Washwater	Yes
31	9/24/90, 4/17/91	Yes	No	Yes	NA	Tap Water	No
38	3/26/91, 6/18/91, 4/17/91, 7/25/91, 10/15/91, 9/17/92	Yes	No	Yes	NA	Tap Water	No
38	10/24/90, 1/15/91	Yes	No	No	NA	Natural Water	No
39	10/24/90, 1/15/91, 3/26/91	Yes	No	Yes	NA	Tap Water	No
40	6/18/91, 7/25/91, 9/17/92	Yes	Yes	NA	No	Washwater	Yes

A006599

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
40	4/17/91	Yes	No	No	NA	Natural Water	No

(continued)

Table F-5. Flow Chart Method for Identifying Most Significant Flow Component

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
40z	6/18/91	Yes	Yes	NA	Yes	Sanitary Wastewater	Yes
42	10/24/90, 1/15/91, 3/26/91, 4/17/91, 7/25/91	Yes	No	Yes	NA	Tap Water	No
42	6/18/91, 10/15/91, 9/17/92, 3/5/93	Yes	No	No	NA	Natural Water	No
45	3/26/91, 4/17/91, 6/18/91, 7/25/91	Yes	No	No	NA	Natural Water	No
48	10/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 9/17/92	Yes	No	No	NA	Natural Water	No
48	8/2/91, 10/15/91	Yes	Yes	NA	No	Washwater	Yes
48	7/25/91	Yes	Yes	NA	Yes	Sanitary Wastewater	Yes
52	10/31/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes
52	10/15/91, 9/21/92	Yes	No	No	NA	Natural Water	No
53	10/31/90, 4/17/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes
60	10/31/90	Yes	No	Yes	NA	Tap Water	No
60	1/15/91, 3/26/91, 10/15/91, 9/21/91	Yes	No	No	NA	Natural Water	No
60	4/17/91, 6/18/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
60a	4/17/91, 9/21/92	Yes	No	Yes	NA	Tap Water	No
64	11/14/90, 4/17/91	Yes	No	Yes	NA	Tap Water	No
64	1/15/91, 3/26/91, 6/18/91, 7/25/91, 10/15/91, 9/21/92	Yes	No	No	NA	Natural Water	No
65	11/14/90, 1/15/91, 3/26/91, 4/17/91, 6/15/91, 7/25/91, 10/15/91, 9/21/92	Yes	No	Yes	NA	Tap Water	No

A006601

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
14	9/18/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	X	O	O
	4/17/91	Yes	NS	NS	NS
	6/18/91	Yes	NS	NS	NS
	7/25/91	Yes	NS	NS	NS
	10/15/91	Yes	NS	NS	NS
	9/15/92	Yes	NS	NS	NS
	3/3/93	Yes	NA	O	O
14z	9/18/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	O	O	O
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	No	NS	NS	NS
16	9/18/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	NA	O	O
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	No	NS	NS	NS
20	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O

A006602

	10/15/91	Yes	NA	O	O
	9/15/92	Yes	NA	O	O
	3/3/93	Yes	NA	O	O

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
21	9/24/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	X	X	X
	4/17/91	Yes	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	Yes	NA	X	X
	9/15/92	Yes	NA	X	X
22	9/24/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	X	X	X
	4/17/91	Yes	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	X	X
24	9/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	O	O
26	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O

A006603

	6/18/91	Yes	O	O	O
	7/25/91	Yes	NA	O	O
	10/15/91	Yes	NA	O	O
	9/15/92	Yes	NA	O	O
	3/3/93	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
28	9/24/90	No	NS	NS	NS
	1/15/90	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	Yes	O	X	X
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	X	X
29z	9/24/90	No	NS	NS	NS
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O
31	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	NA	X	X
	4/17/91	Yes	NA	X	O
	6/18/91	No	NS	NS	NS
	7/25/91	Yes	X	O	X
	10/15/91	No	NS	NS	NS
	9/17/92	Yes	NA	X	X
38	10/24/90	Yes	O	O	O

A006504

	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
39	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
40	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	NA	X	X
	10/15/91	No	NS	NS	NS
	9/17/92	Yes	NA	X	X
40z	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	O	X	X
	7/25/91	No	NS	NS	NS

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	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
42	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O
	3/5/93	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
45	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	Yes	O	O	O
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
48	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	X	X
	8/2/91	Yes	NA	X	X
	10/15/91	Yes	NA	X	X
	9/17/92	Yes	NA	O	O
52	10/31/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X

A006606

	3/26/91	Yes	O	X	X
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	O	X	X
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
53	10/31/90	Yes	X	X	X
	1/15/91	Yes	NS	NS	NS
	3/26/91	Yes	NS	NS	NS
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NS	NS	NS
	7/25/91	Yes	X	X	X
	10/15/91	Yes	NS	NS	NS
	9/21/92	Yes	NS	NS	NS

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
60	10/31/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	O	X	X
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
60a	10/31/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	Yes	O	O	O
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/92	No	NS	NS	NS
	9/21/92	Yes	NA	O	O

A006507

64	11/14/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
65	11/14/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	X	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	X	O	O
	10/15/91	Yes	NA	O	O
	7/25/91	Yes	X	O	O

X - Problem indicated at outfall
O - No problem indicated at outfall
NA - Information not avaiable
NS - No sample taken

A006608

Table F-7. Variability Among Outfalls Based on the Three Analysis Methods

Outfall Number	Number of Samples Collected (flow present)	Percentage of Outfall Visits with Problems Indicated by Physical Indicators	Percentage of Outfall Visits with Problems Indicated by the Detergent Method	Percentage of Outfall Visits with Problems Indicated by the Flow Chart Method
14	4	50	0	0
14z	1	0	0	0
16	1	NA	0	0
20	9	0	0	0
21	5	40	100	100
22	4	50	100	100
24	1	NA	0	0
26	9	0	0	0
28	2	0	100	100
29z	7	0	0	0
31	6	16.6	80	66
38	8	0	0	0
39	3	0	0	0
40	4	NA	75	75
40z	1	0	100	100
42	9	0	0	0
45	4	0	0	0
48	9	0	33	33
52	8	25	75	75
53	3	100	100	100
60	8	12.5	37.5	37.5
60a	2	0	0	0
64	8	12.5	0	0
65	8	50	0	0

NA - Information not available

A006609

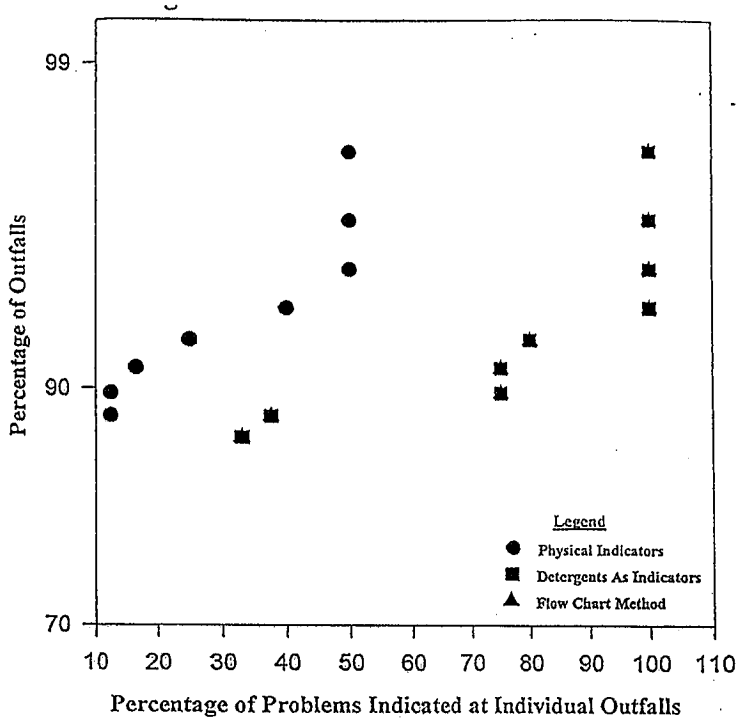

Figure F-2. Problem outfalls found using different methods.

Relationship of Rainfall History to the Presence of Problems Indicated at Outfalls

The presence of flow at outfalls with respect to rainfall amounts occurring prior to outfall collection visits was investigated. It is commonly assumed that recent rains increase the likelihood of dry-weather flows. Monthly summaries of climatological data for Birmingham, AL, from the National Oceanic and Atmospheric Administration (NOAA) were used to determine rainfall amounts 2, 7, and 30 days before each outfall collection date. The percentage of outfalls flowing on each sampling date was compared to these rainfall amount totals and is summarized in Table F-8.

The amount of rainfall 2, 7, and 30 days prior to collection date with respect to the total number of problems indicated by the three methods is illustrated on scatter plots (Figures F-3 through F-5). The Pearson Product Moment Correlation statistical test was used to determine if any significant relationships existed between the total number of problems indicated by the three methods and rainfall amounts 2, 7, and 30 days before outfall collection dates. This statistical test is designed to determine if a relationship exists between variables and the strength of that relationship. The Pearson Correlation determined that there were no significant relationships between number of problems indicated and rainfall amounts.

Seasonal Variability with Respect to the Number of Problem Outfalls Indicated

Figure F-6 illustrates the relationship between outfalls with problems indicated by the detergent and flow chart methods and month of the year. The detergent method and the flow chart method were consistent in identifying problem outfalls so the monthly variation of problems indicated is applicable to both methods. The Pearson Product Moment Correlation was used to determine the relationship between the total number of problems indicated by the detergent and flow chart methods and month. The Pearson Correlation found no relationship between these variables.

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Table F-8. Variability of Flow Among Outfalls with Respect to Collection Date and Rainfall Amounts

Collection Date	Rainfall Amount 2 Days Before Sampling (in.)	Rainfall Amount 7 Days Before Sampling (in.)	Rainfall Amount 30 Days Before Sampling (in.)	Outfall(s) Flowing on Specified Date	Number of Outfalls Visited on Each Date	Percentage of All Outfalls Evaluated That Had Flow on Date (%)
9/18/90	0.00	1.62	2.00	14	18	5.6
9/24/90	0.00	0.07	2.04	20,21,22,26,31	17	29
10/24/90	1.10	2.08	2.95	38,39,42,48	15	27
10/31/90	0.00	0.03	2.98	52,53,60	8	37.5
11/14/90	0.00	2.30	4.85	64,65	7	28.6
1/15/91	0.00	0.58	6.08	14,20,21,22,26,29z,31,38,39,42,52 60,64,65	73	19.2
3/26/91	0.00	0.05	0.05	14,20,21,22,26,29z,31,38,39,42,45 48,52,60,64,65	73	21.9
4/17/91	0.01	0.24	6.91	20,26,29z,31,38,40,42,45,48,52, 53,60,60a,64,65	73	20.5
6/18/91	1.51	2.26	6.63	14z,16,20,26,29z,38,40,40z,42,45, 48,52,60,54,65	73	20.5
7/25/91	0.67	0.67	4.24	20,26,28,29z,31,38,40,42,45,48, 52,53,60,64,65	73	20.5
10/15/91	0.03	0.03	2.76	20,21,26,29z,42,48,52,53,64,65	73	13.7
9/15/92	0.00	0.23	9.52	20,21,22,24,26,29z	32	18.8
9/17/92	0.00	0.23	9.52	29z,31,40,42,48	17	29.4
9/21/92	0.00	0.41	7.24	52,60,60a,65	24	16.7

A0951

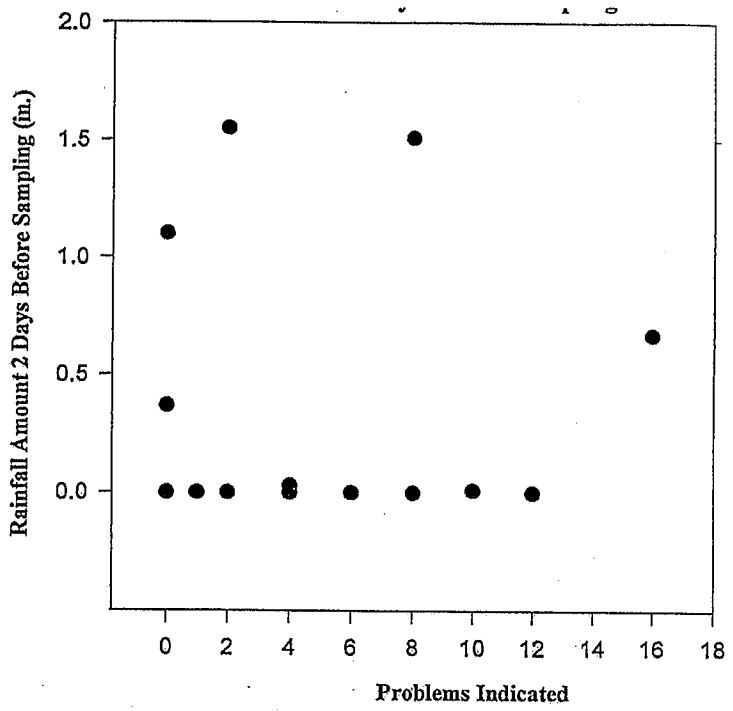

Figure F-3. Rainfall amounts within two days of sampling and numbers of problem outfalls identified.

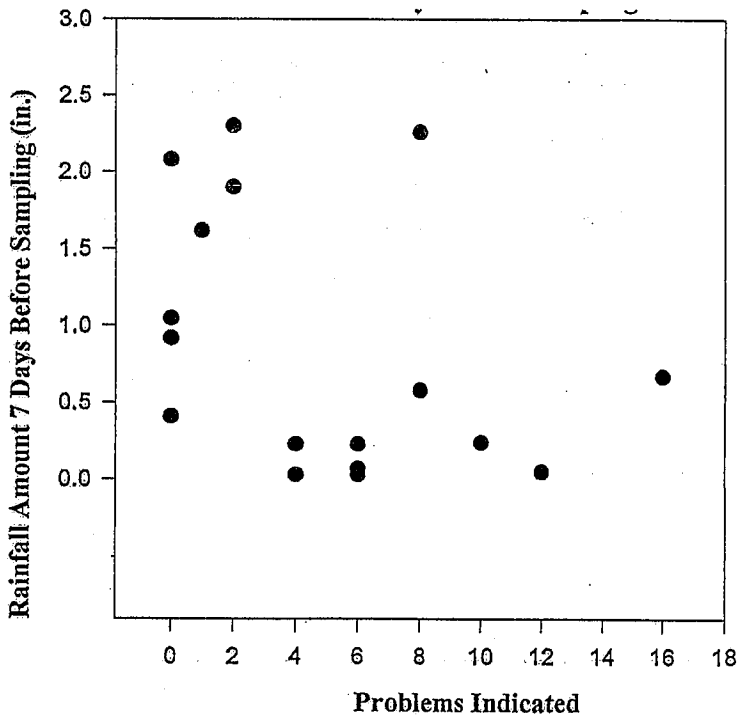

Figure F-4. Rainfall amounts within seven days of sampling and numbers of problem outfalls identified.

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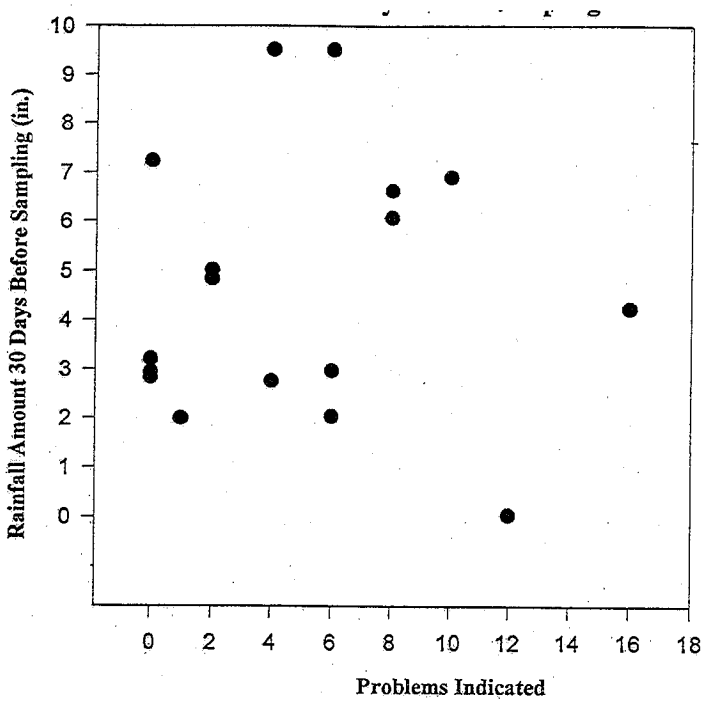

Figure F-5. Rainfall amounts within 30 days of sampling and numbers of problem outfalls identified.

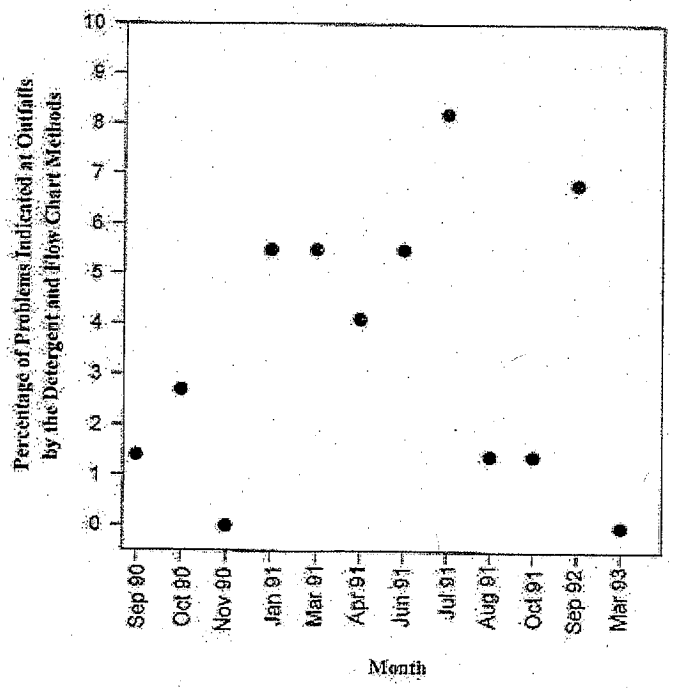

Figure F-6. Percentage of problems found during each month of sampling.

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Sampling Requirements to Achieve an Adequate Screening Program for Problem Outfalls
In order to have a successful screening program for problem outfalls, an adequate number of collection visits to the outfalls over a specified time period is required. However, to determine the number of outfall visits needed, a preliminary estimate of the frequency of occurrence of problems at the outfalls and the desired error is needed.

This assessment was made by reviewing the presence of a problem at each outfall, for each outfall visit. A problem was defined using the detergent and flow chart methods for each of the 24 outfalls that ever had observed dry-weather flows during this study. Figure F-7 presents several example plots that were used in this analysis. These examples show that if consistent conditions exist at an outfall where the frequency of problem occurrence is either 0% (outfall# 65) or 100% (outfall # 21), few outfall visits are obviously needed. However, for intermediate levels of occurrence, many more visits are needed. It is quite easy to miss a problem outfall at most locations if only 1 or 2 visits are made.

Table F-9 presents the observed data relating the number of visits to an outfall (within a 1-½ year time period) to the errors associated in identifying the outfall as a problem. At least 4 outfall visits are likely needed for many intermittent conditions. If the outfall has a problem most of the time (say at least 60% of the time), four visits should result in less than a 25% error in identifying this problem. In contrast, if the outfall only has a problem infrequently (such as 20% of the time), the possible error could be much larger. In most cases, more than 5 observations seldom resulted in additional useful information.

Table F-9. Errors Associated with Number of Outfall Sampling Visits and Occurrence of Problems

	Occurrence of Problems:					
# of Observations	0%	20%	40%	60%	80%	100%
1	0	100 to 400%	100 to 150	67 to 100	25 to 100	0
2	0	100 to 150	25 to 150	17 to 100	25 to 38	0
3	0	65 to 100	18 to 100	12 to 67	16 to 25	0
4	0	25 to 100	25 to 38	17 to 25	6 to 25	0
5	0	0	0	0	0	0

A006614

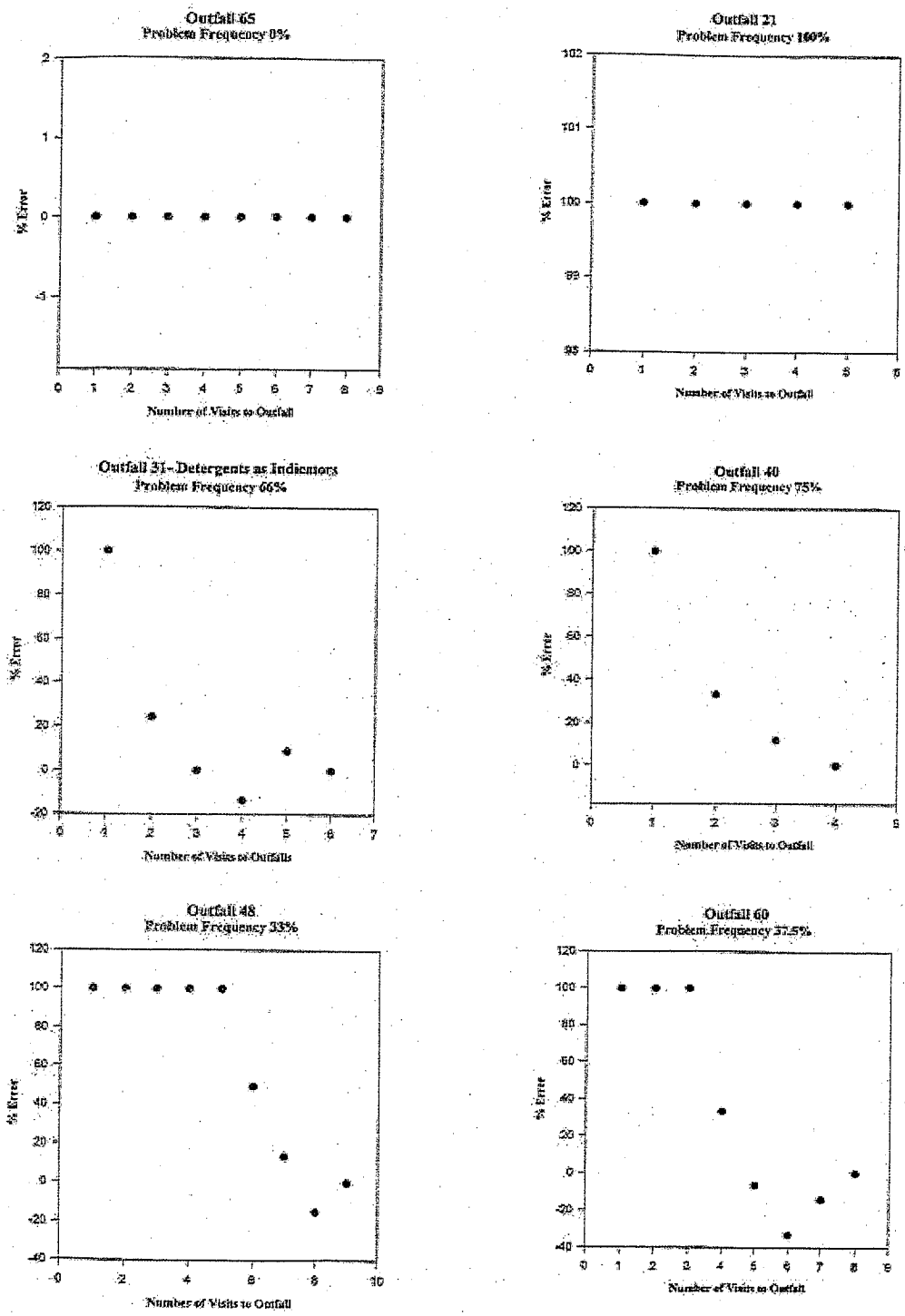

Figure F-7. Observed errors associated with different sampling efforts.

A0066 15

Summary of Evaluation of all Field Data

The presence of detergent method and the flow chart method are both very effective in identifying non-stormwater entry problems in storm drainage systems. Detergents as indicators and the flow chart method gave very consistent results in identifying problem outfalls. The detergent method is recommended for identifying non-stormwater entries because it is simple in technique and has minimal associated error. Unfortunately, the analytical method uses hazardous materials and care must be taken during the analysis and to ensure proper disposal of the wastes. The flow chart method (which also uses detergent data) is capable of also identifying the likely problem flow source. Based on the available data from the field sheets, the physical indicators method to identify contamination at outfalls is of limited use. The physical indicators method resulted in numerous false negative and false positive indications of problem outfalls.

Dry-weather flows at the outfalls in this study were variable. About 50 of the 73 outfalls never had any observed dry-weather flow. Only 9 outfalls (20, 26, 38, 42, 48, 52, 60, 64 and 65) of the 24 outfalls that ever had dry-weather flows were flowing for every outfall visit. The detergent and flow chart methods indicated identical frequencies of problems for 23 out of the 24 outfalls for every visit. The frequencies of problems indicated using the physical indicators of contamination method when flow was present were variable and revealed numerous false positive (33%) and false negative (66%) results.

The amount of rainfall occurring before an outfall visit is not related to non-stormwater pollutant entries to storm drainage systems. A wide range of indicated frequencies of problems at outfalls were associated with varying antecedent rainfall amounts. Also, the indicated frequencies of problems at outfalls varied widely with respect to month of the year.

An estimate of the expected frequency of problems and the desired error rate must be known to determine the number of outfall collection visits needed to adequately determine the magnitude of problems indicated at outfalls. For example, referencing Table F-9, if the expected frequency of problems is 40% and the desired error is 20%, or less, approximately 4 visits to the outfall would be required. In contrast, if the expected frequency of problems is 100% and the desired error is 0%, 1 visit to the outfall would obviously be required.

A006616

Appendix G
Chemical Mass Balance Model with Monte Carlo Simulation

This appendix contains an example for the computer program developed to help solve simultaneous equations using matrix algebra (Lalor 1993). The code was prepared by Ed Kujawski, a UAB Honors' Student. This example lists the program input and output. Also included in this appendix is the Pascal source code for the program.

In this example, eight possible source water types and eight tracer parameters were selected and is based on sample data from outfall #20, collected on March 3, 1993. Based on this analysis, the following lists the likely sources of the water affecting this outfall, as determined using 10,000 runs of the Monte Carlo model:

	Calculated Likelihood of Occurrence of Source Water		
Potential Source Water	10th percentile	median	90th percentile
Spring water	0.28	0.33	0.39
Tap water	0.46	0.60	0.75
Sewage wastewater	-0.06	0.001	0.05
Carwash wastewater	-0.004	0.0002	0.006
Landscape irrigation water	0.03	0.08	0.15
Infiltrating groundwater	-0.23	0.006	0.31
Septic tank discharge wastewater	-0.005	0.004	0.03
Commercial laundry wash wastewater	-0.01	-0.007	-0.003

The water collected at this outfall is therefore not likely a problem as it is comprised of approximately 60% tap water, 33% spring water, and 8% landscaped irrigation water. The maximum contribution of any of the wastewaters (at the 90th percentile) is less than 5%, and more likely much less.

Example Input and Output from Chemical Mass Balance Program with Monte Carlo Simulation

MAIN.LIB

[Sources]
Irrigation Runoff, Tap Water, Spring Water, Commercial Car Wash, Commercial Laundry, Septic, Shallow Ground Water, Sewage

[Parameters]
Conductivity = µmhos/cm
Fluoride = mg/L
Hardness = mg/L CaC03
Detergent = mg/L
Floresc. = % scale
Potassium = mg/L

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Ammonia = mg/L
Color = units

[Sample]
Conductivity = 188
Fluoride = 0.61
Hardness = 127
Detergent = 0
Floresc. = 13
Potassium = 1.98
Ammonia = 0.03
Color = 0

[Irrigation Runoff]	Median conc.	COV	Distribution
Conductivity =	104.93	0.07	N
Fluoride =	0.90	0.11	N
Hardness =	40.15	0.04	N
Detergent =	0	0	
Floresc. =	214.40	0.16	N
Potassium =	6.08	0.26	N
Ammonia =	0.37	0.25	N
Color =	10.00	0.36	N

[Plating Bath]	Median conc.	COV	Distribution
Conductivity =	10352	0.45	N
Fluoride =	5.13	0.47	N
Hardness =	1430	0.32	N
Detergent =	6.81	0.68	N
Floresc. =	293	0.70	N
Potassium =	1008.8	1.24	L
Ammonia =	65.65	0.66	N
Color =	103.8	0.91	N

[Tap Water]	Median conc.	COV	Distribution
Conductivity =	111.6	0.01	N
Fluoride =	0.97	0.01	N
Hardness =	49.3	0.03	N
Detergent =	0	0	
Floresc. =	4.63	0.08	N
Potassium =	1.55	0.04	N
Ammonia =	0.03	0.23	N
Color =	0	0	

A006618

[Spring Water]	Median conc.	COV	Distribution
Conductivity =	301.2	0.04	N
Fluoride =	0.03	0.87	N
Hardness =	239.8	0.03	N
Detergent =	0	0	
Floresc. =	6.80	0.43	N
Potassium =	0.73	0.10	N
Ammonia =	0.01	0.70	L
Color =	0	0	

[Commercial Car Wash]	Median conc.	COV	Distribution
Conductivity =	485.3	0.06	N
Fluoride =	12.3	0.19	N
Hardness =	156.5	0.05	N
Detergent =	48.96	0.10	N
Floresc. =	1190	0.11	N
Potassium =	42.69	0.37	N
Ammonia =	0.239	0.28	N
Color =	221.5	0.35	N

[Radiator]	Median conc.	COV	Distribution
Conductivity =	3280	0.21	N
Fluoride =	149.32	0.16	N
Hardness =	5.60	1.88	N
Detergent =	15.0	0.11	N
Floresc. =	22046	0.04	N
Potassium =	2801.8	0.13	N
Ammonia =	26.23	0.89	N
Color =	2999	0.01	N

[Commercial Laundry]	Median conc.	COV	Distribution
Conductivity =	562.9	0.21	N
Fluoride =	32.82	0.38	N
Hardness =	36.15	0.08	N
Detergent =	26.90	0.25	N
Floresc. =	1024.6	0.12	N
Potassium =	3.48	0.11	N
Ammonia =	0.82	0.14	N
Color =	46.7	0.27	N

A006619

[Septic]	Median conc.	COV	Distribution
Conductivity =	501.74	0.42	N
Fluoride =	0.93	0.39	N
Hardness =	56.84	0.36	L
Detergent =	3.27	1.33	L
Floresc. =	381.88	0.22	N
Potassium =	18.82	0.42	N
Ammonia =	87.21	0.40	N
Color =	70.60	0.39	N

[Shallow Ground Water]	Median conc.	COV	Distribution
Conductivity =	51.4	0.84	N
Fluoride =	0.06	0.50	L
Hardness =	27.30	0.39	N
Detergent =	0	0	
Floresc. =	29.90	1.55	L
Potassium =	1.19	0.44	N
Ammonia =	0.24	1.26	N
Color =	8.00	1.42	L

[Sewage]	Median conc.	COV	Distribution
Conductivity =	419.86	0.13	N
Fluoride =	0.76	0.23	N
Hardness =	142.92	0.11	N
Detergent =	1.5	0.82	N
Floresc. =	250.89	0.20	N
Potassium =	5.97	0.23	N
Ammonia =	9.92	0.34	L
Color =	37.89	0.55	N

A006620

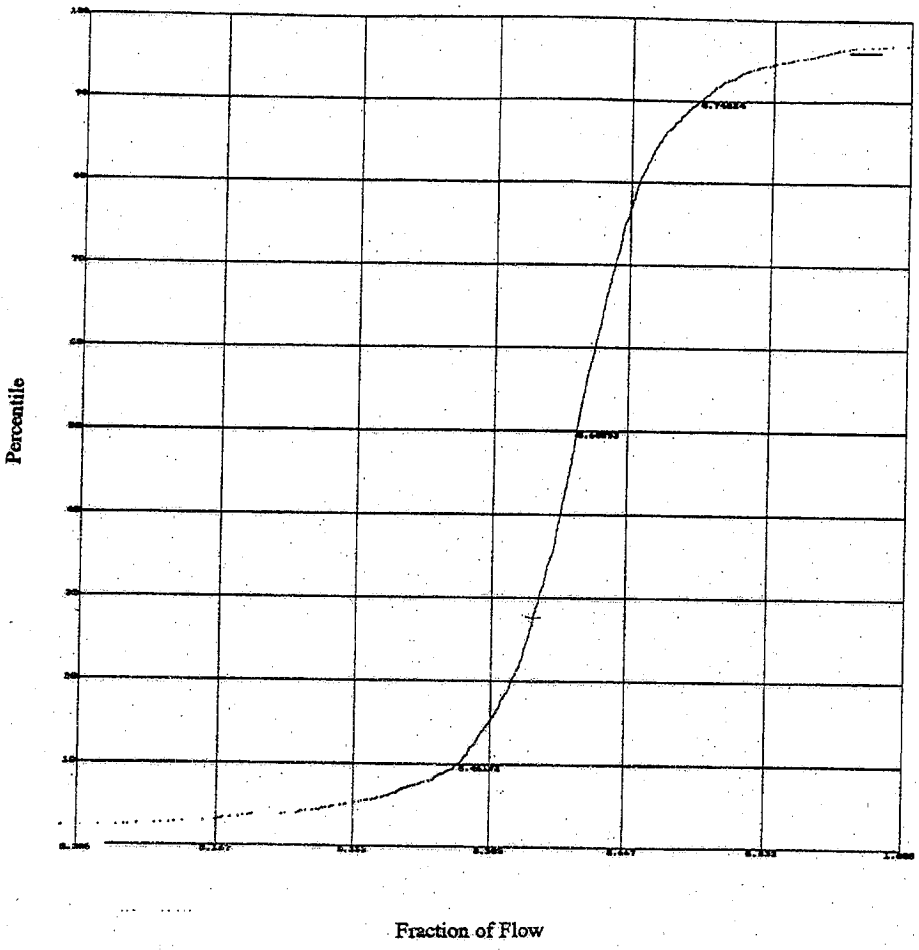

Figure G-1. Probability distribution for tap water source in mixed outfall sample.

A006621

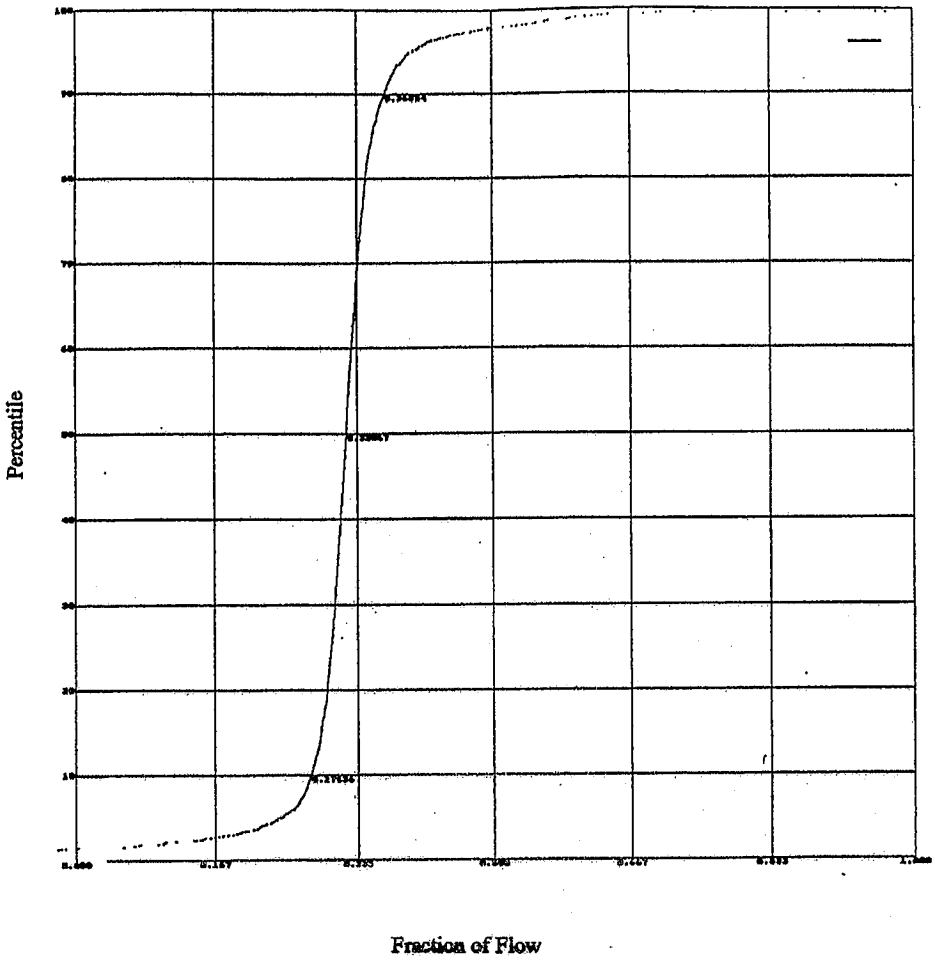

Figure G-2. Probability distribution for spring water source in mixed outfall sample.

A006622

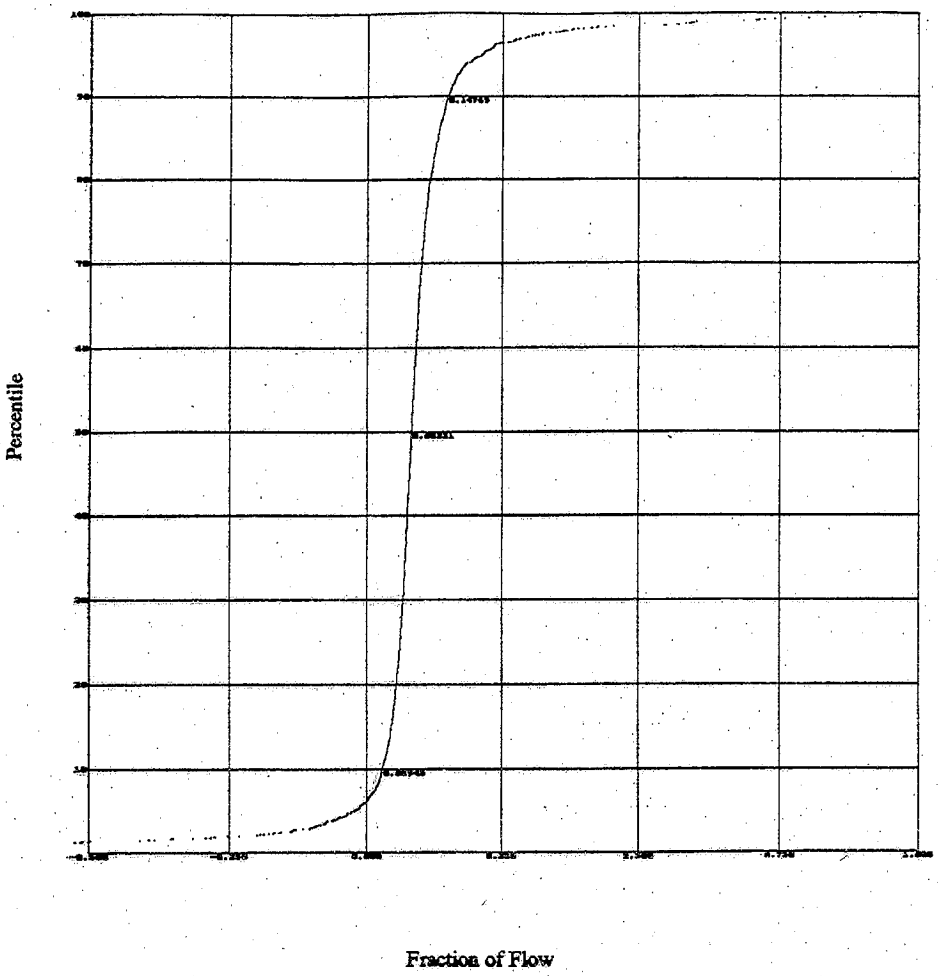

Figure G-3. Probability distribution for landscape irrigation runoff water source in mixed outfall sample.

A006623

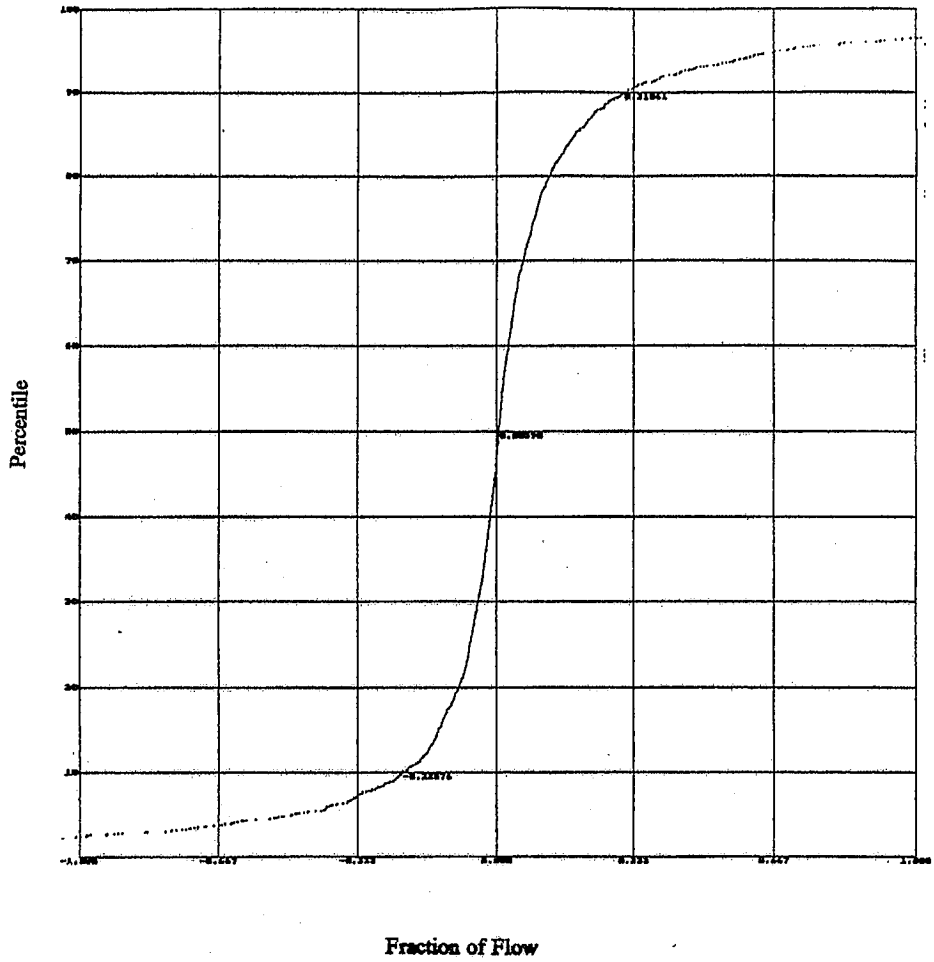

Figure G-4. Probability distribution for infiltrating groundwater source in mixed outfall sample.

A006624

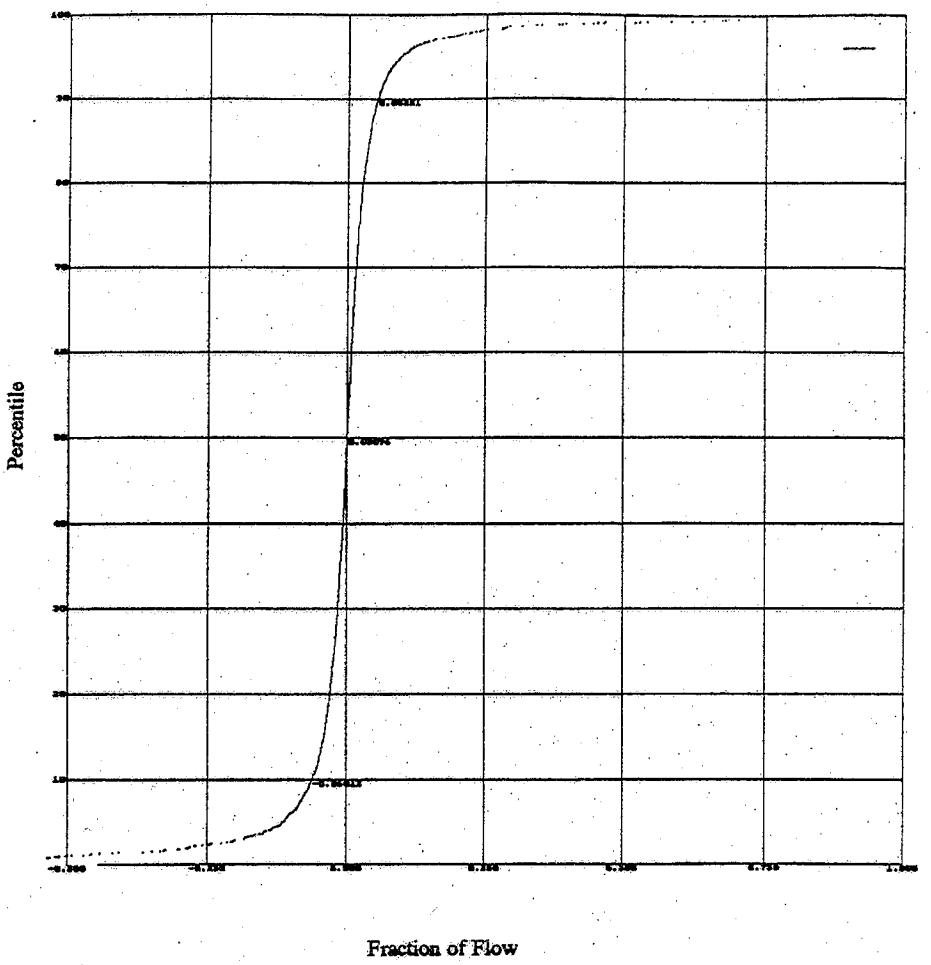

Figure G-5. Probability distribution for sanitary sewage wastewater source in mixed outfall sample.

A006625

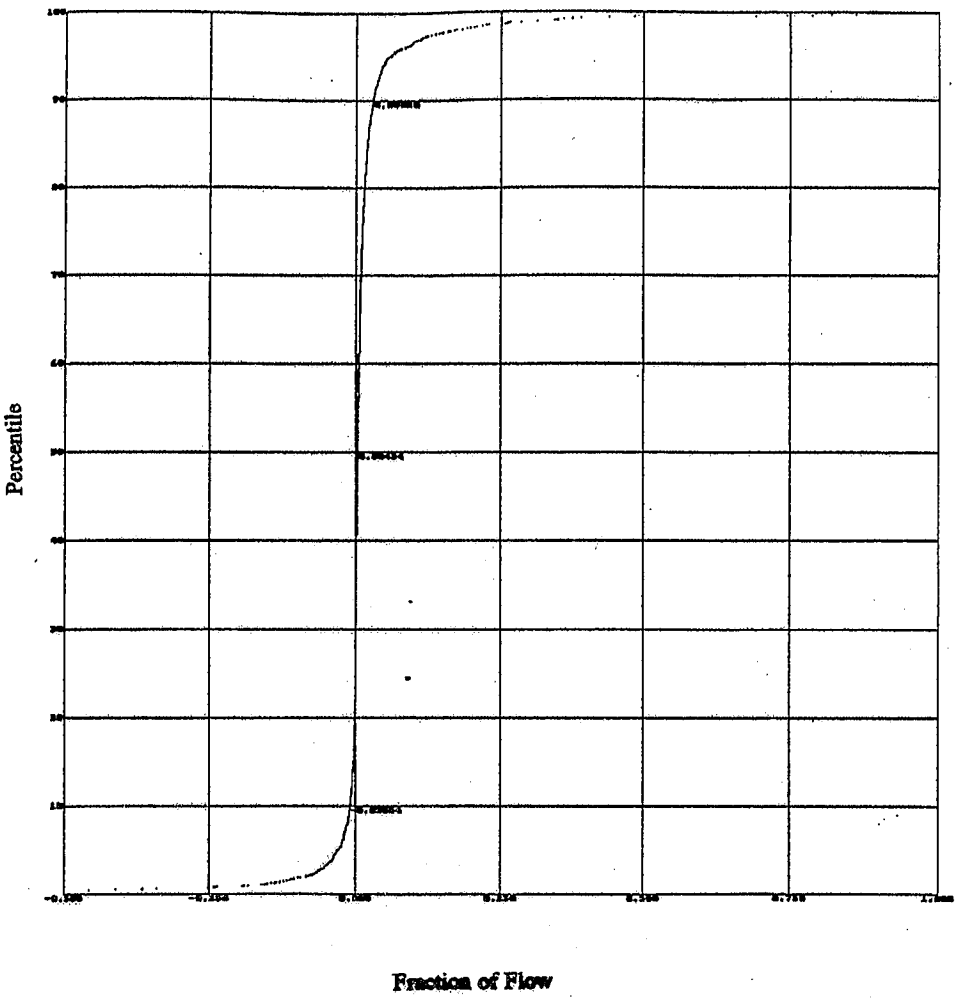

Figure G-6. Probability distribution for septic tank discharge water source in mixed outfall sample.

A006626

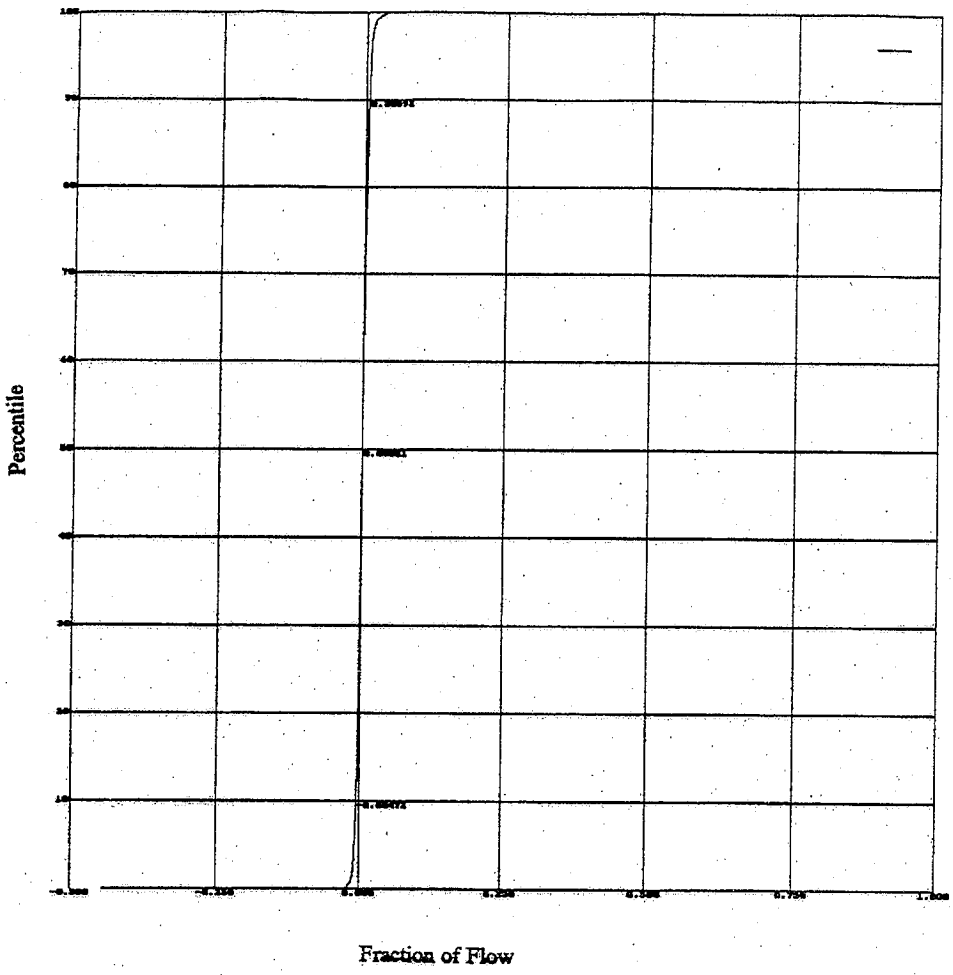

Figure G-7. Probability distribution for commercial car wash wastewater source in mixed outfall sample.

A086627

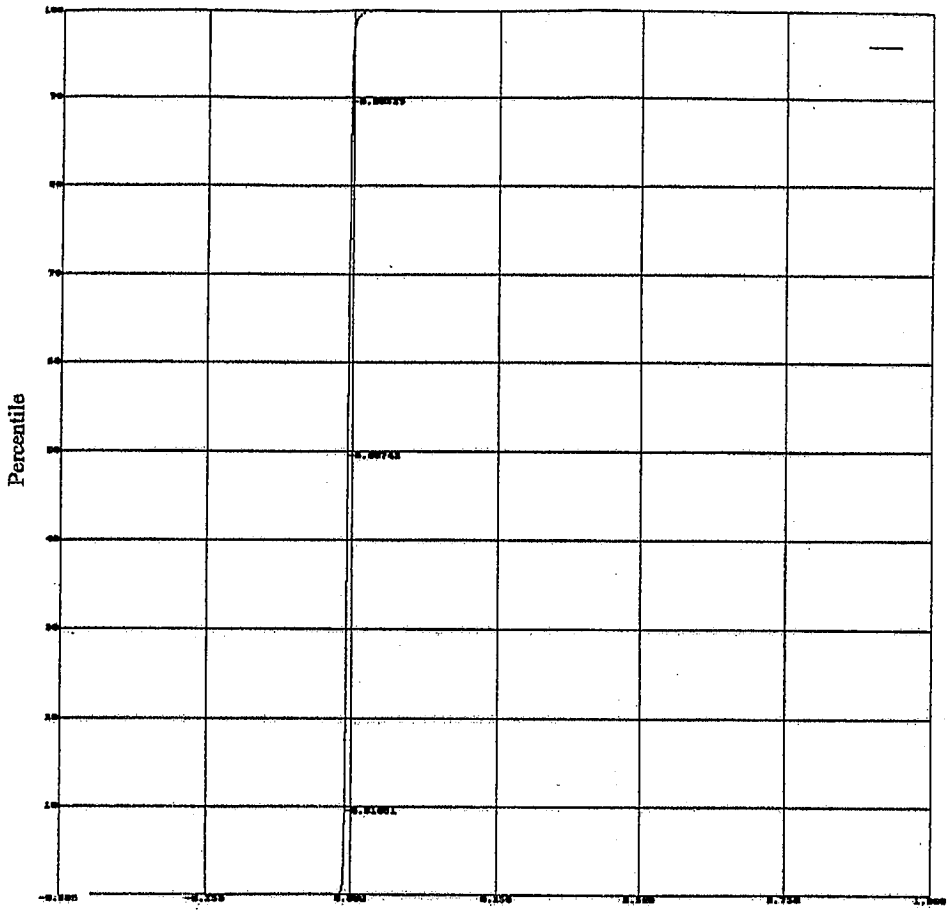

Figure G-8. Probability distribution for commercial laundry wastewater source in mixed outfall sample.

A006528

User Guide for Pol-Sit, the Monte Carlo Model to Determine the Most Likely Source Components

Introduction

Pol-Sit uses Monte Carlo simulation techniques to predict the most likely source area components in a mixed outfall sample. The files necessary to run POL-SIT include: POL-SIT.EXE the executable program, and MAINLIB a library file. To run a Monte-Carlo simulation, type:

```
POL-SIT {library filename}
```

For example, if the library filename is MAIN.LIB (the default name) then the following command will run the program:

```
POL-SITE
```

If MAIN.LIB is not the name of the library file, then type POL-SIT followed by the library filename. As an example, if the library filename is TEST.LIB, then the following command will run the program:

```
POL-SIT TEST.LIB
```

Library File

The library file consists of four main parts. Each part is separated by a header surrounded by left bracket ([) and right bracket (]) characters. The first part is identified by a header of available sources, the second part by parameters, and the third part by the sample characteristics. The fourth part of the library consists of many entries under each of the source's name. The following lists an example of these file parts:

Sources

Under the header for sources is a list of all the sources in the library. The list can be comma delimited, for example:

```
[Sources]
Irrigation Runoff, Plating Bath, Tap Water,
Spring Water, Commercial Car Wash,
Radiator, Commercial Laundry, Septic,
Shallow Ground Water, Sewage
```

Parameters

Under this header are all of the parameters that will be used in the Monte Carlo simulation. After each parameter, the units are listed. The units are used only in the output to make it more readable. An example parameters section looks like:

```
[Parameters]
Conductivity = µmhos/cm
Fluoride = mg/L
Hardness = mg/L CaC0₃
Detergent = mg/L
Fluorescence = % scale
Potassium = mg/L
Ammonia = mg/L
pH = units
Color = units
```


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Toxicity = I_{25} % light reduction, Microtox

Sample

Under this header are the mixed outfall sample data. Each of the parameters given in the parameters section must be given a numerical value. An example sample section looks like:

```
[Sample]
Conductivity = 486.3
Fluoride = 12.3
Hardness = 156.5
Detergent = 48.96
Fluorescence = 1190
Potassium = 42.69
Ammonia = .239
pH = 6.72
Color = 221.5
Toxicity = 99.0
```

Site Parameters

Under this header are the characterization data for all of the parameters for each potential source component. The header text is the source component name. After the parameter title, the mean, coefficient of variation, and the distribution type are listed. The data distribution can be labeled as either log-normal (L) or normal (N). An example source parameter section for one component looks like:

```
[Irrigation Runoff]
Conductivity=     105.12      10.34       N
Fluoride=           0.86       0.13       N
Hardness=          39.64       1.31       N
Detergent=             0          0
Floresc.=         231.94      25.38       N
Potassium=          6.22       2.24       N
Ammonia=            0.39       0.11       N
pH=                 6.99       0.09       N
Color=             12.60       2.51       N
Chloride=           0.04       0.03       N
Toxicity=              0          0
Copper=                0          0
Phenols=               0          0
```

* Note that the value of 0 was given for the coefficient of variation for several parameters. POL-SIT interpolates this by assuming the concentration distribution is a constant and it will then use the mean in all calculations, instead of determining a random sample based upon the mean and coefficient of variation.

Editing the Library File

Any text processor can be used to edit the library file. For example, use Windows Notebook or the MS-DOS Edit command. Do not use word processors such as Microsoft Word or Word Perfect, unless the text is saved as a text-only file.

Mathematical Model

The model used for calculating the pollution concentrations in POL-SIT are linear equations that express the concentration of a pollutant in a sample based on the concentration of the pollutant in the potential source components and the amount of each source component in the sample (the unknown). Equation 1 shows the

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relationship between the mixed pollutant concentration, the source component, and the source component pollution concentrations.

$$\sum_{a=0}^{b} Aa, cBa = Cc$$

(1)

b is the number of pollutants that are included in the matrix for evaluation, c is the pollutant concentration in the mixed sample at the outfall. During each run, there are as many simultaneous equations as pollutants in the library. Matrix A holds the data for the concentrations of pollutants at the sources. Matrix B holds the amount of the source components in the sample. Matrix C is the mixed sample pollutant data for the outfall sample. For each iteration, the matrix in equation 2 is solved.

$$AB=C$$

(2)

During the Monte Carlo simulation, the values used in the A matrix are determined by the library file. In the library file, each source has the pollutant mean, coefficient of variation, and distribution type. Only two sampling types are available, normal and log-normal distribution. If the normal distribution is selected, then the value placed in the A matrix is determined by the following routine.

```
S:=0:
for I:=1 to 12 do
  S:=S+Random(10000)/10000:
S:=S-6.0:
FindNormal:=Mean+SD*S:
```

Where *SD* is the standard deviation, *Mean* is the mean of the data, and *FindNormal* is the resulting value with a mean of *Mean* and a standard deviation of *SD*. When the log-normal distribution is requested, the following routine is used.

```
MeanY:=ln(Mean)-(0.5*ln(CV*CV+1));
VarianceY:=ln(CV*CV+1):
repeat
  A:=Random(10000)/10000.0:
  B:=Random(10000)/10000.0:

S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY)
:
until (S>0) and (S<Mean*2):
FindLogNormal:=S:
```

Where *CV* is the coefficient of variation, *Mean* is the mean value of the library data and *FindLogNormal* is the resulting value with a mean of *Mean* and log-normal distribution with a coefficient of variation of *CV*.

Simulation Run

During the simulation, there is a loop which executes many times (typically 10,000 trials) to make up the Mont Carlo simulation. The steps in the simulation include: Initialization, Solving Matrix, and Saving the data. Data in the library file for the pollutants include mean and variation data. Matrix A is filled with randomly selected data based on the library file. Once Matrix A is filled, Matrix B is evaluated using equation 2. Finally, Matrix B is saved in memory.

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Once all of the Monte Carlo simulations have been run, the Matrix B values are saved in memory and are sorted and plotted on the screen. From these probability plots, the most likely source components of the sample are displayed.

A006632

Program Parameter_Source;

```
uses
  Objects,Dos,Crt,
  EdLib,PolUtl,Matrix;

var
  ParameterNo:Byte;              {# of Parameters in library}
  Sources:TCollection;           {list of the Source data}
  Parameters:TCollection;        {Parameter units and sample data}
  LibFileName:ComStr;            {Filename for the library file}

{*****************************************************************
************            initvars          ***************************
*****************************************************************
This procedure initializes all of the variables needed for the program}
```

procedure InitVars;

```
procedure InitVars;
  var
    Dir: DirStr;
    Name: NameStr;
    Ext: ExtStr;
  begin

  {Setup the name of the library file}
  if ParamCount1 then
    begin
    LibFileName:=ParamStr(0);
    FSplit(LibFileName,Dir,Name,Ext);
    LibFileName:=Dir+'Main.Lib';
    end
  else
    if Pos('?',ParamStr(1))0 then
      begin
      DisplayHelpscreen;
      halt(0);
      end
    else
      LibFileName:=ParamStr(1);


  Sources.Init(25,5);
  Parameters.Init(25,5);

  SetVars;  {initialize Variables in Matrix unit}
end;

{*****************************************************************
************            ReadLibrary          ***************************
*****************************************************************
Open library and parce all the information}
```

1

procedure ReadLibrary;

```
procedure ReadLibrary;

  procedure AddSource(Source:String);
    begin
    Sources.Insert(New(PSource,Init(Source)));
  end;

  procedure AddSources(Sources:String);
    var
      I,J:Byte;
    begin
    I:=1;
    repeat
      {first skip over any white spaces}
      while Sources[I] in [" ",",",#9] do
        Inc(I);
      {Move J to first comma or tab}
      J:=1;
      while (J.pth(Sources)) and not (Sources[I] in [",",#9]) do
        Inc(J);
      AddSource(Copy(Sources,I,J-1));

      I:=J+1;
      {Move to next}
      while Sources[I] in [" ",",",#9] do
        Inc(I);
    until (Length(Sources));
  end;

  procedure ReadSourceNames(var LibFile:Text);
    var
      S:String;
    begin
    PositionFile(LibFile,"Sources");
    repeat
      ReadLn(LibFile,S);
      if (S"") and (S[1]"[") then
        AddSources(S);
    until (S="") or (S[1]="[");
  end;

  procedure AddParameter(S:String);
    var
      Parameter,Units:String;
    begin
    SplitLabel(S,Parameter,Units);
    Parameters.Insert(New(PParameterName,Init(Parameter,Units)));
  end;

  procedure ReadParameterUnits(var LibFile:Text);
    var
      S:String;
    begin
    PositionFile(LibFile,"Parameters");
    repeat
      ReadLn(LibFile,S);
      if (S"") and (S[1]"[") then
        AddParameter(S);
    until (S="") or (S[1]="[");
  end;

  procedure ReadParameters;
      var LibFile:Text;
      var Parameters:TCollection;
      var Names:TCollection;
    var
      S,Name:String;
      Mean,SD:RealType;
      Dist:DistributionType;
    begin
    Dist:=Normal;Mean:=0.0;SD:=0.0;
    repeat
      ReadLn(LibFile,S);
      if (S"") and (S[1]"[") then
        begin
        ParceParameterLine(S,Name,Mean,SD,Dist);
        Parameters.Insert(New(PParameter,Init(Mean,SD,Dist)));
        Names.Insert(New(PParameterName,Init(Name,"")));
      end;
    until (S="") or (S[1]="[");
  end;


  procedure LoadParameters(var LibFile:Text;Source:PSource);

    var
      TempParameters,TempNames:TCollection;
      F:PParameterName;
```

2

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```
    I:Word;
    S:String;

  Function SearchComp(P:PParameterName):Boolean; far;
    begin
    SearchComp:=UpStr(P^.GetName)=S;
  end;

  begin
  TempParameters.Init(20,5);
  TempNames.Init(20,5);
  PositionFile(LibFile,Source^.GetName);
  ReadParameters(LibFile,TempParameters,TempNames);
  for I:=0 to Parameters.Count-1 do
    begin
    P:=Parameters.At(I);
    S:=UpStr(P^.GetName);
    if TempNames.FirstThat(@SearchComp)<>nil then
      Source^.Parameters.Insert(
          TempParameters.At(
          TempNames.IndexOf(
          TempNames.FirstThat(@SearchComp))))
    else
      begin
      Writeln(output,'Could not find '+S+' Parameter in ');
      Writeln(output,'the Source data for '+UpStr(Source^.Get-
                     Name)+'.');
      Halt(1);
    end;
  end;
end;

procedure ReadSourceData(var LibFile:Text);
  var
    I:Word;
    CurrentSource:PSource;
  begin
  for I:=0 to Sources.Count-1 do
    begin
    CurrentSource:=Sources.At(I);
    LoadParameters(LibFile,CurrentSource);
  end;
end;
```

```
procedure ReadSourceSample(var LibFile:Text);
  var
    S,Name:String;
    Sample:RealType;

  Function SearchPol(P:PParameterName):Boolean; far;
    begin
    if UpStr(P^.GetName)=UpStr(Name) then
      begin
      P^.SetSample(Sample);
      SearchPol:=True;
      end
    else
      SearchPol:=False;
  end;

  Function SearchError(P:PParameterName):Boolean; far;
    begin
    SearchError:=P^.SampleTouched;
  end;

  begin
  PositionFile(LibFile,'Sample');
  repeat
    Readln(LibFile,S);
    if (S<>'') and (S[1]<>'[') then
      begin
      ParceSampleLine(S,Name,Sample);
      if Parameters.FirstThat(@SearchPol)=nil then
        begin
        Writeln(output,'Error: Sample include the Parameter '+Name);
        Writeln(output,'       that is not in the Parameter table');
        Halt(1);
        end;
      end;
  until (S='') or (S[1]='[');
  if Parameters.FirstThat(@SearchError)=nil then
    begin
    Writeln(output,'Error: Not all Parameters were found in the sam-
                    ple');
    Halt(1);
    end;
  end;
```

3

```
  var
    LibFile:Text;
  begin
  Writeln(output,'Reading data from library file');
  Assign(LibFile,LibFileName);
  Reset(LibFile);
  Check(IOResult=0);
  ReadSourceNames(LibFile);
  ReadParameterUnits(LibFile);
  ReadSourceData(LibFile);
  ReadSourceSample(LibFile);
  Close(LibFile);
  Writeln(output,'Finished reading data from library file');
end;
```

```
procedure SelectPoints;
  var
    I,J:Word;
  begin
  for I:=0 to MaterialNo do
    for J:=0 to SourceNo do
      Mixture[I,J]:=PSource(Sources.At(J-1))^.GetSample(I-1);
end;



const
  SampleNo=200;
  Abbrev:Array[0..9] of char=('1','2','3','4','5','6','7','8','9','0');
var
  I,J,K:Byte;
  S:PSource;
  St:String;
  P:PParameterName;
  F:Text;
  CurrentIteration:Word;
  X:Real;
begin
Randomize;
RandSeed:=2;
DirectWrite:=False;
Writeln(output,'Psi-Sit - A program by Edward T. Tufte, 1982/7/23');
MaterialNo:=MaterialNo;
SourceNo:=SourceNo;
Init;
ReadLibrary;

{*
Assign(F,'PSI');
{$I-}Append(F);{$I+}
If IOResult<>0 then}
Rewrite(F);

Writeln(F,'Output.Sample');
for I:=0 to Parameters.Count-1 do
  Write(F,',',PParameterName(Parameters.At(I))^.GetName);
Writeln(F);
for I:=0 to Sources.Count-1 do
  begin
  S:=Sources.At(I);
```


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```
    for J:=1 to SampleNo do
      begin
      Write(F,Abbrev[I],',',J);
      for K:=0 to Parameters.Count-1 do
        begin
        Str(S^.GetSample(K):0:2,St);
        RemoveSpace(St);
        Write(F,',',St);
      end;
      WRiteln(F);
    end;
  end;
  Close(F);
  end.
  *)


  Materials:=Parameters.Count;
  SourceNo:=Sources.Count;
  for I:=1 to MaterialNo do
    Sample[I]:=PParameterName(Parameters.At(I-1))^.Sample;

  CurrentIterations:=0;
  Writeln(output);
  Writeln(output);
  Writeln(output,'Press any key to abort additional calculations.');
  Write(output,'On iteration #');
  X:=WhereX;
  Y:=WhereY;
  repeat
    inc(CurrentIterations);
    repeat
      SelectPoints;
      CalculateConcentration;
    until SampleOK(X,Y,CurrentIterations) or KeyPressed;
    if SampleOK(X,Y,CurrentIterations) then
      StoreResults(CurrentIterations);
    if (CurrentIterations and 7) = 7 then
      begin
      Goto(X,Y);
      Write(output,CurrentIterations);
    end;
  until KeyPressed or (CurrentIterations=Iterations);
```

```
  Goto(X,Y);
  WriteLn(output,CurrentIterations);
  SortIterations(CurrentIterations);
  if KeyPressed then
    ScanKBD(InputScan);
  PrintResults(CurrentIterations,Sources,Parameters);
  PlotResults(CurrentIterations,Sources);
  end.

  {Assign(F,'[:\200');}
  Assign(rt(F);
  Rewrite(F);

  Write(F,'Groups.Sample%');
  for I:=0 to Parameters.Count-1 do
    Write(F,',',PParameterName(Parameters.At(I))^.GetName);
  WriteLn(F);
  for I:=0 to Sources.Count-1 do
    begin
    S:=Sources.At(I);
    for J:=1 to SampleNo do
      begin
      Write(F,Abbrev[I],',',J);
      for K:=0 to Parameters.Count-1 do
        begin
        Str(S^.GetSample(K):0:2,St);
        RemoveSpace(St);
        Write(F,',',St);
      end;
      WRiteln(F);
    end;
  end;
  Close(F);
  end.

  {Just Display Data}
  for I:=1 to Sources.Count do
    begin
    S:=Sources.At(I-1);
    Writeln(S^.GetName);
  end;

  for I:=1 to Parameters.Count do
    begin
```



```
  P:=Parameters.At(I-1);
  Writeln(P^.GetName);
end;
end.
```


A006635

Unit PolUtl;

```
{This unit includes utility procedured for pol-sit}

INTERFACE

{$define Test1}             {Test for positive samples}
{ $define Test3}             {Test if  then =0}

uses
  Objects,
  EdLib;

type
  RealType=Single;
  DistributionType=(Normal,LogNormal);
  PSource=^TSource;
  TSource=Object(TObject)
      Name:PString;
      Parameters:TCollection;
      constructor Init(SourceName:String);
      function GetName:String;
      function GetSample(ParameterNo:Word):RealType;
    end;
  PParameterName=^TParameterName;
  TParameterName=Object(TObject)
      Name:PString;
      Units:PString;
      Sample:RealType;
      SampleTouched:Boolean;
      constructor Init(ParameterName,UnitName:String);
      function GetName:String;
      procedure SetSample(A:RealType);
  end;
  PParameter=^TParameter;
  TParameter=Object(TObject)
      Mean,SD:RealType;
      Dist:DistributionType;
      constructor Init(NewMean,NewCoV:RealType;NewDist:DistributionType);
      function GetSample:RealType;
  end;
```



```
procedure DisplayHelpScreen;
procedure PositionFile(var F:Text;FindStr:String);
procedure RemoveSpace(var S:String);
procedure AbortOnEOF(var F:Text;ErrMsg:String);
procedure SplitLabel(S:String;var Lab:String;var Equat:String);
procedure ParceParameterLine(S:String;var ParameterName:String;
    var Mean,SD:RealType;Dist:DistributionType);
procedure ParceSampleLine(S:String;var Name:String;var Sample:RealType);
function FindLogNormal(Mean,SD:RealType):RealType;
function FindNormal(Mean,SD:RealType):RealType;
procedure CheckIOResult;

IMPLEMENTATION
```



```
procedure DisplayHelpScreen;
  begin
   Writeln(Output,'This is the help screen for the command line - not com-
                   plete yet');
end;
```

```
procedure PositionFile(var F:Text;FindStr:String);
  var
    S:String;
  begin
  Reset(F);
  FindStr:='['+UpStr(FindStr)+']';
{  RemoveSpace(FindStr);}
  repeat
    ReadLn(F,S);
  until EOF(F) or (UpStr(S)=FindStr);
  AbortOnEOF(F,'Searching for '+FindStr);
end;
```


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```
procedure RemoveSpace(var S:String);
  var
    I:Byte;
  begin
  I:=1;
  while I<=Length(S) do
    if S[I]=' ' then
      Delete(S,I,1)
    else
      I:=I+1;
end;
```

```
procedure AbortOnEOF(var F:Text;ErrMsg:String);
  begin
  if EOF(F) then
    begin
    Close(F);
    writeln(output,'Unexpected EOF.  ',ErrMsg);
    Halt(1);
  end;
end;
```



```
procedure ParseParameterLine(S:String;var ParameterName:String;
    var Mean,SD:RealType;Dist:DistributionType);

  procedure CheckErr(Err:Integer;I:Byte);
    begin
    if (Err<>0) or (I<>Length(S)) then
      begin
      WriteLn(output,'Error in library.  Something is wrong with the');
      WriteLn(output,'                   number(s) on the following
                      line:');
      WriteLn(output,S);
      Halt(1);
      end;
    end;

  var
    I,J:Byte;
    Err:Integer;
  begin
  ParameterName:=Copy(S,1,Pos('=',S)-1);
  I:=Pos('=',S)+1;

    while S[I] in [' ','=',',',#9] do
      Inc(I);
    J:=I;
    while not (S[I] in [' ',',',#9]) do
      Inc(I);
    Val(Copy(S,J,I-J),Mean,Err);
    CheckErr(Err,I);

    I:=I+1;
    while S[I] in [' ',',',#9] do
      Inc(I);
    J:=I;
    while not (S[I] in [' ',',',#9]) do
      Inc(I);
    Val(Copy(S,I,J-I),SD,Err);
    CheckErr(Err,I-1);

    if SD=0 then
      Dist:=Normal
    else
      begin
      I:=I+1;
```

```
    while S[I] in [' ',',',#9] do
      Inc(I);
    case UpCase(S[I]) of
      'L':  Dist:=LogNormal;
      'N':  Dist:=Normal;
    else
      begin
      writeln(output,'Error in library.  The following line has an in-
                      valid');
      writeln(output,'                   distribution token.');
      writeln(output,S);
      Halt(1);
      end
    end;
  end;
end;
```


A006637

procedure ParceSampleLine(S:String;var Name:String;var Sample:RealType);

```
procedure ParceSampleLine(S:String;var Name:String;var Sample:RealType);
  var
    I,J:Byte;
    Err:integer;
  begin
  Name:=Copy(S,1,Pos('=',S)-1);
  I:=Pos('=',S)+1;

  while S[I] in [' ',',',#9] do
    Inc(I);
  J:=I;
  while not (S[J] in [' ',',',#9]) do
    Inc(J);
  Val(Copy(S,I,J-1),Sample,Err);

  if Err0 then
    begin
    Writeln(output,'Error in library.  Something is wrong with the');
    Writeln(output,'                   number(s) on the following
                    line:');
    Writeln(output,S);
    Halt(1);
  end;
end;
```

```
{*****************************************************************
************              SplitLabel          **************************
*****************************************************************}
{Split the line
  Ammonia=mg/l
into
  Ammonia
  mg/l                    }
```

```
procedure SplitLabel(
        S:String;
    var Lab:String;
    var Equat:String);
  begin
  Lab:=Copy(S,1,Pos('=',S)-1);
  Equat:=Copy(S,Pos('=',S)+1,Length(S)-Pos('=',S));
  while (Equat[Length(Equat)] in [' ',',',#9]) and (Length(Equat)0) do
    Delete(Equat,Length(Equat),1);
  if Equat='' then
    Equat:='-';
end;

{*****************************************************************
************              TSource Definition   **************************
*****************************************************************}
```

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constructor TSource.Init(SourceName:String);

```
constructor TSource.Init(SourceName:String);
  begin
  Name:=NewStr(SourceName);
  Parameters.Init(20,5);
end;
```

```
function TSource.GetName:String;
  begin
  GetName:=Name^;
end;
```

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function TSource.GetSample(ParameterNo:Word):RealType;

```
function TSource.GetSample(ParameterNo:Word):RealType;
  var
    P:PParameter;
  begin
  P:=Parameters.At(ParameterNo);
  GetSample:=PParameter(P)^.GetSample;
end;

{*************************************************************************
***********              TParameterName Definition**********************
*************************************************************************}
```

```
constructor TParameterName.Init(ParameterName,UnitName:String);
  begin
  Name:=NewStr(ParameterName);
  Units:=NewStr(UnitName);
  SampleTouched:=False;
end;
```


function TParameterName.GetNameString;

```
function TParameterName.GetName:String;
  begin
  GetName:=Name^+':'+Units^;
end;
```

```
procedure TParameterName.SetSample(A:RealType);
  begin
  Sample:=A;
  SampleTouched:=True;
end;

{*************************************************************************
************              TParameter Definition**************************
*************************************************************************}
```


A006639

```
constructor TParameter.Init(NewMean,NewCoV:RealType;NewDist:DistributionType);
```

```
constructor TParameter.Init(NewMean,NewCoV:RealType;NewDist:Distribution-
Type);
  begin
  case NewDist of
    LogNormal: begin
      if NewMean0 then
        Mean:=ln(NewMean)
      else
        Mean:=NewMean;
      if NewCoV0 then
        SD:=ln(NewCoV*Mean)
      else
        SD:=NewCoV*Mean;
      end;
    Normal: begin
      Mean:=NewMean;
      SD:=NewCoV*Mean;
    end;
  end;
  Dist:=NewDist;
end;
```

```
function TParameter.GetSample:RealType;
  begin
  if SD=0 then
    GetSample:=Mean
  else
  if Dist=Normal then
    GetSample:=FindNormal(Mean,Sd)
  else
    GetSample:=FindLogNormal(Mean,Sd);
end;
```



```
function FindLogNormal(Mean,SD:RealType):RealType;
```

```
function FindLogNormal(Mean,SD:RealType):RealType;
  var
    CV,A,B,VarianceY,MeanY,S:RealType;
    I:Byte;
  begin
  CV:=SD/Mean;
  MeanY:=ln(Mean)-(0.5*ln(CV*CV+1));
  VarianceY:=ln(CV*CV+1);
  {$ifdef test1}
    repeat
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY);
    until (SQ){ and (San*2));
    FindLogNormal:=S;
  {$else}
    {$ifdef Test3}
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY);
      if S then
        FindLogNormal:=0
      else
        FindLogNormal:=S;
    {$else}
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      FindLogNormal:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*Vari-
                         anceY+MeanY);
    {$endif}
  {$endif}
end;
```

```
function FindNormal(Mean,SD:RealType):RealType;
  function Dolt:RealType;
    var
      S:RealType;
      I:Byte;
    begin
    S:=0;
    for I:=1 to 12 do
      S:=S+Random(10000)/10000;
    S:=S-6.0;
    Dolt:=Mean+SD*S;
  end;

  var
    S:RealType;
  begin
  {$ifdef test1}
    repeat
      S:=Dolt;
    until (SQ){ and (San*2));
  {$else}
    {$ifdef test3}
      S:=Dolt;
      if S then
        S:=0;
    {$else}
      S:=Dolt;
    {$endif}
  {$endif}
  FindNormal:=S;
end;
```


A006640

procedure CheckIOResult;

```
procedure CheckIOResult;
  var
    Error:Word;
  begin
  Error:=IOResult;
  if Error0 then
    begin
    Writeln(output,'IO Error! #',Error);
    Halt;
  end;
end;

end.
```

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procedure CheckIOResult;

Unit Matrix;

```
INTERFACE

{ Define Test2}                  {Test for positive results}

uses
  Crt,Graph,Objects,Crlib,PBGraph,PCrivers,PRT_IMS,
  IdLib,GrLibDEGA,
  ToUtl;

const
  MaxSourceNo=25;
  MaxMaterialNo=25;
  Mean=1;
  Minimum=2;
  Maximum=3;
  MaxIterations=2000;
  MaxXPlot=6;
  MaxYPlot=10;

type
  IterationLibraryType=Array[1..MaxMaterialNo,1..MaxSourceNo] of Re-
                       alType;
  IterationConcentrationType=Array[1..MaxSourceNo] of RealType; {In per-
                       cent}
  SampleType=Array[1..MaxMaterialNo] of RealType;
  RawType=Array[1..MaxSourceNo] of RealType;

var
  SourceNo:Byte;
  MaterialNo:Byte;
  Iterations:Word;
{ Library:Array[1..MaxMaterialNo,1..MaxSourceNo,1..3] of RealType;}
  IterLib:IterationLibraryType;
  IterConcentration:IterationConcentrationType;
  Sample:SampleType;
  Answer:Array[1..MaxMaterialNo] of RealType;
  RawData:Array[1..MaxIterations] of ^RawType;
  TotalPercent:RealType;

procedure SetVars;
procedure CalculateConcentration;
procedure StoreResults(IterNo:Word);
procedure SortIterations(Iterations:Word);
procedure PlotResults(Iterations_:Word;Sources_:TCollection);
procedure PrintResults(
        Iterations:Word;
    var Sources:TCollection;
    var Parameters:TCollection);
function SampleTest(X,Y:Word;CurrentIterations:LongInt):Boolean;

implementation
```

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procedure SetVars;

```
procedure SetVars;
  var
    I,J:Word;
    Total:RealType;
    TestLib:IterationLibraryType; {define!!}
    TestSample:SampleType;        {define!!}
  begin
  I:=0;
  repeat
    Inc(I);
    New(RawData[I]);
{    Write(MemAvail,',');}
  until (I=MaxIterations) or (MaxAvailP);
  Iterations:=I;
  Writeln(output,'Using a maximum of ',I,' itterations.');

  (*
  for I:=1 to MaterialNo do
    for J:=1 to SourceNo do
      begin
{      Library[I,J,Mean]:=Random(300)/30;}
      Library[I,J,Mean]:=TestLib[I,J];
      Library[I,J,Minimum]:=Library[I,J,Mean]*0.9;
      Library[I,J,Maximum]:=Library[I,J,Mean]*1.1;
    end;
  for I:=1 to MaterialNo do
    Answer[I]:=Random(300)/300;
  for I:=1 to MaterialNo do
    begin
    Sample[I]:=0;
    for J:=1 to SourceNo do
      Sample[I]:=Sample[I]+Answer[I]*Library[I,J,Mean];
  end;
  Sample:=TestSample;
  *)
end;
```

```
procedure CalculateConcentration;
  procedure GaussianElimination(
      var A:IterationLibraryType;
      var B:IterationconcentrationType;
          C:SampleType);
      {Solve for B in AB=C}
{   const
      TrialA:IterationLibraryType=(
          (10,-7,0),
          (0,2.5,5),
          (0,0,6.2));
      TrialC:SampleType=(7,2.5,6.2);}
    var
      I,J,K:Word;
      Scale,Sum:RealType;
    begin
{   A:=TrialA;
    C:=TrialC;}
    {Triangalize matrix}
    for I:=2 to MaterialNo do
      for J:=1 to MaterialNo do
        if A[J,I-1]0 then
          begin
          Scale:=-A[J,I-1]/A[I-1,I-1];
          A[J,I-1]:=0;
          for K:=I to MaterialNo do
            A[J,K]:=A[J,K]+A[I-1,K]*Scale;
          C[J]:=C[J]+C[I-1]*Scale;
        end;

{   Writeln;
    for I:=1 to MaterialNo do
      begin
      for J:=1 to MaterialNo do
        Write(A[I,J]:10:6);
      Writeln;
    end;
    Writeln;

    {Solve for B by reverse substitution}
    B[MaterialNo]:=C[MaterialNo]/A[MaterialNo,SourceNo];
    for I:=MaterialNo-1 downto 1 do
      begin
      Sum:=0;
```

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```
      for J:=I+1 to SourceNo do
        Sum:=Sum+A[I,J]*B[J];
      B[I]:=(C[I]-Sum)/A[I,I];
    end;

  end;


    {This assums a square matrix!}
  var
    I,J:Word;
    Total:RealType;
  begin
  if SourceNoMaterialNo then
    writeln(output,'SourceNoMaterialNo !!');
  GaussianElimination(IterLib,IterConcentration,Sample);
end;
```

procedure StoreResults(IterNo:Word);

```
procedure StoreResults(IterNo:Word);
  var
    I:Word;
  begin
  for I:=1 to SourceNo do
    RawData[IterNo]^[I]:=IterConcentration[I];
end;
```

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```
procedure Sort(Iterations:Iterations:Word);
  procedure SortSource(Source:Word);
    procedure sort(l,r: Integer);
      var
        i,j: Integer;
        X,Y: RealType;
      begin
      i:=l; j:=r; x:=RawData[(l+r) DIV 2]^[Source];
      repeat
        while RawData[i]^[Source]<x do i:=i+1;
        while x<
                    RawData[j]^[Source] do j:=j-1;
        if i <= j then
          begin
          y:=RawData[i]^[Source];
                    RawData[i]^[Source]:=RawData[j]^[Source];
                    RawData[j]^[Source]:=y;
          i:=i+1; j:=j-1;
        end;
      until i>j;
      if l < j then sort(l,j);
      if i <
                        then sort(i,r);
    end;

    begin
    sort(1,Iterations);
  end;

  var
    i:Word;
  begin
  Write(output,'Sorting Source #1');
  for i:=1 to SourceNo do
    begin
    if i>1 then
      Write(output,',',i);
    SortSource(i);
  end;
  WriteLn;
end;
```

```
procedure SortIterations(Iterations:Word);

procedure ShowData(Var OutFile:Text);
  type
    SourceRec=Record
      Mean,Median,SD,Coef:RealType;
    end;
  var
    Data:Array[1..MaxSourceNo] of SourceRec;
  begin

end;
```



```
procedure PrintResults(
        Iterations:Word;
    var Sources:TCollection;
    var Parameters:TCollection);

  procedure ShowData(Var OutFile:Text);
    type
      SourceRec=Record
        Mean,Median,SD,Coef:RealType;
        SourceNo:Byte;
      end;
    var
      Data:Array[0..MaxSourceNo] of SourceRec;
      I:Byte;
      J:Word;

    procedure SortData;
      procedure sort(l,r: integer);
        var
          i,j: integer;
          X,Y: SourceRec;
        begin
        i:=l; j:=r; x:=Data[(l+r) DIV 2];
        repeat
          while Data[i].Mean<Mean do i:=i+1;
          while x:Meanata[j].Mean do j:=j-1;
          if i then
            begin
            y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
            i:=i+1; j:=j-1;
          end;
        until ij;
        if l then sort(l,j);
        if i
                        then sort(i,r);
      end;

    begin
      sort(1,Sources.Count);
    end;

    begin
    for I:=1 to Sources.Count do
      begin
```

```
procedure PrintResults(

      Data[I].Mean:=0;
      for J:=1 to Iterations do
        Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
      Data[I].Mean:=Data[I].Mean/Iterations;
      Data[I].Median:=RawData[Iterations div 2]^[I];

      Data[I].SD:=0;
      for J:=1 to Iterations do
        Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
      Data[I].SD:=Sqrt(Data[I].SD/Iterations);

      Data[I].Coef:=Data[I].SD/Data[I].Mean;
      Data[I].SourceNo:=I;
    end;

    SortData;

    WriteLn(OutFile,'Result Summary:');
    WriteLn(OutFile,'Source:,Mean,Median,Std Dev.,Co. Var.,"10%","90%"');
    for I:=Sources.Count downto 1 do
      WriteLn(OutFile,PSource(Sources.At(Data[I].SourceNo-1))^.Get-
                      Name,',',
          Data[I].Mean,',',
          Data[I].Median,',',
          Data[I].SD,',',
          Data[I].Coef,',',
          RawData[Iterations div 10]^[Data[I].SourceNo],',',
          RawData[9*Iterations div 10]^[Data[I].SourceNo]);

  end;

  procedure ShowData_SCR;
    type
      SourceRec=Record
        Mean,Median,SD,Coef:RealType;
        SourceNo:Byte;
      end;
    var
      Data:Array[0..MaxSourceNo] of SourceRec;
      I:Byte;
      J:Word;

    procedure SortData;
      procedure sort(l,r: integer);
```


A0066543

```
    var
      i,j: integer;
      X,Y: SourceRec;
    begin
    i:=l; j:=r; x:=Data[(l+r) DIV 2];
    repeat
      while Data[i].Mean<Mean do i:=i+1;
      while x.Meanata[j].Mean do j:=j-1;
      if i then
        begin
        y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
        i:=i+1; j:=j-1;
      end;
    until ij;
    if l then sort(l,j);
    if i
                  then sort(i,r);
  end;

  begin
  sort(1,Sources.Count);
end;

begin
for I:=1 to Sources.Count do
  begin
  Data[I].Mean:=0;
  for J:=1 to Iterations do
    Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
  Data[I].Mean:=Data[I].Mean/Iterations;
  Data[I].Median:=RawData[Iterations div 2]^[I];

  Data[I].SD:=0;
  for J:=1 to Iterations do
    Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
  Data[I].SD:=Sqrt(Data[I].SD/Iterations);

  Data[I].Coef:=Data[I].SD/Data[I].Mean;
  Data[I].SourceNo:=I;
end;

SortData;

Writeln('Result Summary:');
```

procedure PrintResults;

```
  Writeln('Source:                    Mean   Median    Std Dev.
                        Co. Var.');
  for I:=Sources.Count downto 1 do
    Writeln(PSource(Sources.At(Data[I].SourceNo-1))^.GetName:20,
        Data[I].Mean:10:5,
        Data[I].Median:9:5,
        Data[I].SD:12:5,
        Data[I].Coef:13:5);

end;

var
  I,J:Word;
  OutFile:Text;
  X,Y:Byte;
begin
ShowData_SCR;
Assign(OutFile,'Data.txt');
Rewrite(OutFile);
WriteLn(output,'Press any key to stop creating DATA.TXT.');
Write(output,'Creating DATA.TXT progress: ');
X:=WhereX;
Y:=WhereY;

Writeln(OutFile,'Sample tested:');
Writeln(OutFile,'Name:,Sample:,Units:');
for I:=0 to Parameters.Count-1 do
  Writeln(Outfile,
      PParameterName(Parameters.At(I))^.GetName,',',
      PParameterName(Parameters.At(I))^.Sample:8:7,',',
      PParameterName(Parameters.At(I))^.Units^);
Writeln(OutFile);
Writeln(OutFile,'Most Likely: (in percent)');
for I:=0 to Sources.Count-1 do
  Writeln(Outfile,
      PParameterName(Sources.At(I))^.GetName,',',
        RawData[Iterations div 2]^[I+1]*100:8:5);
Writeln(OutFile);
ShowData(OutFile);
Writeln(OutFile);
Writeln(OutFile,'RawData:');
Writeln(OutFile,'position#,Parameter#1,Parameter#2...');
Write(OutFile,'Sample#,,');
for I:=0 to Parameters.Count-2 do
```


function Trim(X:RealType):Integer;

```
  Write(Outfile,PParameterName(Parameters.At(I))^.GetName,',');
Writeln(OutFile,PParameterName(Parameters.At(Parameters.Count-1))^.Get-
                    Name);
I:=0;
repeat
  Inc(I);
  Write(OutFile,I,',',100.0*I/Iterations,',');
  for J:=1 to SourceNo-1 do
    Write(OutFile,RawData[I]^[J]:8:7,',');
  Writeln(OutFile,RawData[I]^[SourceNo]:8:7);
  if (I and 63) = 63 then
    begin
    GotoXY(X,Y);
    Write(output,I/Iterations*100:4:1,'%   ');
  end;
until (I=Iterations) or Keypressed;

if KeyPressed then
  ScanKBD(InputScan);
Close(OutFile);
end;
```

```
function Trim(X:RealType):Integer;
  begin
  if X32767 then
    Trim:=32767
  else if X32768 then
    Trim:=-32768
  else Trim:=Trunc(X);
end;



type
  PByte=^Byte;

var
 DS_Iterations:Word;
 Sources:PCollection;
 PRTdrv,PRTmode,rc: integer;

  procedure ShowData_SCR;
    type
      SourceRec=Record
        Mean,Median,SD,Coef:RealType;
        SourceNo:Byte;
      end;
    var
      Data:Array[0..MaxSourceNo] of SourceRec;
      I:Byte;
      J:Word;

    procedure SortData;
      procedure sort(l,r: integer);
        var
          i,j: integer;
          X,Y: SourceRec;
        begin
        i:=l; j:=r; x:=Data[(l+r) DIV 2];
        repeat
          while Data[i].Mean<Mean do i:=i+1;
          while X.Meanata[j].Mean do j:=j-1;
          if i then
            begin
            y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
```


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```
        i:=i+1; j:=j-1;
      end;
    until i>j;
    if l<j then sort(l,j);
    if i<r
                  then sort(i,r);
  end;

  begin
  sort(1,Sources^.Count);
end;

begin
GotoXY(1,1);
ClearViewPort;
for I:=1 to Sources^.Count do
  begin
  Data[I].Mean:=0;
  for J:=1 to DS_Iterations do
    Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
  Data[I].Mean:=Data[I].Mean/DS_Iterations;
  Data[I].Median:=RawData[DS_Iterations div 2]^[I];

  Data[I].SD:=0;
  for J:=1 to DS_Iterations do
    Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
  Data[I].SD:=Sqrt(Data[I].SD/DS_Iterations);

  Data[I].Coef:=Data[I].SD/Data[I].Mean;
  Data[I].SourceNo:=I;
end;

SortData;

Writeln('Result Summary:');
Writeln('Source:                    Mean    Median    Std Dev.
                  Co. Var.');
for I:=Sources^.Count downto 1 do
  Writeln(PSource(Sources^.At(Data[I].SourceNo-1))^.GetName:20,
      Data[I].Mean:10:5,
      Data[I].Median:9:5,
      Data[I].SD:12:6,
      Data[I].Coef:13:5);
Writeln;
```

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```
function Trim(X:RealType):Integer;

  WriteLn('Press up/down arrow to see next screen');
  Writeln('Press ESC to exit program.');
end;
{$F+}
```

```
function DisplaySource(UserPointer:pointer): integer;
  var
    Min,Max:RealType;
    I:Word;
    MaxX,MinX,MaxY,MinY:Word;
    S:String;
    Source:Byte;
  begin
  Source:=PByte(UserPointer)^;
  if Source<>0 then
    begin
    MinX:=30;
    MaxX:=GetMaxX-20;
    MinY:=5;
    MaxY:=GetMaxY-10;
    Max:=0;
    Min:=0;
    for I:=1 to DS_Iterations-(DS_Iterations div 20) do
      if RawData[I]^[Source]>Max then
        Max:=RawData[I]^[Source];
    Max:=Max*1.3;
    if Max<>0 then
      Max:=1;
    Max:=Round(Max/0.5)*0.5;

    for I:=DS_Iterations div 20 to DS_Iterations do
      if RawData[I]^[Source] < then
        Min:=RawData[I]^[Source];
    if Min<>0 then
      Min:=Round(Min/0.5-1)*0.5;

    ClearDevice;
    SetTextStyle(DefaultFont,HorizDir,1);

    SetColor(Blue);
    Line(MinX,MaxY,MaxX,MaxY);
    Line(MinX,MinY,MinX,MaxY);
    SetTextJustify(CenterText,TopText);
    for I:=0 to MaxXPlot do
      begin
      SetColor(Cyan);
      Str((Max-Min)*I/MaxXPlot+Min:5:3,S);
      OutTextXY(Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MaxY+2,S);
      SetColor(Blue);
```

```
function DisplaySource(UserPointer:pointer): integer;

    Line(Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MaxY,
         Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MinY);
    end;
    SetColor(Yellow);
    Line(Trunc((MaxX-MinX)*(-Min)/(Max-Min)+MinX),MaxY,
         Trunc((MaxX-MinX)*(-Min)/(Max-Min)+MinX),MinY);

    SetTextJustify(RightText,CenterText);
    for I:=1 to MaxYPlot do
      begin
      SetColor(Cyan);
      Str(100*I/MaxYPlot:3:0,S);
      OutTextXY(MinX-1,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot),S);
      SetColor(Blue);
      Line(MinX,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot),
           MaxX,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot));
    end;

    SetColor(Cyan);
    SetTextJustify(RightText,TopText);
    SetTextStyle(DefaultFont,VertDir,1);
    Str(Source,S);
    OutTextXY(GetMaxX,0,
        '(C) Edward T. Kujawski 7/2/92 Press ESC to quit Source #'+S);
    OutTextXY(GetMaxX,0,
        '(C) Edward T. Kujawski 7/2/92  Source:
                              '+PSource(Sources^.At(Source-1))^.GetName);

    for I:=1 to DS_Iterations do
      PutPixel(Trim((MaxX-MinX)*(RawData[I]^[Source]-Min)/(Max-
                    Min)+MinX),
        Trim(MaxY-(MaxY-MinY)*(-0.5+I)/DS_Iterations),Cyan);

    SetColor(Cyan);
    SetTextJustify(LeftText,TopText);
    SetTextStyle(DefaultFont,HorizDir,1);
    Str(RawData[DS_Iterations div 2]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[DS_Iterations div 2]^[Source]-
                    Min)/(Max-Min)+MinX)+2,
      MaxY-((MaxY-MinY) div 2)+2,S);
    Str(RawData[DS_Iterations div 10]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[DS_Iterations div 10]^[Source]-
                    Min)/(Max-Min)+MinX)+2,
      MaxY-((MaxY-MinY) div 10)+2,S);
```

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```
    Str(RawData[9*DS_Iterations div 10]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[9*DS_Iterations div
                    10]^[Source]-Min)/(Max-Min)+MinX)+2,
        MaxY-(9*(MaxY-MinY) div 10)+2,S);
    DisplaySource:=0;
    end
  else
    begin
    ShowData_SCR;
  end;
end;

{$F-}
```

```
procedure PlotResults(Iterations_:Word;Sources_:TCollection);

  procedure PrintScreen(Funct:DrawFunct;Source:PByte);
    var
      PRTmode,rc, Mode: integer;
    begin
    writeln(MemAvail,',',MaxAvail);
    rc := PRT_SetDriver ( LaserJet, LaserJet_150x150, 7500,7500, PRT_IN-
                          VERSE );
{   Writeln(RC);}
{   PRTdrv := PRT_installuserdriver ( 'BitImage', NIL );
    Writeln(RC);
    rc := PRT_registerbgidriver ( @BitImage );
    Writeln(RC);}

{   rc := PRT_SetOutName('c:\temp\file.tst');
    Writeln(RC);}
{   PRTdrv:=Detect;}
    PRTmode := 0;
    rc := PRT_PrintBGI ( PRTdrv, PRTmode, '', Funct, Source );
{   Writeln(RC);
    writeln(MemAvail,',',MaxAvail);}
    mode := getgraphmode;
    restorecrtmode;
    rc:=PRT_Send(#$0C);    (*Form Feed*)
    setgraphmode(mode);
    rc:=graphresult;
  end;

  var
    i:Word;
    CurrentSource:ShortInt;
  begin
  Sources:=@Sources_;
  DS_Iterations:=Iterations_;
  DirectVideo:=False;
  Graphics(HiMode);
  CurrentSource:=0;
  InputScan.Scan:=Key_A;
  repeat
    DisplaySource(@CurrentSource);
    ScanKBD(InputScan);
    case InputScan.Scan of
      Key_Up:   Inc (CurrentSource);
```



```
      Key_Down: Dec (CurrentSource);
      Key_P:    if CurrentSource0 then
                  PrintScreen(DisplaySource,@CurrentSource);
    end;
    if CurrentSource then
      CurrentSource:=SourceNo;
    if CurrentSourceSourceNo then
      CurrentSource:=0;
  until InputScan.Scan=Key_ESC;

  CloseGraph;
  DirectVideo:=True;
end;

var
  FailedNo:LongInt;
```

```
function SampleOK(X,Y:Word;CurrentIterations:LongInt):Boolean;
  var
    T:Boolean;
    I:Byte;
  begin
  {$ifdef test2}
    T:=True;
    for I:=1 to SourceNo do
      if (IterConcentration[I]0.1) or (IterConcentration[I]1.1) then
        T:=False;
    SampleOK:=T;
    inc(FailedNo);
    if (FailedNo mod 27) =0 then
      begin
      GotoXY(X,Y);
      Write(CurrentIterations,'/',FailedNo);
    end;
  {$endif}
end;

begin
    PRTdrv := PRT_installuserdriver ( 'BitImage', NIL );
    rc := PRT_registerbgidriver ( @BitImage );
    FailedNo:=0;

    DirectVideo:=False;
end.
```


A006646

```
unit edlib;

{Edward's personal library of procedures}

interface

uses
  {$ifdef OpCrt}
    Opcrt,
  {$else}
    Crt,
  {$endif}
  dos,graph,Printer;

const {Scan code values}

  mode_r_shf=1;  mode_l_shf=2;  mode_ctrl=4;    mode_alt=8;
  mode_scroll=16;mode_num=32;   mode_caps=64;   mode_ins=128;

  key_1=2;       key_q=16;      key_a=30;       key_z=44;
  key_2=3;       key_w=17;      key_s=31;       key_x=45;
  key_3=4;       key_e=18;      key_d=32;       key_c=46;
  key_4=5;       key_r=19;      key_f=33;       key_v=47;
  key_5=6;       key_t=20;      key_g=34;       key_b=48;
  key_6=7;       key_y=21;      key_h=35;       key_n=49;
  key_7=8;       key_u=22;      key_j=36;       key_m=50;
  key_8=9;       key_i=23;      key_k=37;       key_comma=51;
  key_9=10;      key_o=24;      key_l=38;       key_period=52;
  key_0=11;      key_p=25;      key_semi=39;    key_slash=53;
  key_dash=12;   key_l_br=26;   key_quote=40;
  key_equ=13;    key_r_br=27;

  key_esc=1;     key_bs=14;     key_tab=15;     key_ret=28;
  key_tilda=41;  key_b_slash=43;key_space=57;   key_prtscr=55;
  key_break=0;

  key_f1=59;     key_shift_f1=84;   key_ctrl_f1=94;   key_alt_f1=104;
  key_f2=60;     key_shift_f2=85;   key_ctrl_f2=95;   key_alt_f2=105;
  key_f3=61;     key_shift_f3=86;   key_ctrl_f3=96;   key_alt_f3=106;
  key_f4=62;     key_shift_f4=87;   key_ctrl_f4=97;   key_alt_f4=107;
  key_f5=63;     key_shift_f5=88;   key_ctrl_f5=98;   key_alt_f5=108;
  key_f6=64;     key_shift_f6=89;   key_ctrl_f6=99;   key_alt_f6=109;
  key_f7=65;     key_shift_f7=90;   key_ctrl_f7=100;  key_alt_f7=110;
  key_f8=66;     key_shift_f8=91;   key_ctrl_f8=101;  key_alt_f8=111;
  key_f9=67;     key_shift_f9=92;   key_ctrl_f9=102;  key_alt_f9=112;
  key_f10=68;    key_shift_f10=93;  key_ctrl_f10=103; key_alt_f10=113;

  key_home=71;   key_ctrl_home=119;
  key_up=72;
  key_pgup=73;   key_ctrl_pgup=132;
  key_minus=74;
  key_left=75;   key_ctrl_left=115;
  key_right=77;  key_ctrl_right=116;
  key_plus=78;
  key_end=79;    key_ctrl_end=117;
  key_down=80;
  key_pgdn=81;   key_ctrl_pgdn=118;
  key_ins=82;
  key_del=83;

{not used: 29,42,54,56,58,69,70,76,114,120-131,133-}

type
  scantype=record
    modify,ascii,scan:byte
  end;
  graphicscreentype=array[1..16512] of byte;
  textscreentype=array[1..25,1..80] of integer;
{  MessageSendType=Array[1..5] of String;}

Const
  KeySense:Boolean=True;

Var
  EdgeColor:       Byte;    {Back ground and forground}
  BodyColor:       Byte;
  PromptColor:     Byte;
  EntryColor:      Byte;

  Scr:graphicscreentype absolute $b800:0;
  TextScr:textscreentype absolute $b800:0;
  TextScr0:TextScreenType absolute $b800:0;
  TextScr1:TextScreenType absolute $b8F9:$70;
  TextScr2:TextScreenType absolute $b9F2:$E0;
  TextScr3:TextScreenType absolute $bAfb:$50;
  Reg:Registers;
  InputScan:ScanType;

  PauseAbort:Boolean;

procedure scankbd(var input:scantype);
function GetVideoMode:Byte;
function GetVideoPage:Byte;
procedure erasecurser;
procedure normalcurser;
Function UpStr(S : String) : String;
procedure PutXY(x,y,v:integer);
function power(number,exponent:real):real;

{Procedure SetMessageColor(EColor,BColor,PColor:Byte);
Procedure Message(Str:MessageSendType);}

function VideoModeStr(Mode:Byte):String;
procedure SetTextPage(NewPage:Byte);

procedure ClearScr(var Scr:TextScreenType);
procedure SetPageCurser(PageNo,X,Y:Byte);

procedure Center(S:String);

procedure Pause(Length:Word);

implementation

function SampleOK(X,Y:Word;CurrentIterations:LongInt):Boolean;

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procedure scankbd(var InputScanType);

procedure scankbd(var Input:ScanType);
  begin
  reg.ah:=0;
  intr(22,reg);
  input.ascii:=reg.al;
  input.scan:=reg.ah;
  reg.ah:=2;
  intr(22,reg);
  input.modify:=reg.al;
end;
```

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A00647

```
Function GetVideoMode:Byte;
  var
    Reg:Registers;
  begin
  Reg.ah:=$F;
  Intr($10,Reg);
  GetVideoMode:=Reg.al;
{ Reg.ah is columns number
  Reg.bh is current display page}
end;
```

```
Function GetVideoPage:Byte;
  var
    Reg:Registers;
  begin
  Reg.ah:=$F;
  Intr($10,Reg);
  GetVideoPage:=Reg.bh;
end;
```

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```
procedure erasecurser;
  begin
  reg.ah:=1;  reg.ch:=32;  reg.cl:=0;
  intr(16,reg);
end;
```

```
procedure normalcurser;
  begin
  if GetVideoMode=$7 then
    begin
    reg.ah:=1;
    reg.ch:=11;
    reg.cl:=12;
    end
  else
    begin
    reg.ah:=1;
    reg.ch:=6;
    reg.cl:=7;
  end;
  intr(16,reg);
end;
```

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A0066548

This Page Intentionally
Left Blank

```
function LoCase(C : Char) : Char ;
  begin
  if C in ['A'..'Z'] then
    LoCase:=Chr(Ord(C)+32)
  else
    LoCase:=C;
end;
```

function LoCase(C : Char) : Char ;

```
Function UpStr(S : String) : String;
{ Converts all chars in string to upper case }

  var
    I : Word;
    T : String;
  begin
  T := S;
  I := Length(T);
  While I  0 do begin
    T[I] := UpCase(T[I]);
    dec(I);
  end;   { While I  0 }
  UpStr := T;
end;
```


procedure PutXY(x,y,v:integer);

```
procedure PutXY(x,y,v:integer);
  begin
  textscr[y,x]:=v;
end;
```

```
function power(number,exponent:real):real;
  begin
  if number0.0 then
    power:=exp(exponent*ln(number))
  else
    power:=0.0;
end;

{Procedure SetMessageColor(EColor,BColor,PColor:Byte);
  begin
  EdgeColor:=EColor;
  BodyColor:=BColor;
  PromptColor:=PColor;
end;
```


A006650

```
Procedure Message(Str:MessageSendType);
  Const
    Press='Press Any Key To Continue';
  Type
    ScreenType=Array[1..2000] of Integer;
    RowType=Array[1..80] of Integer;
  Var
    ScreenA:ScreenType absolute $b800:0;
    Screen:^ScreenType;
    RowA:RowType absolute $b800:0;
    Row:^RowType;
    X,Y,I,J:Integer;

  begin
  EraseCursor;
  X:=WhereX;
  Y:=WhereY;
  if MemAvail then
    begin
    New(Row);
    Row^:=RowA;
    GotoXY(1,1);
    Write(Str[1]);
    GotoXY(70,1);
    Write('Any Key');
    Repeat Until KeyPressed;
    RowA:=Row^;
    end
  else
    begin
    New(Screen);
    Screen^:=ScreenA;
    GotoXY(20,10);
    TextColor(EdgeColor);
    Write(#218);
    for I:=21 to 60 do
      Write(#196);
    Write(#191);
    for I:=1 to 5 do
      begin
      GotoXY(20,10+I);
      TextColor(EdgeColor);
      Write(#179);
      TextColor(BodyColor);
```



```
      for J:=1 to (40-Length(Str[I])) div 2 do
        Write(' ');
      Write(Str[I]);
      for J:=1 to Trunc(Round((40-Length(Str[I]))/2)) do
        Write(' ');
      TextColor(EdgeColor);
      Write(#179);
    end;

    GotoXY(20,16);
    TextColor(EdgeColor);
    Write(#179);
    TextColor(PromptColor);
    for J:=1 to (40-Length(Press)) div 2 do
      Write(' ');
    Write(Press);
    for J:=1 to Trunc(Round((40-Length(Press))/2)) do
      Write(' ');
    TextColor(EdgeColor);
    Write(#179);

  GotoXY(20,17);
  TextColor(EdgeColor);
  Write(#192);
  for I:=21 to 60 do
    Write(#196);
  Write(#217);
  Repeat Until KeyPressed;
  ScreenA:=Screen^;
 end;
 GotoXY(X,Y);
 NormalCurser;
end;}
```



```
function VideoModeStr(Mode:Byte):String;
  begin
  case Mode of
    $00: VideoModeStr:='40x25 black and white text';
    $01: VideoModeStr:='40x25 color text';
    $02: VideoModeStr:='80x25 black and white text';
    $03: VideoModeStr:='80x25 color text';
    $04: VideoModeStr:='320x200 4 color graphics';
    $05: VideoModeStr:='320x200 4 color graphics (color burst off)';
    $06: VideoModeStr:='640x200 2 color graphics';
    $07: VideoModeStr:='Monochrome Adapter text display';
    $08: VideoModeStr:='160x200 16 color graphics (PCjr)';
    $09: VideoModeStr:='320x200 16 color graphics (PCjr)';
    $0A: VideoModeStr:='640x200 4 color graphics (PCjr)';
    $0D: VideoModeStr:='320x200 16 color graphics (EGA)';
    $0E: VideoModeStr:='640x200 16 color graphics (EGA)';
    $0F: VideoModeStr:='640x350 monochrome graphics (EGA)';
    $10: VideoModeStr:='640x350 4 color or 16 color graphics (EGA)';
  else
    VideoModeStr:='Reserved Mode.';
  end;
end;
```

```
procedure SetTextPage(NewPage:Byte);
    {InsLind and some other procedures work on the view page}
  var
    Reg:Registers;
  begin
  Reg.ah:=$5;
  Reg.al:=NewPage;
  Intr($10,Reg);
end;
```


A006651

```
procedure ClearScr(var Scr:TextScreenType);
  var
    I:Byte;
  begin
  for I:=1 to 80 do
    Scr[1,I]:=TextAttr shl 8;
  for I:=2 to 25 do
    Scr[I]:=Scr[1];
end;
```

```
procedure SetPageCurser(PageNo,X,Y:Byte);
  var
    Reg:Registers;
  begin
  Reg.ah:=2;
  Reg.bh:=PageNo;
  Reg.dh:=Y-1;
  Reg.dl:=X-1;
  Intr($10,Reg);
end;
```

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```
procedure Center(S:String);
  begin
  GotoXY(40-Length(S) shr 1,WhereY);
  Writeln(S);
end;
```

```
procedure Pause;
  var
    I:Word;
  begin
  I:=0;
  while KeyPressed do
    ScanKBD(InputScan);
  repeat
    Inc(I);
    Delay(5);
  until KeyPressed or (I>Length);
  InputScan.Scan:=29;
  if KeyPressed then
    ScanKBD(InputScan);
  PauseAbort:=InputScan.Scan=Key_ESC;
end;

End.
```

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A006652

```
unit GrLibEGA;

{Limited graphics - Linked library for EGA and VGA ONLY}

interface

uses
  Graph,Mouse13;

const
  HiMode=1;
  MedMode=2;
  LowMode=3;
  CgaHiMode=4;
  CgaLowMode=5;
  _640x350VEga=6;

var
  EgaVgaDriverProc:Pointer;


procedure Graphics(Mode:Integer);

procedure LoadImage(
    PosX,PosY:Word;
    ForeGround:Byte;
    FileName:String);
procedure LoadMouse(
    PosX,PosY:Word;
    FileName:String);
procedure DisplayText(
  Mini,MiniY,MaxX,MaxY:Word;
  FileName:String);

procedure DrawBox(X,Y:Word);
procedure EraseBox(X,Y:Word);

implementation
```

```
procedure EgaVgaDriverProc; external;
{$L EgaVga.BGI }
```



```
procedure Graphics(Mode:Integer);
  var
    Gd,I:Integer;
    Error:Integer;
  begin
  DetectGraph(Gd,I);
  if Mode then
    begin
    case Mode of
      LowMode:
        case Gd of
          CGA:      Mode:=CGAC0;
          MCGA:     Mode:=MCGAC0;
          EGA:      Mode:=EGALo;
          EGA64:    Mode:=EGA64Lo;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400C0;
          VGA:      Mode:=VGALo;
          Pc3270:   Mode:=Pc3270Hi;
        end;
      MedMode:
        case Gd of
          CGA:      Mode:=CGAC1;
          MCGA:     Mode:=MCGAMed;
          EGA:      Mode:=EGALo;
          EGA64:    Mode:=EGA64Lo;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400Med;
          VGA:      Mode:=VGAMed;
          Pc3270:   Mode:=Pc3270Hi;
        end;
      HiMode:
        case Gd of
          CGA:      Mode:=CGAHi;
          MCGA:     Mode:=MCGAHi;
          EGA:      Mode:=EGAHi;
          EGA64:    Mode:=EGA64Hi;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400Hi;
          VGA:      Mode:=VGAHi;
          Pc3270:   Mode:=Pc3270Hi;
```


procedure Graphics(Mode:Integer);

```
        end;
      _640x350VEga:
          case Gd of
            EGA:      Mode:=EGAHi;
            VGA:      Mode:=VGAMed;
          end;
      CgaHiMode:
          begin
          Gd:=Cga;
          Mode:=CgaHi;
        end;
      CgaLowMode:
          begin
          Gd:=Cga;
          mode:=CgaC1;
        end;
    end;
  end;
  InitGraph(Gd,Mode,'');
  if (Gd=Cga) and (Mode=CgaHi) then
    SetPalette(0,Magenta);
  Error:=GraphResult;
  if Error then
    begin
    Write(GraphErrorMsg(Error));
    Halt;
  end;
  SetMouseLimit(0,0,GetMaxX,GetMaxY);
end;
```


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```
procedure LoadImage(
    PosX,PosY:Word;
    ForeGround:Byte;
    FileName:String);

  const
    MaxBuffer=5000;

  type
    BufferType=Array[0..MaxBuffer] of Byte;

  var
    InFile:File;
    FileBuffer,Buffer:BufferType;
    FileRead,BufferPos:Integer;
    ColorBits:Byte;
    Xm,Ym:LongInt;


  procedure OpenFile;
    begin
    Assign(InFile,FileName+'.bmp');
    ReSet(InFile,1);
    FileRead:=1;
    BufferPos:=1;
  end;

  procedure ReadFile(
          Amount:LongInt;
      var Buffer:BufferType);
    var
      B:LongInt;
    begin
    B:=0;
    repeat
      while ((FileRead-BufferPos)>0) and (Amount>0) do
        begin
        Inc(B);
        Buffer[B]:=FileBuffer[BufferPos];
        Inc(BufferPos);
        Dec(Amount);
      end;

      if (FileRead-BufferPos)=0 then
```

```
        begin
        BlockRead(InFile,FileBuffer,MaxBuffer,FileRead);
        BufferPos:=0;
      end;
    until (Amount=0) or (Eof(InFile) and (BufferPos=FileRead));
  end;

  procedure DrawBMP;
    var
      X,Y:Word;
      I:Byte;
    begin
    for Y:=Ym downto 0 do
      begin
      ReadFile(Xm div 8+Fudge,Buffer);
      if PosY+Y<GetMaxY then
        for X:=0 to Xm do
          if (Buffer[X div 8] and (1 shl (7-(X mod 8))))>0 then
            PutPixel(PosX+X,PosY+Y,ForeGround);
    end;
  end;

  var
    I,J:Word;

  begin
  OpenFile;
  for I:=1 to MaxBuffer do
    Buffer[I]:=255;
  ReadFile(62,Buffer);
  Xm:=Buffer[19]+Buffer[20] *256;
  Ym:=Buffer[23]+Buffer[24] *256;
  ColorBits:=Buffer[29];

  DrawBMP;
  Fudge:=0;
  Close(InFile);
end;
```



```
procedure LoadImage16(
    PosX,PosY:Word;
    FileName:String);

  function Convert(A:Byte):Byte;
    begin
    case a of
      Black:      Convert:=Black;
      red:        Convert:=Blue;
      LightRed:   Convert:=LightBlue;
      Brown:      Convert:=Cyan;
      LightGray:  Convert:=LightGray;
      Magenta:    Convert:=Magenta;
    else
      Convert:=Yellow;
    end;
  end;


  const
    MaxBuffer=5000;

  type
    BufferType=Array[0..MaxBuffer] of Byte;

  var
    InFile:File;
    FileBuffer,Buffer:BufferType;
    FileRead,BufferPos:Integer;
    ColorBits:Byte;
    Xm,Ym:LongInt;


  procedure OpenFile;
    begin
    Assign(InFile,FileName+'.bmp');
    ReSet(InFile,1);
    FileRead:=1;
    BufferPos:=1;
  end;

  procedure ReadFile(
          Amount:LongInt;
      var Buffer:BufferType);
```

```
    var
      B:LongInt;
    begin
    B:=0;
    repeat
      while ((FileRead-BufferPos)>0) and (Amount>0) do
        begin
        Inc(B);
        Buffer[B]:=FileBuffer[BufferPos];
        Inc(BufferPos);
        Dec(Amount);
      end;

      if (FileRead-BufferPos)=0 then
        begin
        BlockRead(InFile,FileBuffer,MaxBuffer,FileRead);
        BufferPos:=0;
      end;
    until (Amount=0) or (Eof(InFile) and (BufferPos=FileRead));
  end;

  procedure DrawBMP;
    var
      X,Y:Word;
      I:Byte;
    begin
    for Y:=Ym downto 0 do
      begin
      ReadFile(Xm div 2+Fudge,Buffer);
      if PosY+Y<GetMaxY then
        for X:=0 to Xm do
          PutPixel(PosX+X,PosY+Y,
              Convert((Buffer[X div 2] and (15 shl (4*(1-(X mod 2))))
                      shr (4*(1-(X mod 2))))));
    end;
  end;

  var
    I,J:Word;

  begin
  OpenFile;
  for I:=1 to MaxBuffer do
    Buffer[I]:=255;
```


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```
  ReadFile(62+16*3+8,Buffer);
  Xm:=Buffer[19]+Buffer[20] *256;
  Ym:=Buffer[23]+Buffer[24] *256;
  ColorBits:=Buffer[29];

  DrawBMP;
  Fudge:=0;
  Close(InFile);
end;
```

```
procedure DisplayText(
    MinX,MinY,MaxX,MaxY:Word;
    FileName:String);

  var
    LineHeight:Byte;
    InFile:Text;
    S,S2:String;
    Width:Word;
    Line:Word;
  begin
  Assign(InFile,FileName+'.Txt');
  ReSet(InFile);
  SetTextJustify(Lefttext,TopText);
  LineHeight:=(TextHeight('Text')*5) div 4;
  S:='';
  S2:='';
  Line:=0;
  ReadLn(InFile,S);
  repeat
    Width:=1;
    repeat
      S2:=S2+S;
      while (TextWidth(Copy(S2,1,Width))<MaxX-MinX) and (Width<Length(S2)) do
        Inc(Width);
      ReadLn(InFile,S);
    until (TextWidth(Copy(S2,1,Width))>MaxX-MinX) or Eof(InFile);
    while (S2[Width]<>' ') and (Width<>0) do
      Dec(Width);
    OutTextXY(MinX,MinY+Line*LineHeight,Copy(S2,1,Width));
    Inc(Line);
    Delete(S2,1,Width);
  until Eof(InFile);

  while Length(S2)<>0 do
    begin
    Width:=1;
    while (TextWidth(Copy(S2,1,Width))<MaxX-MinX) and (Width<Length(S2)) do
      Inc(Width);
    while S2[Width]<>' ' do
      Dec(Width);
    OutTextXY(MinX,MinY+Line*LineHeight,Copy(S2,1,Width));
    Inc(Line);
    Delete(S2,1,Width);
```

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```
  end;
  Close(InFile);
end;
```

```
procedure DrawBox(X,Y:Word);
  var
    I,J:Word;
  begin
  for I:=1 to 20 do
    for J:=0 to I*2-1 do
      begin
      PutPixel(X+I,Y-J+I,GetPixel(X+I,Y-J+I)+1);
      PutPixel(X-J+I,Y-I,GetPixel(X-J+I,Y-I)+1);
      PutPixel(X-I,Y+J-I,GetPixel(X-I,Y+J-I)+1);
      PutPixel(X+J-I,Y+I,GetPixel(X+J-I,Y+I)+1);
    end;
end;
```

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procedure EraseBox(X,Y:Word);

```
procedure EraseBox(X,Y:Word);
  var
    I,J:Word;
  begin
  for I:=1 to 20 do
    for J:=0 to I*2-1 do
      begin
      PutPixel(X+I,Y-J+I,GetPixel(X+I,Y-J+1)-1);
      PutPixel(X-J+1,Y-I,GetPixel(X-J+1,Y-1)-1);
      PutPixel(X-1,Y+J-1,GetPixel(X-1,Y+J-1)-1);
      PutPixel(X+J-I,Y+1,GetPixel(X+J-1,Y+1)-1);
    end;
end;



var
  I:integer;

begin
I:=RegisterBGIdriver(@EgaVgaDriverProc);
Fudge:=0;
end.
```


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Appendix H
Glossary

Accuracy - The combination of bias and precision of an analytical procedure which reflects the closeness of a measured value to a true value.

Baseflow - The dry-weather flow occurring in a drainage system, with no apparent source. Likely to be mostly infiltrating groundwaters in a sanitary or storm drainage system, but can also be contaminated with illicit wastewaters. See constant (or continual) dry-weather flow.

Batch dump - The disposal of a large volume of waste material during a short period of time. Usually an industrial waste.
Bias - A consistent deviation of measured values from the true value, caused by systematic errors in a procedure.

Coefficient of Variation (COV) - A measure of the spread of data (ratio of the standard deviation to the mean).

Combined Sewer - A sewer designed for receiving intercepted surface (dry- and wet-weather) runoff, municipal (sanitary and industrial) wastewater and subsurface waters from infiltration. It is designed as both a sanitary sewer and as a storm sewer [40 CFR 35.2005 (b) (11)]. During dry weather, it acts as a sanitary sewer, but it also carries stormwater during periods of rain. Untreated combined sewer overflows (CSO) to receiving waters occur during wet weather when the stormwater plus sanitary wastewater flow rate exceeds the sewer capacity.

Combined sewer overflow (CSO) - Flow from an outfall (discharge conduit) of a combined sewer collection system, in excess of the interceptor capacity, that is discharged into a receiving water and/or an auxiliary CSO control storage-treatment system.
Constant (or continual) dry-weather flow - Uninterrupted flow in a storm sewer or drainage ditch occurring in the absence of rain. See baseflow.
Deposits and stains - Any type of coating that remains at an outfall after a dry-weather discharge has occurred.
Detection limit - A number of different detection limits have been defined: IDL (instrument detection limit), is the constituent concentration that produces a signal greater than five times the signal to noise ratio of the instrument; MDL (method detection limit) is the constituent concentration that, when processed through a complete method, produces a signal with a 99% probability that it is different from a blank; PQL (practical quantification limit) is the lowest constituent concentration achievable among laboratories within specified limits during routine laboratory operations. The ratios of these limits are approximately: IDL:MDL:PQL = 1:4:20 (APHA, *et al.* 1989).
Direct (dry-weather) entries into the storm drainage system - Sources which enter a storm drainage system directly, usually by direct piping connections between the wastewater piping and the storm drain.
Domestic sanitary wastewater - Sewage derived principally from residential buildings.

Dry-weather flow - Flow in a storm sewer or drainage ditch occurring in the absence of rain. See baseflow.

Entries to storm drainage - water (clean or polluted) discharged into a stormwater drain from sources such as, but not limited to, direct industrial or sanitary wastewater connections, roof leaders, yard and area drains, cooling water connections, manhole covers, etc.

Floatables - Large coarse floating materials, which are either part of the waste streams discharged to a stormwater system, or collected by flows which enters a stormwater drainage system.

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Geographic Information System (GIS) - Computer software that maps land areas and shows information relating to the land area, e.g., topography, drainage, public utilities, roads, buildings, industry, land use, etc.

Groundwater infiltration - Seepage of groundwater into stormwater or sanitary wastewater drainage systems, through such means as defective pipes, pipe joints, connections, or manhole walls.

Hardness - Caused by the presence of divalent cations in water, especially calcium and magnesium. Causes an increased amount of soap usage before producing a lather and causes scale to form in hot water pipes, cooling systems, kettles, etc.

Indirect dry-weather entries into the storm drainage system - Non-stormwater sources which enter a storm drainage system indirectly, usually by floor drains or inlets.
Industrial dry-weather entries into the storm drainage system - Any solid or liquid waste coming from industrial sources which enter storm drainage systems during periods of dry weather.

Infiltration - The process whereby water enters a drainage system underground through such means as defective pipes, pipe joints, connections, manhole walls, etc.

Inflow - The process whereby water enters a sanitary wastewater drainage system from surface locations, such as through manhole covers.

Intercepted stormwater/groundwater - The portion of surface runoff or groundwater moving through the soil that enters a storm drainage, combined sewer, or sanitary sewer system.

Interceptor - A sewer that receives flows from a number of transverse wastewater trunk lines.

Intermittent dry-weather flow - Irregular flow in a storm drainage system occurring in the absence of rain.

Lateral - A drain or sewer that has no other drains or sewers discharging into it, except for service connections.

Leaching field - A system of underground perforated pipes which distribute the effluent from a septic tank to the soil. This is typically done by a pipe and infiltrating trench system which takes the partially treated effluent from the septic tank and distributes it through the leaching field where further treatment occurs before discharge to the ground.

Monte Carlo probabilistic simulation - A statistical modeling approach used to determine the expected frequency and magnitude of an output by running repetitive simulations using statistically selected inputs for the model parameters.

Municipal sewage/wastewater - Sewage/wastewater from a community which may be composed of domestic sewage/wastewater, industrial wastewater and/or commercial wastewater, together with any infiltration.

National Pollution Discharge Elimination System (NPDES) - A national system of permits issued to industrial, commercial, and municipal dischargers to limit the amount of pollutants that can be discharged to waters of the USA.

Non-contact cooling water - Water that decreases the temperature of an object, without ever physically touching the object.

Nonpoint pollution source- Any unconfined and nondiscrete conveyance from which pollutants are discharged.

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Outfall - In this User's Guide, an outfall refers to a point at which a stormwater drainage system discharges to a receiving water. There is often a concrete structure or retaining wall at this location to protect the end of the discharge pipe and prevent local erosion of the receiving water bank.

Pathogen - A disease-causing microorganism.

Point source - Any discernible, confined, and discrete conveyance from which pollutants are, or may be, discharged.

Pollutant - Any material in water or wastewater interfering with designated beneficial uses.

Potable domestic water - Water that has been treated, or is naturally fit, for drinking, i.e., the water has no harmful contents to make it unsuitable for human consumption.

Precision - The measure of the degree of agreement among replicate analyses of a sample, usually expressed as the standard deviation.

Pretreatment - The removal of material such as, gross solids, grit, grease, metals, toxicants. etc. or treatment such as aeration, pH adjustment, etc. to improve the quality of a wastewater prior to discharge to a municipal wastewater system. This is usually done by the industrial user of the water, but can also refer to the initial treatment processes of a sewage treatment plant.

Process line discharge - The disposal of anything used in, or resulting from, a manufacturing process.

Process water - Water used in industry to perform a variety of functions, or as an actual product ingredient.

Receiving waters - Natural or man-made water systems into which stormwaters, or other wastewaters, are discharged for disposal.

Rinse water - Water that cleans or reduces the temperature of an object through actual physical contact with the object.

Sanitary sewer - A sanitary wastewater drainage system intended to carry wastewaters from residences, commercial buildings, industrial plants, and institutions together with minor quantities of groundwater, stormwater and surface water that are not admitted intentionally [40 CFR 35.2005 (b) (37)].
Sanitary wastewater - Wastewater of human origin.

Septic Tank - A rectangular tank divided into two compartments for the treatment of residential (most common) wastewaters by anaerobic digestion, floatation, and sedimentation. Partially treated septic tank effluent is then discharged to a leaching field for additional treatment in the soil system and for final disposal.

Sewage - Sanitary wastewater.

Sewer - A pipe or conduit generally closed, but normally not flowing full, for carrying wastewater.

Sewerage - System of piping, with appurtenances, for collecting and conveying wastewaters from source to discharge.

Specific Conductivity - Expressed in microSiemens/cm (or micromhos/cm). It is an indication of the amount of dissolved solids in a liquid.

Storm drainage discharge - Flow from a storm drain that is discharged to a receiving water.

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Storm drain - A pipe, or natural or man-made channel, or ditch, that is designed to carry only stormwater, surface runoff, street washwaters, and drainage from source to point of discharge [40 CFR 35.2005 (b) (47)].
Stormwater - Water resulting from precipitation which does not percolate into the soil; it runs freely from the surface, or is captured by storm drainage, combined sewer, and to a limited degree, by sanitary sewer facilities.

Surfactants - Surface-active agent and common component in detergents which affects the surface tension of water and can cause foaming.

SIC - Standard Industrial Classification, a code used to describe an industry.

Total solids - The entire quantity of solids in the liquid flow or volume including the dissolved and particulate (suspended, floatable and settleable) fractions.

Toxicity - The degree to which a pollutant causes physiological harm to the health of an organism.

Tracer - In this User's Guide, a tracer is a distinct component, or combination of components ("fingerprint"), of a polluting source which is identified in order to confirm the entry of the polluting source to a storm drainage system.

Trace Metals - Metals present in small concentrations. From a regulatory standpoint, this usually refers to metal concentrations that can cause toxicity at trace concentrations.

Turbidity - A measure of the lack of clarity in the water usually caused by suspended particulate matter.

Urban runoff - Any discharge from a stormwater drainage system. During wet weather, it is comprised of surface runoff from an urban drainage area. During dry weather, it may be comprised of many baseflow components, both uncontaminated and contaminated.

Urban stormwater runoff - A discharge from a stormwater drainage system occurring during wet weather, comprised of surface runoff from an urban drainage area. See stormwater and urban runoff.

Wet-weather flow - Surface runoff due to precipitation (rain and snow) which may introduce contaminants into storm drainage systems.

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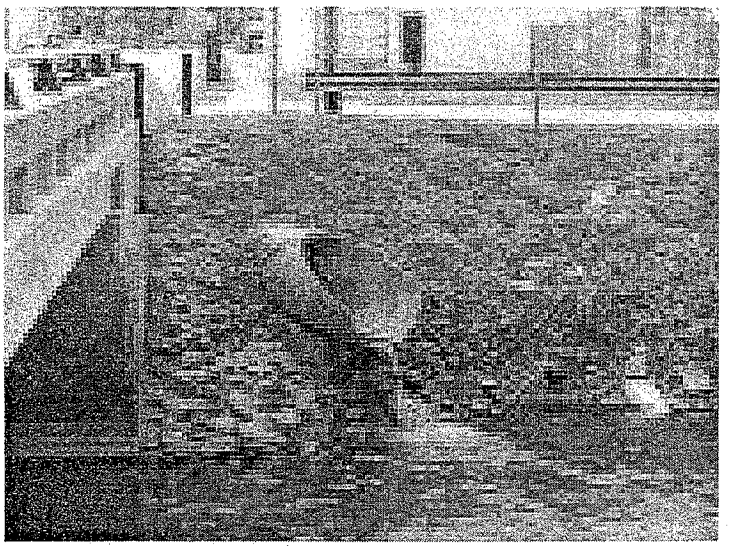
DRAFT MANUAL OF PRACTICE

IDENTIFICATION OF

ILLICIT CONNECTIONS



U.S. ENVIRONMENTAL PROTECTION AGENCY

PERMITS DIVISION (EN-336)

September 1990

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DRAFT MANUAL OF PRACTICE

IDENTIFICATION OF

ILLICIT CONNECTIONS

U.S. ENVIRONMENTAL PROTECTION AGENCY
PERMITS DIVISION (EN-336)
September 1990

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Section 1

INTRODUCTION

The 1972 amendments to the Federal Water Pollution Control Act (FWPCA, also referred to as the Clean Water Act or CWA), prohibited the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Efforts to improve water quality under the NPDES program have focused traditionally on reducing pollutants in discharges of industrial process waste water and from municipal sewage treatment plants. In response to concerns about more diffuse sources of pollutants, the Water Quality Act (WQA) of 1987 added section 402(p) to the CWA to provide a comprehensive framework for the United States Environmental Protection Agency (EPA) to address storm water discharges.

EPA is in the process of developing and implementing comprehensive national strategies to coordinate NPDES permitting efforts for storm water discharges. An important component of these control strategies is the reduction of pollutants from industrial and commercial sites discharged to separate and drainage systems.

Storm water drainage systems can be in the form of open ditches, swales, channels, brooks, and subterranean routes, or closed pipes. Separate storm sewers are designed to convey only storm water, surface runoff, street wash waters and drainage [40 CFR 35.2005(b)(47)].

However, recent research efforts have shown that sources of non-storm water from industrial facilities, commercial facilities, and sanitary sewage can contribute significant amounts of pollutants to separate storm drainage systems and ultimately to surface waters. Illicit connections are point source discharges of pollutants to separate storm drainage systems which are not composed entirely of storm water and are not authorized by an NPDES permit. There are two categories of illicit

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connections - pronounced and subtle. Pronounced connections are from direct hook-ups to storm drainage systems. Subtle connections are indirect, intermittent, and usually do not involve piping.

Both pronounced and subtle illicit connections to separate storm sewers may adversely affect the quality of receiving waters. The removal and prevention of such discharges can result in improvements in the quality of receiving waters. Nationwide studies have shown that illicit connections can be prominent in commercial and industrial sites. The type of materials that are illegally discharged through separate storm water sewers to surface waters varies considerably. Distinct physical and chemical characteristics can be used to identify non-storm water from storm water discharge.

The purpose of this manual is to present a procedure for the identification of illicit connections into storm drainage systems. The manual takes two perspectives: 1) that of evaluating which industrial facility discharges non-storm water to a separate storm sewer system serving multiple facilities; and 2) that of evaluating a targeted facility for non-storm discharges to separate storm sewers. The goal is to ensure that storm drainage systems do not receive non-storm water or other non-permitted discharges. The methodology presented has been designed to be flexible so as to accommodate both industrial and commercial facilities. In an effort to simplify the text, the word "industrial" has been used to connote both industrial and commercial facilities.

The methodology of this manual has been organized as a step-by-step procedure to follow and implement. These procedures are guidelines for use with reasonable judgement on a case-by-case basis.

The intended use for this manual is by regulatory or industrial personnel. It is important to note that this document has been written for a non-technical audience.

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Section 2

MANUAL APPROACH

This manual takes a two phased approach to evaluating illicit connections to separate storm sewers. The first phase involves the screening of storm sewer systems which drain multiple facilities for indications of possible contamination from non-storm water discharges from industrial and commercial sources. The second phase is the investigation of the industrial or commercial facility for identification of actual illicit connections into the storm drainage system.

Both of these phases are divided into a number of sub-sections as shown below which are described in more detail in the following sections.

System Evaluation

- Mapping Effort
- Walking Tour
- Outfall Analysis

On-Site Industrial Evaluation

- Data Collection
- Preliminary Evaluation of Water Use and Other Discharges
- On-Site Investigation
- Confirmatory Analysis

In addition, the final section is a discussion of the field survey techniques essential for both phases. This section provides organizational ideas for field testing procedures. General estimates regarding personnel and time requirements necessary to carry out field surveys as well as equipment cost data are also included in this section.

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Section 3

SYSTEM EVALUATION

This section provides a brief overview of procedures for identification of non-storm water flows in storm water systems which serve a number of facilities.

This initial phase of the procedures consists of three steps. The first step is a mapping effort during which outfalls with a potential for illicit connections. The second step involves conducting field surveys in order to screen priority outfalls for actual signs of contaimination associated with illicit connections. In the third step, storm water outfalls (or other suitable locations) are observed for signs of possible contamination from illicit connections, physical characteristics are observed, elementary chemical analyses are performed, flow patterns are established, field tests are made, samples are collected for comprehensive laboratory analyses, and relevant information is documented.

Actual field testing procedures are discussed in detail in Section 7 of this manual.

STEP 1 - MAPPING EFFORT

The purpose of the mapping effort is to identify all storm water outfalls with potential for contamination from illicit connections, and to identify industrial facilities that potentially may be sources of non-storm water to these outfalls. This process involves the acquisition and study of land-use, drainage (topographic), and sewer maps for the area under investigation.

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Once the industrial outfalls have been located and the contributing area delineated, they can be classified as having either high or low potential for illicit connections. The purpose of this classification exercise is to organize the outfalls according to their potential for illicit connections. Those most likely to exhibit contamination from illicit connections are the first to be visited during the field survey. Several factors can aid in the classification of outfalls into high or low potential for illicit connection categories. A few of these factors are briefly described below:

- Density of industrial activities within delineated areas. If several industries are confined to a relatively small area, then the potential for illicit or inadvertent cross-connections is greater.

- Type of industrial activity. The industrial activity in terms of principal products or services provided should be correlated with the nature of the water quality problems of the receiving water, if such information is known. Often a single industry may contribute significant levels of pollutants to a water body. For example, in one study, highly odorous and colored discharges at an outfall were attributed to a tannery.

- Proximity of industries. The proximity of an industry to an outfall should also be correlated with the water quality of the receiving water if such information is known.

Mapping and other available information required for outfall identification and classification are described in the following sections.

Land Use

Land use maps document the land surface according to generalized uses. This is valuable because the type of land use has been

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found to be highly correlated to the pollution characteristics of storm waters that originate from an area. Land use maps are usually maintained by local and/or regional governments. Generally, land use is categorized according to the following classifications:

- residential
- industrial
- commercial
- recreational
- agricultural
- open space

Drainage/Topography

These maps document the elevations and general relief of the land surface. The topography of a land surface determines the direction of overland flow of storm water runoff. For example, in an area drained by two streams, it is possible to identify the contributing areas to the flows of each stream by examination of topographic maps. Water will flow in the path of decreasing elevation. Therefore, using topographic maps, it is possible to construct the probable drainage path of surface runoff.

Aerial Photographs

Aerial photographs are another means of determining features on the land surface. The aerial photographs should be of large enough scale so that industrial areas can be identified. Aerial photographs can also be used to identify storage areas at industrial sites that may contribute significant amounts of pollutants during wet weather. Finally, they can also be used to determine the proximity and density of industrial areas relative to outfall locations. Aerial photographs may be obtained from local land use planning committees as well as from state agencies.

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Sewers

Developed areas in the United States have extensive networks of sewers. They can be classified as follows:

- Sanitary Sewer. These are conduits intended to carry liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions together with minor quantities of ground, storm, and surface water that are not admitted intentionally [40 CFR 35.2005(b)(37)].

- Storm Sewer. A sewer designed to carry only storm waters, surface runoff, street wash waters, and drainage [40 CFR 35.2005(b)(47)].

- Combined Sewer. A sewer that is designed as a sanitary sewer an a storm sewer [40 CFR 35.2005(b)(11)].

Sewer maps may be obtained from state agencies, local engineering departments, or from other authorities such as publicly owned treatment works. They can be used to determine where industrial manufacturing process and operational wastestreams should discharge.

Summary

Mapping and data obtained for the study area should be summarized as follows:

- Assign an identification number to each industrial storm sewer outfall with potential industrial sources
- Delineate a contributing industrial area to each outfall
- Identify industries within these areas

Based on the likelihood for illicit connections, the field surveys should be organized such that outfalls exhibiting the highest potential for illicit connections are the first to be surveyed.

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STEP 2 - WALKING TOUR

The purpose of the walking tour is to identify storm water outfalls exhibiting characteristics of possible contamination by illicit connections for further analysis. In addition, other outfalls not identified during the mapping effort may be discovered. It is important to note that storm sewers may discharge below the water level or may be inaccessible for some other reason. Thus, the screening of both inaccessible and directly accessible storm water outfalls is addressed.

Inaccessible Outfalls

If a storm sewer outfall is submerged under water or inaccessible for some other reason, it will be necessary to evaluate the storm sewer sewer at an accessible upstream location.

The storm sewer manhole nearest to the outfall discharge point should be located. During a period of dry weather, the manhole cover can be removed and visual observations made to detect any non-storm water discharges. If a dry weather flow is discovered, the flow can be evaluated in a number of ways. Odors or residues can be indications of illicit connections. Grab samples can be collected and analyzed using either simple colormetric methods or comprehensive laboratory analysis. Noticeable physical and elementary chemical properties of the discharge should also be recorded. These signs indicate the need for additional observations in order to detect the potential discharge at the manhole.

Accessible Outfalls

If the outfall is accessible, the inspectors should visit each of the selected outfalls to perform initial visual inspections for signs of illicit discharges. When walking from one outfall to the next, inspectors should check for outfalls from storm drains

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or other pipes which are not indicated on maps. Visual observations should also be made at any newly-discovered outfalls as well. Identification data should be noted for unmarked outfalls so that current maps can be updated.

When performing a visual outfall inspection, the inspector should first check for discharges or parameters which may indicate the presence of discharges such as wet pavement or residues. Flows during dry weather, when it has not rained recently, are a definite sign of possible illicit connections.

After checking for the presence of discharges, the following physical characteristics of any detected flows, the outfall, and surrounding area should be observed.

Physical Characteristics

Odor

The odor of a discharge can vary widely and often directly reflects the source(s) of contamination. Thus, potential non-storm water discharges will often cause a flow to smell like a particular spoiled product, sewage, oil, gasoline, certain chemicals and solvents, or whatever else may be the cause or a component of the contamination. For example, in many facilities the decomposition of organic wastes will release sulfur into the atmosphere creating a smell of rotten eggs. Industries involved in the production of meats, dairy products, and the preservation of vegetables or fruits, are commonly found to discharge organic materials into storm drains. As these organic products or byproducts spoil and decay, the sulfur production creates this readily apparent and unpleasant smell.

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Color

Non-storm water discharge can be any color. Often they are a darker color, such as brown, gray or black. Outfall discharges may become highly colored from the direct discharge of industrial wastes. For instance, the color of industrial wastewaters from meat processing industries is usually a deep reddish-brown. Paper mill wastes are also brown. In contrast, textile wastes are varied, intense colors, while plating-mill wastes are often yellow. The waste from spray paint booths which may be washed down to floor drains may also result in varied colors. Field measurements of color can be performed using a colorimeter.

Turbidity

Turbidity determines the clarity of an outfall discharge. It is a measurement of the amount of suspended matter which interferes with the passage of light through water. Turbidity may be caused by both fine and coarse suspended materials. These materials may range from purely inorganic substances to those that are largely organic in nature. Turbidity values may range from essentially zero in pure water to several thousand in highly polluted conditions. Many industrial wastewaters are highly turbid. Thus, a dry weather discharge at an outfall with a high degree of turbidity is a strong sign of a possible contamination from an industrial discharge.

Floatables

A contaminated flow may also contain floatables. These are any floating solids or liquids derived from non-storm water discharge or storm water washoff. Evaluation of floatables often leads to the identity of the source of industrial pollution since these substances are usually direct products or byproducts of a manufacturing process. Floatables may include substances such as animal fats, spoiled food products, oils, plant parts, solvents,

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sawdust, foams, packing materials, or any type of fuel.

Residue

Residue refers to any type of coating which remains after a non-storm water discharge has taken place. Residues tend to coat the area surrounding the outfall and are usually a dark color. They often will contain fragments of floatable substances and may take the form of a crystalline or amorphous powder. These situations are illustrated by the grayish-black residue, containing fragments of animal flesh and hair, which is often produced by leather tanneries or the white crystalline powder which commonly coats sewer outfalls at nitrogenous fertilizer plants.

Vegetation

Vegetation surrounding an outfall will also show the effects of intermittent or random non-storm water discharge. Pollutants will often cause a substantial alteration in the chemical composition and pH of the discharge stream. This alteration will affect plant growth even when the exposure is intermittent. For example, decaying organic materials coming from various food product wastes would cause an increase in plant life. The loss of chemical dye and inorganic pigments from textile mills could noticeably decrease vegetation as these non-storm water discharges often have a very acidic pH. In either case, even if the source of pollution is not continuous, the vegetation surrounding the outfall may show the effects of the contamination.

To evaulate if the vegetation surrounding an outfall is normal, the observer should consider the climate as well as the time of year. In addition, the vegetation of outfalls close in proximity to the one under investigation should also be noted as a means of comparison. Inhibited plant growth as well as dead and decaying

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foliage can indicate the season or weather conditions in addition to being a sign of pollution.

Structural Damage

Structural damage is another highly visible indication of both continuous and intermittent non-storm water discharge contamination. This occurs when certain pollutants cause structural damage such as cracking, deterioration, and spauling of the concrete or peeling of surface paint. These contaminants are usually very acidic or basic in nature. For example, batch dumps of highly acidic wastes at primary metal industries can cause structural damage.

STEP 3 - DISCHARGE ANALYSIS

Closer analysis of an outfall is warranted if any flows are detected and/or any physical characteristics appear to indicate the potential for illicit connections during the initial inspection. If a flow is occurring during dry weather, the time and day of the week should immediately be recorded. Next, documentation of the observed physical characteristics at the contaminated outfall should also be recorded.

Testing for pH, total dissolved solids, and conductivity can be easily performed in the field with specialized meters. Further testing for specific elements, total phenol, free cyanide, and for many other chemicals can also be done in the field using field kits (such as those using colormetric methods). These parameters, as well as other pollutant parameters, can also be analyzed through laboratory analysis of samples.

Observation of basic chemical characteristics may reveal a great deal of information about the flow quality of a discharge as well. Once preliminary documentation has been completed, an

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elementary chemical analysis of any discharges should also be performed.

pH

Measurement of pH determines if a solution is either acidic or alkaline. Several kinds of pH meters are available which can be used to determine the approximate acidic or alkaline condition of a discharge. The possibility of direct discharge of industrial wastewater is often indicated by dry weather flows which are found to be acidic, alkaline, or which alternate between the two extremes.

The normal pH of storm water is usually between 6 and 7.5. However, the pH of a discharge affected by a source of non-storm water may vary in the range from 3 to 12. Illicit connections conveying discharges from manufacturing or other commerical processes could lead to extreme pH levels.

Acidic, non-storm water discharges in the range of 3 to 6 are possible from textile mills, pharmaceutical manufacturers, metal fabricators as well as companies producing resins, fertilizers, pesticides, or other similar materials. Wastes containing sulfuric, hydrochloric, or nitric acids are the common cause of acidic contamination.

Alkalis may cause non-storm water discharges to become more basic and enter the higher pH range of 8 to 12. Many industrial alkaline wastes contain chemicals such as sodium cyanide, sodium sulfide, and sodium hydroxide. High concentrations of these contaminants are found in non-storm water discharges from soap manufacturers, textile mills, metal plating industries, steel mills, and producers of rubber or plastic. In addition, alkaline wash waters used by many industries to clean floors or manufacturing machinery are a typical source of illicit

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discharges.

Total Dissolved Solids

Total Dissolved Solids (TDS) refers to the amount of solid material completely dissolved in a water sample. Dissolved solids consist mainly of inorganic salts, small amounts of organic matter, and dissolved gases. A high amount of total dissolved solids is a strong indication that flows from sources other than storm water could be entering the storm water system.

Ranges of possible TDS readings are as follows:

Clear Water	100 - 200 ppm
Rainwater	150 - 500 ppm
Storm water Runoff	200 - 5,000 ppm
Non-Storm water Discharge	- greater than 2,000 ppm
Undiluted Industrial Wastes	- greater than 10,000 ppm

Conductivity

The conductivity of a solution is a measure of its ability to conduct an electrical current. Conductivity measurements may be taken with a special meter to provide a rapid estimate of the dissolved solids content of a water sample.

Only charged particles such as ions carry electrical current. Therefore, water samples with high proportions of uncharged organic molecules will have low specific conductivity values. It should be noted, however, that samples with very high or low pH values will show high specific conductivities due to the high concentrations of H^+ and OH^- ions. Conductivity measurements are also temperature dependent.

If a discharge is present at the time of the initial inspection, elementary chemical analysis for pH, total dissolved solids, and

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specific conductivity can be performed. Results of any testing should always be recorded. (Parameters of concern for laboratory analysis are discussed in detail in the section on Field Survey Techniques.)

SUMMARY

If signs of an illicit discharge appear evident but there is no flow occurring, additional field surveys of the outfall will be necessary. Further inspections of the outfall should be scheduled for various times and days throughout the week in order to completely evaluate the discharge. Or, as an alternative, an automatic sampler may be installed and checked on a regular basis. Once the discharge has been discovered, the time and day of the week on which the flow occurred should be recorded. Elementary chemical analysis can be performed using either field testing methods or more comprehensive laboratory analysis.

Once the field surveys of all outfalls scheduled for the walking tour have been completed and initial inspections for illicit discharges have been fully documented, the identification of potential industrial sources may be pursued.

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Section 4

IDENTIFICATION OF POTENTIAL INDUSTRIAL SOURCES OF NON-STORM WATER

The purpose of this section is to define guidelines to assist in finding sources of non-storm water at industrial facilities which may be responsible for an illicit discharge to a municipal seperate storm sewer. Information is also presented which will aid in the correlation between an illicit discharge and the suspected industrial source. This section should serve as a basis for organizing data in a fashion which will allow the user of this manual to narrow the choices and select the industrial source most likely responsible for the illicit discharge.

In order to identify the potential sources of a non-storm water discharge when industrial contributors are suspected, the following questions should be considered:

- What is the flow pattern of the non-storm water discharge?
- What distinctive qualities of the non-storm water discharge are revealed by the observed physical and chemical properties?

Answering these questions will lead to a characterization of the discovered illicit discharge. The following text describes the evaluation process to determine which industrial facilities could be responsible according to non-storm water discharge characterization. Step 1 begins with establishing the flow pattern of the non-storm water discharge. In Step 2, documented data is analyzed to reveal any distinguishing characteristics. Step 3 involves making the correlation between an illicit discharge and the most likely industrial source.

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STEP 1 - EVALUATE FLOW PATTERN

The flow pattern of an illicit discharge may be either continuous or intermittent, as described below.

Continuous Dry Weather Flow

Dry weather flows in a storm water drainage system pipe or drainage ditch may be a visible sign of non-storm water discharges. Flow in the absence of a storm events clearly indicates that a secondary source (or sources) is contributing flows to the storm drain flow.

Continuous discharges will release water or other liquids at a uniform and uninterrupted rate. Typical sources of continuous flows include leaks from manufacturing equipment, constant overflows from wet processes, and released non-contact cooling water which has been contaminated. Continuous dry weather flows are not always contaminated. They may also originate from either groundwater infiltration and/or industrial discharges authorized by an NPDES permit.

Continuous discharges may result from non-industrial sources as well. Several examples of potential non-industrial sources are listed below:

Sewage Sources:
- raw sewage from leaking sanitary sewers
- septage from improperly operating septic tank systems

Groundwater infiltration

Intermittent Dry Weather Flow

Intermittent flow during dry weather can also be a strong indicator of non-storm water discharge. Intermittent discharges release flow periodically. This may be a fixed cycle, for

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example at every half hour, or at variable intervals. If the source is industrial, discharge may occur on a regular basis or randomly, depending on production schedules. The main sources are rinse waters, batch dumps, process dumps, process line discharge, or spills.

Intermittent discharges may result from non-industrial sources as well. Several examples of potential non-industrial sources are listed below:

Household Automobile and Maintenance:

- car washing runoff
- radiator flushing
- improper oil disposal

Residential Watering Runoff

Roadway and Other Accidents:

- fuel spills
- spills of truck contents
- pipeline spills

Other:

- washing of ready-mix trucks
- laundry wastes
- improper disposal of other household toxic substances
- sump pump discharges

Infiltration of groundwater into sewers in areas with high groundwater tables may result in flows observed in sewer systems as noted above. However, flows will typically not exhibit fluctuations, such as short-term, hourly variations which may be more typical for industrial discharges.

If the flow pattern was not established during the initial outfall inspection from the walking tour, additional field

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surveys will be necessary. These inspections should be scheduled for various times and days throughout the week or an automatic monitor may be used to determine the flow pattern.

STEP 2 - ANALYSIS OF DATA

The purpose of this step is to review all recorded data for distinguishing characteristics of the potentially illicit discharge. This review typically includes an analysis of all physical observations and chemical parameters which appear as unusual.

Physical observations which work well include the odor and color of the discharge as well as any floating material or residues. Extremely high or low values for the various parameters as measured from the elementary chemical analysis or the comprehensive laboratory testing are also strong indicators. These factors can be used to identify possible industrial sources.

All distinguishing characteristics should be noted before proceeding to the next step.

STEP 3 - CORRELATION TO POSSIBLE INDUSTRIAL SOURCES

In this step, an answer to the following question is sought:

- Which industrial sources could be responsible for this particular non-storm water discharge?

The following support data has been provided to simplify the task of selecting the most likely industrial source for an illicit discharge.

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Sources of Non-Storm Water Discharge Related to Industry

Table 1 is provided to rank the most likely ways in which various facilities could produce non-storm water discharges. The categories considered included loading and unloading of dry bulk or liquids, water usage in reference to cooling and process waters, and illicit or inadvertent industrial connections. The likelihood of a facility producing a non-storm water discharge in each of these categories was rated on the basis of high, moderate, or low potential or not applicable if there was no evident correlation.

Chemical and Physical Properties

The information in Table 2 indicates possible chemical and physical characteristics of contaminated non-storm water discharge which could come from various facilities. The chemical properties considered are pH and Total Dissolved Solids. The physical properties included are odor, color, turbidity, floatable substances, vegetation, and structural damage. The descriptions in each of these categories explain the most likely test results for a contaminated non-storm water discharge coming from a particular industrial facility. It should be noted that any combination of these characteristics may occur at an outfall.

Waste Characterization

Appendix A provides detailed information regarding wastestream identification and characterization for various facilities listed under industrial SIC categories. The following data are included for each SIC code:

- SIC Subcategory Listing
- Typical Sources of Wastestream Flows
- Wastestream Characterization

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TABLE 1
SOURCES OF NON-STORMWATER DISCHARGE RELATED TO INDUSTRY

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS	LOADING/UNLOADING DRY BULK	LOADING/UNLOADING LIQUIDS	WATER USAGE COOLING	WATER USAGE PROCESS	ILLICIT/ INADVERTANT CONNECTIONS
PRIMARY INDUSTRIES					
20 FOOD AND KINDRED PRODUCTS					
201 MEAT PRODUCTS	H	L	H	H	H
202 DAIRY PRODUCTS PROCESSING INDUSTRY	H	H	H	H	H
203 CANNED AND PRESERVED FRUITS AND VEGETABLES	H	H	H	H	H
204 GRAIN MILL PRODUCTS	H	H	H	H	H
205 BAKERY PRODUCTS	H	M	NA	H	L
206 SUGAR AND CONFECTIONARY PRODUCTS	H	M	L	M	L
207 FATS AND OILS	H	H	H	H	M
208 BEVERAGES	H	H	H	H	L
21 TOBACCO MANUFACTURES	H	M	NA	M	M
22 TEXTILE MILL PRODUCTS	H	L	H	H	H
23 APPAREL AND OTHER FINISHED PRODUCTS MADE FROM FABRICS AND SIMILAR MATERIALS	H	L	NA	M	L
MATERIAL MANUFACTURE					
24 LUMBER AND WOOD PRODUCTS	H	L	NA	M	L
25 FURNITURE AND FIXTURES	H	M	NA	L	L
26 PAPER AND ALLIED PRODUCTS	H	H	H	H	H
27 PRINTING, PUBLISHING, AND ALLIED INDUSTRIES	H	M	NA	M	L
31 LEATHER AND LEATHER PRODUCTS	H	H	L	H	H
32 STONE, CLAY, GLASS, AND CONCRETE PRODUCTS	H	M	L	H	L
33 PRIMARY METAL INDUSTRIES	H	M	H	H	H
34 FABRICATED METAL PRODUCTS	H	H	H	H	H
37 TRANSPORTATION EQUIPMENT	L	H	H	H	H
CHEMICAL MANUFACTURE					
28 CHEMICALS AND ALLIED PRODUCTS					
281 INDUSTRIAL INORGANIC CHEMICALS	H	H	H	H	H
282 PLASTIC MATERIALS AND SYNTHETICS	H	H	H	M	H
283 DRUGS	L	L	H	M	L

(H - HIGH, M - MODERATE, L - LOW, NA - NOT APPLICABLE)

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TABLE 1

SOURCES OF NON-STORMWATER DISCHARGE RELATED TO INDUSTRY

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS	LOADING/UNLOADING DRY BULK	LOADING/UNLOADING LIQUIDS	WATER USAGE COOLING	WATER USAGE PROCESS	ILLICIT/ INADVERTANT CONNECTIONS
CHEMICAL MANUFACTURE (continued)					
284 SOAP, DETERGENTS, AND CLEANING PREPARATIONS	H	H	H	H	H
285 PAINTS, VARNISHES, LACQUERS, ENAMELS, AND ALLIED PRODUCTS	H	H	L	H	L
286 INDUSTRIAL ORGANIC CHEMICALS	H	H	H	H	M
287 AGRICULTURAL CHEMICALS	L	L	H	L	L
29 PETROLEUM REFINING AND RELATED INDUSTRIES					
291 PETROLEUM REFINING	L	H	H	L	H
295 PAVING AND ROOFING MATERIALS	H	H	NA	M	L
30 RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS	H	H	H	H	M
TRANSPORTATION AND CONSTRUCTION					
15 BUILDING CONSTRUCTION	M	L	NA	L	L
16 HEAVY CONSTRUCTION	M	L	NA	L	L
RETAIL					
52 BUILDING MATERIALS, HARDWARE, GARDEN SUPPLY, AND MOBILE HOME DEALERS	H	L	NA	L	L
53 GENERAL MERCHANDISE STORES	H	M	NA	L	L
54 FOOD STORES	H	H	NA	M	L
55 AUTOMOTIVE DEALERS AND GASOLINE SERVICE STATIONS	H	H	NA	M	M
56 APPAREL AND ACCESSORY STORES	H	L	NA	L	L
57 HOME FURNITURE, FURNISHINGS, AND EQUIPMENT STORES	H	L	NA	L	L
58 EATING AND DRINKING PLACES	H	M	NA	M	M
OTHER					
COAL STEAM ELECTRIC POWER	H	L	H	L	L
NUCLEAR STEAM ELECTRIC POWER	NA	L	H	L	NA

(H - HIGH, M - MODERATE, L - LOW, NA - NOT APPLICABLE)

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TABLE 2
CHEMICAL AND PHYSICAL PROPERTIES

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS		ODOR	COLOR	TURBIDITY	FLOATABLES	RESIDUE	STRUCTURAL	VEGETATION	pH	TI
PRIMARY INDUSTRIES										
20	FOOD AND KINDRED PRODUCTS									
201	MEAT PRODUCTS	SPOILED MEATS ROTTEN EGGS AND FLESH	BROWN TO REDDISH-BROWN	HIGH	ANIMAL FATS, BYPRODUCTS PIECES OF PROCESSED MEATS	BROWN TO BLACK	HIGH	FLOURISH	NORMAL	H
202	DAIRY PRODUCTS	SPOILED MILK RANCID BUTTER	GREY TO WHITE	HIGH	ANIMAL FATS SPOILED MILK PRODUCTS	GREY TO LIGHT-BROWN	HIGH	FLOURISH	ACIDIC	H
203	CANNED AND PRESERVED FRUITS AND VEGETABLES	DECAYING PRODUCTS COMPOST PILE	VARIOUS	HIGH	VEGETABLE WAXES, SEEDS, SKINS, CORES, LEAVES	BROWN	LOW	NORMAL	WIDE RANGE	H
204	GRAIN MILL PRODUCTS	SLIGHTLY SWEET AND MUSTY GRAINY	BROWN TO REDDISH-BROWN	HIGH	GRAIN HULLS AND SKINS STRAW AND PLANT FRAGMENTS	LIGHT BROWN	LOW	NORMAL	NORMAL	H
205	BAKERY PRODUCTS	SWEET AND OR SPOILED	BROWN TO BLACK	HIGH	COOKING OILS, LARD FLOUR, SUGAR	GREY TO LIGHT BROWN	LOW	NORMAL	NORMAL	H
206	SUGAR AND CONFECTIONARY PRODUCTS	NA	NA	LOW	LOW POTENTIAL	WHITE CRYSTALS	LOW	NORMAL	NORMAL	H
207	FATS AND OILS	SPOILED MEATS LARD OR GREASE	BROWN TO BLACK	HIGH	ANIMAL FATS, LARD	GREY TO LIGHT-BROWN	LOW	NORMAL	NORMAL	H
208	BEVERAGES	FLAT SODA, BEER, OR WINE ALCOHOL, YEAST	VARIOUS	MODERATE	GRAINS AND HOPS, BROKEN GLASS DISCARDED CANNING ITEMS	LIGHT BROWN	HIGH	INHIBITED	WIDE RANGE	H
21	TOBACCO MANUFACTURES	DRIED TOBACCO CIGARS, CIGARETTES	BROWN TO BLACK	LOW	TOBACCO STEMS AND LEAVES PAPERS AND FILLERS	BROWN	LOW	NORMAL	NORMAL	L
22	TEXTILE MILL PRODUCTS	WET BURLAP, BLEACH SOAP, DETERGENTS	VARIOUS	HIGH	FIBERS, OILS, GREASE	GREY TO BLACK	LOW	INHIBITED	BASIC	H
23	APPAREL AND OTHER FINISHED PRODUCTS	NA	VARIOUS	LOW	SOME FABRIC PARTICLES	NA	LOW	NORMAL	NORMAL	L

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TABLE 2
CHEMICAL AND PHYSICAL PROPERTIES

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS	ODOR	COLOR	TURBIDITY	FLOATABLES	RESIDUE	STRUCTURAL	VEGETATION	pH	TDS
MATERIAL MANUFACTURE									
24 LUMBER AND WOOD PRODUCTS	NA	NA	LOW	SOME SAWDUST	LIGHT BROWN	LOW	NORMAL	NORMAL	LOW
25 FURNITURE AND FIXTURES	VARIOUS	VARIOUS	LOW	SOME SAWDUST, SOLVENTS	LIGHT BROWN	LOW	NORMAL	NORMAL	LOW
26 PAPER AND ALLIED PRODUCTS	BLEACH VARIOUS CHEMICALS	VARIOUS	MODERATE	SAWDUST, PULP PAPER WAXES, OILS	LIGHT BROWN	LOW	NORMAL	WIDE RANGE	LOW
27 PRINTING, PUBLISHING, AND ALLIED INDUSTRIES	INK, SOLVENTS	BROWN TO BLACK	MODERATE	PAPER DUST, SOLVENTS	GREY TO LIGHT-BROWN	LOW	INHIBITED	NORMAL	HIG
31 LEATHER AND LEATHER PRODUCTS	LEATHER, BLEACH ROTTEN EGGS OR FLESH	VARIOUS	HIGH	ANIMAL FLESH AND HAIR OILS, GREASE	GREY TO BLACK SALT CRYSTALS	HIGH	HIGHLY INHIBITED	WIDE RANGE	HIG
33 PRIMARY METAL INDUSTRIES	VARIOUS	BROWN TO BLACK	MODERATE	ORE, COKE, LIMESTONE MILLSCALE, OILS	GREY TO BLACK	HIGH	INHIBITED	ACIDIC	HIG
34 FABRICATED METAL PRODUCTS	DETERGENTS ROTTEN EGGS	BROWN TO BLACK	HIGH	DIRT, GREASE, OILS SAND, CLAY DUST	GREY TO BLACK	LOW	INHIBITED	WIDE RANGE	HIG
32 STONE, CLAY, GLASS, AND CONCRETE PRODUCTS	WET CLAY, MUD DETERGENTS	BROWN TO REDDISH-BROWN	MODERATE	GLASS PARTICLES DUST FROM CLAY OR STONE	GREY TO LIGHT-BROWN	LOW	NORMAL	BASIC	LOW
CHEMICAL MANUFACTURE									
28 CHEMICALS AND ALLIED PRODUCTS									
2812 ALKALIES AND CHLORINE	STRONG HALOGEN OR CHLORINE PUNGENT BURNING	ALKALIES - NA CHLORINE - YELLOW TO GREEN	LOW	NA	ALKALIES - WHITHIGH CARBONATE SCALE CHLORINE - NA		HIGHLY INHIBITED	BASIC	HIG
2816 INORGANIC PIGMENTS	NA	VARIOUS	HIGH	LOW POTENTIAL	VARIOUS	LOW	HIGHLY	WIDE RANGE	HIG
28 CHEMICALS AND ALLIED PRODUCTS									
282 PLASTIC MATERIALS AND SYNTHETICS	PUNGENT, FISHY	VARIOUS	HIGH	PLASTIC FRAGMENTS, PIECES OF SYNTHETIC PRODUCTS	VARIOUS	LOW	INHIBITED	WIDE RANGE	HIG

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TABLE 2
CHEMICAL AND PHYSICAL PROPERTIES

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS		ODOR	COLOR	TURBIDITY	FLOATABLES	RESIDUE	STRUCTURAL VEGETATION	pH	TD
CHEMICAL MANUFACTURE (Continued)									
283	DRUGS	NA	VARIOUS	HIGH	GELATIN BYPRODUCTS FOR CAPSILLATING DRUGS	VARIOUS	LOW	HIGHLY INHIBITED NORMAL	HIG
284	SOAP, DETERGENTS, AND CLEANING PREPARATIONS	SWEET OR FLOWERY	VARIOUS	HIGH	OILS, GREASE	GREY TO BLACK	LOW	INHIBITED BASIC	HIG
285	PAINTS, VARNISHES, LACQUERS, ENAMELS, AND ALLIED PRODUCTS (SB = SOLVENT BASE)	LATEX - AMMONIA SB - DEPENDANT UPON SOLVENT (PAINT THINNER, MINERAL SPIRITS)	VARIOUS	HIGH	LATEX - NA SB - ALL SOLVENTS	GREY TO BLACK	LOW	INHIBITED LATEX - BASIC SB - NORMAL	
286	INDUSTRIAL ORGANIC CHEMICALS								
2861	GUM AND WOOD CHEMICALS	PINE SPIRITS	BROWN TO BLACK	HIGH	ROSINS AND PINE TARS	GREY TO BLACK	LOW	INHIBITED ACIDIC	HIG
2865	CYCLIC CRUDES, AND CYCLIC INTERMEDIATES, DYES, AND ORGANIC PIGMENTS	SWEET ORGANIC SHELL	NA	LOW	TRANSLUCENT SHEEN	NA	LOW	HIGHLY INHIBITED NORMAL	LOW
287	AGRICULTURAL CHEMICALS								
2873	NITROGENOUS FERTILIZERS	NA	NA	LOW	NA	WHITE CRYSTALLI	HIGH	INHIBITED ACIDIC	HIG
2874	PHOSPHATIC FERTILIZERS	PUNGENT SWEET	MILKY WHITE	HIGH	NA	WHITE AMORPHOUS POWDER	HIGH	INHIBITED ACIDIC	HIG
2875	FERTILIZERS, MIXING ONLY	VARIOUS	BROWN TO BLACK	HIGH	PELLETIZED FERTILIZERS	BROWN AMORPHOUS POWDER	LOW	NORMAL NORMAL	HIG
29	PETROLEUM REFINING AND RELATED INDUSTRIES								
291	PETROLEUM REFINING	ROTTEN EGGS KEROSENE, GASOLINE	BROWN TO BLACK	HIGH	ANY CRUDE OR PROCESSED FUEL	BLACK SALT CRYSTALS	LOW	INHIBITED WIDE RANGE	HIG
30	RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS	ROTTEN EGGS CHLORINE, PEROXIDE	BROWN TO BLACK	MODERATE	SCHREDDED RUBBER PIECES OF FABRIC OR METAL	GREY TO BLACK	LOW	INHIBITED WIDE RANGE	HIG

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TABLE 2
CHEMICAL AND PHYSICAL PROPERTIES

INDUSTRIAL CATEGORIES MAJOR CLASSIFICATIONS SIC GROUP NUMBERS	ODOR	COLOR	TURBIDITY	FLOATABLES	RESIDUE	STRUCTURAL	VEGETATION	pH	TDS
					POWDER				
TRANSPORTATION AND CONSTRUCTION									
15 BUILDING CONSTRUCTION	VARIOUS	BROWN TO BLACK	HIGH	OILS, GREASE, FUELS	GREY TO BLACK	LOW	NORMAL	NORMAL	HIGH
16 HEAVY CONSTRUCTION	VARIOUS	BROWN TO BLACK	HIGH	OILS, GREASE, FUELS DILUTED ASPHALT OR CEMENT	GREY TO BLACK	LOW	NORMAL	NORMAL	HIGH
RETAIL									
52 BUILDING MATERIALS, HARDWARE, GARDEN SUPPLY, AND MOBILE HOME DEALERS	NA	BROWN TO BLACK	LOW	SOME SEEDS, PLANT PARTS, DIRT, SAWDUST, OR OIL	LIGHT BROWN	LOW	NORMAL	NORMAL	LOW
53 GENERAL MERCHANDISE STORES	NA	NA	NA	NA	NA	LOW	NORMAL	NORMAL	LOW
54 FOOD STORES	SPOILED PRODUCE RANCID, SOUR	VARIOUS	LOW	FRAGMENTS OF FOOD DECAYING PRODUCE	LIGHT BROWN	LOW	FLOURISH	NORMAL	LOW
55 AUTOMOTIVE DEALERS AND GASOLINE SERVICE STATIONS	OIL OR GASOLINE	BROWN TO BLACK	MODERATE	OIL OR GASOLINE	BROWN	LOW	INHIBITED	NORMAL	LOW
56 APPAREL AND ACCESSORY STORES	NA	NA	LOW	NA	NA	LOW	NORMAL	NORMAL	LOW
57 HOME FURNITURE, FURNISHINGS, AND EQUIPMENT STORES	NA	NA	LOW	NA	NA	LOW	NORMAL	NORMAL	LOW
58 EATING AND DRINKING PLACES	SPOILED FOODS OIL AND GREASE	BROWN TO BLACK	LOW	SPOILED OR LEFTOVER FOODS OIL AND GREASE	BROWN	LOW	NORMAL	NORMAL	LOW
COAL STEAM ELECTRIC POWER	NA	BROWN TO BLACK	HIGH	COAL DUST	BLACK AMORPHOUS POWDER	LOW	NORMAL	SLIGHTLY ACIDIC	LOW
NUCLEAR STEAM ELECTRIC POWER	NA	LIGHT BROWN	LOW	OILS, LUBRICANTS	LIGHT BROWN	LOW	NORMAL	NORMAL	LOW

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Common sources of wastestream flows as well as typical values for conventional and toxic pollutants are presented to aid in the industrial identification process.

These tables and appendix were organized according to the SIC code. The intent of classifying by SIC code was that similar facilities should produce non-storm water discharges in basically the same manner with fairly identical characteristics. Furthermore, SIC codes give the best estimate of typical wastewater discharges by virtue of principal manufacturing operations. Thus, those facilities which are not individually listed should have qualities resembling those of other facilities with which they are classified in the SIC code.

Correlation Process

The correlation process begins by generating a list of all industries in the area which could have a connection to the drainage system pipe network leading to the contaminated storm water outfall. Once this list is completed, the selected industries should be organized according to their appropriate SIC classification and, if possible, by subcategory. Next, the outstanding characteristics which were determined in the previous steps should be compared - industry by industry - to the coded support data.

The flow pattern established in Step 1 should be compared to Table 1. High cooling and process water usage indicates a greater likelihood for a continual discharge or a very frequent intermittent discharge. While low water usage would generally indicate a random discharge of little volume or perhaps none at all.

The distinguishing characteristics as determined in Step 2 should be compared to Table 2. A particular industrial facility could

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be the actual source when there are several correlations between noted features and those listed in the table.

The results from the comprehensive laboratory testing of the grab samples should be compared to the typical conventional and toxic pollutant values listed in Appendix A. Strong similarities between the test results and typical listed values may indicate a particular facility as the possible industrial source of the non-storm water discharge.

Age of Facilities

A final factor of consideration is the age of an industrial facility. There is a high potential for unauthorized connections for industries that occupy older buildings. Sanitary sewers may not have been in existence, since storm sewers predate the development of sanitary sewers. During the time of an industry's development there may have been a lack of information regarding the location of sanitary and storm sewer lines which led to confusion as to the proper function of a storm sewer line. In addition, over time as the activities within an industry change or expand, there is a possibility for illicit or inadvertent connections as floor drains and other storm sewer connections may begin to process non-storm water discharges which require treatment.

Also, since pollution control requirements regarding storm water have been minimal or non-existent in the past, older industrial facilities possess a greater potential for having illicit connections to the storm water drainage system.

Upon the completion of this correlation process, it will become evident that many of the previously listed industrial facilities should be eliminated as possible sources of the illicit discharge. In most cases, either one particular industry may

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clearly appear to be the most likely source or several facilities may still seem to all be possible sources.

At this point, the only way of identifying the actual source of an illicit discharge is to perform an on-site industrial investigation for illicit connections to the storm water drainage system. On-site industrial investigations should proceed from the most to the least likely facility appearing to be the source of the illicit discharge. A priority listing of investigations should be generated based upon the findings of the correlation process.

A brief discussion of common types of industrial non-storm water discharges and illicit connections is presented in Section 5. This information is provided to serve as a basis for Section 6 which defines a methodology for performing an on-site industrial investigation for illicit connections.

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Section 5

INDUSTRIAL WATER USE AND SPILL POTENTIAL

This section describes typical water uses and potential sources of spills at industrial facilities and is intended to provide technical background for the investigative team. The descriptions provided are by no means exhaustive. Therefore, the investigative team is encouraged to consult with plant personnel for more complete descriptions of water use processes during actual on-site investigations.

NON-CONTACT COOLING WATER

Non-contact cooling water is water that decreases the temperature of a particular part or process without ever physically touching it. "Non-contact" is achieved by allowing cooling waters to circulate around the part or process in a contained jacket or external channel.

In order to discharge non-contact cooling water into a storm drain, an industry must obtain an NPDES permit. These discharges should not be contaminated as long as cooling waters remain fully separated from the part or process they are cooling, the discharges are not above permit temperature limits, and chemical additives are not used. However, when cooling systems are not functioning properly, they become potential sources for contamination as cooling waters may come in contact with various toxic substances and carry them into storm sewers.

Industries will use large amounts of non-contact cooling water for several reasons. Non-contact water is often used to cool raw materials, final products, and machinery such as compressors or

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rectifiers. For example, the turbines and boilers used in coal steam electric power generation are cooled by using non-contact waters. These cooling waters are also frequently used for temperature control of chemical reaction vats or metal plating baths. The temperature of reactor vessels used in the production of plastics and synthetics is controlled by non-contact cooling waters. These could become contaminated by leaks and spillovers in the primary process.

At some industrial facilities chemicals are added to cooling waters to prevent the deposition of scale on pipes and equipment, and also to prevent rust formation. They are also added to cooling waters to prevent biological growth. These chemicals may be toxic or harmful to animal, plant, or aquatic life. Such cooling water discharges are usually discharged into sanitary sewers, with appropriate pretreatment when applicable.

RINSE WATER

Rinse water is water which cleans or reduces the temperature of an object through actual physical contact with the object. Discharges resulting from rinse waters are often allowed to enter floor drains which may be inadvertently connected to storm sewers rather than to sanitary sewers. They can also enter storm sewers through direct connections by piping. A high potential for continuous or intermittent dry weather flow exists for those industries in which raw materials, final products, or production machinery must be sanitized or cooled by using rinse waters.

Rinse waters may originate from facilities that utilize regular washdown procedures. For instance, soft drink bottling plants use rinse waters for removal of waste liquids, debris, and labels from returned bottles. Rinse waters can also be used for temperature reduction by dipping, washing, or spraying objects

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with cool water. For example, rinse water is sometimes sprayed over the final products in the metal plating industry in order to cool them.

Rinse waters which are most likely to cause an intermittent flow are those used for clean-up at the end of a work shift, before product changeover, or after raw materials have been unloaded. One such case could be the flushing of a chemical delivery tank at an unloading dock. This would lead to contamination if toxic chemicals were washed down to floor drains connected to the storm water system.

PROCESS WATER

Process water may also be discharged into floor drains or could be piped directly into the storm water sewer system. Process water is used in a facility to perform a variety of functions or an actual product ingredient. Process waters which are likely to cause continual dry weather flows are those used for filtration, dilution, soaking, and conveyance.

PROCESS LINE DISCHARGE

Process line discharge refers to the disposal of anything used in or resulting from a manufacturing process including substances such as wastes, byproducts, chemicals, and fuels. This type of waste is often seen in the food processing industry. For instance, cannery procedures for vegetables often produce process line discharge. The process line wastes usually consist of solids from sorting, peeling, and coring operations as well as can spillage from filling and sealing procedures.

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BATCH DUMPS

Batch dumps are the disposal of process batches which may be composed of a wide variety of substances. However, some of the more common batches include combinations of chemicals, solvents, dyes, paints, or may simply be rinse water baths. A common example of batch dump waste comes from the pickling process used in steel mills. To remove dirt and grease, steel is immersed in dilute batches or sulfuric acid. This process produces a waste known as "pickling liquor" which is mainly composed of iron sulfate. Batch dump disposal occurs when the iron sulfate concentration has increased enough to inhibit the pickling process. At this point the pickling liquor is replaced by a fresh batch of sulfuric acid.

In the cases of both batch dumps as well as process line discharge described above, these substances may be disposed of by allowing them to drain to the storm water sewer system.

BLOWDOWN

Blowdown represents a portion of water purposely wasted from a water system to help control buildup of solids or minerals. Two common examples are blowdown from boilers as well as that from cooling towers. In some cases the volume of blowdown generated by an individual plant is significant and it may require treatment before discharge. More frequently, however, contributions of blowdown are very small, and it is merely combined with other wastewater prior to discharge.

The water used in boilers or cooling towers is often subjected to treatment designed to control corrosion and scale formation. In most cases, chemical agents such as zinc or sodium chromate, caustics, and acids are used for these purposes. Therefore, the existence of these chemicals qualifies blowdown as an industrial

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process wastestream.

INDUSTRIAL SPILLS

The previous situations are most likely to cause continuous or intermittent dry weather flows on a fairly regular basis. In some cases, observed flows may exhibit random behavior. A primary cause of random flows is industrial spills, since they are accidental. After a spill has taken place, the spilled materials are often washed down to floor drains which may be connected to storm sewers. Unless there is some dilution (such as rainwater), this type of pollution will be very concentrated.

Spills result from many activities, but among the most common are:

Boil Overs: Boil overs principally result from bulk overheating, hot spots, uncontrolled exothermic reactions, and overloading.

Transfer To and From Storage: Inadequate personnel training, poor maintenance and irregular inspections may be causative factors for spills during transfer. In addition, inadvertent damage to facilities, i.e., valves, piping and storage tanks by vehicles or work crews may contribute to accidental discharge.

Transfer To and From Carriers: Spills during transfer to and from carriers generally result from improper or poorly maintained facilities and equipment, malfunctions of equipment, and operator error.

Storage Facility Leaks and Failures: Leaks in storage tanks that escape detection may result in large amounts of pollutants reaching separate storm sewers via illicit connections. These spills are typical for storage tanks and/or lagoons used for the temporary storage of concentrated wastes or reject materials.

Process Facilities and Failures: This type of spill may result from operator inattention, poor equipment up-keep, or

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faulty piping connections.

Storm Water Drainage: Storm water may discharge large quantities of pollutants from areas that include:

- Spilled dry materials,
- Dust collector accumulations,
- Small leaks which are impounded by topography,
- Rubbish piles, and
- Containers with residues.

The causes of such storm water runoff hazards can include operator neglect, poor maintenance, and poor housekeeping. Loading and unloading areas as well as outdoor storage of raw or waste materials are where spills are most likely to occur.

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Section 6

ON-SITE INDUSTRIAL INVESTIGATION

This section presents a methodology for conducting on-site investigations to detect illicit connections to the storm water drainage system at an industrial site. The methodology for the on-site industrial investigation is divided into four steps.

- Step 1 - Data Collection
- Step 2 - Preliminary Analysis of Water Use and Other Discharges
- Step 3 - On-Site Investigation
- Step 4 - Confirmatory Analysis

It is suggested that industry personnel participate as members of the investigative team since they are the most familiar with the processes and operations within a facility.

STEP 1 - DATA COLLECTION

The objective of this step of the methodology is to obtain and evaluate all relevant mapping and spill history information pertaining to the industrial site under investigation. The information necessary to complete this step is discussed below.

Mapping Information

Mapping information is essential for identification of key features of the storm water drainage system relative to potential sources of non-storm water at an industrial site. Key features of the storm water drainage system may include swales, open ditches, channels, brooks, closed pipes, or sewer lines. Various industrial processes and operations are determined on a site-by-site basis.

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Pertinent mapping information, when available, should include:

- Plant Layout Drawings (Schematics)
- Sewer System Maps
- Topographic Maps

Available mapping usually reflects the intended design of the facility. Due to process modification these maps may not represent existing conditions and may need to be updated.

The following sections describe the various types of mapping information.

Plant Layout Drawings (Schematics)

These drawings should show the actual physical layout of an industrial plant. They may also indicate the locations of major industrial or commercial processes and equipment within the facility. Plant layout drawings will show the geographic orientation of the facility relative to local streets as well.

Additionally, plant layout drawings may show an overview of the in-facility piping and sewer locations. The piping and sewer plans show the location of floor drains and hard piping connections to plumbing fixtures, wet processes or other equipment. Plant layout drawings may also show the locations of both indoor and outdoor storage areas. Figure 1 shows a typical plant layout drawing.

Sewer System Maps

Most municipalities provide storm and sanitary sewer service at the property line. Facilities may have complete drawings of sanitary and storm water sewers to which its wastewaters and

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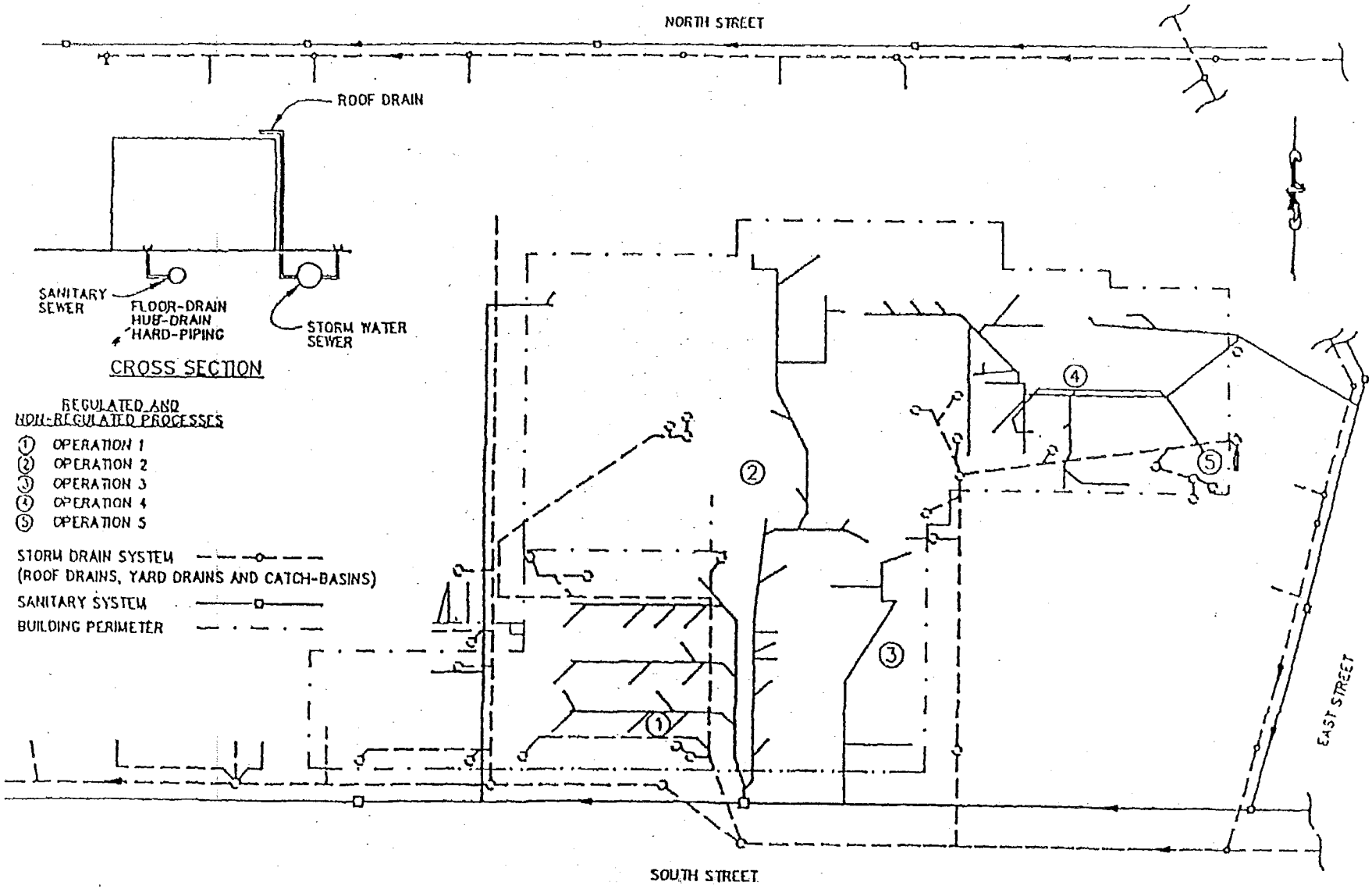
Figure 1
TYPICAL PLANT LAYOUT AND SEWER OVERVIEW



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storm water runoff drain. Sewer maps also show the junction points at which storm and sanitary laterals from a facility connect to the municipal sewer systems. Figure 2 is a diagram showing storm and sanitary sewers in an industrial area.

Municipal sewer system schematics are generally shown on street maps. These maps will show connection locations to municipal sewer systems. During this initial mapping overview effort, it is important to note and distinguish between storm water and sanitary sewer lines. Manholes for each type of sewer (sanitary or storm) should be clearly labeled or numbered. This is necessary for manhole observations which are discussed in a later section.

Topographic Maps

Topographic maps, which show the ground elevations at a site, are useful when determining the direction of flow of storm water runoff. In situations where raw or waste materials at a facility are stored outdoors, storm water runoff may carry pollutants into separate storm water drainage systems.

Summary

The following check list summarizes the necessary actions for acquiring accurate mapping data.

Data Collection

- Make a listing of all available maps and schematics
- Note the dates when such maps and schematics were printed
- Obtain, if possible, older versions of the maps and schematics and determine if changes have occurred
- Note what changes were made

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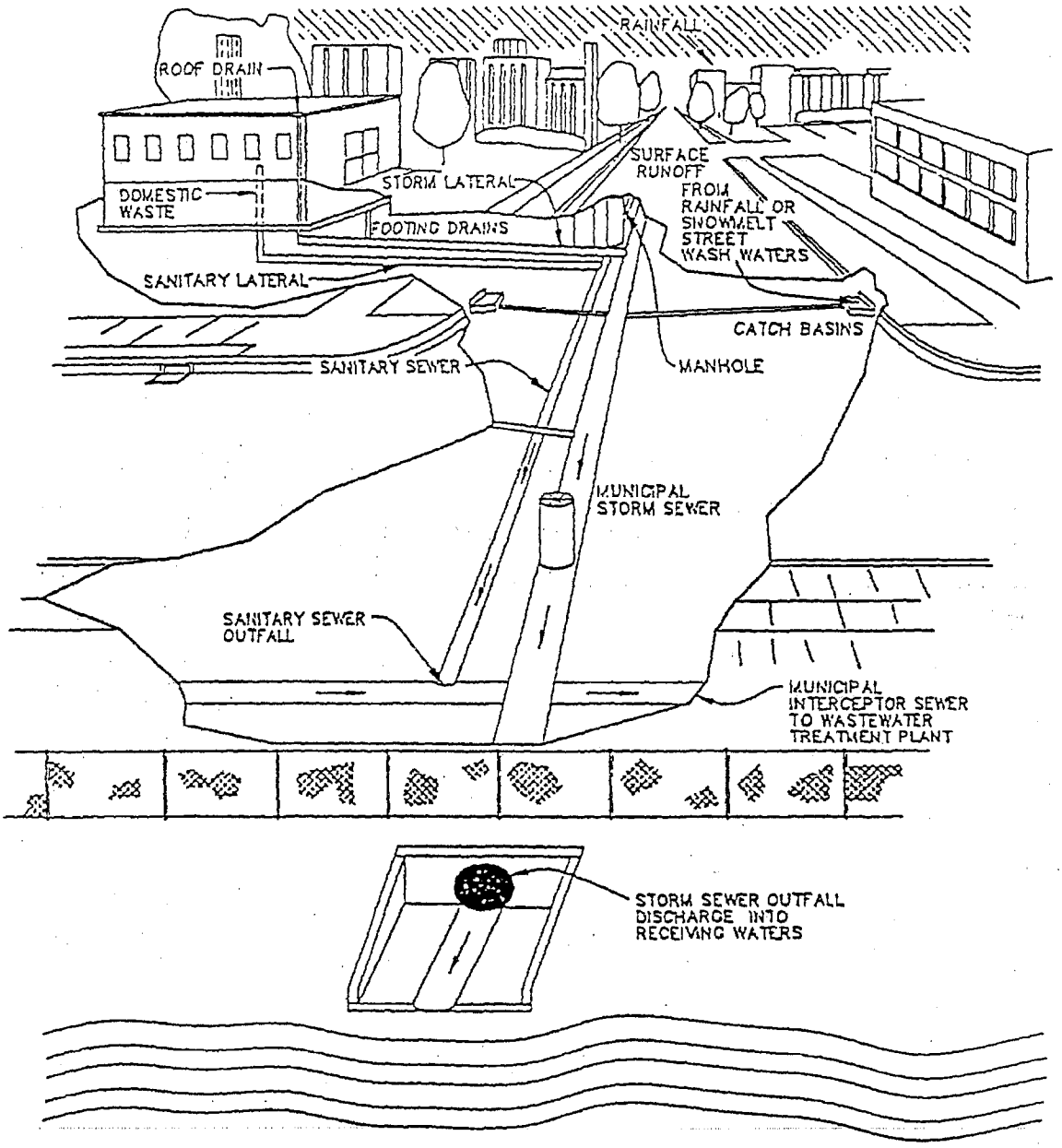
Figure 2
STORM AND SANITARY SEWERS DIAGRAM



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Plant Layout Drawings

- List all major processes and equipment at the facility from the most recent maps (schematics)
- Identify and label all indoor and outdoor material storage areas
- Note and label all floor drains within the facility

Sewer Maps

- Distinguish between sanitary and storm sewers
- Identify all manhole locations and label accordingly

Spill History

Spill history records should be examined in order to determine the nature of materials which have been spilled as well as the frequency of occurrence of any spills. Typical sources of industrial spills were listed in the previous section. Drainage patterns of areas where spills can occur should be evaluated. The specific process or area in which the spill occurred should be investigated in greater detail.

A facility may have developed a spill contingency plan, which may provide details regarding the spill potential at a facility. If a plan is not available, the necessary information will have to be determined from facility records and industry personnel.

If an industry has previously experienced a spill which resulted in the discharge of unacceptable material to a separate storm sewer, information should be gathered so that the corrective actions taken to eliminate contaimination associated with these spills can be evaluated.

The following check list summarizes the actions for acquiring accurate spill history data.

- Obtain spill history records and prevention plan
- Evaluate the potential of spills in process and storage area(s)
- Determine frequency and nature of past spills

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- Note volumes and type of materials spilled
- Note the recorded cause of any spills
- Note corrective actions taken

STEP 2 - PRELIMINARY EVALUATION OF WATER USE AND OTHER DISCHARGES

The purpose of this step is to evaluate the water usage and other discharges at the industrial facility under consideration. This information can serve as a useful aid in determining the probable source of an illicit connection.

Typical sources of industrial water use were listed in the previous section. These processes, as well as any other water-consuming operations, should be identified for the industrial site. Facilities may also use a wide array of solvents, oils, and other liquids for various applications in manufacturing. Processes utilizing these substances should be determined as well.

A preliminary step in listing these processes is the examination of all discharge permits. These permits generally provide information on the characteristics and quantities of all discharges allowed to surface waters or in some cases to sanitary sewer collection systems. Other discharges of non-storm water not requiring a discharge permit may be identified through inquiry with industry personnel and/or from an evaluation of plant operations.

The following check list summarizes the data which should be gathered during this step.

- List which processes use water and which use other liquids.
- Note any distinctive physical or chemical characteristics of the other liquids used.

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- Note the potential for contamination associated with water use at the facility.

- Note the flow pattern of any unconfined discharges (e.g. cleaning, rinse and wash waters, etc.) and potential spills.

- Note the point of discharge as either connecting to the sanitary sewer, storm sewer, or as an unknown connection.

STEP 3 - ON-SITE INVESTIGATION

The previous steps described the collection and evaluation of available data and information at a given facility. It was noted that available information may not reflect existing conditions at a site. Therefore, the purpose of the third step is to:

- Confirm, modify and update available information
- Identify processes or areas that exhibit the potential for illicit connections

The on-site investigation procedure should add to the already existing information. For example, not all manholes may have been indicated on the sewer maps. Therefore, the actual on-site investigation may result in the identification of additional manholes.

The success of the on-site investigation depends upon careful visual inspections of both indoor and outdoor areas of the facility.

Outdoor Inspection

Depending upon the size of the facility, the outdoor inspection may be conducted by walking and/or driving. The specific objectives of the inspection are to locate all:

- Manholes
- Catch basins
- Storm water runoff directions and inlets
- Material storage areas

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In addition, the general condition of the site grounds should be observed. These observations should focus on:

- Cleanliness of loading and unloading areas
- Spill control of outdoor material storage areas
- The nature and condition of waste storage facilities at the site
- The potential for contact of outdoor material storage with storm water runoff

Indoor Inspection

The indoor inspection should be conducted in a similar fashion to the outdoor inspection (i.e., careful visual observation). This step of the procedure can be expediently executed by using a list (as determined in Step 2) of manufacturing processes, equipment locations, and on-site storage facilities. The investigative team should query the plant personnel on the following issues:

Processes and Equipment

- Record name and brief description
- Identify nature of chemicals used
- Determine the nature of discharges (continuous, intermittent, or batch)
- Identify if the process wastes are regulated for discharge

Floor Drains/Other Discharge Points for the Process

- Identify the point of discharge for the process
- Locate nearest floor drain
- Identify the catch basin
- Determine the sump pump location

Inside Storage Locations

- Determine all storage areas
- Identify if spill control measures are in place

At the conclusion of the indoor inspection, all existing information should be updated. Processes or equipment whose

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discharge points are not known should be considered suspect (i.e., exhibiting illicit connections). Material storage areas that show any physical evidence of spills (e.g., powder, stains, or discolorations) should also be considered suspect. Additional guidance regarding typical sources of wastestream flows within various facilities as classified by SIC codes is provided in Appendix A of this manual.

By using the updated information from both the indoor and outdoor inspections, it is now possible to conduct the confirmatory analysis.

STEP 4 - CONFIRMATORY ANALYSIS

Upon conclusion of the on-site investigation, one or several sources from the industrial facility may appear to be the cause of an illicit discharge. The purpose of the fourth step is to determine the actual location of the illicit connection to the storm water drainage system.

This step of the procedure involves implementation of investigative strategies to pinpoint the source of the contaminated discharge. The confirmatory analysis begins with examination for dry weather storm sewer discharges from the industrial facility. This is followed by pipeline examination to verify the location of the illicit connection.

Dry Weather Discharge Examination

The examination for dry weather discharges to the storm sewerage system fulfills the following two objectives:

> Verification that the discharge from the particular industrial site under investigation is the same one as originally detected at the storm water outfall.

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- Indication of the industrial source of the illicit discharge by virtue of relative site location as well as by discharge composition.

Procedure

This procedure involves determining outfall locations or the junction points at which a storm water sewer line from the facility connects to a municipal separate storm sewer line. Direct access to these junction points may be possible as manholes are often placed prior to private-municipal separate storm sewer line connections.

Observation for dry weather discharges from the facility entails either direct observation of an outfall or physically removing manhole covers at the selected locations and visually inspecting for the presence of flow. Proper precautions should be taken to ensure worker safety.

Tming of the observations is a crucial factor. Observations should take place at those times when various sources of non-storm water are being used at the facility and flows from illicit connections may be occurring. How much earlier the inspection should take place is dependent upon the distance from the sewer line connection to the contaminated storm sewer outfall. In general, the farther apart these two locations are, the earlier the manhole inspection time should take place from the time of the recorded outfall discharge detection.

If a dry weather discharge is detected during a manhole observation, the flow should be characterized in the same manner as was discussed in Section 3.

The following physical and chemical properties of the dry weather discharge should be observed and recorded:

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Physical Properties

- Odor
- Color
- Temperature
- Turbidity
- Floatables
- Residue

Chemical Properties

- pH
- Total Dissolved Solids
- Specific Conductivity

Grab samples of the dry weather discharge can be taken to a laboratory for detailed chemical analysis. This analysis should focus upon chemicals known to be used at the industry. Guidance regarding typical conventional and toxic pollutant concentrations is provided as part of the industrial wastestream characterization classified by SIC codes in Appendix A of this manual. Additional information regarding chemical parameters, which should be tested for, may also be obtained through reference to NPDES discharge limitations or consultation with industry personnel.

It should be noted, however, that the detected dry weather discharge may be a permitted discharge (such as non-contact cooling water) from the industrial facility to the storm sewerage system. This case may be confirmed by checking if a discharge permit exists for that particular sewer line connection, as well as from the chemical composition and physical nautre of the flow.

If the observed dry weather discharge is determined as being non-permitted and/or contaminated, the results of the recorded analysis should be compared against potential sources of non-storm water at the facility.

Comparisons should seek to find common pollutant characteristics

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between the observed dry weather discharges, and potential non-storm water sources at suspect industrial processes or spill areas.

If waste flows can be established as essentially identical, then it may be assumed that the industrial source responsible for the detected illicit discharge has been identified.

In some cases, more than one dry weather discharge may be observed at various manholes. It is possible that more than one illicit connection to the storm water drainage system may exist within the industrial facility and that the contaminated outfall discharge is the result of a culmination of several flows. Therefore, all suspect industrial sources of observed manhole discharges should be identified before proceeding on to the pipeline examination.

Summary

- Locate industrial-municipal sewer line connections
- Select manhole observation points
- Determine the presence of dry weather discharges
- Characterize observed dry weather discharges
- Determine if discharge is permitted or contaminated
- If discharge is not permitted, conduct a comparison of characteristics to identify the industrial source
- Identify all industrial sources of all dry weather discharges observed

Pipeline Examination

The major objective of the pipeline examination is to identify the specific point at which the illicit connection exists. Illicit connections may result from failing plumbing fixtures, direct connections, or in many cases inadvertent connections. The pipeline examination also serves to verify the industrial source responsible for an observed discharge.

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Inadvertent connections result when a storm sewer is mistaken for a sanitary sewer. In some cases, illicit connections were actually permitted at the time they were built. Regardless of the reason behind an illicit connection, a number of procedures have proven to be successful in identifying their actual locations. The main objective of these procedures is to trace the path taken by a discharge from a process to a downstream point. Two procedures recommended for use are:

- Dye tracer tests
- Internal pipe investigations
  - Manual visual inspections
  - Television (TV) inspections

Dye Tracer Tests

Dye tracer tests involve the introduction of a fluorescent dye such as fluorescein into the discharge point of the industrial or commercial process suspected of exhibiting illicit connections. The discharge points for all processes were determined during the indoor investigation of the facility.

The dye, once introduced, is flushed down with clear water. Various observation points are then observed. If the fluorescent dye comes through, then an illicit connection has been identified. In most cases, illicit connections can be identified by conducting dye tracer studies. However, situations may arise in which the dye tracing process fails to identify illicit connections. This may be the case when there is a break or crack in an adjacent sanitary sewer. In such cases, an internal investigation of the sewer lines may be necessary.

Internal Pipe Investigations

When sewer systems are large enough, they should be inspected by

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walking through them in order to locate the entry points of polluted discharges. In such cases, appropriate safety precautions as described under the OSHA confined space entry requirements should be employed.

The use of TV inspections is relatively expensive. This is an alternative to manual inspections and may be used when sewers are smaller or for safety reasons.

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Section 7

FIELD SURVEY TECHNIQUES

The objective of this section is to provide detailed information regarding the field survey techniques discussed in previous sections of this manual. The relative success of this methodology for identifying illicit industrial connections relies heavily upon careful field organization. Topics are addressed in the following order:

- Necessary Equipment and Materials
- Personnel Requirements
- Estimated Timeline
- Organizational Ideas

NECESSARY EQUIPMENT AND MATERIALS

Necessary equipment and materials must be gathered prior to conducting the field survey. A list of essential equipment and materials for both the outfall screening and the on-site investigation is provided in Table 3 and discussed below.

Field Test Kit

Elementary chemical analysis can be performed with a field test kit. These kits can be used to provide estimates of concentrations of varous parameters in flow samples. There are several brands of kits with features suited to the needs of this manual. Information regarding typical field test kits is presented in Appendix B. The data provided includes the manufacturer, model number, general capabilities, and cost.

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pH and Conductivity Meters

The pH meter and conductivity meter are also used to determine initial values for discharges detected at storm water outfalls and during manhole observations. Highly sophisticated models are generally not be necessary. Rather, a moderately priced meter can be selected. Buffer solutions are also essential and should always be brought along to calibrate the meters prior to taking readings. Information regarding typical pH and conductivity meters is presented in Appendix B. The data provided include the manufacturer, model number, general capabilities, and cost.

Automatic Sampler

An automatic sampler can be used at the storm water outfall to detect flows, collect samples, and determine flow patterns. The use of an automatic sampler eliminates the need for inspectors to constantly observe a sampling point for intermittent discharges at sampling locations exhibiting characteristics of industrial contamination. There are many brands of automatic samplers available with a diversity of characteristics. Table 4 presents a list of considerations for an automatic sampler suitable to the needs outlined in this manual. Additional information regarding typical automatic samplers is presented in Appendix B. The data provided include the manufacturer, model number, general capabilities, and cost.

Instant Camera and Film

An instant camera should be used to photograph all locations exhibiting signs of contamination by potential illicit connections. This photo will serve as a visual aid for each location and also supplement the written documentation of the observed pollutant characteristics. Photographs may also be taken during the on-site investigation to log various suspect

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processes or potential spill areas. This may be especially helpful for large facilities with extensive manufacturing operations.

It is important to note that most facilities have strict policies concerning photographs taken by visitors. The inspector should always ask the plant manager about the plant's policy before carrying a camera into a manufacturing area. The inspector might need to obtain special permission or agree to have all photographs reviewed by the plant manager.

The instant camera selected for use should produce color photographs. A one-step model is generally the easiest to use as no waste paper is produced from the photographing.

Collecting Samples

Samples of discharges are collected at storm water outfalls, from manholes, and occasionally from industrial processes. Plastic bottles are preferred for a container since they will not break and are easily labeled. A waterproof marker should be used to label each sample immediately after it has been collected. Identification data should always include the date, time of day, inspector name, sample number, and the location from which the sample was taken. Once labeled, all samples should be tightly sealed and packed in ice.

Recordkeeping

Recordkeeping materials include a clipboard, pad of paper, and pen or pencil. Data Inventory Forms on which to summarize pertinent information should also be used to simplify documentation during field surveys. Typical forms are discussed under the topic of organizational ideas at the end of this

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section. In addition, any maps or plant layout drawings should be kept with the recordkeeping material. Maps and drawings brought along should be of manageable size, if possible, 8-1/2 by 11 inches. Finally, it is highly suggested that all documentation be organized into a three-ring binder. This will keep information readily available and ensure that little potential exists for losing or misplacing important data.

Outfall Identification

All contaminated and newly discovered storm water outfalls should be physically labeled with an identification number, in order to prevent confusion or mix-ups during additional field surveys. Visible outfall id numbers will also reduce unnecessary referencing to maps and thus save time as well. Outfall marking can be accomplished with wooden stakes. The stakes should be spray painted a fluorescent color with the id number of the outfall carefully marked in black. A thick waterproof marker should be used for stake labeling. Each stake should be placed next to its corresponding storm water outfall in an area away from trees or shrubbery for easy visibility. A hammer may be necessary to pound the stakes into the ground as it may be quite hard due to the fact that analysis is conducted during dry weather.

Manhole Observation Equipment

Manhole observation for illicit discharges requires several kinds of equipment. A crowbar will be necessary in order to remove the manhole lid. Also, a bright flashlight will be helpful for visual inspection inside of the manhole.

If dry weather flows are detected inside of a manhole but entry to obtain a sample is impossible or unsafe, an alternative sampling procedure must be employed. If the manhole is not too

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deep, one method of obtaining a sample is to tape the sampling bottle to a long stick which can reach the discharge. A fold-up tape measure is a compact way of carrying a long stick. Heavy duty tape should also be used to ensure that the sampling bottle remains affixed.

Finally, if the manholes are located along a roadway or street, precautionary measures should be taken to protect the inspectors and minimize traffic disruption. Orange safety cones and/or a flashing barricade should be used to segregate the necessary working area. Also, all inspectors should wear orange safety vests.

Pipeline Examination

Fluorescein dye tracer may be needed to conduct pipeline examinations. Ample dye should be brought along as several tests may be necessary.

Inspector Safety

Attention to safety procedures is a must during all field surveys. This includes inspector apparel from head to toe. Work clothes should always be worn for all inspections. Rubber boots should be brought along in case of wet or muddy conditions during the screening of storm water outfalls. Essential materials for the industrial on-site investigation include safety shoes, safety glasses, a hard hat, and hearing protection. Protective gloves should always be worn when collecting samples of any potentially dangerous discharges. Finally, a complete first aid kit should always be kept on hand in case of an emergency.

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TABLE 3

FIELD EQUIPMENT AND MATERIALS

Field Test Kit
pH Meter and Buffer Solution
Conductivity Meter and Buffer Solution
Batteries
Automatic Sampler
Instant Camera and Film
Sampling Bottles and Waterproof Marker
Tracer
Cooler
Clipboard, Pad, Pen or Pencil
Data Inventory Forms
Maps
Marked Stakes
Hammer
Flashing Barricade
Orange Safety Cones
Orange Safety Vest
Crowbar
Flashlight and

Fold-Up Tape Measure
Heavy Duty Tape
Fluorescein Dye

Work Clothes
Rubber Boots
Safety Shoes
Safety Glasses
Hard Hats
Hearing Protection
Protective Gloves
First Aid Kit

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TABLE 4

CONSIDERATIONS FOR AUTOMATIC SAMPLER

-- Capability for AC/DC operation with adequate dry battery energy storage for 120-hour operation at 1-hour sampling intervals

-- Total weight including batteries

-- Sample collection interval (adjustability from 10 minutes to 4 hours)

-- Capability for time proportional sample - constant sample volume, time interval between samples proportional to stream flow

-- Capability for collecting discrete samples in 24 containers

-- Watertight exterior case to protect components in the event of rain or submersion

-- Exterior case capable of being locked to prevent tampering and provide security

-- No metal parts in contact with waste source or samples

-- An integral sample container compartment capable of maintaining samples at 4 to 6°C for a period of 24 hours at ambient temperatures ranging from -30 to 50°C

-- Operation capabilities in the temperature range from -30 to 50°C

-- Sampler exterior surface painted light color to reflect sunlight

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PERSONNEL REQUIREMENTS

The objective of the following discussion is to provide general information regarding the personnel demand and training necessary to perform the methodology outlined in this manual.

Clearly, as the size of the industrial area to be investigated increases, so too does the demand for personnel. The following suggestions are based upon an optimum fixed number of inspectors per phase of the field survey. These suggestions were offered in order to set a standard as well as to simplify the overall procedure.

Phase I - Screening of Storm Water Outfalls

It is suggested that a minimum of two (2) investigators perform the observations and analyses at a storm water outfall. There are several reasons behind this selected minimum among which the most important are the following:

- Correspondence regarding visual observations and elementary chemical analyses
- Safety in numbers
- Load distribution for carried equipment

Thus, a coupled effort will result in greater efficiency as well as mobility. When very large numbers of storm water outfalls exist for screening in an industrial area, it is suggested that several pairs of investigators perform outfall surveys in order to expedite the process.

Phase II - Industrial On-Site Investigation

In order to perform the industrial on-site investigation, it is suggested that either three investigators be aided by one industry personnel or two investigators be aided by two industry

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personnel. The reasoning behind a total number of four being such that the on-site investigation may be divided into two tasks. Thus, one pair of investigators may perform the outside inspection while the other pair focuses their attention upon the inside inspection.
The selected industry personnel should have a thorough knowledge of the operations performed at the facility. In addition, it is beneficial if they also have a practical understanding of environmental management procedures as well.

Personnel Training

In addition to efficiency, the inspectors performing a field survey must also be accurate. High levels of accuracy may only be obtained through complete and proper training. Training should encompass a formal orientation of the methodology presented in this manual along with practical field techniques.

Therefore, inspectors should have an understanding of the various identification strategies presented in this text. They should also be knowledgeable of typical kinds and sources of industrial waste. If possible, training should include an actual field orientation of common industrial water use processes and types of spills. Factual information should also be provided summarizing the contacts and access details necessary for obtaining pertinent data such as sewer maps or environmental records.

Inspectors must be able to correctly operate all field equipment - in particular specialized meters and automatic samplers. Training should include the proper procedures for collecting samples as well as for performing manhole observations. Finally, steps must always be taken to make personnel aware of potential occupational hazards, precautionary measures to prevent them, and special plans to follow in the event of an emergency.

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TIMELINE

There are several steps to be performed when following the methodology outlined in this manual. The following chart is intended to provide a generalized indication of the time required for each step.

It is important to note that the chart provided does not take into account unexpected problems such as poor weather or equipment failure. In addition, the time needed to conduct the on-site industrial investigation and confirmatory analysis is highly dependent upon the size of the facility. Thus, these estimates should be considered only as idealized guidelines.

Procedure and Step	Time Range (days)
Outfall Evaluation	
Step 1 - Mapping Effort	1-3
Step 2 - Walking Tour	2 outfalls surveyed/day*
Step 3 - Outfall Analysis	2 outfalls analyzed/day
Identification of Potential Industrial Sources	
Step 1 - Establish Flow Pattern	3-7
Step 2 - Analysis of Recorded Data	1-3
Step 3 - Correlation to Possible Industrial Sources	1-3
On-Site Industrial Investigation	
Step 1 - Data Collection	2-4
Step 2 - Preliminary Evaluation of Water Use and Other Discharges	2-4
Step 3 - On-Site Investigation	3-7
Step 4 - Confirmatory Analysis	3-7

*NOTE:
Inspectors should be able to complete the initial survey and analysis for two outfalls per day.

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ORGANIZATIONAL IDEAS

The use of Data Inventory Forms can greatly simplify the process of recording information. A variety of Data Inventory Forms are provided in Appendix C of this manual. Thus, the objective of the following discussion is to briefly describe the function for each form.

Outfall Analysis Data

This three-page form should be used to record data collected from the screening of storm water outfalls. The form organizes information regarding the detected flow pattern, physical observations, and elementary chemical analysis results for a particular outfall.

Laboratory Analysis

This two-page form should be used to check off the parameters which should be tested for in a grab sample laboratory analysis. The form summarizes the grab sample identification details, laboratory information, and provides a listing for conventional as well as toxic pollutants. The toxic pollutants were determined according to the listing provided originally in the Clean Water Act.

Process Data: Direct Discharge

This form summarizes information regarding industrial processes which directly discharge into a receiving water body. Data regarding a particular industrial process as well as any permit details are to be recorded on this form.

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Process Data: Indirect Discharge

This form summarizes information regarding industrial processes which discharge to the local POTW for treatment before entrance to a receiving water body. The information recorded includes details of the particular industrial process and any pretreatment for it discharges as well as general data for the local POTW.

Spill History

This form should be used to record information regarding any past spills which occurred at an industrial facility.

Spill Potential

This form should be used to summarize information regarding industrial processes which have spill potential.

Facility Runoff

This form should be used during the outside portion of the industrial on-site investigation. The form summarizes potential sources of pollutants associated with storm water runoff.

Correlation of Data

This form should be used during the correlation process to determine similarities between the detected illicit discharge and suspect industrial process discharges. Comparisons are drawn based upon the wastestream characterization of discharges from the contaminated outfall, manhole observations, and suspect industrial process discharges.

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Section 8

SUMMARY

This manual has outlined a procedure which begins with the screening of stormwater outfalls for signs of contamination from sources of non-storm water. The methodology then proceeds to the identification of likely sources for the detected non-stormwater discharge. Then, procedures to pinpoint the location of the industrial illicit connection are discussed. This manual concludes with a section focusing upon field survey techniques as the success of this methodology depends largely upon the careful collection and analysis of site information.

The strategy underlying this methodology involves correlating the characteristics of discharges observed at outfalls and that of various sources of non-storm water, such as industrial manufacturing or operational process discharges.

By applying common sense and professional judgement to the procedures outlined in this manual, successful evaluation of a facility's separate storm sewer for the presence of non-storm water discharges can be accomplished.

A006728

APPENDIX A
WASTE CHARACTERIZATION

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WASTE CHARACTERIZATION

The objective of the following section is to provide a general survey of information regarding wastestream identification and characterization for various facilities listed under industrial SIC categories. Listings of the subcategories falling under each industrial SIC category will be followed by potential sources of wastestream flows. In addition, a characterization of the potential wastewaters discharged from each of the defined subcategories will be presented. This characterization will define typical values for chemical and physical parameters as determined from laboratory wastestream analysis.

Some of the subcategories for listed classifications have been eliminated due to their insignificance in the industry. In addition, the parameters defined for the wastestream characterization vary according to the data available for a particular industrial category. Thus, the tables presented in this appendix list various combinations of conventional, toxic, and non-toxic pollutants. The values presented in each table may be typical wastestream concentrations or ranges of concentrations. In either case, these tables should provide the user of this manual with guidelines as to the types and general concentrations of pollutants likely to be identified for a specific industrial subcategory.

It is also important to note that each wastestream characterization presents values taken from raw wastewaters prior to discharge into a sewerage system. Thus, the concentrations actually detected at a storm sewer outfall are likely to be lower due to possible dilution from storm water or other wastewaters.

The source referenced to for all detailed information and tables provided in this section was Volume II of the 1980 USEPA Treatability Manual.

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INDUSTRIAL LAUNDRIES

Facilities belonging to this category are linked by the fact that they provide cleaning services for their clients. The main subcategories falling under industrial laundries are as follows:

Subcategories

- Industrial Laundries
- Linen Laundries
- Power Laundries
- Coin-Operated Laundries
- Dry Cleaning Plants
- Car Washes

Sources of Wastestream Flows

The four basic process divisions in the industrial laundries category include water wash, dry cleaning, dual-phase processing, and car wash processes. Typical sources of wastestream flows for industrial laundries will be generated from the operations involved for these processes.

Facilities utilizing a water wash first sort soiled materials. Stains which may set are removed which generally involves the use of acids, bleaches, and/or various organic solvents. Wetting, sudsing with detergents, and rinsing of the materials then takes place to clean the fabric.

Primary cleaning for dry cleaning processes is accomplished through the use of an organic-based solvent along with detergent and a controlled amount of water. Solvents are generally filtered and recovered for further use.

In dual-phase processing, the water-detergent wash is followed by a separate solvent wash. This is used almost exclusively to clean items that contain large amounts of water-soluble soils as well as oil and grease, such as for work shirts and wiping rags.

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Car washes are considered a variation of the water wash process. Facilities are designed for either automatic or self-service washing of vehicles. Operational processes generally include washing with various detergents, waxing, rinsing, and drying.

Wastestream Characterization

The chemical and physical characteristics of laundry wastewaters are influenced by three primary factors: the type of cleansing process utilized, the types and quantities of soil present, and the composition of the various chemical additives used in the process. Wastestream flows deriving from water wash operations may contain all of the soil removed from the materials as well as the chemical cleaning agents or detergents added to facilitate the laundering process. While wastestream flows from dry cleaning processes tend to contain removed soils along with appreciable quantities of organic-based solvent. The primary wastes present in car wash wastewater are suspended and dissolved solids, oil and grease, lead, and zinc.

An important factor to keep in mind when investigating facilities falling under this category is that the sources of wastes may originate from the cleaning processes as well as from the materials being cleaned. This in turn increases the potential number of pollutants to be found in wastestream flows from industrial laundries and car washes.

Table 1 presents subcategory wastewater descriptions for conventional and toxic pollutants found in this industry.

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TABLE 1

WASTEWATER CHARACTERIZATION OF
AUTO AND OTHER LAUNDRIES

	Industrial Laundries		Linen Laundries		Power Laundries	
	Number Analyzed	Mean	Number Analyzed	Mean	Number Analyzed	Mean
Pollutant (mg/l)						
BOD_5	51	1,300	50	620	8	340
COD	60	5,000	26	1,600	11	660
TOC	24	1,400	28	400	4	150
TSS	69	1,000	59	400	11	220
Total Phosphorus	12	12.2	5	18.7	6	7.3
Total Phenols	19	0.32	7	0.12	5	0.31
Oil and Grease	66	1,100	52	330	9	110
pH, pH Units	62	10.4	58	10.1	14	9.4
Toxic Pollutant (mg/l)						
Antimony	22	240	7	10	6	160
Arsenic	24	77	7	7	6	<15
Beryllium	14	<1				
Cadmium	36	88	36	9	5	11
Chromium	35	880	36	100	7	76
Copper	36	1,700	15	520	7	160
Cyanide	28	140	7	33	5	<28
Lead	36	4,500	36	460	7	110
Mercury	24	2	36	3	8	0.7
Nickel	36	290	36	61	7	14
Selenium	16	8	7	2		
Silver	26	26	7	8	7	<7
Thallium			7	5		
Zinc	36	3,000	37	900	6	37

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TABLE 1 (cont.)

WASTEWATER CHARACTERIZATION OF
AUTO AND OTHER LAUNDRIES

	Coin-Operated Laundries		Dry Cleaning Plants		Car Washes	
	Number Analyzed	Mean	Number Analyzed	Mean	Number Analyzed	Mean
Pollutant (mg/l)						
BOD_5	31	140	1	---	45	58
COD	18	340	1	---	NA	---
TOC	1	---	1	---	NA	---
TSS	28	140	1	---	45	270
Total Phosphorus	2	9.8	1	---	NA	---
Total Phenols	3	0.10	2	<0.003	6	<0.006
Oil and Grease	13	26	1	---	45	26
pH, pH Units	29	7.9	1	---	7	7.1
Toxic Pollutant (mg/l)						
Antimony	3	10			7	7,9
Arsenic	3	<10			7	230
Beryllium					7	<5
Cadmium	3	8			7	17
Chromium	3	<5			7	34
Copper	3	67	2	25	7	340
Cyanide						
Lead	3	36	2	20	45[c]	890
Mercury	3	1			7	<1
Nickel					7	260
Selenium					7	<5
Silver					7	<5
Thallium					7	<2
Zinc	3	310			45[c]	750

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ELECTROPLATING

Facilities which belong to the electroplating category are those that apply a metallic surface coating to a second material. This is generally done by electrodeposition but may also be accomplished through various coating processes or through electroless plating. The main subcategories falling under electroplating are as follows:

Subcategories

- Common Metals Plating
- Precious Metals Plating
- Anodizing
- Coating
- Chemical Milling and Etching
- Electroless Plating
- Printed Circuit Board Manufacture

Sources of Wastestream Flows

The three basic process divisions in electroplating include: surface preparation, plating, and posttreatment. These steps are common to all subcategories and are the sources from which wastewater flows will be generated.

Surface preparation of the basic material is necessary to ensure that the exterior is cleaned and descaled prior to plating. Cleaning removes oil, grease, and any other dirt which may interfere in the plating of the material. Several cleaning methods can be used for this step including solvent, alkaline, acid, emulsion with organic solvents, and salt bath descaling.

In the plating step, a surface coating is applied to a material for either functional or decorative purposes. The type of electroplating done at facilities can vary greatly in size as well as character. However, all tend to rely upon appreciable use of various acid and alkaline solutions. In addition, large quantities of rinse water are also generated often containing these solutions in a diluted form.

Posttreatment after the initial plating of a material is completed in order to provide an additional coating. This extra coating is applied for a variety of reasons such as corrosion protection or to prepare the surface for painting. Posttreatment processes include chromating, phosphating, and conversion coating operations.

10123MAP

Wastestream Characterization

Wastewater from electroplating processes is typically due to the processing and finishing solutions generated from alkaline and acid cleaning operations, plating processes, and posttreatment. While the quantities of wastewater generated are not excessive, they tend to be very strong in nature. Untreated wastestreams may contain appreciable amounts of acids, detergents, solvents, and metals in significant quantities.

Predominant wastewater constituents for the electroplating industry include various chemical cleaners and plating solutions as well as the following metals: copper, nickel, chromium, zinc, lead, tin, cadmium, gold, silver, and platinum.

Table 2 presents raw discharge pollutant concentration ranges for the subcategories of the electroplating industry.

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TABLE 2
POLLUTANT CONCENTRATION RANGES
FOR THE SUBCATEFORIES OF THE
ELECTROPLATING INDUSTRY

Pollutant Parameter	Concentration Range			
	Common Metals Plating	Precious Metals Plating	Electroless	Anodizing
Conventional Pollutants, mg/l				
TSS	0.1 - 10,000	0.1 - 10,000	0.1 - 39.0	36.0 - 920
Toxic Inorganic Pollutants, mg/l				
Cadmium	7 - 21,6,000			
Chromium, Total	88 - 530,000			270 - 79,000
Chromium, VI	5 - 330,000			5 - 5,000
Copper	32 - 270,000		2 - 48,000	
Cyanide, Total	5 - 15,000	5 - 10,000	5 - 12,000	5 - 78,000
Cyanide, A	3 - 130,000	3 - 8,400	5 - 1,000	4 - 68,000
Lead	660 - 25,000			
Nickel	19 - 3,000,000		28 - 47,000	
Silver		50 - 180,000		
Zinc	110 - 250,000			
Non-Toxic Pollutants, mg/l				
Fluoride	22 - 140,000		110 - 18,000	
Gold		13 - 25,000		
Iron	250 - 1,500,000			
Palladium		27 - 630		
Phosphorus	20 - 140,000	20 - 140,000	30 - 109,000	180 - 33,000
Platinum		110 - 6,500		
Rhodium[a]		34		
Tin	60 - 100,000		60 - 90,000	

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TABLE 2 (cont.)

Pollutant Parameter	Concentration Range		
	Coating	Chemical Milling & Etching	Printed Circuit Boards
Conventional Pollutants, mg/l			
TSS	19.0 - 5,300	0.1 - 4,300	1.0 - 610
Toxic Inorganic Pollutants, mg/l			
Cadmium			
Chromium, Total	190 - 79,000	88 - 530,000	5 - 48,000
Chromium, VI	5 - 5,000	5 - 330,000	5 - 4,400
Copper		210 - 270,000	200 - 540,000
Cyanide, Total	5 - 130,000	5 - 130,000	5 - 11,000
Cyanide, A	4 - 68,000	5 - 100,000	5 - 9,400
Lead			10 - 10,000
Nickel			27 - 13,000
Silver			1 - 480
Zinc	140 - 200	110 - 200,000	
Non-Toxic Pollutants, mg/l			
Fluoride		22 - 140,000	280 - 680,000
Gold			6 - 110
Iron	410 - 170,000	75 - 260,000	
Palladium			5 - 230
Phosphorus	60 - 53,000	60 - 140,000	51 - 54,000
Platinum			
Rhodium[a]			
Tin	100 - 6,600	340 - 6,600	60 - 54,000

NOTE: Blanks indicate data not available.

[a] Only one plant had a measurable level of this pollutant.

10123TB2

INORGANIC CHEMICALS MANUFACTURING

Facilities belonging to this category are those which produce alkalies and chlorine, industrial gases, inorganic pigments, and those producing other inorganic chemicals. The main subcategories falling under inorganic chemicals manufacture are as follows:

Subcategories

- Aluminum- Fluoride
- Chlor-Alkali (Mercury Cell and Metal Anode)
- Chrome Pigments
- Copper Sulfate
- Hydrofluoric Acid
- Hydrogen Cyanide
- Nickel Sulfate
- Sodium Bisulfate
- Sodium Dichromate
- Sodium Hydrosulfite
- Titanium Dioxide (Chloride and Sulfate)

Sources of Wastestream Flows

The sources of wastestream flows for the inorganic chemicals industry can vary considerably. Each subcategory will have unique waste sources which would not be found in another type of inorganics facility. Descriptions of all these sources is beyond the scope of this manual. However, there are several wastestream flows which have a potential for being common to all of these subcategories. The following is a listing of typical wastestream sources:

- Noncontact Cooling Water
- Rinse Water
- Floor and Equipment Washings
- Scrubber Wastewater
- Spent Chemical Solutions and Solvents
- Condenser Drainage
- Boiler Blowdown

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Wastestream Characterization

The pollutants which may be found in the wastewaters from the inorganic chemicals industry also vary widely for each of the subcategories listed. Toxic pollutants are generally metals. In addition, the concentrations of the wastewater flows may vary from insignificant to appreciable concentrations. Table 3 presents the maximum concentration of each toxic pollutant found in each subcategory for the inorganic chemicals industry.

10123MAP

TABLE 3
MAXIMUM RAW WASTEWATER CONCENTRATIONS
OF TOXIC POLLUTANTS FOUND AT
SAMPLED INORGANIC CHEMICAL PLANTS

		Chlor-Alkali		
	Aluminum Fluoride	Mercury Cell	Metal Anode	Chrome Pigments
Toxic Pollutant (ug/l)				
Antimony	200	<200	20	7,700
Arsenic		<10	10	
Asbestos				
Beryllium				
Cadmium	0,85	0,4	2	79
Chromium	77	7,7	940	55,000
Copper	120	350	525	7,500
Cyanide				360
Lead		1	255	36,000
Mercury	2	150	9	
Nickel	150	<100	54,400	160
Selenium	110			<10
Silver		0,6	<9	7
Thallium		<250	14	
Zinc		230	24	4,100

	Copper Sulfate	Hydrofluoric Acid	Hydrogen Cyanide	Nickel Sulfate
Toxic Pollutant (ug/l)				
Antimony	307	70		
Arsenic	3,500	10		
Asbestos				
Beryllium				
Cadmium	870	2		9
Chromium		73	1,300	
Copper	1,850,000	770		73,300
Cyanide			166	
Lead	175	5,190		55
Mercury		2		4
Nickel	112,000	150		175,500
Selenium		25		<235
Silver				
Thallium		5.5	25	21
Zinc	11,000	8,120		

TABLE 3 (cont.)
MAXIMUM RAW WASTEWATER CONCENTRATIONS
OF TOXIC POLLUTANTS FOUND AT
SAMPLED INORGANIC CHEMICAL PLANTS

Toxic Pollutant (ug/l)	Sodium Bisulfate	Sodium Dichromate	Sodium Hydrosulfite	Titanium Dioxide Chloride	Titanium Dioxide Sulfate
Antimony	30				20
Arsenic					11
Asbestos					
Beryllium					
Cadmium	6		43		338
Chromium	17	252,000	9,300	15,200	124,000
Copper	375	35	1,450		1,480
Cyanide			101		
Lead	8		1,290	5,150	3,730
Mercury	3		28		
Nickel	250	12,500	1,660	6,230	6,370
Selenium		<5	34		
Silver	2	<0.5	128		64
Thallium					19
Zinc	2,480	544	27,400	3,110	3,840

NOTE: Blanks indicate data not available.

10123TB2

Tables 5, 6, and 7 summarize conventional and toxic wastestream characteristics for these subcategories as they represent the largest portion of the leather tanning and finishing industry.

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TABLE 5

WASTEWATER CHARACTERIZATION OF
LEATHER TANNING AND FINISHING

Hair Pulp/Chrome Tan/Retan-Wet Finish Subcategory

Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Data Points	Mean
BOD_5	205	210 - 4,300	1,600
COD	170	180 - 27,000	4,600
TSS	210	25 - 36,000	2,400
TKN	58	90.0 - 630	330
Total Phenols	15	0.140 - 110	1.0
Sulfides	170	0.800 - 200	64
Oil and Grease	75	15 - 10,000	400
Total Chromium	180	3.00 - 350	76
Ammonia	168	17.0 - 380	100

Toxic Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Range	Mean
Metals and Inorganics			
Chromium	3	43,000 - 180,000	80,000
Copper	3	50 - 380	173
Cyanide	2	20 - 60	40
Lead	3	1,100 - 2,400	1,700
Nickel	3	20 - 60	40
Zinc	3	200 - 580	430

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TABLE 6

WASTEWATER CHARACTERIZATION OF
LEATHER TANNING AND FINISHING

Hair Save/Chrome Tan/Retan-Wet Finish Subcategory

Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Data Points	Mean
BOD_5	101	140 - 2,800	980
COD	30	700 - 5,700	2,600
TSS	82	94.0 - 8,600	1,900
TKN	56	63.0 - 3,600	140
Total Phenols	24	0.440 - 6,80	2.2
Sulfides	70	0.030 - 300	20
Oil and Grease	30	49.0 - 620	240
Total Chromium	56	0.006 - 390	31
Ammonia	31	0.400 - 660	90

Toxic Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Data Points	Mean
Metals and Inorganics			
Chromium	2	31,000 - 150,000	90,500
Cyanide	2	20 - 50	35
Lead	2	100 - 1,300	700
Nickel	2	5 - 40	22
Zinc	2	240 - 400	15

10123TBL

TABLE 7

WASTEWATER CHARACTERIZATION OF
LEATHER TANNING AND FINISHING

Nonchrome Tan/Retan-Wet Finish Subcategory

Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Data Points	Mean
BOD_5	48	1.00 - 7,800	1,200
COD	40	1,100 - 75,000	5,100
TSS	55	28.0 - 8,200	1,700
TKN	21	130 - 1,200	200
Total Phenols	16	0.280 - 100	1.2
Sulfides	29	1.100 - 330	68
Oil and Grease	32	2.00 - 1,300	340
Total Chromium	30	0.250 - 110	11
Ammonia	20	23 - 680	90

Toxic Pollutant	Number of Data Points	Concentration (mg/l) Range of Individual Data Points	Mean
Metals and Inorganics			
Chromium	4	430 - 10,000	5,100
Copper	4	100 - 740	380
Cyanide	3	60 - 100	80
Lead	4	100 - 200	140
Nickel	4	40 - 95	61
Zinc	4	300 - 700	490

10123TBL

APPENDIX B
COST ESTIMATES

A006747

INDIVIDUAL FIELD TEST KITS

HACH COMPANY

TEST	MODEL	METHOD/CHEMISTRY	PRICE
Acidity	AC-6 2223-01	Drop Count Titration/ Sodium Hydroxide	$25.75
	AC-DT 20640-00	Digital Titrator/ Sodium Hydroxide	$136.50
Alkalinity	AL-AP 1433-01	Drop Count Titration/ Sulfuric Acid	$20.75
	AL-DT 20637-00	Digital Titrator/ Sulfuric Acid	$136.50
Aluminum	DR 100 41101-01	Colorimeter/ Eriochrome Cyanine R	$215.00
Chloride	8-P 1440-01	Drop Count Titration/ Silver Nitrate	$25.00
	CD-DT 20635-00	Digital Titrator/ Mercuric Nitrate	$136.50
Chlorine, low range (Free and Total)	CN-80 21290-00	Color Disc/ DPD	$67.75
	DR 100 41100-02	Colorimeter/ DPD	$215.00
Chlorine, high range (Total)	CN-65 2254-01	Drop Count Titration/ Thiosulfate	$45.00
	CN-DT 0-1000	Digital Titrator/ Thiosulfate	$139.00

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HACH COMPANY

TEST	MODEL	METHOD/CHEMISTRY	PRICE
Chromium, low range (hexavalent)	CH-8 1834-00	Color Disc/ Diphenylcarbazide	$35.00
	DR 100 41100-03	Colorimeter/ Diphenylcarbazide	$215.00
Chromium, high range (hexavalent)	CH-14 2227-02	Drop Count Titration/ Thiosulfate	$31.50
	CH-DT 20634-00	Digital Titrator/ Thiosulfate	$140.00
Copper (free)	CU-5 14213-00	Color Disc/ Bicinchoninate	$37.50
	DR 100 41100-06	Colorimeter/ Bicinchoninate	$215.00
Cyanide (free)	CYN-3 2010-02	Color Disc/ Pyridine-pyrazolone	$91.00
	DR 100 41100-07	Colorimeter/ Pyridine-pyrazolone	$215.00
Detergents	DE-2 1432-03	Color Disc/	$155.00
Dissolved Oxygen	OX-2P 1469-00	Drop Count Titration/ Modified Winkler	$39.95
	OX-DT 20631-00	Digital Titrator/ Modified Winkler	$160.00
Hydrogen Sulfide	HS-7 2239-00	Color Chart/ Effervescence of Pb_5	$16.75
Lead	DR 100 41100-48	Colorimeter/ Fast Column Extraction	$215.00

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HACH COMPANY

TEST	MODEL	METHOD/CHEMISTRY	PRICE
Manganese	MN-5 1467-00	Color Disc/ Cold Periodate	$66.75
	DR 100 41100-11	Colorimeter/ Cold Periodate	$215.00
Nickel	DR 100 41100-41	Colorimeter PAN	$275.00
Phosphate (Total)	PO-24 2250-01	Color Disk/ Ascorbic Acid	$99.75
Silver	DR 100 41100-42	Colorimeter/ Colorimetric	$275.00
Sulfate	SF-1 2251-00	Extinction/ Turbidimetric	$33.00
	DR 100 41100-19	Colorimetric/ Turbidimetric	$215.00
Sulfite	SU-5 1480-02	Drop Count Titration/ Iodimetric	$45.00
	SU-DT 20633-00	Digital Titrator/ Iodimetric	$140.00
Zinc	DR 100 41100-20	Colorimeter Zincon	$215.00

NOTE: Listed analysis kits and prices are those available for 1990.

10123-2

A006750

FIELD TEST KIT

VWR SCIENTIFIC

BASIC KIT	MODEL	FEATURES	PRICE
Complete Water Action Set	Milton Roy 33-10-41	- Mini 20 Spectophotometer - Portable, lightweight - Includes nephelometer module, DPD chlorine reagent system - Chlorine reagent system	$1,245.00

ADDITIONAL INDIVIDUAL TESTS	MODEL	METHOD/CHEMISTRY	PRICE
Alkalinity	3-09-01 66122-304	Titration drop count $CaCO_3$ alkalinity/liter	$56.00
Chloride	33-09-12 66122-406	Titration drop count Cl/liter	$80.00
Chloride (5-300)	EM-14401-1	Manual Test	$82.95
Chlorine (free and total	33-09-03 66122-428	Spectophotometric, DPD Cl_2/liter	~~$70.00~~
Chromium (hexavalent)	33-09-17 66122-461	Spectophotometric, alkaline hypobromite oxidation	$70.00
Copper	33-09-17 66122-508	Spectophotometric, cuprethol	$72.00
Copper (.05-.50) (.3-5.0)	EM-14414-1 EM-14417-1		$82.95 $82.95
Cyanide (0.002-0.03 ppm)	EM-14417-1	Manual Test	$87.10
Cyanide (0.03-0.7 ppm)	EM-14429-1	Manual Test	$82.95

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VWR SCIENTIFIC

ADDITIONAL INDIVIDUAL TESTS	MODEL	METHOD/CHEMISTRY	PRICE
Dissolved Oxygen	33-09-08 66123-034	Titration drop count Dissolved oxygen/liter	$80.00
Hydrogen Sulfide (0.02-0.25 ppm)	EM-14416-1	Manual Test	$82.95
Hydrogen Sulfide (0.2-5.0 ppm)	EM-14435-1	Manual Test	$82.95
Manganese	33-09-21 66122-756	Spectophotometric	$120.00
Nickel (0.25-8.0)	EM-14420-1	Manual Test	$82.95
Phosphate (Total)	33-09-23 66123-147	Spectophotometric acid hydrolysis and persulphate oxidation	$72.00
Phosphate (.1-.16)	EM-14409-1	Manual Test	$82.95
Phosphate (.1-2.5)	EM-14431-1	Manual Test	$82.95
Sulphate	33-09-14 66123-227	Spectophotometric, Turbidimetric, SO_4/liter	$70.00
Sulphate (25-300)	EM-14411-1	Manual Test	$82.95
Zinc (0.1-5)	EM-14412-1	Manual Test	$82.95

NOTE: Listed analysis kits and prices are those available for 1990.

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A006752

INDIVIDUAL FIELD TEST KITS

COLE-PARMER INSTRUMENT COMPANY

TEST	MODEL	METHOD/CHEMISTRY	PRICE
Acidity (0-500 ppm)	L-02652-20	Titrimetric	$23.95
Alkalinity (0-300 ppm)	L-02652-02	Titrimetric	$21.95
Aluminum (0-.5 ppm)	L-05554-20	Titrimetric tablets	$37.50
Chloride (0-2.5 ppm)	L-02652-10	Mercurimetric titration	$23.95
Copper (0-1, 1-10 ppm) (total soluble)	95-00290-50	Colorimetric	$53.00
Cyanide	L-05542-09		$52.00
Dissolved Oxygen (0-10 ppm)	L-02652-00	Winkler titration	$37.95
Lead (0-50 ppb)	L-00291-50	Colorimetric	$64.50
Phosphate (0-5 ppm)	L-02652-38	Colorimetric	$23.95
Sulphate (0-750 mg/l)	L-05542-23		$58.50
Sulphite (0-200 ppm)	L-02652-24	Iodometric titration	$30.75
Zinc (0-10 mg/l)	L-05542021		$72.50

10123-F

A006753

pH METER

SUPPLIER	MODEL	CAPABILITIES	PRICE
Hach	Hach One System No. 43800-00	- Non-Clogging Reference Junction - mV Resolution of 0.1 Unit - Auto and Manual Mode for Calibration - One Year Warranty	$395.00
Cole-Parmer	pH Wand with Electrode Module N-05830-00	- Easy to Replace Electrode Module - Automatic Signal Amplification - Automatic Temp. Compensation - ± 0.01 pH Accuracy	$120.00
V.W.R Scientific	Beckman BK123132	- Auto Buffer Recognition/Standardization - Auto Read Stability Indicator - Simultaneous Temp. Display - Standardization Indicators - Error Messages - Auto Display Off	$310.00
McMaster Carr	Compact pH Meter (LCD) No. 8508T9	- 0 to 14 pH Range - LCD Display for Outdoor Use - ± 0.01 pH Accuracy	$217.00
Omega	Model PHH-43	-Combination pH, Milli Volt, And Temperature Meter -Easy pH Calibration -Microprocessor Based Temperature Compensation And pH Calibration	$255.00

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CONDUCTIVITY METER

SUPPLIER	MODEL	CAPABILITIES	PRICE
Cole-Parmer	Hand Held Model No. N-01481-40	- Adjustable Temp. Coefficient - Auto. Temp. Compensation - Wide Conductivity Range	$275.00
V.W.R. Scientific	NBS Digital Meter Cat. No. 23266-501	- Chemical Resistant ABS Housing - Fast Response Probe - Battery - NBS Certificate	$218.00
Hach	Digital Model 44600	- Digital Display - Conductivity, TDS, Temp. - Patented Probe - Carrying Case	$395.00
Omega	Portable Model CDH-70	- Chemical Resistant Case - Temp., Conductivity, Cell Constant - Built-in Temp. Compensation - Membrane Keyboard	$291.00
Extech Instruments	P341650	-3 1/2 Digit LCD Display -Adjustable Hinged Cover -Neckstrap For Hands Free Operation -9V or AC Adaptor -Measures Conductivity 0.1 to 200,000 μs/cm -Automatic 0 to 100°c Temperature Compensation	$229.00

10123-M2

PORTABLE AUTOSAMPLER

MANUFACTURER: American Sigma

MODEL: Model No. 800SL

CAPABILITIES:

- Compact design passes through 18" manhole opening.
- 24# dry wt.
- Accepts 8# ice in base.
- Corrosion resistant Delrin pump.
- Peristalic pump has no contact with media.
- Liquid sensing system.
- Serial interface for downloading to IBM P.C. or Hand Held Data Transfer Unit.
- Large 16 character display.
- Electronic isolation sealed in NEMA 4X, 6 housing.
- Vertical lift 27 ft.
- Transport velocity of 2.7 ft/sec.
- Temperature limits $32^{O}F$ - $120^{O}F$.
- Time and flow proportional sampling capabilities

REQUIRED ACCESSORIES:

1 - Compact base part No. 1405.
1 - Gel electrolyte, 12 VDC, 6 AMP/HR battery No. 1414.
1 - Battery charger No. 913.
2 - 24-575 ml polypropylene bottles w/caps No. 1369.
1 - Retainer ring No. 1376.
1 - Distributor assembly for compact base No. 1375.
25'-3/8" I.D. Vinyl tubing No. 920.
1 - Teflon/S.S. weighted strainer No. 926.
1 - Silicone pump tubing insert No. 1358.

PRICE: $2,535.00

NOTE: Listed accessories included as part of total price.

10123-4

A005756

PORTABLE AUTOSAMPLER

MANUFACTURER:	Manning
MODEL.	Model No. S-4040
CAPABILITIES:	- Max. sample lift 22 ft. - Time and flow proportional sampling capabilities. - Watertight, ABS plastic housing. - Superior sample transport velocity of 3 ft/sec minimum. - Precise equal volume samples. - Reliable operation w/discreet sampling and rotating spout assembly. - Purge pressure minimum 20 psi. - Temperature limits 32°F - 120°F. - Interface for Manning portable flowmeters. - 31 pound dry weight.
REQUIRED ACCESSORIES:	24 - 500 ml autoclave polypropylene bottles w/caps 1 - Battery charger. 1 - 12 VDC, 16 amp/hr wet cell battery. 1 - Composite base. 1 - (.375") I.D. nylon reinforced PVC tubing w/weighted PVC strainer, various lengths available.
PRICE:	$2,090.00

NOTE: Listed accessories not included as part of total price.

10123-4

PORTABLE AUTOSAMPLER

MANUFACTURER:	ISCO
MODEL:	Model No. 3700
CAPABILITIES:	- Rugged corrosion resistant exterior. - Exclusive LD90 liquid presence detector. - Watertight, dust tight, corrosion resistant. - Peristalic pump. - No cross contamination. - User friendly programming. - 40 character LCD. - Real time date clock. - Sealed controller. - Sequential 24 bottle sampling. - Time and flow proportional sampling capabilities. - Temperature limits $32^{o}F$ - $120^{o}F$. - Pump rate 3500 ml/min. (3 ft. head) - 37 pound dry weight.
REQUIRED ACCESSORIES:	1 - Nickel cadmium battery. 1 - AC-power converter/battery charger. 1 - 25'-3/8" I.D. vinyl suction line with strainer.
PRICE:	$2,865.00

NOTE: Listed accessories included as part of total price.

10123-4

ESTIMATED MISCELLANEOUS SURVEY COSTS

ITEM	AMOUNT	PRICE
Instant Camera	1 - Polaroid One-Step	45.00
Color Film	1 - 20 Exposure Film	18.00
Plastic Sampling Bottles	150 - 16 oz. Bottles	60.00
Storage Cooler	1 - 48 qt. Cooler	20.00
Wooden Stakes	20 - 2 in. x 4 in. x 3 ft.	15.00
Hammer	1 - One-Piece Steel	15.00
Flashing Barricade	1 - 36" Barricade	70.00
Orange Safety Cones	10 - Fluorescent 18" Cones	70.00
Orange SAfety Vests	2 - Nylon Vests	10.00
Crowbar	1 - Crowbar	20.00
Flashlight & Batteries	2 - Explosion Proof	15.00
Fold-Up Tape Measure	1 - 8 ft. Tape Measure	8.00
Heavy Duty Tape	1 - 60 yd. 2 in. Duct Tape	8.00
Fluorescein Dye Tracer	200 Tablets	18.00
pH Buffer Solution	1 Pint	5.00
Conductivity Buffer Solution	1 Pint	5.00
Gloves	2 Pair	5.00
Rubber Boots	1 Pair-10 in. Overshoe	35.00
Safety Shoes	2 Pair	100.00
Safety Glasses	2 Pair	8.00
Hard Hats	2 Hats	15.00
Work Coveralls	2 Coveralls	50.00
First Aid Kit	1 - Basic Unit	35.00
	TOTAL ESTIMATED COST	**$650.00**

10123-M2

APPENDIX C
DATA INVENTORY FORMS

A006760

OUTFALL ANALYSIS DATA

Outfall ID _____ Date _____

Inspector(s) _____ Time _____

_____

Weather Conditions _____

_____

Surrounding Industrial _____

Facilities _____

_____

_____

_____

Flow Pattern _____

TIME(S) OF DETECTED DISCHARGE

Day of Week	Start Time	End Time
1) _____	1) _____	1) _____
2) _____	2) _____	2) _____
3) _____	3) _____	3) _____
4) _____	4) _____	4) _____
5) _____	5) _____	5) _____

Other Comments _____

_____

_____

10123FRM

OUTFALL ANALYSIS DATA (cont.)

Outfall ID _____ Date _____

Inspector(s) _____ Time _____

_____

PHYSICAL OBSERVATIONS

Odor _____

Color _____

Turbidity _____

Floatables _____

Residue _____

Vegetation _____

Structural Damage _____

Other Comments _____

10123FRM

OUTFALL ANALYSIS DATA (cont.)

Outfall ID _____ Date _____

Inspector(s) _____ Time _____

_____

CHEMICAL ANALYSIS

pH

Type of Test _____ Reading 1)_____

Manufacturer _____ 2)_____

Model No. _____ 3)_____

Total Dissolved Solids

Type of Test _____ Reading 1)_____

Manufacturer _____ 2)_____

Model No. _____ 3)_____

Conductivity

Type of Test _____ Reading 1)_____

Manufacturer _____ 2)_____

Model No. _____ 3)_____

Grab Samples

Sample ID _____ _____

_____ _____

Laboratory Address _____

_____

_____

Phone _____

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LABORATORY ANALYSIS

Inspector(s) _____ Date _____

_____ Time _____

Sample Location _____

_____

Sample ID _____

Laboratory Address _____

_____

_____

Phone _____

Date Submitted _____

Date Completed _____

Parameters for Testing

CONVENTIONAL POLLUTANTS

_____ pH

_____ Conductivity

_____ Total Solids

_____ Total Suspended Solids

_____ Total Dissolved Solids

_____ BOD (5 day)

_____ Organic Solids

_____ Inorganic Solids

_____ Oil and Grease

A006764

LABORATORY ANALYSIS (cont.)

Sample Location _____ Sample ID _____

TOXIC POLLUTANTS (As Listed by the Clean Water Act)

_____ Acenaphthene
_____ Acrolein
_____ Acrylonitrile
_____ Aldrin/Dieldrin
_____ Antimony and compounds
_____ Arsenic and compounds
_____ Asbestos
_____ Benzene
_____ Benzidine
_____ Beryllium and compounds
_____ Cadmium and compounds
_____ Carbon tetrachloride
_____ Chlordane
_____ Chlorinated benzenes
_____ Chlorinated ethanes
_____ Chloroalkyl ethers
_____ Chlorinated naphthalene
_____ Chlorinated phenols
_____ Chloroform
_____ Chlorophenol
_____ Chromium and compounds
_____ Copper and compounds
_____ Cyanides
_____ DDT and metabolites
_____ Dichlorobenzenes
_____ Dichlorobenzidine
_____ Dichloroethylenes
_____ 2,4-Dichlorophenol
_____ Dichloropropane & dichloropropene
_____ 2,4-Dimethylphenol
_____ Dinitrotoluene
_____ Diphenylhydrazine
_____ Endosulfan and metabolites
_____ Endrin and metabolites
_____ Ethylbenzene
_____ Fluoranthene
_____ Haloethers
_____ Halomethanes
_____ Heptachlor and metabolites
_____ Hexachlorobutadiene
_____ Hexachlorocyclohexane
_____ Hexachlorocyclopentadiene
_____ Isophorone
_____ Lead and compounds
_____ Mercury and compounds
_____ Naphthalene
_____ Nickel and compounds
_____ Nitrobenzene
_____ Nitrophenols
_____ Nitrosamines
_____ Pentachlorophenol
_____ Phenol
_____ Phthalate esters
_____ Polychlorinated biphenyls
_____ Polynuclear aromatic hydrocarbons
_____ Selenium and compounds
_____ Silver and compounds
_____ 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin
_____ Tetrachloroethylene
_____ Thallium and compounds
_____ Toluene
_____ Toxaphene
_____ Trichloroethylene
_____ Vinyl chloride
_____ Zinc and compounds

OTHER PARAMETERS

_____ _____
_____ _____
_____ _____
_____ _____
_____ _____

10123FRM

PROCESS DATA: DIRECT DISCHARGE

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

Process Description _____

_____

_____

Discharge Point Location _____

_____

Discharge Point ID _____

_____

Receiving Water _____

Is Discharge Covered by an NPDES Permit? _____

If No, Why Not? _____

NPDES Permit No._____ Expiration Date _____

Issuing Agency _____ Contact_____ Phone_____

Permitted Parameters _____

_____

_____

_____

_____

Exceedence History _____

_____

Other Comments _____

_____

10123FRM

PROCESS DATA: INDIRECT DISCHARGE

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

Process Description _____

_____

_____

Discharge Point Location _____

_____

Discharge Point ID _____

Final Receiving Water _____

Name of POTW _____

POTW Contact _____ Phone _____

Is Discharge Covered by a POTW Contract? _____

Has POTW Instituted a Pretreatment Program? _____

If Yes, Describe Type of Treatment _____

_____

Limited Parameters _____

_____

_____

_____

_____

Other Comments _____

_____

10123FRM

SPILL POTENTIAL

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

SPCC Plan Available _____ If Yes, Date Written _____

Other Sources _____

of Data _____

_____

Type of Spill _____

_____

Process Location _____

_____

Type of Materials _____

_____

Potential Volume _____

_____

Possible Causes _____

_____

_____

Spill Containment _____

_____

Other Comments _____

_____

10123FRM

SPILL HISTORY

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

SPCC Plan Available _____ If Yes, Date Written _____

Other Sources _____

of Data _____

_____

Date of Spill _____

Type of Spill _____

_____

Process Location _____

_____

Spilled Materials _____

_____

Volume Spilled _____

_____

Recorded Cause _____

_____

_____

Corrective Actions _____

_____

Other Comments _____

_____

10123FRM

FACILITY RUNOFF

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

Runoff Collection Point _____

_____

Description of Contributing Area _____

_____

_____

_____

POTENTIAL RUNOFF CHARACTER

Description of Source	Contamination Potential	Drainage Path
Parking Lots		
Shipping Areas		
Receiving Areas		
Material Storage		
Other Areas		

10123FRM

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CORRELATION OF DATA

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

Outfall ID _____

Outfall Location _____

_____

Manhole ID _____

Manhole Location _____

_____

Process ID _____

Process Location _____

_____

Process Description _____

_____

_____

Other Comments _____

_____

_____

10123FRM

CORRELATION OF DATA (cont.)

SIMILAR CHARACTERISTICS

	Outfall ID	Manhole ID	Process ID
Physical Observations			
Odor			
Color			
Turbidity			
Floatables			
Residue			
Vegetation			
Structural Damage			
Chemical Analysis			
pH			
TDS			
Conductivity			
Other Parameters			

10123FRM

FACILITY RUNOFF

Inspector(s) _____ Date _____

_____

Industrial Facility _____

Industrial Address _____

_____

_____

Industrial Contact _____ Phone _____

Runoff Collection Point _____

_____

Description of Contributing Area _____

_____

_____

_____

POTENTIAL RUNOFF CHARACTER

Description of Source	Contamination Potential	Drainage Path
Parking Lots		
Shipping Areas		
Receiving Areas		
Material Storage		
Other Areas		

10123FRM

Pipeline Examination

Fluorescein dye tracer will be needed to conduct pipeline examinations. Ample dye should be brought along as several tests may be necessary to identify one or more illicit connections at an industrial site.

Inspector Safety

Attention to safety procedures is a must during all field surveys. This includes inspector apparel from head to toe. Work clothes should always be worn for all inspections. Rubber boots should be brought along in case of wet or muddy conditions during the screening of storm water outfalls. Essential materials for the industrial on-site investigation include safety shoes, safety glasses, a hard hat, and hearing protection. Protective gloves should always be worn when collecting samples of any potentially dangerous discharges. Finally, a complete first aid kit should always be kept on hand in case of an emergency.

TABLE 3

FIELD EQUIPMENT AND MATERIALS

Field Test Kit
pH Meter and Buffer Solution
Conductivity Meter and Buffer Solution
Automatic Sampler
Instant Camera and Film
Sampling Bottles and Waterproof Marker
Cooler
Clipboard, Pad, Pen or Pencil
Data Inventory Forms
Maps
Marked Stakes
Hammer
Flashing Barricade
Orange Safety Cones
Orange Safety Vest
Crowbar
Flashlight and Batteries
Fold-Up Tape Measure
Heavy Duty Tape
Fluorescein Dye Tracer
Work Clothes
Rubber Boots
Safety Shoes
Safety Glasses
Hard Hats
Hearing Protection
Protective Gloves
First Aid Kit

A006774

TABLE 4

CONSIDERATIONS FOR AUTOMATIC SAMPLER

- Capability for AC/DC operation with adequate dry battery energy storage for 120-hour operation at 1-hour sampling intervals
- Total weight including batteries
- Sample collection interval (adjustability from 10 minutes to 4 hours)
- Capability for:
  - Flow proportional sample - constant time interval between samples, sample volume proportional to stream flow at time of sampling (variation in flow > 15%)
  - Time proportional sample - constant sample volume, time interval between samples proportional to stream flow
- Capability for collecting discrete samples in 24 containers
- Watertight exterior case to protect components in the event of rain or submersion
- Exterior case capable of being locked to prevent tampering and provide security
- No metal parts in contact with waste source or samples
- An integral sample container compartment capable of maintaining samples at 4 to 6°C for a period of 24 hours at ambient temperatures ranging from -30 to 50°C
- Operation capabilities in the temperature range from -30 to 50°C
- Sampler exterior surface painted light color to reflect sunlight

A006775

PERSONNEL REQUIREMENTS

The objective of the following discussion is to provide general information regarding the personnel demand and training necessary to perform the methodology outlined in this manual.

Clearly, as the size of the industrial area to be investigated increases, so too does the demand for personnel. The following suggestions are based upon an optimum fixed number of inspectors per phase of the field survey. These suggestions were offered in order to set a standard as well as to simplify the overall procedure.

Phase I - Screening of Storm Water Outfalls

It is suggested that a minimum of two (2) investigators perform the observations and analyses at a storm water outfall. There are several reasons behind this selected minimum among which the most important are the following:

- Correspondence regarding visual observations and elementary chemical analyses
- Safety in numbers
- Load distribution for carried equipment

Thus, a coupled effort will result in greater efficiency as well as mobility. When very large numbers of storm water outfalls exist for screening in an industrial area, it is suggested that several pairs of investigators perform outfall surveys in order to expedite the process.

Phase II - Industrial On-Site Investigation

In order to perform the industrial on-site investigation, it is suggested that either three investigators be aided by one industry personnel or two investigators be aided by two industry personnel. The reasoning behind a total number of four being such that the on-site investigation may be divided into two tasks. Thus, one pair of investigators may perform the outside inspection while the other pair focuses their attention upon the inside inspection.

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The selected industry personnel should have a thorough knowledge of the operations performed at the facility. In addition, it is beneficial if they also have a practical understanding of environmental management procedures as well.

Personnel Training

In addition to efficiency, the inspectors performing a field survey must also be accurate. High levels of accuracy may only be obtained through complete and proper training. Training should encompass a formal orientation of the methodology presented in this manual along with practical field techniques.

Therefore, inspectors should have an understanding of the various identification strategies presented in this text. They should also be knowledgeable of typical kinds and sources of industrial waste. If possible, training should include an actual field orientation of common industrial water use processes and types of spills. Factual information should also be provided summarizing the contacts and access details necessary for obtaining pertinent data such as sewer maps or environmental records.

Inspectors must be able to correctly operate all field equipment - in particular specialized meters and automatic samplers. Training should include the proper procedures for collecting samples as well as for performing manhole observations. Finally, steps must always be taken to make personnel aware of potential occupational hazards, precautionary measures to prevent them, and special plans to follow in the event of an emergency.

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TIMELINE

There are several steps to be performed when following the methodology outlined in this manual. The following chart is intended to provide a generalized indication of the time required for each step.

It is important to note that the chart provided does not take into account unexpected problems such as poor weather or equipment failure. In addition, the time needed to conduct the on-site industrial investigation and confirmatory analysis is highly dependent upon the size of the facility. Thus, these estimates should be considered only as idealized guidelines.

Procedure and Step	Time Range (days)
Outfall Evaluation	
Step 1 - Mapping Effort	1-3
Step 2 - Walking Tour	2 outfalls surveyed/day*
Step 3 - Outfall Analysis	2 outfalls analyzed/day
Identification of Potential Industrial Sources	
Step 1 - Establish Flow Pattern	3-7
Step 2 - Analysis of Recorded Data	1-3
Step 3 - Correlation to Possible Industrial Sources	1-3
On-Site Industrial Investigation	
Step 1 - Data Collection	2-4
Step 2 - Preliminary Evaluation of Water Use and Other Discharges	2-4
Step 3 - On-Site Investigation	3-7
Step 4 - Confirmatory Analysis	3-7

*NOTE:
Inspectors should be able to complete the initial survey and analysis for two outfalls per day.

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ORGANIZATIONAL IDEAS

The use of Data Inventory Forms can greatly simplify the process of recording information. A variety of Data Inventory Forms are provided in Appendix C of this manual. Thus, the objective of the following discussion is to briefly describe the function for each form.

Outfall Analysis Data

This three-page form should be used to record data collected from the screening of storm water outfalls. The form organizes information regarding the detected flow pattern, physical observations, and elementary chemical analysis results for a particular outfall.

Laboratory Analysis

This two-page form should be used to check off the parameters which should be tested for in a grab sample laboratory analysis. The form summarizes the grab sample identification details, laboratory information, and provides a listing for conventional as well as toxic pollutants. The toxic pollutants were determined according to the listing provided originally in the Clean Water Act.

Process Data: Direct Discharge

This form summarizes information regarding industrial processes which directly discharge into a receiving water body. Data regarding a particular industrial process as well as any permit details are to be recorded on this form.

Process Data: Indirect Discharge

This form summarizes information regarding industrial processes which discharge to the local POTW for treatment before entrance to a receiving water body. The information recorded includes details of the particular industrial process and any pretreatment for it discharges as well as general data for the local POTW.

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Spill History

This form should be used to record information regarding any past spills which occurred at an industrial facility.

Spill Potential

This form should be used to summarize information regarding industrial processes which have spill potential.

Facility Runoff

This form should be used during the outside portion of the industrial on-site investigation. The form summarizes potential sources of illicit discharges due to storm water runoff contamination.

Correlation of Data

This form should be used during the correlation process to determine similarities between the detected illicit discharge and suspect industrial process discharges. Comparisons are drawn based upon the wastestream characterization of discharges from the contaminated outfall, manhole observations, and suspect industrial process discharges.

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Section 8

SUMMARY

This manual has outlined a procedure which begins with the screening of stormwater outfalls for signs of industrial discharge contamination. The methodology then proceeds to the identification of likely sources for the detected non-stormwater discharge. Ultimately, the actual location of the industrial illicit connection to the storm drainage system is pinpointed. This manual concludes with a section focusing solely upon necessary field survey techniques as the success of this methodology depends largely upon the careful collection of data and analysis of pertinent information.

The actual strategy underlying this methodology involves a correlation process between the characteristics of discharges observed at outfalls and that of various industrial manufacturing or operational process discharges. It is possible that several options may appear to be viable solutions while at other times no alternatives may seem to be the correct choice. Therefore, more than one on-site industrial investigation may be necessary in order to identify the source of an illicit connection.

By applying common sense and professional judgement to the procedures outlined in this manual, successful assessments of a facility's illicit storm water connections can be accomplished.

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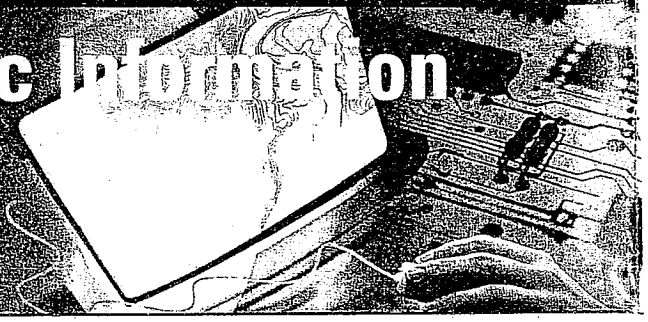
USGS
science for a changing world

Geographic Information Systems



U.S. Department of the Interior
U.S. Geological Survey

Geographic information system (GIS) technology can be used for scientific investigations, resource management, and development planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, or a GIS might be used to find wetlands that need protection from pollution.

What is a GIS?

A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system.

How does a GIS work?

Relating information from different sources

The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. When rainfall information is collected, it is important to know where the rainfall is located. This is done by using a location reference system, such as longitude and latitude, and perhaps elevation. Comparing the rainfall information with other information, such as the location of marshes across the landscape, may show that certain marshes receive little rainfall. This fact may indicate that these marshes are likely to dry up, and this inference can help us make the most appropriate decisions about how humans should interact with the marsh. A GIS, therefore, can reveal important new information that leads to better decisionmaking.

Many computer databases that can be directly entered into a GIS are being produced by Federal, State, tribal, and local governments, private companies, academia, and nonprofit organizations. Different kinds of data in map form can be entered into a GIS (figs. 1a, 1b, 1c, 1d, 1e, 1f, and 2). A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images can be analyzed to produce a map of digital information about land use and land cover (figs. 3 and 4). Likewise, census or hydrologic tabular data can be converted to a maplike form and serve as layers of thematic information in a GIS (figs. 5 and 6).

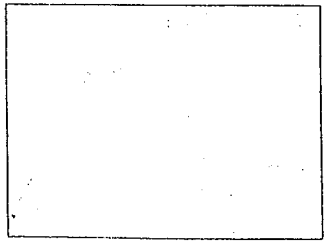


Figure 1a. U.S. Geological Survey (USGS) digital line graph (DLG) data of roads

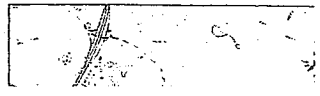


Figure 1b. USGS DLG of rivers



Figure 1c. USGS DLG of contour lines (hypsography)







Data capture

How can a GIS use the information in a map? If the data to be used are not already in digital form, that is, in a form the computer can recognize, various techniques can capture the information. Maps can be digitized by hand-tracing with a computer mouse on the screen or on a digitizing tablet to collect the coordinates of features. Electronic scanners can also convert maps to digits (fig. 7). Coordinates from Global Positioning System (GPS) receivers can also be uploaded into a GIS (fig. 8).

A GIS can be used to emphasize the spatial relationships among the objects being mapped. While a computer-aided mapping system may represent a road simply as a line, a GIS may also recognize that road as the boundary between wetland and urban development between two census statistical areas.

Data capture—putting the information into the system—involves identifying the objects on the map, their absolute location on the Earth's surface, and their spatial relationships. Software tools that automatically extract features from satellite images or aerial photographs are gradually replacing what has traditionally been a time-consuming capture process. Objects are identified in a series of attribute tables—the "information" part of a GIS. Spatial relationships, such as whether features intersect or whether they are adjacent, are the key to all GIS-based analysis.



Figure 7. Scanning paper maps to produce digital files for input into a GIS.



Figure 8. Collecting latitude and longitude coordinates with a Global Positioning System (GPS) receiver.

Data integration

A GIS makes it possible to link, or integrate, information that is difficult to associate through any other means. Thus, a GIS can use combinations of mapped variables to build and analyze new variables (fig. 9).

For example, using GIS technology, it is possible to combine agricultural records with hydrography data to determine which streams will carry certain levels of fertilizer runoff. Agricultural records can indicate how much pesticide has been applied to a parcel of land. By locating these parcels and intersecting them with streams, the GIS can be used to predict the amount of nutrient runoff in each stream. Then as streams converge, the total loads can be calculated downstream where the stream enters a lake.

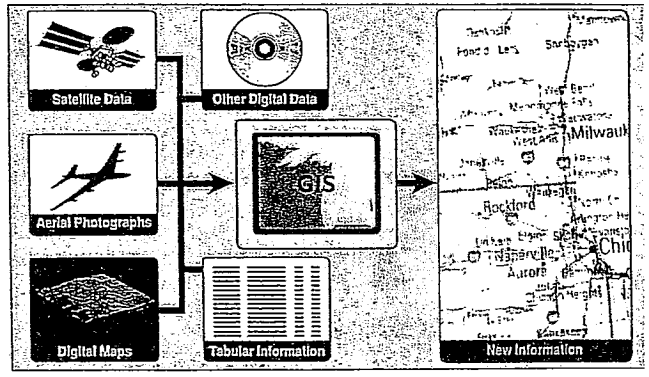


Figure 9. Data integration is the linking of information in different forms through a GIS

Projection and registration

A property ownership map might be at a different scale than a soils map. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from

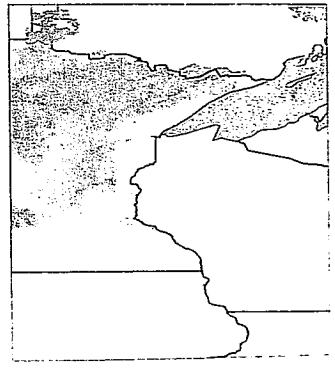


Figure 10a. An elevation image classified from satellite image for Minnesota exists in a different projection and

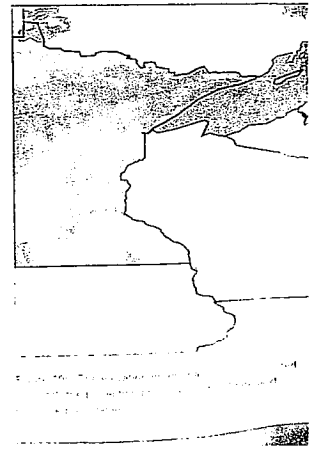




Figure 1d. USGS digital elevation model (DEM).

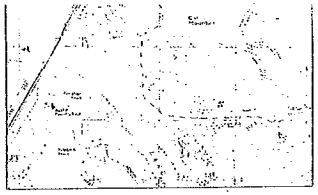


Figure 1e. USGS scanned, rectified topographic map, called a digital raster graphic (DRG)

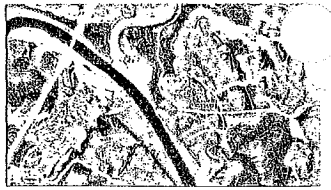
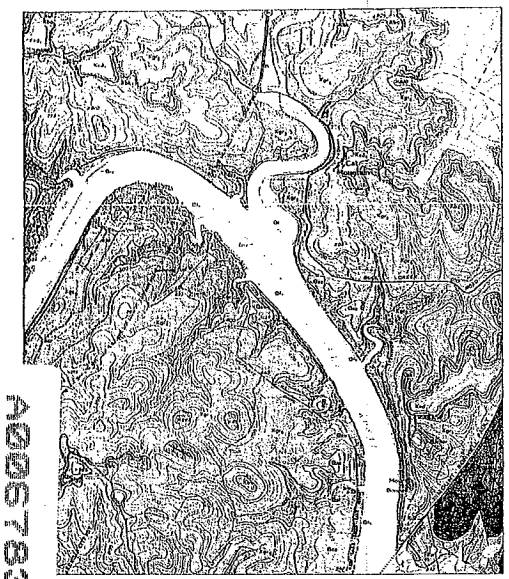


Figure 1f. USGS digital orthophoto quadrangle (DOQ).



2. USGS geologic map.

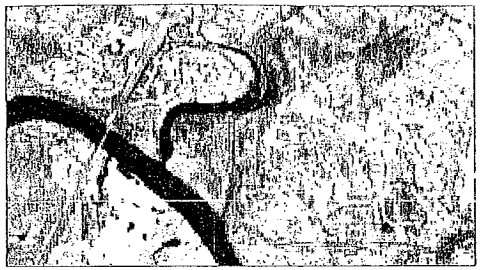


Figure 3. Landsat 7 satellite image from which land cover information can be derived.



Figure 4. Satellite image data in figure 3 have been analyzed to indicate classes of land use and land cover.

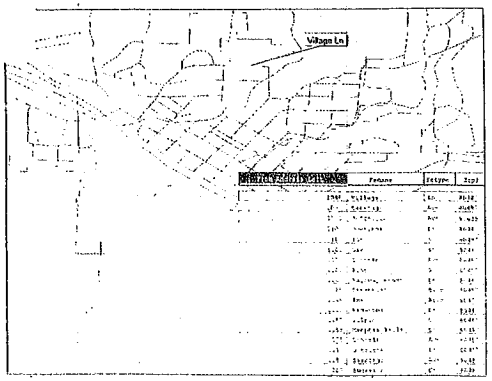


Figure 5. Part of a census data file containing address information

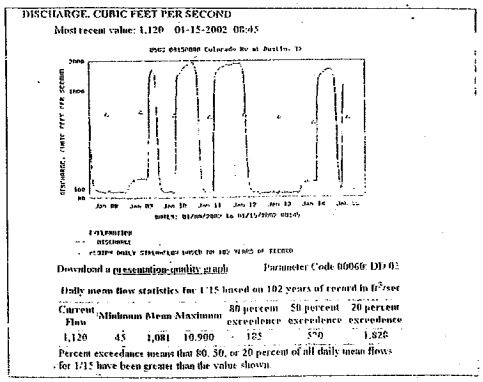


Figure 6. Part of a hydrologic data report indicating the discharge and amount of river

other maps. Before the digital data can be analyzed, they may have to undergo other manipulations — projection conversions, for example — that integrate them into a GIS.

Projection is a fundamental component of mapmaking. A projection is a mathematical means of transferring information from the Earth's three-dimensional, curved surface to a two-dimensional medium — paper or a computer screen. Different projections are used for different types of maps because each projection is particularly appropriate for certain uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes.

Since much of the information in a GIS comes from existing maps, a GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections, to a common projection (figs. 10a and b).

Data structures

a land use map be related to a satellite ge, a timely indicator of land use? Yes. because digital data are collected and ored in different ways, the two data sources ay not be entirely compatible. Therefore, GIS must be able to convert data from ne structure to another.

Satellite image data that have been interpreted by a computer to produce a land use map can be "read into" the GIS in raster format. Raster data files consist of rows of uniform cells coded according to data values. An example is land cover classification (fig. 11). Raster files can be manipulated quickly by the computer, but they are often less detailed and may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps. Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines) (fig. 12). An example of data typically held in a vector file would be the property boundaries for a particular housing subdivision.

Data restructuring can be performed by a GIS to convert data between different formats. For example, a GIS can be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the spatial relationships of the cell, such as adjacency or inclusion (fig. 13).

and Province boundaries.

1	1	1	1	1	1	1	3	3
1	1	1	1	1	1	1	3	3
1	1	1	1	1	1	3	3	3
1	1	1	2	2	2	2	3	3
1	1	1	2	2	2	2	3	3
1	1	1	2	2	2	2	3	3
1	1	1	1	2	2	2	3	3
1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	3	3
1	1	1	1	1	1	1	1	3

Figure 11. Example of the structure of a raster data file

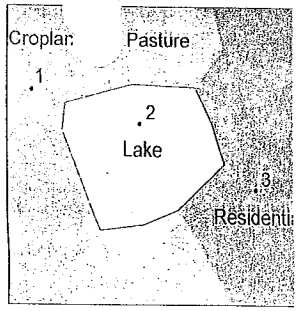


Figure 12. Example of the structure of a vector data file

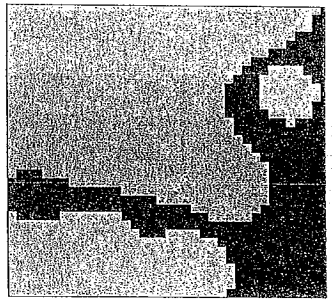


Figure 13a. Magnified view of the same GIS data file, shown in raster format.



Figure 13b. Magnified view of the same GIS data file, converted into vector format.

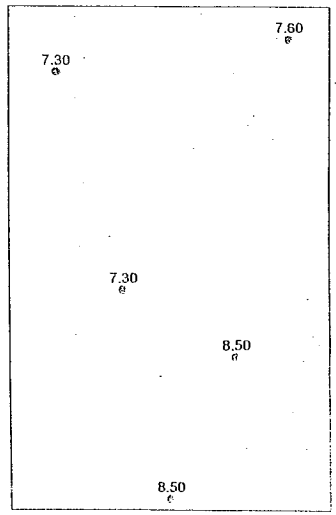


Figure 14. Points with pH values of soil

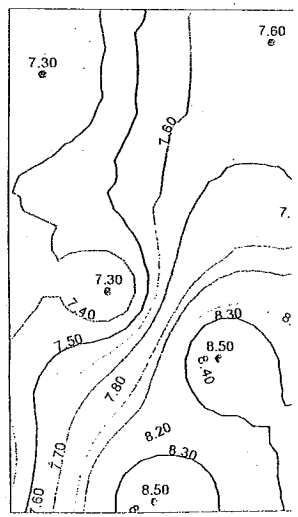


Figure 15. Contour map made from soil pH values shown in figure 14

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Data modeling

It is impossible to co[illegible]u over every square meter of the Ea[illegible]rface. Therefore, samples must be taken at discrete locations. A GIS can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from points where samples have been collected.

For example, a GIS can quickly generate a map with isolines that indicate the pH of soil from test points (figs. 14 and 15). Such a map can be thought of as a soil pH contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. Two- and three-dimensional contour maps created from the surface modeling of sample points from pH measurements can be analyzed together with any other map in a GIS covering the area.

What's special about a GIS?

The way maps and other data have been stored or filed as layers of information in a GIS makes it possible to perform complex analyses.

rmation retrieval

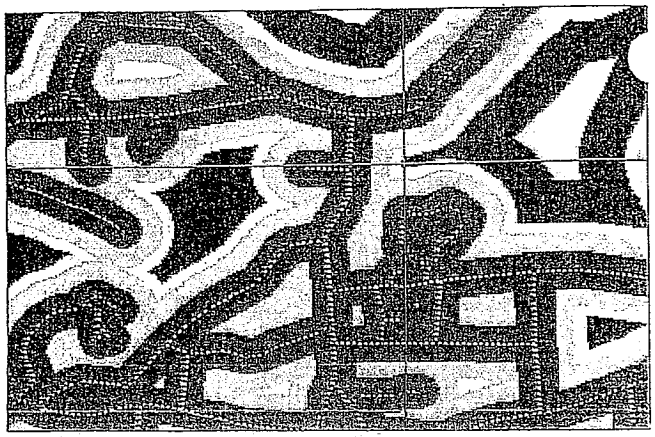
do you know about the swampy area end of your street? With a GIS you can at" at a location, object, or area on the n and retrieve recorded information about m offscreen files (fig. 16). Using scanned photographs as a visual guide, you can GIS about the geology or hydrology of rea or even about how close a swamp is e end of a street. This type of analysis ws you to draw conclusions about the mp's environmental sensitivity.

ological modeling

e there ever been gas stations or factories that operated next to the swamp? Were any of these uphill from and within 2 miles of the swamp? A GIS can recognize and analyze the spatial relationships among mapped phenomena. Conditions of adjacency (what is next to what), containment (what is enclosed by what), and proximity (how close something is to something else) can be determined with a GIS (fig. 17).

Networks

When nutrients from farmland are running off into streams, it is important to know in which direction the streams flow and which streams empty into other streams. This is done by using a linear network. It allows the computer to determine how the nutrients are transported downstream. Additional information on water volume and speed throughout the spatial network can help the GIS determine how long it will take the nutrients to travel downstream (figs. 18a and b).



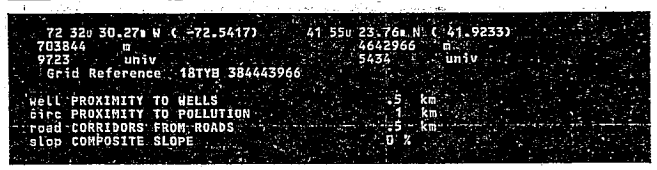


Figure 16. A crosshair pointer (top) can be used to point at a location stored in a GIS. The bottom illustration depicts a computer screen containing the kind of information stored about the location—for example, the latitude, longitude, projection, coordinates, closeness to wells, sources of production, roads, and slope of the land.

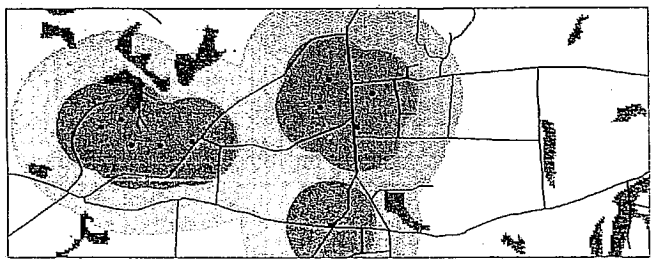


Figure 17. Sources of pollution are represented as points. The colored circles show distance from pollution sources. The wetlands are in dark green.

Overlay

Using maps of wetlands, slopes, streams, land use, and soils (figs. 19a–e), the GIS might produce a new map layer or overlay that ranks the wetlands according to their relative sensitivity to damage from nutrient runoff.

Data output

A critical component of a GIS is its ability to produce graphics on the screen or on paper to convey the results of analyses to the people who make decisions about resources. Wall maps, Internet-ready maps, interactive maps, and other graphics can be generated, allowing the decisionmakers to visualize and thereby understand the results of analyses or simulations of potential events (fig. 20).

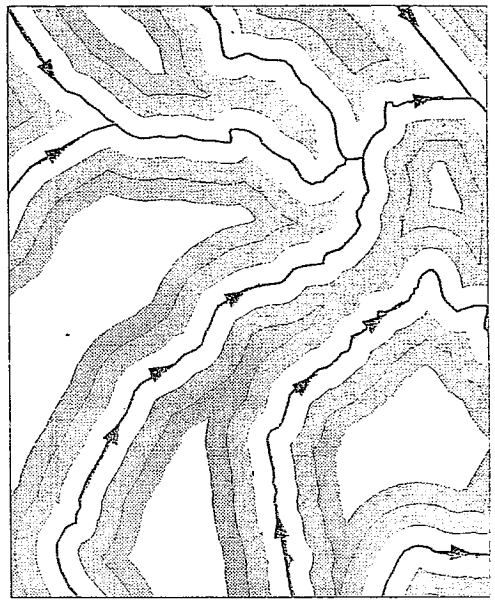


Figure 19c. Distances to streams as measured by three 200-meter buffers derived from a digital map of hydrography.

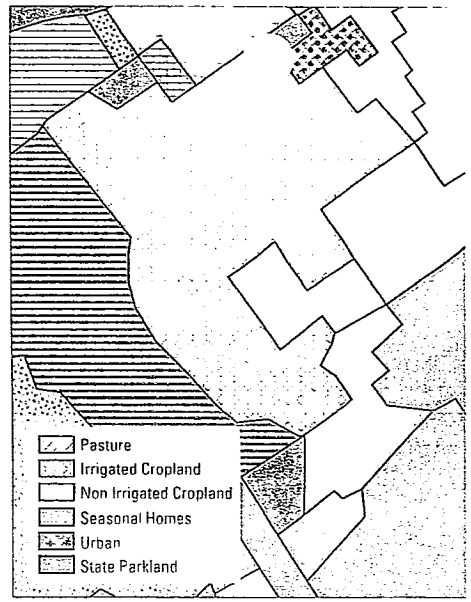


Figure 19d. Map indicating various land uses in the study area.

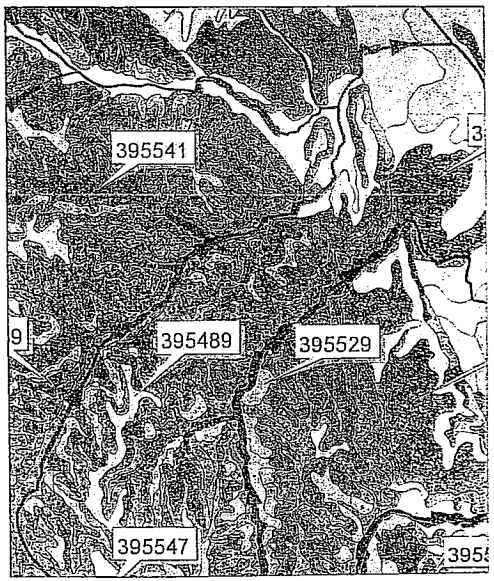


Figure 19e. A soils map stored in a GIS database. Numbers indicate the type of soil.

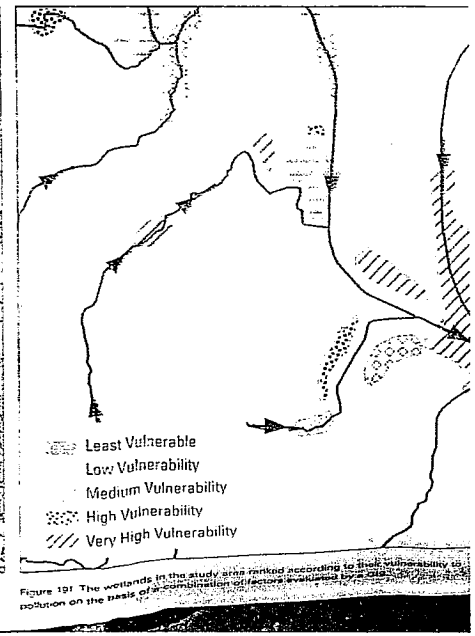


Figure 19f. The wetlands in the study area ranked according to their vulnerability to pollution on the basis of a combination of factors evaluated by the GIS.

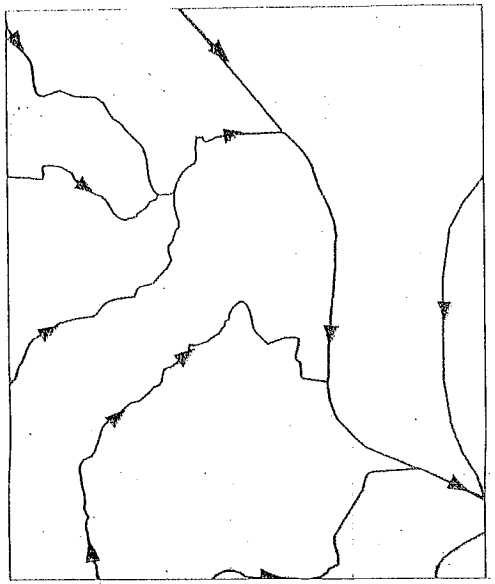


Figure 18a. A GIS can simulate the movement of materials along a network of lines. These illustrations show the route of pollutants through a stream system. Flow directions are indicated by arrows.



Figure 18b. Flow superimposed on a digital orthophotoquad of the area.

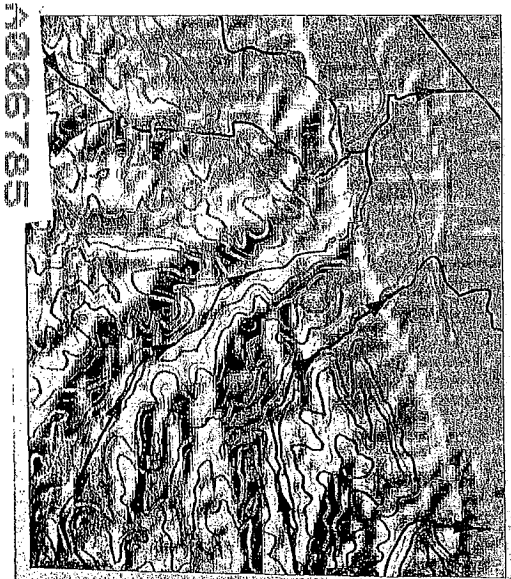


Figure 19a. Shaded relief map and contour lines generated from the digital elevation model of the study area.



Figure 19b. Map showing the steepness of slopes in the study area, created by a GIS from the digital elevation model.



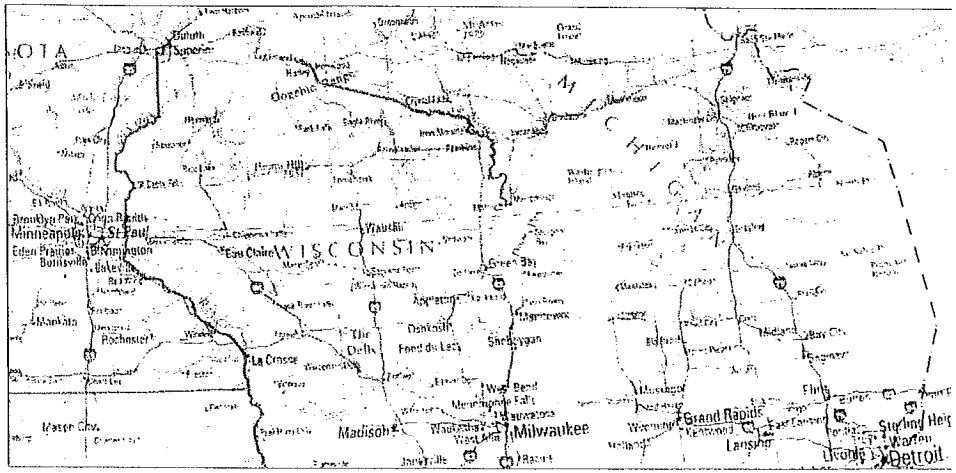


Figure 20. Examples of finished maps that can be generated using a GIS, showing landforms and geology (top) and human-built and physical features (bottom)

Framework for cooperation

The use of a GIS can encourage cooperation and communication among the organizations involved in environmental protection, planning, and resource management. The collection of data for a GIS is costly. Data collection can require very specialized computer equipment and technical expertise.

Standard data formats ease the exchange of digital information among users of different systems. Standardization helps to stretch data collection funds further by allowing data sharing, and, in many cases, gives users access to data that they could not otherwise collect for economic or technical reasons. Organizations such as the University Consortium for Geographic Information Science (www.ucgis.org) and the Federal Geographic Data Committee (www.fgdc.gov) seek to encourage standardization efforts.

For more informatio

Good places to learn more about GIS technology and methods include the geography department of your local university, the GIS site at www.gis.com, your county planning department, your state department of natural resources, or a USGS Earth Science Information Center (ESIC). To locate your nearest ESIC, call 1-888-ASK-USGS, or visit www.usgs.gov.

Applications of GIS



Figure 1. Group of stags (cave painting), Lascaux Caves, France (Art Resource, N.Y.).

GIS through history

Some 35,000 years ago, Cro-Magnon hunters drew pictures of the animals they hunted on the walls of caves near Lascaux, France, (fig. 1). Associated with the animal drawings are track lines and tallies thought to depict migration routes. These early records followed the two-element structure of modern geographic information systems (GIS): a graphic linked to an attribute database.

Today, biologists use collar transmitters and satellite receivers to track the migration routes of caribou and polar bears to help design programs to protect the animals. In a GIS, the migration routes were indicated by different colors for each month for 21 months (fig. 2). Researchers then used the GIS to superimpose the migration routes on maps of oil development plans to determine the potential for interference with the animals.

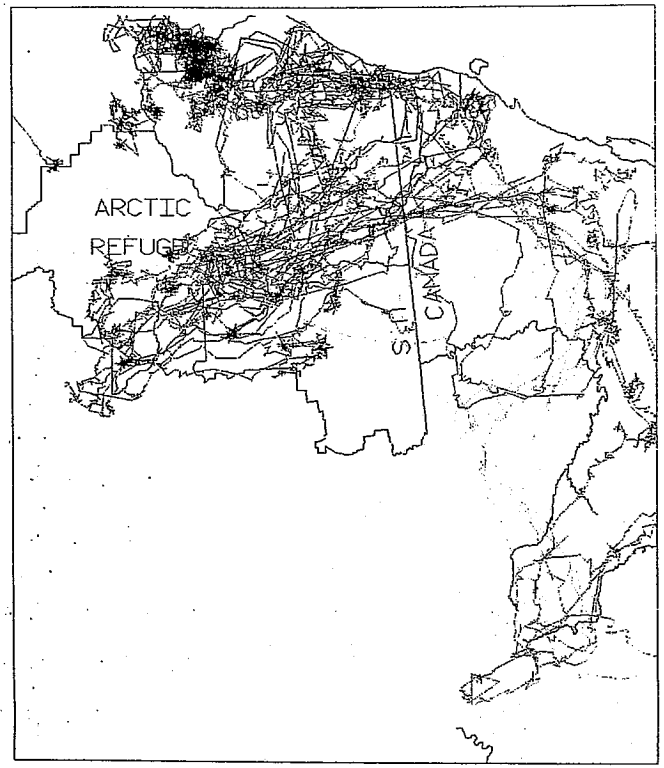


Figure 2. Tracks of caribou routes in Alaska from April 1985 to December 1986 (U.S. Fish and Wildlife Service).

Mapmaking

Researchers are working to incorporate the mapmaking processes of traditional cartographers into GIS technology for the automated production of maps.

One of the most common products of a GIS is a map. Maps are generally easy to make using a GIS and they are often the most effective means of communicating the results of the GIS process. Therefore, the GIS is usually a prolific producer of maps. The users of a GIS must be concerned with the quality of the maps produced because the GIS normally does not regulate common cartographic principles. One of these principles is the concept of generalization, which deals with the content and detail of information at various scales. The GIS user can

GIS. They used the proximity function in the GIS to draw a half-mile buffer zone around the water company service area (fig. 6). This buffer zone was the "window" used to view and combine the various map coverages relevant to the well site selection.

The land use and land cover map for the two areas shows that the area is partly developed (fig. 7). A GIS was used to select undeveloped areas from the land use and land cover map as the first step in finding well sites. The developed areas were eliminated from further consideration (fig. 8).

The quality of water in Connecticut streams is closely monitored. Some of the streams in

most likely to store water that could be tapped with wells. Areas underlain by sand and gravel were selected from the surficial geology map (fig. 15). They were combined with the results of the previous selections to produce a map consisting of: (1) sites in underdeveloped areas underlain by sand and gravel, (2) more than 500 meters from point sources of pollution, and (3) more than 100 meters from unsuitable streams (fig. 16).

A map that shows the thickness of saturated sediments was created by using the GIS to subtract the bedrock elevation from the surface elevation (fig. 17). For this analysis, areas having more than 40 feet of saturated sediments were selected and combined with the

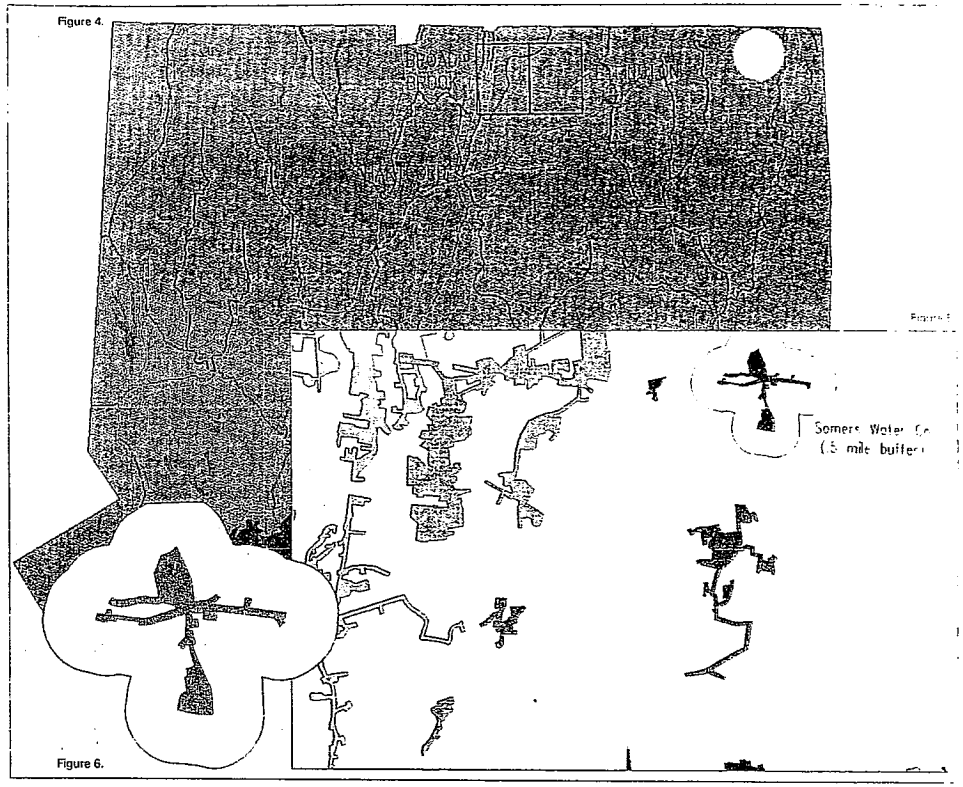


Figure 4. USGS digital line graph map of the State of Connecticut from 1:2,000,000-scale data. The Broad Brook and Ellington 7.5-minute quadrangle areas are outlined in black in the upper middle.

Figure 5. Map of the areas covered by the Broad Brook and Ellington 7.5-minute quadrangles showing the Somers Water Company service area at a scale of 1:24,000.

Figure 6. Enlarged view of figure 5 showing a half-mi buffer zone drawn around the service area of the Somers Water Company.

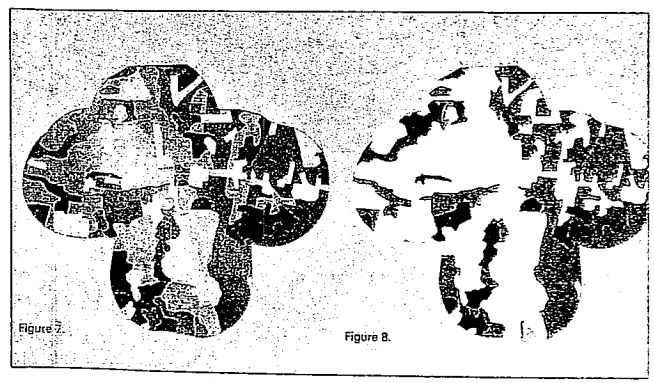
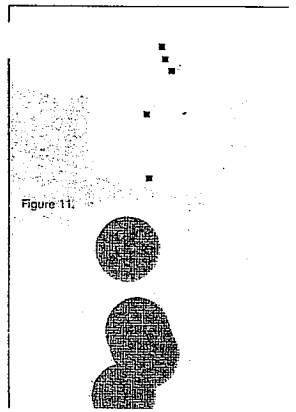


Figure 7. Land use and land cover data for the area bounded by the half-mile buffer zone around the

Figure 8. Land use and land cover data shown in figure 7 have been



change scale at the [redacted] a button, but controlling content and [redacted] often not so easy. Mapmakers have long [redacted]zed that content and detail need to change as the scale of the map changes. For example, the State of New Jersey can be mapped at various scales, from the small scale of 1:500,000 to the larger scale of 1:250,000 and the yet larger scale of 1:100,000 (Fig.3a), but each scale requires an appropriate level of generalization (figs. 3b, c, and d).

Site selection

The U.S. Geological Survey (USGS), in a cooperative project with the Connecticut Department of Natural Resources, digitized more than 40 map layers for the areas covered by the USGS Broad Brook and Ellington 7.5-minute topographic quadrangle maps (fig. 4). This information can be combined and manipulated in a GIS to address planning and natural resource issues. GIS information was used to locate a potential site for a new water well within half a mile of the Somers Water Company service area (fig. 5).

To prepare the analysis, cartographers stored digital maps of the water service areas in the [redacted] is closely monitored. Some of the streams in the study area were known to be unusable as drinking water sources. To avoid pulling water from these streams into the wells, 100-meter buffer zones were created around the unsuitable streams using the GIS, and the zones were plotted on the map (fig. 9). The map showing the buffered zones was combined with the land use and land cover map to eliminate areas around unsuitable streams from the analysis (fig. 10). The areas in blue have the characteristics desired for a water well site.

Point sources of pollution are recorded by the Connecticut Department of Natural Resources. These records consist of a location and a text description of the pollutant (fig. 11). To avoid these toxic areas, a buffer zone of 500 meters was established around each point (fig. 12). This information was combined with the previous two map layers to produce a new map of areas suitable for well sites (fig. 13).

The map of surficial geology shows the earth materials that lie above bedrock (fig. 14). Since the area under consideration in Connecticut is covered by glacial deposits, the surface consists largely of sand and gravel, with some glacial till and fine-grained sediments. Of these materials, sand and gravel are the [redacted] previous overlays.

The resulting site selection map shows areas that are undeveloped, are situated outside the buffered pollution areas, and are underlain by 40 feet or more of water-saturated sand and gravel (fig. 18). Because of map resolution and the limits of precision in digitizing, the very small polygons (areas) may not have all of the characteristics analyzed, so another GIS function was used to screen out areas smaller than 10 acres. The final six sites are displayed with the road and stream network and selected place names for use in the field (fig. 19).

The process illustrated by this site selection analysis has been used for many common applications, including transportation planning and waste disposal site location. The technique is particularly useful when several physical factors must be considered and integrated over a large area.

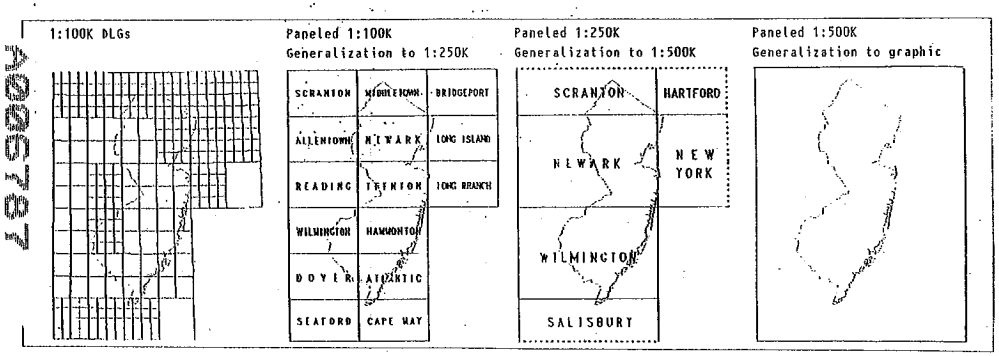


Figure 3a. Digital revision of 1:100,000-scale digital line graph data to produce a 1:500,000-scale New Jersey State base map. Paneling and generalization are shown in three stages from 1:100,000 scale, to 1:250,000 scale, to 1:500,000 scale.



Figure 3b, c, d. These digital maps of Boone County, N.J., are all at a scale of 1:500,000. The information content of the maps has been reduced through the process of generalization in two stages, from 1:100,000 scale on the left to 1:250,000 scale in the center, then from 1:250,000 scale to 1:500,000 scale on the right.

[redacted] water company service area.

[redacted] developed areas.

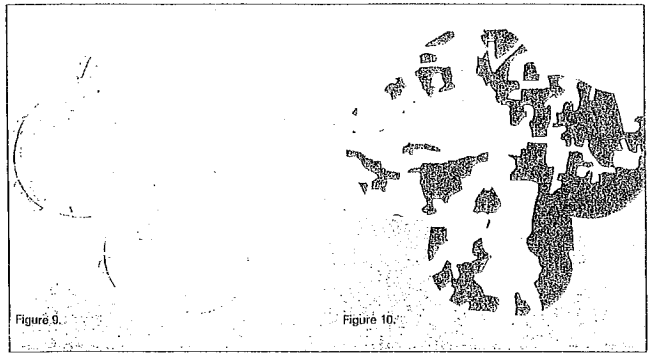


Figure 9. Buffer zones of 100 meters are drawn around polluted streams in the water service area.

Figure 10. Buffered streams shown in the figure 9 area subtracted from areas previously selected with the land use and land cover data.

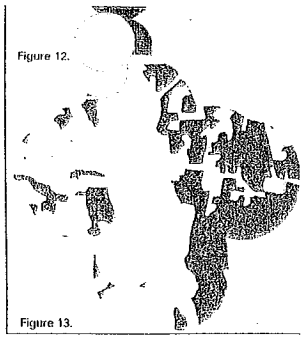


Figure 11. Point sources of pollution in the water service area are identified and entered into a GIS.
Figure 12. Buffer zones of 500 meters are drawn around point sources of pollution
Figure 13. A new map is created in a GIS by eliminating the buffered sources of pollution from the previously selected areas shown in figure 10.

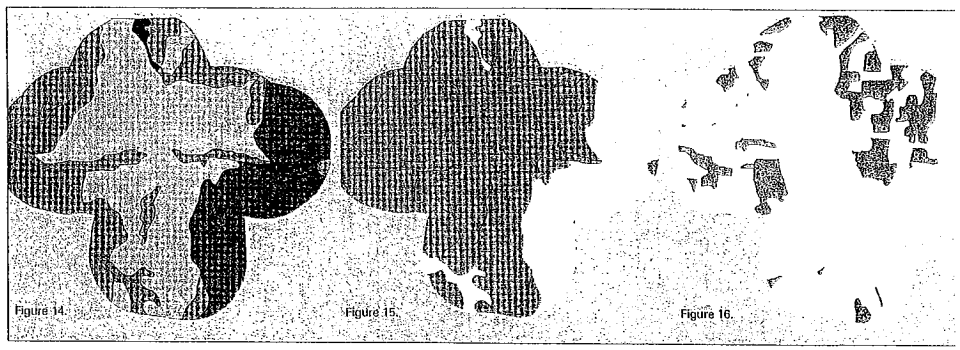


Figure 14. Map of surficial geology of the water service area.

Figure 15. Selection of areas of sand and gravel from the map of surficial geology.

Figure 16. Map produced by combining the areas compos of sand and gravel with the previous selection from figure

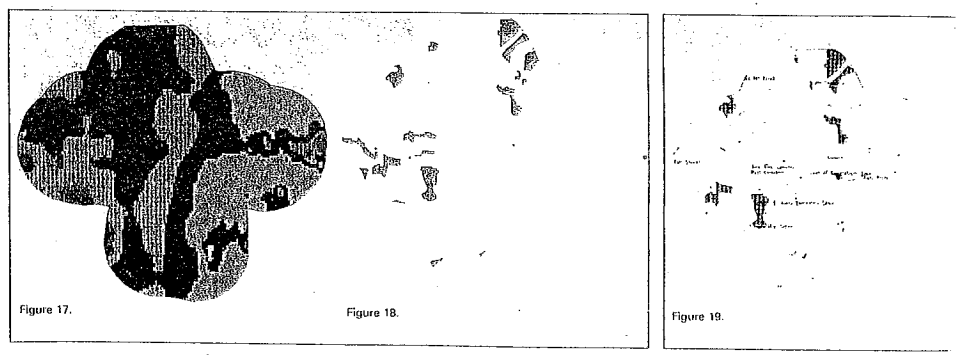


Figure 17. A bedrock elevation subtracted from surface elevation by a GIS to show the thickness of water-saturated sediment.

Figure 18. Potential sites with saturated thicknesses of sediments greater than 40 feet

Figure 19. Potential water well sites, roads, streams, and place names

Emergency response planning

The Wasatch Fault zone through Salt Lake City [illegible] the foot of the Wasatch Mountains in north-central Utah (fig. 20).

A GIS was used to combine road network and earth-science information to analyze the effect of an earthquake on the response time of fire and rescue squads. The area covered by the USGS's Sugar House 7.5-minute topographic quadrangle map was selected for the study because it includes both undeveloped areas in the mountains and a part of Salt Lake City. Digitized earth science information was available for the entire region.

The road network from a USGS digital line graph includes information on the types of roads, which range from rough trails to divided highways (fig. 21). The locations of fire stations were plotted on the road network. A GIS function called network analysis was used to calculate the time necessary for emergency vehicles to travel from the fire stations to different areas of the city. The network analysis function considers two elements: (1) distance from the fire station, and (2) speed of travel based on the type of road. The analysis shows that under normal conditions, most of the area within the city will be served in less than 7 minutes and 30 seconds because of the distribution and density of fire stations and the continuous network of roads.

The accompanying illustration (fig. 22) depicts the blockage of the road network that would result from an earthquake, assuming that any road crossing the fault trace would become impassable. The primary effect on emergency response time would occur in neighborhoods west of the fault trace, where travel times from the fire stations would be noticeably lengthened.

The Salt Lake City area lies on lake sediments of varying thicknesses. These sediments range from clay to sand and gravel, and most are water-saturated. In an earthquake, these materials may momentarily lose their ability to support surface structures, including roads. The potential for this phenomenon, known as liquefaction, is shown in a composite map portraying the inferred relative stability of the land surface during an earthquake. Areas near the fault and underlain by thick, loosely consolidated, water-saturated sediments will suffer the most intense surface motion during an earthquake (fig. 23). Areas on the mountain front with thin surface sediments will experience less additional ground acceleration. The map of liquefaction potential was combined with the road network analysis to show the additional effect of liquefaction on response times.

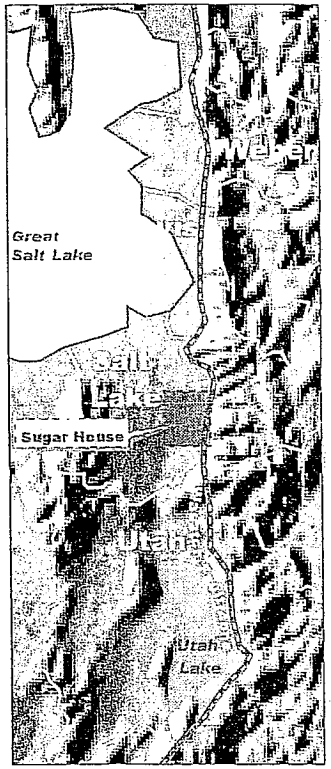


Figure 20. Map of the area surrounding the USGS Sugar House 7.5-minute quadrangle, Salt lake City, Utah, showing the location of the Wasatch Fault zone.

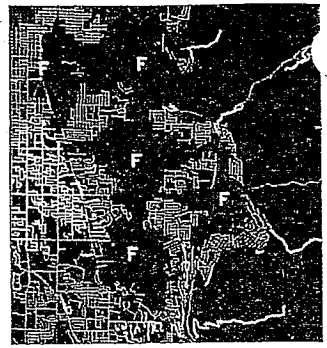


Figure 22. After faulting, initial model. Network analysis in a GIS produces a map of travel times from the stations after faulting. The fault is in red. Emergency response times have increased for areas west of the fault.

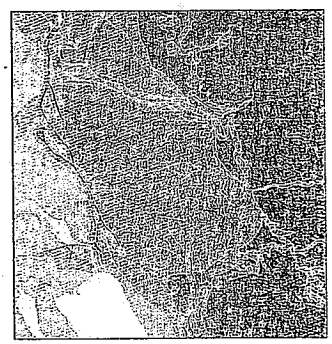


Figure 23. Map of potential ground liquefaction during an earthquake. The least stable areas are shown by yellows and oranges, the most stable by grays and browns.

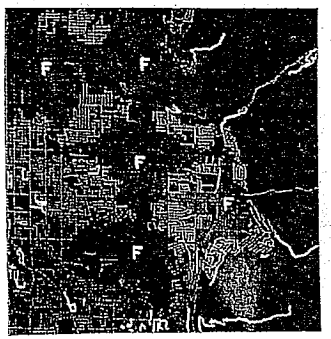


Figure 21. Before faulting. Road network of area covered by the Sugar House quadrangle plotted from USGS digital line graph data, indicating the locations of fire stations and the travel times of emergency vehicles. Areas in blue can receive service within 2 1/2 minutes, areas in green within [illegible] minutes, areas in yellow within 7 1/2 minutes, and areas

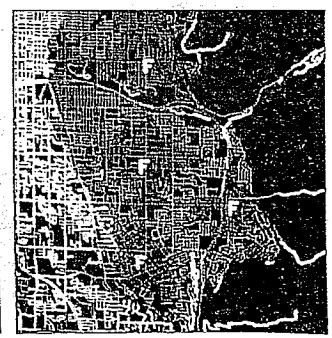


Figure 24. After faulting, final model. A map showing the effect of an earthquake on emergency travel times is produced by combining the liquefaction potential information from figure 23 with the network analysis from figure 22.

Graphic display techniques

Traditional maps are abstractions of the real world; each map is a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of the land surface with contour lines. Graphic display techniques in GISs make relationships among map elements more visible, heightening one's ability to extract and analyze information.

Two types of data were combined in a GIS to produce a perspective view of a part of San Mateo County, Calif. The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevations as black (fig. 27). The accompanying Landsat thematic mapper image shows a false-color infrared image of the same area in 30-meter pixels, or picture elements (fig. 28). A GIS was used to register and combine the two images to produce the three-dimensional perspective view looking down the San Andreas Fault (fig. 29).

Visualization

Maps have traditionally been used to explore the Earth. GIS technology has enhanced the efficiency and analytical power of traditional cartography. As the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Map and satellite information sources can be combined in models that simulate the interactions of complex natural systems.

Through a process known as visualization, a GIS can be used to produce images--- not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that they never could before. The images often are helpful in conveying the technical concepts of a GIS to nonscientists.

Adding the element of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting normalized vegetation index [illegible]

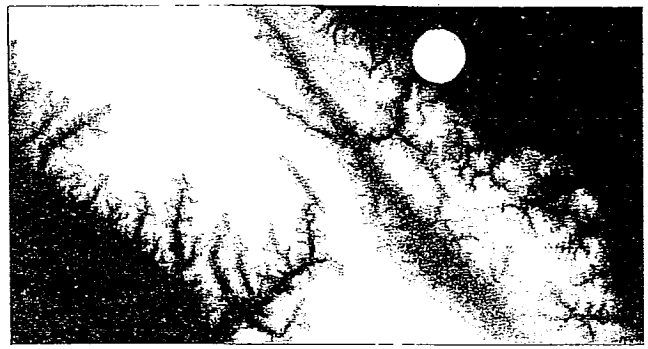


Figure 27. Digital elevation model of San Mateo County, Calif.

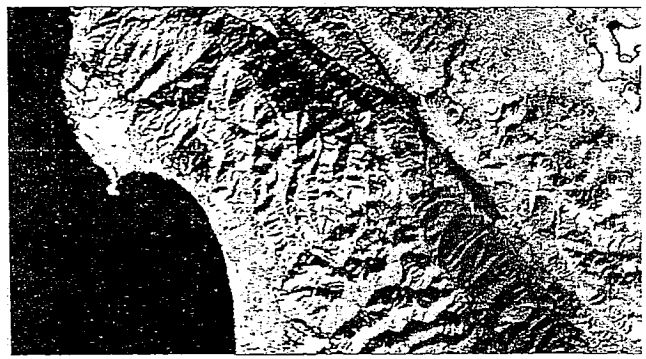


Figure 28. Landsat Thematic Mapper image of San Mateo County, Calif.



Figure 29. Perspective view of San Mateo County, Calif.

Serving GIS over the Internet

Through Internet map server technology, spatial data can be accessed and analyzed over the Internet. For example, current wildfire perime-

photogrammetry, and geography, the GIS has evolved into a discipline with its own research base known as geographic information sciences. An active GIS market has resulted in lower costs and continual improvement in GIS

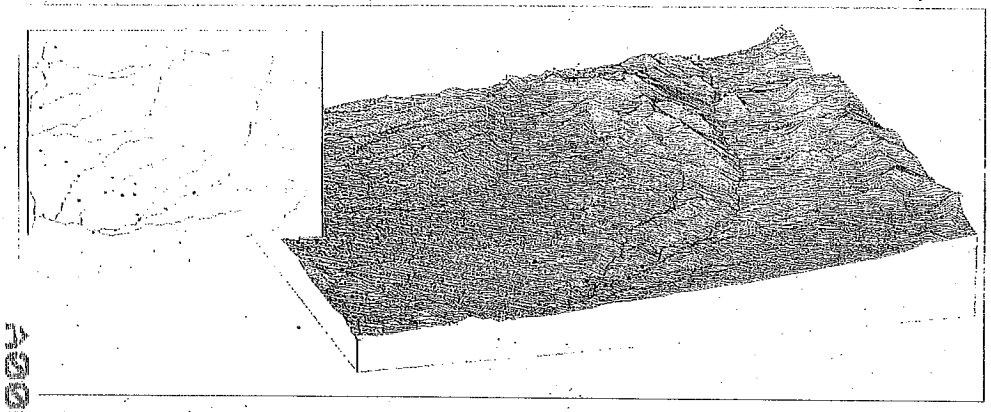
The final map s , areas near the fault, as well as those a thick, water-saturated sediments, a t to more road disruptions and slower emergency response than are other areas of the city (fig. 24)

5 minutes; areas in yellow within 7 1/2 minutes; and areas in magenta within 10 minutes. Areas in white cannot receive service in 10 minutes.

Three-dimensional GIS

To more realistically analyze the effect of the Earth's terrain, we use three-dimensional models within a GIS. A GIS can display the Earth in realistic, three-dimensional perspective views and animations that convey information more effectively and to wider audiences than traditional, two-dimensional, static maps. The U.S. Forest Service was offered a land swap by a mining company seeking development rights to a mineral deposit in Arizona's Prescott National Forest. Using a GIS, the USGS and the U.S. Forest Service created perspective views of the area to depict the terrain as it would appear after mining (fig. 25).

To assess the potential hazard of landslides both on land and underwater, the USGS generated a three-dimensional image of the San Francisco Bay area (fig. 26). It created the image by mosaicking eight scenes of natural color composite Landsat 7 enhanced thematic mapper imagery on California fault data using approximately 700 digital elevation models at 1:24,000 scale.



ure 25. Prescott National Forest, showing altered topography due to mine development.



Figure 26. Thre- -imensional image of the San Francisco Bay created to assess the potential of land and underwater avalanches.

was most extensive in a particular region. The resulting normalized vegetation index represents a rough measure of plant health (fig. 30). Working with two variables over time will allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. The satellite sensor used in this analysis is the advanced very high resolution radiometer (AVHRR), which detects the amounts of energy reflected from the Earth's surface at a 1-kilometer resolution twice a day. Other sensors provide spatial resolutions of less than 1 meter.

Internet. For example, current wildfire perimeters are displayed with a standard web browser, allowing fire managers to better respond to fires while in the field and helping homeowners to take precautionary measures (fig. 31).

The future of GIS

Environmental studies, geography, geology, planning, business marketing, and other disciplines have benefitted from GIS tools and methods. Together with cartography, remote sensing, global positioning systems,

ences. An e GIS market has resulted in lower cos ntinua improvements in GI hardware e, and data. These developments wil a much wider application of the techn throughout government, business, and industry.

GIS and related technologies will help analyze large datasets, allowing a better understanding of terrestrial processes and human activities to improve economic vitality and environmental quality.

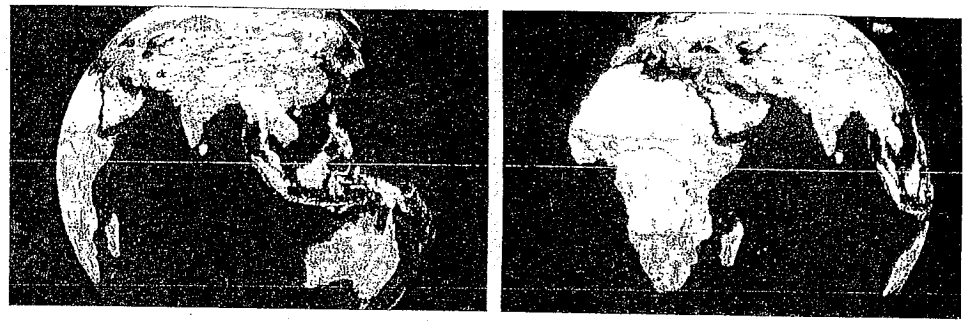


Figure 30. One time slice of the vegetation index for part of the globe from AVHRR data.

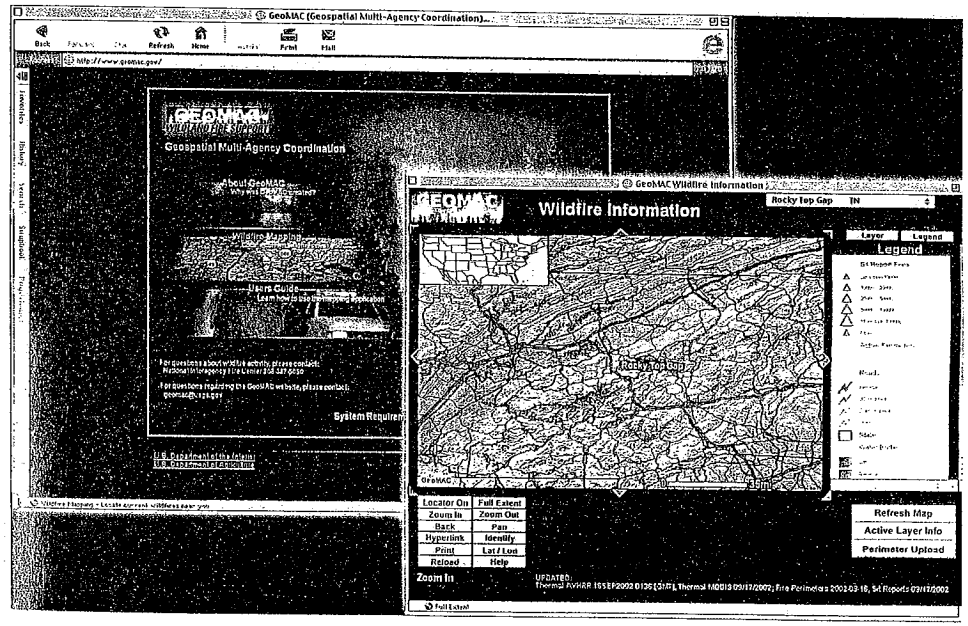


Figure 31. Wildfires burning for the past 24 hours accessible by means of a web browser and Internet map server GIS technology.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 13 2008

OFFICE OF
WATER

MEMORANDUM

SUBJECT: Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program

TO: Water Division Directors, Regions 1-10

FROM: Linda Boornazian, Director
Water Permits Division (MC 4203M)

Steve Heare, Director
Drinking Water Protection Division (MC 4606M)

Over the past several years stormwater infiltration has become an increasingly effective tool in the management of stormwater runoff. Although primary stormwater management responsibilities within EPA fall under the Clean Water Act (CWA), the infiltration of stormwater is, in some cases, regulated under the Safe Drinking Water Act (SDWA) with the goal of protecting underground sources of drinking water (USDWs). Surface and ground water protection requires effective integration between the overlapping programs. This memorandum is a step forward in that effort and is meant to provide clarification on stormwater implementation and green infrastructure, in particular under the CWA, which is consistent with the requirements of the SDWA's Underground Injection Control (UIC) Program.

In April 2007, EPA entered into a collaborative partnership with four national groups (the Association of State and Interstate Water Pollution Control Administrators, the Low Impact Development Center, the National Association of Clean Water Agencies, and the Natural Resources Defense Council) to promote green infrastructure as a cost-effective, sustainable, and environmentally friendly approach to stormwater management. The primary goals of this collaborative effort are to reduce runoff volumes and sewer overflow events through the use of green infrastructure wet weather management practices.

Within the context of this collaborative partnership, green infrastructure includes a suite of management practices that use soils and vegetation for infiltration, treatment, and evapotranspiration of stormwater. Rain gardens, vegetated swales, riparian buffers and porous pavements are all common examples of green infrastructure techniques that capture and treat stormwater runoff close to its source. Green infrastructure management practices typically do not include commercially manufactured or proprietary infiltration

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devices or other infiltration practices such as simple drywells, which do not provide for pre-treatment prior to infiltration.

The partnership is promoting green infrastructure as an effective approach to stormwater management because these practices are associated with a number of environmental benefits. In addition to reducing and delaying runoff volumes, green infrastructure approaches can also reduce pollutant levels in stormwater, enhance ground water recharge, protect surface water from stormwater runoff, increase carbon sequestration, mitigate urban heat islands, and increase wildlife habitat.

Given the multiple benefits that green infrastructure can provide, EPA and its partners have increased efforts to incorporate green infrastructure techniques into stormwater management strategies nationwide. In recent years, public support for these practices has gradually increased. For more information on green infrastructure, please visit www.epa.gov/npdes/greeninfrastructure.

There are cases where stormwater infiltration practices are regulated as Class V wells under the UIC program, and State and local stormwater managers report that some developers are hesitant to incorporate green infrastructure practices because they fear regulatory approvals will slow the process and increase costs. EPA believes those fears are unfounded and notes that most green infrastructure practices do not meet the Class V well definition and can be installed without regulatory oversight by the UIC Program. However, EPA remains committed to the protection of USDWs and emphasizes the need for UIC program compliance (per 40 CFR 144).

To provide clarification on which stormwater infiltration techniques meet EPA's UIC Class V well definition, EPA's Office of Water has developed the attached "Class V Well Identification Guide." State or Regional stormwater and nonpoint source control programs, developers, and other interested parties are requested to contact the State or Regional UIC Program Director with primary authority for the UIC Class V program when considering the use of practices that have been identified, or potentially identified, as Class V wells. UIC program managers should consider the proximity to sensitive ground water areas when looking at the suitability of stormwater infiltration practices. Depending on local conditions, infiltration without pretreatment may not be appropriate in areas where ground waters are a source of drinking water or other areas identified by federal, state, or local governments as sensitive ground water areas, such as aquifers overlain with thin, porous soils.

Please share this memo and the attached guide with your State and Regional stormwater, nonpoint source control, UIC and other ground water managers, as well as with appropriate green infrastructure contacts. These programs are encouraged to coordinate on stormwater management efforts when sensitive ground water issues arise.

Attachment

Underground Injection Control (UIC) Program Class V Well Identification Guide

This reference guide can be used to determine which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells. Class V wells are wells that are not included in Classes I through IV. Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. By definition, a well is "any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system" and an "injection well" is a "well" into which "fluids" are being injected (40 CFR §144.3). Federal regulations (40 CFR §144.83) require all owners/operators of Class V wells to submit information to the appropriate regulatory authorities including the following:

1. Facility name and location
2. Name and address of legal contact
3. Ownership of property
4. Nature and type of injection well(s)
5. Operating status of injection well(s)

For more information on Class V well requirements, please visit http://www.epa.gov/safewater/uic/class5/comply_minrequirements.html. For more information on green infrastructure, please visit http://www.epa.gov/npdes/greeninfrastructure.

The stormwater infiltration practices/technologies in rows A through I below are generally not considered to be wells as defined in 40 CFR §144.3 because typically they are not subsurface fluid distribution systems or holes deeper than their widest surface dimensions. If these practices/technologies are designed in an atypical manner to include subsurface fluid distribution systems and/or holes deeper than their widest surface dimensions, then they may be subject to the Class V UIC regulations. The stormwater infiltration practices/technologies in rows J through K however, depending upon their design and construction probably would be subject to UIC regulations.

	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
A	Rain Gardens & Bioretention Areas	Rain gardens and bioretention areas are landscaping features adapted to provide on-site infiltration and treatment of stormwater runoff using soils and vegetation. They are commonly located within small pockets of residential land where surface runoff is directed into shallow, landscaped depressions; or in landscaped areas around buildings; or, in more urbanized settings, to parking lot islands and green street applications.	No.
B	Vegetated Swales	Swales (e.g., grassed channels, dry swales, wet swales, or bioswales) are vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff. As stormwater runoff flows along these channels, vegetation slows the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils.	No.
C	Pocket Wetlands & Stormwater Wetlands	Pocket/Stormwater wetlands are structural practices similar to wet ponds that incorporate wetland plants into the design. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake. Several design variations of the stormwater wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.	No.
D	Vegetated Landscaping	Self-Explanatory.	No.
E	Vegetated Buffers	Vegetated buffers are areas of natural or established vegetation maintained to protect the water quality of neighboring areas. Buffer zones slow stormwater runoff, provide an area where runoff can infiltrate the soil, contribute to ground water recharge, and filter sediment. Slowing runoff also helps to prevent soil and stream bank erosion.	No

4995793

	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
F	Tree Boxes & Planter Boxes	Tree boxes and planter boxes are generally found in the right-of-ways alongside city streets. These areas provide permeable areas where stormwater can infiltrate. The sizes of these boxes can vary considerably.	No.
G	Permeable Pavement	Permeable pavement is a porous or pervious pavement surface, often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Permeable pavement is an environmentally preferable alternative to traditional pavement that allows stormwater to infiltrate into the subsoil. There are various types of permeable surfaces, including permeable asphalt, permeable concrete and even grass or permeable pavers.	No.
H	Reforestation	Reforestation can be used throughout a community to reestablish forested cover on a cleared site, establish a forested buffer to filter pollutants and reduce flood hazards along stream corridors; provide shade and improve aesthetics in neighborhoods or parks, and improve the appearance and pedestrian comfort along roadsides and in parking lots.	No.
I	Downspout Disconnection	A practice where downspouts are redirected from sewer inlets to permeable surfaces where runoff can infiltrate.	In certain circumstances, for example, when downspout runoff is directed towards vegetated/pervious areas or is captured in cisterns or rain-barrels for reuse, these practices generally would not be considered Class V wells.
J	Infiltration Trenches	An infiltration trench is a rock-filled trench designed to receive and infiltrate stormwater runoff. Runoff may or may not pass through one or more pretreatment measures, such as a swale, prior to entering the trench. Within the trench, runoff is stored in the void space between the stones and gradually infiltrates into the soil matrix. There are a number of different design variations.	In certain circumstances, for example, if an infiltration trench is "deeper than its widest surface dimension," or includes an assemblage of perforated pipes, drain tiles, or other similar mechanisms intended to distribute fluids below the surface of the ground, it would probably be considered a Class V injection well.

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	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
K	Commercially Manufactured Stormwater Infiltration Devices	Includes a variety of pre-cast or pre-built proprietary subsurface detention vaults, chambers or other devices designed to capture and infiltrate stormwater runoff.	These devices are generally considered Class V wells since their designs often meet the Class V definition of subsurface fluid distribution system.
L	Drywells, Seepage Pits, Improved Sinkholes.	Includes any bored, drilled, driven, or dug shaft or naturally occurring hole where stormwater is infiltrated.	These devices are generally considered Class V wells if stormwater is directed to any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or has a subsurface fluid distribution system.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAR 5 2007

OFFICE OF
WATER

MEMORANDUM

SUBJECT: Using Green Infrastructure to Protect Water Quality in Stormwater, CSO, Nonpoint Source and other Water Programs

FROM: Benjamin H. Grumbles
Assistant Administrator

TO: EPA Regional Administrators

Green infrastructure can be both a cost effective and an environmentally preferable approach to reduce stormwater and other excess flows entering combined or separate sewer systems in combination with, or in lieu of, centralized hard infrastructure solutions. EPA Water Programs are in a pivotal position to exert leadership in the consistent and reliable implementation of green infrastructure approaches. This memo is to highlight opportunities for the Regions, States, and Headquarters efforts to increase the development and use of green infrastructure in water program implementation.

Several cities, searching for alternatives to traditional hardscape solutions to wet weather discharge problems, have initiated some green infrastructure approaches. The Natural Resources Defense Council (NRDC) has recently published a document with information and case studies on these efforts. I strongly support the use of green infrastructure approaches described in the NRDC report and I suggest you share the report with States and promote other tools for green infrastructure. *Rooftops to Rivers: Green strategies for controlling stormwater and combined sewer overflows* (NRDC, June 2006) is available at:
http://www.nrdc.org/water/pollution/rooftops/contents.asp

Green infrastructure approaches essentially infiltrate, evapotranspirate or reuse stormwater, with significant utilization of soils and vegetation rather than traditional hardscape collection, conveyance and storage structures. Common green infrastructure approaches include green roofs, trees and tree boxes, rain gardens, vegetated swales, pocket wetlands, infiltration planters, vegetated median strips, reforestation, and protection and enhancement of riparian buffers and floodplains. Green infrastructure can be used where soil and vegetation can be worked into the landscape. It is most effective when supplemented with other decentralized storage and infiltration approaches, such as the use of permeable pavement, and rain barrels and cisterns to capture and re-use rainfall for watering plants or flushing toilets. These approaches can be used to keep rainwater out of the sewer system to reduce sewer overflows and to reduce the amount of untreated stormwater discharging to surface waters. Green infrastructure

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facilitates or mimics natural processes that also recharge groundwater, preserve baseflows, moderate temperature impacts, and protect hydrologic and hydraulic stability.

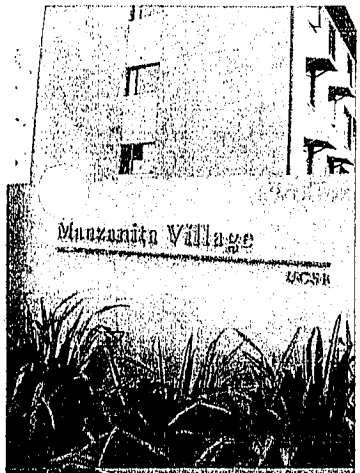
Green infrastructure has a number of benefits:

- *Cleaner Water* – Vegetation and green space reduce the amount of stormwater runoff and, in combined systems, the volume of combined sewer overflows.
- *Enhanced Water Supplies* – Most green infiltration approaches result in stormwater percolation through the soil to recharge the groundwater and the base flow for streams.
- *Cleaner Air* – Trees and vegetation improve air quality by filtering many airborne pollutants and can help reduce the amount of respiratory illness.
- *Reduced Urban Temperatures* – Summer city temperatures can average 10°F higher than nearby suburban temperatures. High temperatures are linked to higher ground level ozone concentrations. Vegetation creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air.
- *Increased Energy Efficiency* – Green space helps lower ambient temperatures and helps shade and insulate buildings, decreasing energy needed for heating and cooling.
- *Community Benefits* – Trees and plants improve urban aesthetics and community livability by providing recreational and wildlife areas and can raise property values.
- *Cost Savings* - Green infrastructure may save capital costs on digging big tunnels and stormwater ponds, operations and maintenance expenses for treatment plants, pipes, and other hard infrastructure; energy costs for pumping water; and costs of wet weather treatment and of repairing stormwater and sewage pollution impacts, such as streambank restoration.

The Office of Water is working with a coalition of organizations, including the Natural Resources Defense Council, the National Association of Clean Water Agencies, and the Low Impact Development Center, to develop additional strategies for green infrastructure approaches to water quality challenges. As those strategies take shape, we will send you additional tools and information on implementing green infrastructure in our water programs.

I am pleased that EPA Regions and States are looking for opportunities to incorporate green infrastructure. We would be very interested in hearing about your efforts, and to the extent they can be applied elsewhere, assist in disseminating information and tools. If you have any questions, please contact me or have your staff call Jenny Molloy at (202) 564-1939 with any questions, comments, ideas or information on green infrastructure approaches.

cc: Water Division Directors
OW Office Directors



Manzanita Village

University of California Santa Barbara

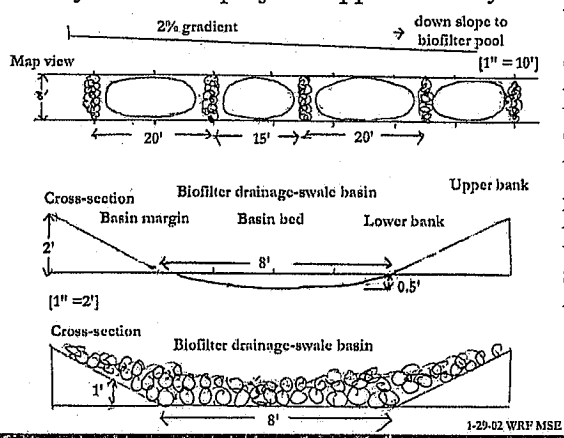
Introduction

Manzanita Village is a part of the University of California, Santa Barbara student housing and residential services program. Located on the northwest edge of the campus on a coastal bluff overlooking Campus Lagoon, the village covers over 217,000 sq ft (six acres) and was complete in 2002. It represents the direction UCSB intends to follow with all future development to increase biodiversity and self-sustaining systems while reducing dependence on fossil fuels and other extracted minerals. The UCSB sustainability mission calls for the use of locally available water resources and manage this resource so it leaves the campus as "pure" as it entered. This policy will help with regulatory requirements for coastal development put forth by the California Coastal Commission and the Regional Water Quality Control Board.

At Manzanita Village irrigation water was limited to the establishment phase for seedlings (and this supplemental watering was done with recycled water from a waste water treatment facility) which resulted in water conservation. Furthermore, no herbicides are used except to control noxious plans such as poison oak and Bermuda grass, thus reducing the introduction of toxins into the environment.

Strom Water Treatment

Manzanita Village project has restored native grassland, vernal pools and vernal marshes, all threatened habitat types, and 1300 linear feet of bioswale creation. More than 80,000 native plants grown from local genotypes at the UCSB Cheadel Center for Biodiversity and Ecological Restoration (CCBER) nursery and greenhouse were planted within the fir. three years of the project. Approximately 40% of the storm water run-off from Manzanita Village flows through some section of bioswale. In place of traditional underground pipe systems, these bioswales convey stormwater and irrigation runoff. In addition, the bioswales serve functions such as reducing nutrient loading to the lagoon, creating habitat for wetland plant and animal species and aesthetically softening the edge between urban and natural areas.



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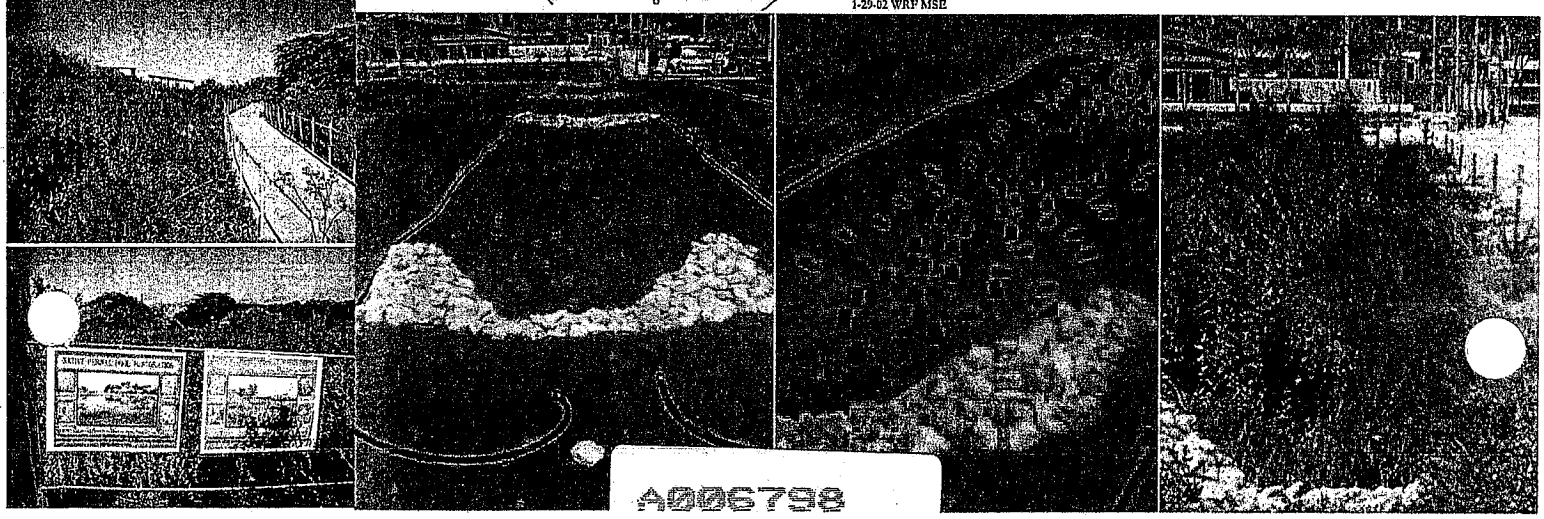

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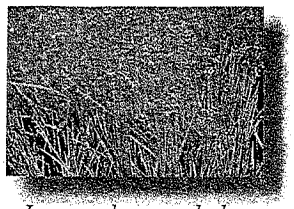
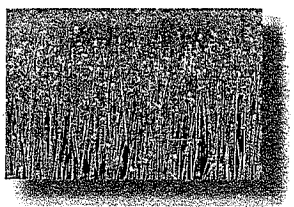


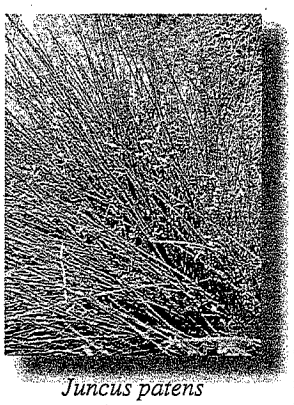
Juncus phaeocephalus
Brown-headed Rush



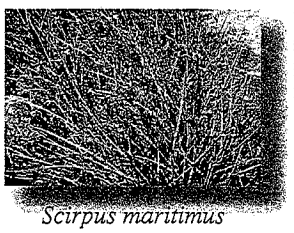
Carex pendula
Hanging Sedge



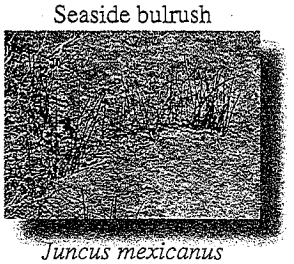
Elecoharis macrostachya
Spike Rush



Juncus patens
Spreading Rush



Scirpus maritimus
Seaside bulrush



Juncus mexicanus
Mexican Rush

Restored Wetlands And Vernal Pools

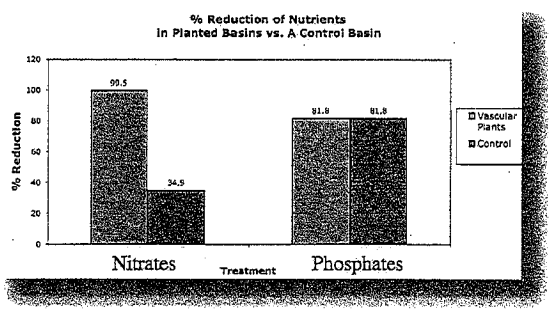
One of the key aspects of Manzanita Village is a vernal marsh. Compared to vernal pools, vernal marshes are deeper and have a longer duration of flooding. The vernal marshes support large emergent vegetation such as California bulrush (Schoenoplectus americanus) and common three square (Schoenoplectus pungens) and provide nesting habitat for red-winged blackbirds, common yellowthroats, mallards, and other birds.

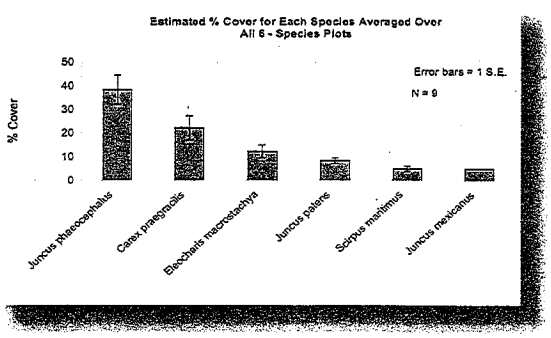
In the western portion of Manzanita Village (separate from the vernal marsh) are three vernal pools, seeded and planted with locally collected materials. Vernal pools are seasonal wetlands that occur in depressions where there is an underlying impermeable layer that becomes saturated during winter rains. The pools pond through the spring and are desiccated through the summer and early fall. A unique suite of plant and animal species adapted to this cyclical process of wetting and drying are found in these pools. Water depth, vegetation cover, and invertebrate populations are monitored regularly.

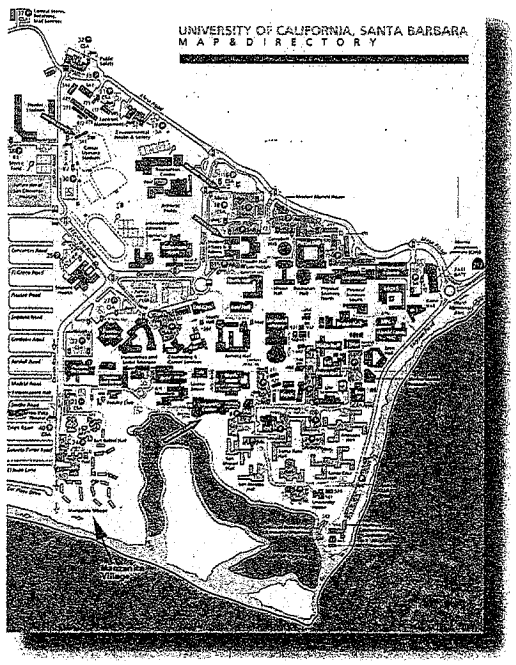
The Biofiltration System combines cobble-lined drains, bioswales, and two shallow marshes strung together to treat and drain approximately 75% of the Manzanita Village project site. This system demonstrates how excess water and nutrients considered to be a waste product of urbanization can be turned into a resource and used to enhance the environment. More than 27 species of local native wetland plants are growing in the Biofiltration System.

For more information about the Manzanita Village project contact:

Melanie Powers
Restoration Project Manager
Cheadle Center For Biodiversity and Ecological Restoration
(805) 893-4222 or powers@lifesci.ucsb.edu







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ZONINGPRACTICE November 2006

AMERICAN PLANNING ASSOCIATION

ISSUE NUMBER ELEVEN

PRACTICE WATERSHED PLANNING



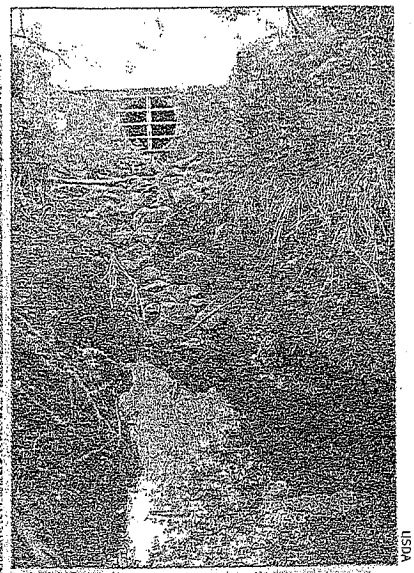
Integrating Stormwater Regulation and Urban Design

By Lisa Nisenson

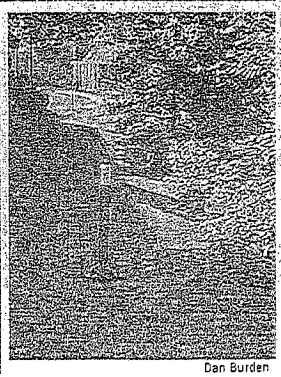
Landmark Supreme Court decisions are the yardsticks by which we judge the constant battle over who can do what and where.



U.S. EPA



USDA



Dan Burden

(Above) Abacoa, Florida, was developed with greenways to handle stormwater. (Right) Emergency response can be supported in creative ways that eliminate excess pavement.

(Above) As streams are scoured by pulses of water, sediment deposits and weak stream banks undermine the waterway's ability to handle stormwater, which can contribute to local flooding.

But every once in a while, groundbreaking events in land use are not heralded by headlines, but rather are contained in the tiny font of local newspaper notices, footnotes, or within regulatory bulletins such as the U.S. government's *Federal Register*.

On December 9, 1999, one such final notice was issued by the U.S. Environmental Protection Agency (EPA) in the vernacular of water engineers under the heading "Stormwater." Terms such as "National Pollutant Discharge Elimination System" and "non-structural techniques" are largely unfamiliar to land-use and zoning managers. The EPA regulation contained two curious clauses that are as much land use as they are water quality. First, the notice directed over 5,000 cities across the country to consider for the first time "post-construction" stormwater control. More importantly, the notice instructed that these new post-construction rules be implemented "by ordinance or other regulatory mechanism" (i.e., zoning and land development regulations).

Most cities have engaged in stormwater control for decades though drainage requirements. But the new EPA rules challenge the old engineering approaches of draining a city's runoff into the most convenient local stream. The new approach scrutinizes the capture and handling of stormwater in nearly every site plan proposal to lessen the impacts of development.

This issue of *Zoning Practice* will demystify the new requirements, link them to common zoning and planning efforts already under way, and offer cautionary observations about the potential for unintended results when merging land-use and water regulations.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

The National Pollutant Discharge Elimination System (NPDES) is the section of the Clean Water Act that regulates discharge into waterways. In the beginning, NPDES looked mainly at discharges with the highest pollutant loads, which typically came from factories and large pipes. In the early 1990s, the regulations were expanded to cover stormwater flows from large cities with populations over 100,000. The 1999 notice (referred to as Phase II) brought smaller urbanized areas under regulation for development projects of one acre or more. NPDES permits require renewal every five years, allowing time for program managers to adapt and customize their systems.

EPA delegates NPDES authority to most states, which then develop a statewide general permit that spells out municipal compliance requirements. For planning and zoning, the most important elements are the post-construction rules and the stormwater management plan that specify best management practices (BMPs). EPA materials issued to date include BMPs for traditional water bodies as well as guidance on using land-use practices such as infill and increasing open space protection—integrated "by ordinance or other regulatory mechanism."

Why Post-Construction?

Post-construction stormwater measures help control runoff after the completion of a project by assigning some measure of responsibility for stormwater control to developments over the life of the project. In the past, the engineer's job was to remove water from the site and into the

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ASK THE AUTHOR—JOIN US ONLINE!

Go online from December 18 to 29 to participate in our "Ask the Author" forum, an interactive feature of Zoning Practice. Lisa Nisenson will be available to answer questions about this article. Go to the APA website at www.planning.org and follow the links to the "Ask the Author" section. From there, just submit your questions about the article using an e-mail link. The author will reply, and Zoning Practice will post the answers cumulatively on the website for the benefit of all subscribers. This feature will be available for selected issues of Zoning Practice at announced times. After each online discussion is closed, the answers will be saved in an online archive available through the APA Zoning Practice web pages.

About the Author

Lisa Nisenson is a principal at Nisenson Consulting. She is also working with Tetratech to develop stormwater program guidance for the U.S. Environmental Protection Agency's Office of Water. Nisenson has worked on smart growth at the national and local levels for nearly 15 years.

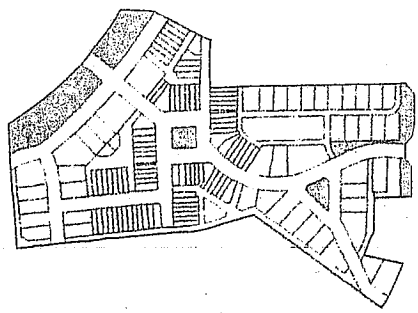
conveyance system as quickly as possible. The approach kept basements and foundations dry but proved catastrophic for local streams that suffered the impact of collective polluted flow from houses, offices, and parking lots.

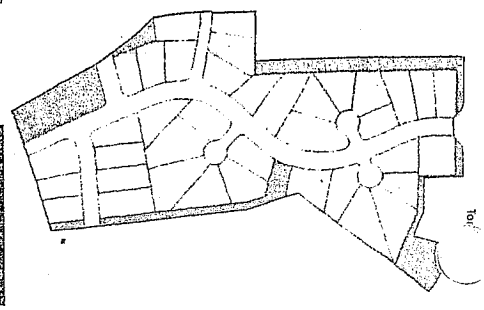
The damage to streams is more than an environmental misfortune. The flow collected from acres of concrete scours riverbanks and creates mud deposits, making streams wider and shallower. The altered water flow poses challenges to floodplain managers, water supply companies, and industries that rely on clean, steady flows. The primary reason for the problem is the location and extent of land development, and the most common indicator is impervious cover—rooftops, parking lots, and roads, and even compacted dirt, gravel, and grassy surfaces.

WHAT DRIVES IMPERVIOUS SURFACE?

Watershed managers and land developers cannot manage the impacts of excess impervious surface without first understanding the reasons for its proliferation. Planning and zoning officials regularly make decisions about impervious cover with respect to:

- *Parking.* Minimum parking standards and cautious lending practices can lead to unnecessarily large parking lots.
- *Site design.* Site design parameters have increased with setbacks and minimum lot size requirements (partially to accommodate more parking) and maximum height limitations that force development outward to meet demand. Even where codes allow multistory development, parking requirements based on square footage ultimately dictate less intensity.
- *Street design and mode choice.* Unconnected, hierarchical street designs often result in dispersed development and an increase in impervious surface, leading to poor transportation choices. Street design also influences mode choice. In places where trips for daily needs cannot be made without a car, businesses will argue that they need generous parking allotments.
- *Separation of uses.* The Euclidean model of separating uses can make walking or combining trips impractical, if not impossible. When businesses and services are spread out, more impervious surfaces are created and people are beholden to vehicular travel.
- *Redevelopment.* Redevelopment is among the best (yet least recognized) watershed protection strategies. By contrast, vacating an urban site to relocate at the basin's edge ultimately means the watershed is burdened with runoff from two sites.
- *Infill.* Infill development was listed in the 1999 notice as a viable strategy for reducing stormwater impacts. This was mostly true. However, planners must track absorbent spaces that are poised for development and balance flows accordingly.
- *New stormwater requirements.* Some of the emerging BMPs require that large portions of a site remain undeveloped (though not necessarily undisturbed). Be careful. The result can favor developers who assemble a parcel large enough to accommodate 200,000 square feet of floorplate, 800 parking spaces, drive aisles, and service bays, plus the calculated land set-aside. Such requirements tend to exacerbate sprawl and impervious cover because big enough parcels can only be found in the outlying areas and require the expansion of roads and other infrastructure.





Vermillion, a development project in North Carolina, is characterized by less street imperviousness per unit of development given its compact footprint and development intensity.

THE ROLE OF PLANNING AND ZONING

Planning and zoning departments can have a big impact on the development and maintenance of stormwater management plans. The question is where to start.

First, establish which federal and state stormwater rules apply, in particular, for post-construction. Among the first questions to ask are (1) *What water quality problems exist today?* and (2) *What are the anticipated problems in the watershed?* The type and nature of water stressors invariably influence planning needs. Also, obtain copies of the comprehensive plan and watershed plan. A strong comprehensive plan is the initial and most important BMP to put into place. Applying BMPs in an ad hoc manner will not protect against stream degradation and flooding in the long term. Ignoring a land-use pattern that creates excess imperviousness will only delay the inevitable costs of stream restoration and flood clean-up that site-specific BMPs cannot control.

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DEVELOPING A COMMON VOCABULARY: BEST PRACTICES IN LAND DEVELOPMENT REGULATIONS AND STORMWATER CONTROL

Municipal governments (cities and counties) covered under Phase II were required to present preliminary stormwater plans (the notice of intent) to the state by March 10, 2003. That submittal triggered a five-year time frame for starting the stormwater program, including ordinance changes. But legal challenges and state decisions have since resulted in delay, leaving municipalities in one of the following scenarios:

Square one: Your stormwater colleagues are just now embarking on code review. Bring to the table the comprehensive plan, the zoning code, and a readiness to talk about pending changes. Outreach to a variety of stakeholders is essential—watershed groups, home builders, public works departments, and interested local businesses. Also invite economic development representatives, developers who specialize in redevelopment, growth management groups, and regional transportation coordinators. The role of planning and zoning is likely to involve modifying land development regulations to include stormwater controls.

At the table: The development of the code is underway and the zoning office has been consulted. You may find several areas where the proposed stormwater regulations are in conflict with desired land development regulations, so your role may involve defending aspects of the plan or code. By the same token, having a stormwater engineer review the comprehensive plan might reveal options not evident when post-construction controls were not yet under consideration. Be prepared to make two lists: one of immediate changes for stormwater management and a running list of longer term improvements for the next NPDES permit cycle or plan review.

Not invited (perhaps not welcome): What if you just heard of changes that are underway and it appears you may not have a say? There is still time. First, recognize that this may just be an oversight. The obscure terms used in the *Federal Register* notice may not have fully revealed that planning and zoning are at the core of regulatory changes. Ask if you can see proposed changes. If the relationship has reached the "hostile" stage, think about where the proposed changes might run counter to popular initiatives and look for common solutions. Municipal managers are loathe to tackle a fight pitting a hard-fought comprehensive plan against a federal environmental mandate.

THE DISTRICT

Once planners understand how to use the elements in both plans, they should look to the district. For watersheds this may be a subwatershed or drainage basin, while in land use it may be a neighborhood, brownfield, planned unit development, or subdivision. This critical level of analysis is often overlooked in water planning for three reasons:

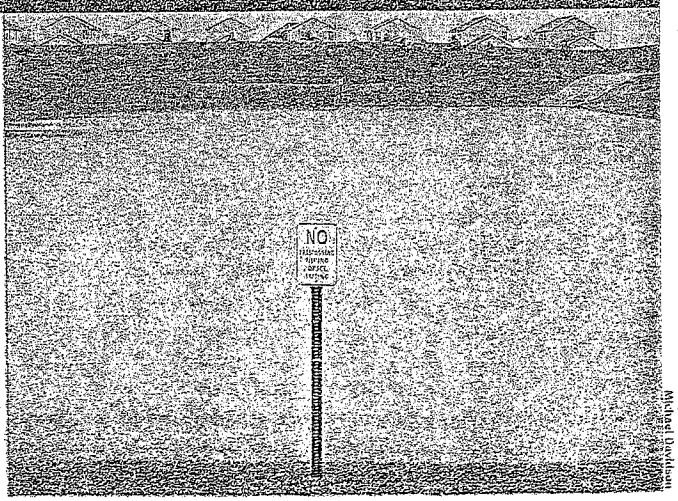
1. The early discussions of watershed-friendly development techniques took place without questioning the impact of highly separated land uses.
2. District planning for compact form and development intensity runs counter to traditional stormwater engineering approaches and performance standards, which are established at the site or project level rather than the district or sub-basin level. Calculating performance for a pond on an individual site is easier than assessing the benefits of redevelopment for a watershed.
3. Like many aspects of infrastructure, the responsibility for stormwater control is increasingly delegated to the developer. As such, site design tends to be inwardly focused to meet the needs of the site rather than to take advantage of an efficient, natural system for the entire basin.

To help improve assessments for districts or sub-basins, planners should work with stormwater and watershed departments. For watersheds, engineers can look at a redevelopment project to measure the amount of impervious surface avoided, or identify drainage basins for redevelopment in an older downtown. Engage economic development departments to see where the municipality's

(Left) The rolled curb of the sidewalk in this Hercules, California, street allows emergency vehicles to navigate the narrower streets that support this walkable neighborhood. (Right) A water body with no purpose other than to move water off the site of a prototypical suburban subdivision. The sign reads "No trespassing, fishing, or ice skating."



Local Government Commission



Michael Davidson

stormwater investments can attract developer interest.

Finally, many stormwater managers are working with planning and zoning departments to identify areas for off-site mitigation. Where site constraints rule out on-site stormwater handling, fees-in-lieu is an alternative. The crux of such a program is to have already identified (at the district and watershed levels) the best areas to invest fees for water quality and flood prevention.

In the end, good stormwater and comprehensive plan will converge on the following goals:

- Minimizing imperviousness at the watershed level by targeting and redirecting development onto smaller footprints,
- identifying and preserving critical ecological areas and contiguous open space,
- maximizing the use of existing infrastructure and developed sites, and
- retrofitting existing properties through home owner and property management campaigns.

LINKING STORMWATER AND LAND USE THROUGH PLANNING AND ZONING

Because stormwater runoff is a growing environmental threat, new rules are aimed at protecting and improving water quality. However, stormwater engineers must also understand that in urban and rapidly developing areas, ordinance drafting does not occur in a vacuum. Many areas have established zoning, planning, and land conservation activities, so the new rules are as much about integrating stormwater strategies into land development regulations as they are about instituting new practices.

Developing a joint water and land development program involves both a management strategy and the components of that strategy. Sample approaches are as follows:

Bare-Bones Ordinance with Design Guidelines

This is good for communities that organize by districts and neighborhoods for governance, infrastructure planning, and growth policies. District plan details are often highly interwoven and require the same integration as stormwater BMPs. With input from the stormwater engineer, communities can recast the pattern book for traditional neighborhood design (TND) as a stormwater design manual. Other design districts might include brownfields, planned unit developments, and downtown redevelopment districts. In the end, you may have several design guidelines for many distinct districts.

For example, Emeryville, California, faced a tough environment for stormwater control because of a high number of contaminated sites, a built-out development portfolio, high water table, and clay soils. First, the city tackled its parking ordinance to reduce the number of spaces and find opportunities for public and off-site parking. Second, the city worked to incorporate greenspace into development sites and to add swales to treat and slow stormwater runoff. Finally, the city encouraged green building techniques such as cisterns and

GOALS WITHIN COMPREHENSIVE AND WATERSHED PLANS SHOULD BE COMPLEMENTARY

Comprehensive Plan	Watershed Plan	Be prepared to:
Create and preserve parks and open space.	Create and protect open space with a focus on land with a higher ecological value for infiltration or flood control.	reexamine land preservation policies for water goals. You may need to add parcels for aquifer recharge and stream bank stabilization.
Compact development form	Reduce impervious surfaces.	argue the two are the same. Compact development is, by definition, highly impervious at the district scale but can save land development in greenfields.
Density	Clustering	use the environmental support for clustering to your advantage when density is challenged. Also look for opportunities to use landscaping in urban site plans for stormwater control. The developer already has it budgeted.
Connected, multimodal streets with narrow widths	Better street design with narrow streets	include emergency responders in the discussion. They often want wider streets for access. In watershed literature, street design is often limited to the site or subdivision scale. Develop the case that connected streets support compact form. In addition, scrutinize the current and future transportation role of sidewalks. While some LID literature supports better cul de sacs, increasingly the advice is to discourage them.
Smart growth	Low-impact design (LID)	answer questions about differences between the two. Some literature says that smart growth is about the pattern while LID is about the site. In reality, both are evolving to include options for the watershed (or region), district, and site. LID is often described as mimicking or reproducing natural hydrology, which in built-out cities may be difficult to fully achieve. Finally, realize that LID techniques are rightly on a path to becoming routine elements in site and architectural designs.

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Redevelopment in ultra urban areas can meet landscaping and stormwater objectives at once through careful design.

Lisa Nisenson

green roofs as architectural details. (See www.ci.emeryville.ca.us/planning/pdf/stormwater_guidelines.pdf.)

Separate Ordinances for New Development, Redevelopment, and Infill

Redevelopment is almost universally more difficult than greenfield development. Without careful application, stormwater requirements may tip the balance for developers who cannot make projects fiscally viable. EPA's post-construction language in the 1999 notice has "new development" and "redevelopment" together, but a good stormwater plan can benefit from developing separate ordinances.

The State of Wisconsin has a nationally recognized program of water protection for lakes and rivers. In determining stormwater standards, the state recognizes that different development types require different rules. Consequently, the state has settled on a system to tier water quality performance measures for best management practices based on whether the site is new development, redevelopment, or infill. (See www.dnr.state.wi.us/org/water/wm/nps/stormwater/post-constr/.)

Overlays for Areas Requiring Special Protection or Incentives

Overlay zones are a popular zoning tool and can also be applied to protect stream buffer areas or target areas with a BMP. Overlays are also an option when the completion of a comprehensive watershed plan is years away, but immediate steps are needed within land development regulations to protect natural resources. To see this approach in action visit the website of the New York Rural Water Association, which uses an overlay zone to protect rural waters as part of a larger rural planning effort. (See www.nyruralwater.org/downloads/bulletins/booklet.pdf.)

A separate stormwater code is good for communities without zoning or for those unable to revisiting an existing code.

Make Land-Efficient Growth Policies Stormwater BMPs

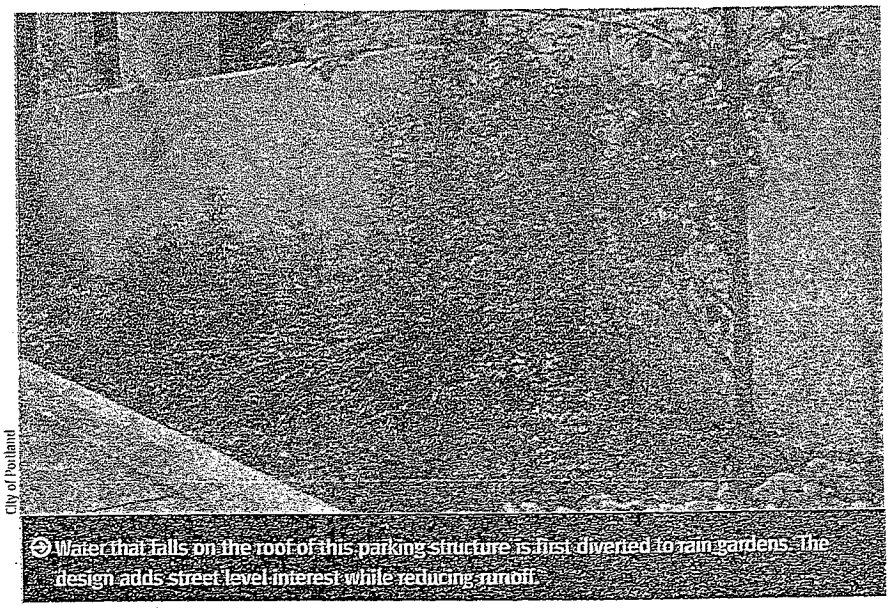
EPA suggests several smart growth practices for a stormwater management program, including infill and guiding growth to areas with existing development.

The City of San Jose, California, takes advantage of state permit flexibility to classify designated affordable housing projects as stormwater BMPs. In recognition that pressure for affordable and workforce housing was pushing development outward, the city created a management structure to consider which housing developments could qualify. (For the code language see www.sanjoseca.gov/planning/stormwater/pol_stormwater.pdf.)

Opportunities within Land Development Regulations

Elements within land development regulations are ripe for reform, including those that would help reduce impervious surfaces. As stated earlier, parking is the frontier for such efforts, along with provisions for lot sizes, height limitations, landscaping, and setbacks that can push development outward.

EPA's *Parking Spaces, Community Places* has numerous examples of flexible parking. If your community uses an aerial photography service for tax assessments or environmental planning, consider using those images to estimate parking demand and oversupply. (See www.epa.gov/smartgrowth.)



Water that falls on the roof of this parking structure is just diverted to rain gardens. The design adds street level interest while reducing runoff.

City of Portland

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ADDITIONAL ONLINE RESOURCES

Stormwater authority
www.stormwaterauthority.org

This site offers links to each state's NPDES page. Go to the small tab named "Regulatory Data" to see a column of states.

Center for Watershed Protection
www.cwp.org

Low Impact Development Center
www.lowimpactdevelopment.org

EPA's smart growth page
www.epa.gov/smartgrowth

EPA's stormwater program home page
http://cfpub.epa.gov/npdes/home.cfm?program_id

Menu of best management practices
www. cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cf

Smart growth techniques as stormwater BMPs
www.epa.gov/dced/pdf/sg_stormwater_BMP.pdf

A Separate Stormwater Code

A separate stormwater code is good for communities without zoning or for those unable to revisiting an existing code. For example, the stormwater ordinance for Lafayette, Indiana, says the requirements of the ordinance are "in addition to" the minimum requirements of other land-use and water codes. The Lafayette code references the state's BMP manual. The key to a new stormwater ordinance is flexibility to respect local site constraints and environmental needs. (See lafayette.in.gov/Content/global/File/engineering/ord2005-08.doc.)

EMERGING ISSUES

The stormwater rules that are the impetus for this article are still making their way through the public process in hundreds of cities and counties. Unfortunately, the complex policy environment under which many of the decisions are made is not well understood. Planning and zoning officials should be knowledgeable of emerging issues.

Human and Financial Resources

Many cities are large enough to facilitate regulation but still too small to have fully funded, state-of-the-art stormwater departments. For these cities, there is the danger that BMP selection will trend toward those measures that are easiest to implement and the most familiar. As such, blanket requirements that apply to all development projects, no matter the context, will rise to the top because of ease of implementation. Conservation subdivision design is emerging as a popular BMP because most communities can easily modify the subdivision ordinance. Unfortunately, this does little to address the much larger implications of dispersed development.

A Veneer of Green

Developers are hopping on the green bandwagon in droves. The move towards green design dovetails nicely with increasing consumer interest to locate next to, or with views of, "green." However, green features are *not* synonymous with sustainable development. The Coalition for Smarter Growth (www.smartergrowth.net) and other groups have emerged to critique designs and advocate for compact development. One of the latest trends is inclusion of walking trails in site design. However, if they are not designed to replace car trips with walk trips, generous parking allotments will continue. Successfully managing impervious cover and stormwater is not just related to how water flows, but also how people flow.

Gray Bias

The green design movement is strong. As noted throughout this article, on-site management for water runoff has taken the engineering world by storm. While the attention is long overdue, the improvement of the gray infrastructure that supports an efficient city form is as important as ever. True, the old gray paradigm of diverting water as quickly as possible to local streams is no longer valid. Now is the time to take advantage of existing investments and augment the gray with green.

IN SUM

Whether intended or not, new stormwater rules provide an opportunity to forge links among disciplines that often move along parallel tracks. Potable water, transportation, housing, and jobs are impacted by stormwater runoff. To that end, good water quality practices equal irrefutably good planning.

ZONING REPORTS

LAND USE IN A NUTSHELL

John R. Nolon and Patricia E. Salkin. Thomson/West, 610 Opperman Drive, P.O. Box 64526, St. Paul, MN 551264-0526. 446 pp. 2006. Available from APA's PlanningBooks.com. $27.50; $25 for APA members.

Those who need a handbook-sized, but remarkably thorough, summary of American land-use law and how it applies to current practice would do well to invest in this new edition (with new authors) of a primary resource. Every chapter gets to the point efficiently and clearly in well-crafted prose. Topics include common law origins of land regulations, comprehensive plans, zoning, subdivision controls, and modern movements such as smart growth. More than a reference work, it can actually provide an interesting refresher on many points that many of us sometimes forget. This book can also serve well as a readable training tool for planning commissioners or inexpensive textbook for university planning students or those studying for the AICP exam.

Cover photo by Justine Hofnacks: A house under several feet of graphically rendered flood waters

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HOW CAN YOU DECREASE THE RISK OF FLOOD?

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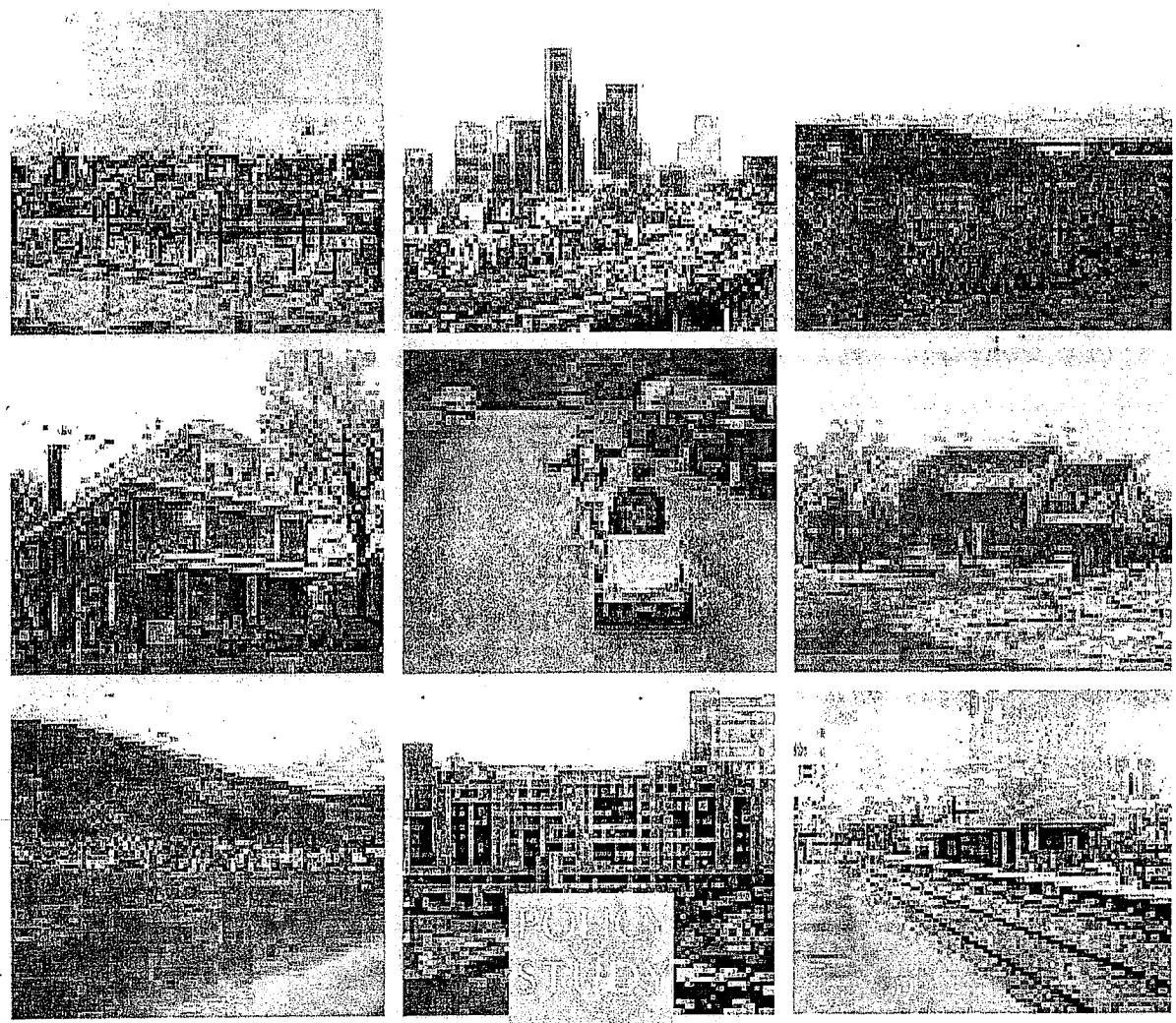
December 2001

Smart Growth in Action:
Housing Capacity and Development in Ventura County

by William Fulton, Chris Williamson, Kathleen Mallory, and Jeff Jones
Project Director: Samuel R. Staley



POLICY STUDY
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Solimar Research Group

Solimar Research Group is public policy analysis firm based in Ventura, California, that focuses on land use, metropolitan growth, and related policy issues. Solimar works with a variety of research and policy analysis partners across the ideological spectrum in order to improve the information available to policy makers and others interested in the field.

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Policy Study No. 288

Smart Growth in Action:
Housing Capacity and Development in Ventura County

By William Fulton, Chris Williamson, Kathleen Mallory, and Jeff Jones

Executive Summary

Urban growth has emerged as a touchstone policy issue, particularly on the state and local levels, ushering in an unprecedented new wave of growth-management and growth-control legislation. More than a dozen states have enacted some form of statewide growth-management law, and 37 others are actively considering growth-management legislation or planning reform laws that will directly affect the pace, pattern, and quality of land development. On the local level, hundreds of growth-management initiatives make it to local and statewide ballots each election cycle. One of the more salient trends in this movement is toward "ballot-box zoning"—the process of passing growth-management legislation and mandates through popular vote. Ballot-box zoning has been particularly prevalent in California, where dozens of cities and counties have adopted urban-growth boundaries and other growth controls to limit new land development.

Growth controls, however, are not implemented in a political vacuum. Once policies are adopted, local politics figure prominently into whether planning goals will be realized. Particularly in the United States, where planning is explicitly local and must be adopted by locally elected officials, these constraints are important elements of the planning process and should be incorporated into an evaluation of their success and recommendations for further reform.

Despite the groundswell of activism and apparent public support for this new wave of growth management, remarkably little analysis has been done on whether local governments actually can, in fact, implement planning goals and visions. In part, the dearth of research is a result of the highly localized nature of growth-management initiatives. Few have yet seen the benefit of analyzing growth-management policies that are targeted toward local problems and framed by local values and issues. While the specifics of local growth-management policies may vary, the implementation issues are applicable to other cities in California and in other states.

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Implementation issues, particularly assessments of the capacity of local communities to implement planning goals, are rarely addressed in the debate over Smart Growth or planning-law reform. This study begins to fill this void by examining the case study of Ventura County, California, a county of some 700,000 residents about 40 miles northwest of downtown Los Angeles and adjacent to Los Angeles County. Home to one of the most aggressive local approaches to growth management in the United States, Ventura County's experience has important lessons for all local governments that attempt to plan development. This study also provides a general framework for citizens and policymakers in other communities to assess their own capacity for accommodating future growth through their local plans and evaluating the potential implications.

Between 1995 and 2000, Ventura County voters passed a series of growth-control measures (the "Save Open-space and Agricultural Resources," or SOAR, initiative) that attempted to lock in existing land-use policies and require voter approval for conversion of agricultural, open space, or rural land to urban use. During the political campaign supporting the SOAR initiatives, proponents argued that the county, based on its current comprehensive plan, had the capacity to accommodate more than 60,000 new housing units before SOAR would expire in 2020. (A community's comprehensive plan is the primary policy document for guiding urban development, and typically outlines where, what kinds, and at what densities new development will take place.) The existence of a suitable planned capacity was a key argument, because opposition to the ballot initiative centered on whether Ventura County could adequately plan for and accommodate new housing in sufficient quantities. No one during the campaign, however, conducted an analysis of housing capacity to verify the advocates' claims.

To assess the ability and willingness of local governments to accommodate new growth, the researchers of this study reviewed housing trends, planning applications, and project approvals for all 10 cities in Ventura County. More than 120 projects, encompassing almost 12,000 approved housing units (covering more than two-thirds of the approved permits issued) were analyzed. After reviewing these projects as well as current planning policies and forecasted future demand, the authors concluded that the county is unlikely to be able to meet future housing demand, and that a crisis in housing supply will occur prior to SOAR's expiration in 2020.

Ventura County will likely need at least 312,000 housing units by 2020—a projected increase of 60,000 units (24 percent) over the 2000 housing stock of 252,000 units. This is close to the estimate that advocates of SOAR used as they urged citizens to pass the initiative. Yet, under current policies, the planned capacity of the county is targeted at somewhere between only 293,500 and 298,500 housing units—an increase of between just 41,500 and 46,500 units, or 16.5 percent and 18.5 percent over the existing housing stock. This, however, is the highest number that might be approved. Since 1996, cities in Ventura County have approved development projects at densities much lower than planned capacities, generally falling 20 percent below zoned capacities and 45 percent below General Plan capacities. Thus, the likely future housing development in the county under current planning policies and entitlement practices will generate about 33,000 units: 55 percent below the regional planning agency's housing target for 2020.

Research also found that the density of most projects was likely reduced during the pre-application stage of the project-approval process. Applications sought considerably fewer housing units than allowed under the General Plan. Then planning commissions and city councils reduced these densities by another 4 percent on average. Not all projects received equal treatment either. Affordable housing projects, multi-family projects, larger projects, and projects with plans tied to specific parcels of land were more likely to be approved at or near the capacity designated by planning policies, while smaller projects and projects in smaller cities tended

to apply for and be approved at housing densities much lower than the capacities designated by planning policies.

Cities, counties, and state legislatures across the nation are considering initiatives that will greatly increase the scope of land-use regulation at all levels of government—reforms that closely resemble the policies implemented in Ventura County. Many of these growth-management and planning reforms involve a significant increase of public participation during the development-control process. Effective implementation of these reforms requires a practical understanding of the implementation issues surrounding growth-management reforms and development control, especially the capacity of local communities to meet their planning goals and objectives.

This study suggests that there are significant deficiencies in the capacity of existing planning systems to accommodate rational planning goals. Despite passing a countywide growth-management initiative in 1998, most cities in Ventura County have not adjusted their plans or their development-approval processes to accommodate expected housing demand, creating conditions that are likely to lead to further housing-price escalation and increased political manipulation of the housing market.

The analysis of Ventura County shows that most of its cities will face significant housing shortages well before the end of the county's 25-year planning horizon. In fact, most cities in Ventura County have no more than 10 years of housing capacity left under current policies and entitlement practices.

SOAR will begin to have a major effect on new housing development between 2005 and 2010 as planned housing capacity is used up—first in a few cities, then gradually countywide. Development pressure will increase within cities to increase zoning densities, change General Plans to allow more housing, and possibly redevelop and rehabilitate existing housing. Projects that try to bring new land inside the growth boundaries for voter approval will need to be different from those approved in the past for development. Unless SOAR is changed or invalidated, the county and its cities are unlikely to meet estimated future demand for additional new housing, and tight housing market effects will increase over time. The lessons learned from the "laboratory" of Ventura County, a county with substantial experience in growth management and planning reform, could be valuable for other cities and counties across the U.S. that are wrestling with growth management.

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Part 1

The Rise of Smart Growth and Growth Management

Population growth and large-scale housing development have made urban growth a touchstone policy issue, particularly at the state and local levels. Although federal policy has yet to coalesce around a common, broad-based theme, the national significance of the issue is difficult to ignore. More than a dozen states have enacted some form of statewide growth-management law focused on further regulating land development and increasing the role of land-use planning in shaping the physical landscape of communities and rural areas. Many statewide growth-management laws, for example, identify curbing "urban sprawl" as an explicit policy goal. Thirty-seven states are actively considering growth-management legislation and planning reform laws that will directly influence the pace, pattern, and quality of land development.[1] At least eight states have endorsed a strong state role in managing growth on the local level by adopting statewide growth-management laws, and eight more have adopted comprehensive planning-reform statutes that give local governments additional planning authority and responsibilities.

The most heralded case may be Oregon, the first geographically diverse state to implement a statewide planning law.[2] The Portland metropolitan area has engaged in top-down regional land-use and transportation planning since 1979 and is often referred to as a national model for the contemporary wave of growth management.[3] It instituted a regional plan in the 1990s (the 2040 Plan) that emphasizes compact, mixed-use development that is transit-focused. Other states have taken different approaches, from top-down state action in Florida to more decentralized and bottom-up approaches in Georgia and Tennessee.

On the local level, concerns about growth have energized dozens of growth-management and growth-control proponents across the nation. Hundreds of growth-management initiatives make it to local and statewide ballots each election cycle. While some high-profile losses have been noted in the press (e.g., Arizona and Colorado), most initiatives supporting increased funding for parks, open space acquisition, and milder forms of growth management successfully passed.[4]

Proponents of growth management have settled on several core principles and elements under the broad rubric of "Smart Growth". Brookings Institution urban policy analyst Anthony Downs notes that, while substantial disagreements on some issues persist (e.g., placing hard limits on outward expansion or reducing automobile use), a consensus seems to be emerging on several policy goals, including preserving large amounts of open space, redeveloping inner-city core areas, removing barriers to urban-design innovation, and the importance of a creating a sense of community and regional interdependence.[5] In addition, while the detail and style of Smart Growth shifts, many of the common themes include a significantly expanded role for local and regional political control over growth.[6] Rick Rosan, president of the Urban Land Institute, notes that

"Smart Growth is an attitude, a process of collaborating and working together to create neighborhoods."[7] This perspective echoes reality. As Tennessee cities and counties began developing their growth plans, Smart Growth was described as "...about finding ways to manage sprawl and improve our total quality of life."[8]

Smart Growth, however, is more than a planning process. Most Smart Growth plans include an explicit goal to prevent low-density residential and commercial development, sometimes called urban sprawl. Broad-based Smart Growth reforms are also intended to create more rationality in land-use planning to ensure community goals are met. Thus, the reforms are not intended to simply increase the inclusiveness of planning process (although that might be one of many outcomes); they are also supposed to achieve specific outcomes. For example, even though Smart Growth in Tennessee is described as a way of planning for communities, the Smart Growth legislation specifies goals and objectives to be included in local government plans. The growth plans, for example, must include a unified design for development and encourage compact, contiguous, and high-density development.[9]

Unfortunately, few efforts have been made to evaluate the capacity of local planning processes to accommodate the goals of growth-management advocates. In part, this is because the movement itself is new and, except for a few states, highly localized. Even statewide growth-management laws with a top-down, state-driven approach still depend on local governments to plan locally and then send the plans to higher levels of government for approval. Some evidence suggests that local-plan implementation issues are significant. More than half of the comprehensive plans for Florida's cities, for example, were rejected by the state Department of Community Affairs because they were out of compliance with the state's growth management laws.[10]

More than a dozen states have enacted some form of statewide growth-management law focused on further regulating land development and increasing the role of land-use planning in shaping the physical landscape of communities and rural areas.

Once plans are adopted, local politics may also figure prominently in whether the goals of the plan will be achieved. Thus, growth-management reforms must also consider the political environment in which the reforms are proposed and implemented. Particularly in the United States, where planning is explicitly local and must be adopted by locally elected officials, these constraints are important elements of the planning process and should be incorporated into an evaluation of their success and recommendations for further reform. However, implementation issues, particularly an assessment of the capacity of local communities to implement a planning vision, are rarely addressed in the debate over Smart Growth or planning-law reform.

This policy study begins filling this void by examining the effects of implementing the modern wave of growth-management policies at the county level using a case study of Ventura County, California. While the specifics of the case study apply most directly to Ventura County, the analysis of how the county's growth-management policies were adopted and the issues concerned with accommodating housing demand and supply hold important lessons for other cities, counties, and states. In addition, the study provides a general framework that can be used by citizens and policymakers in communities throughout the nation to help evaluate the impact of adopting growth-management policies with similar features. More specifically, the study focuses on the following objectives:

- Describing trends between 1990 and 2000 regarding the county's population, housing, and development;

- Comparing planned housing capacity with the likely actual capacity, given the experience of recent housing projects as they worked their way through the approval process and using local comprehensive plans as a benchmark;
- Calculating likely future development "buildout" and comparing it to the projected demand; and
- Discussing possible implications, with and without county growth-management policies in place.

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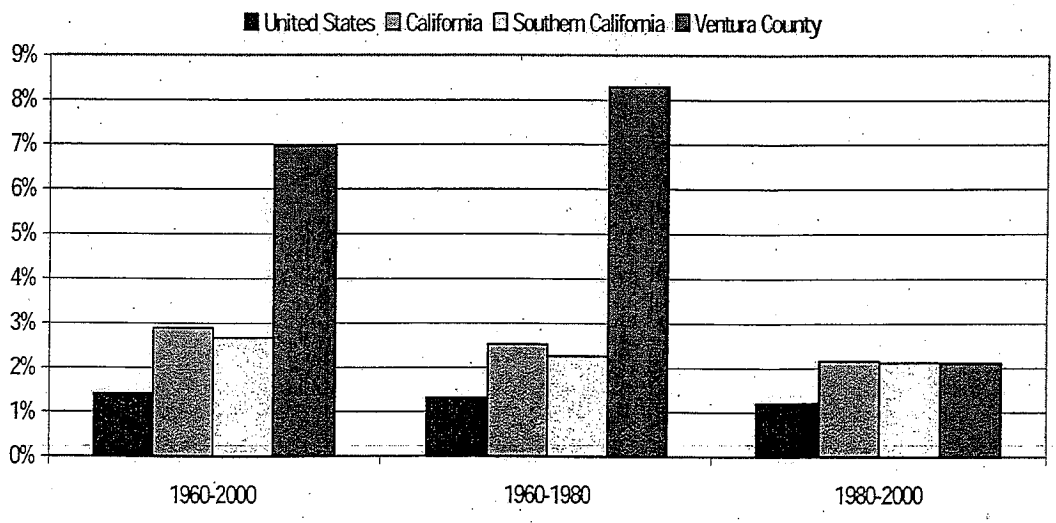
Part 2

Ventura County and Smart Growth

In many ways, Ventura County is an ideal case study of local growth-management policy. A mostly affluent county of 753,000 residents immediately north and west of Los Angeles County, it is also one of the nation's largest counties, ranking in the ninety-eighth percentile in population.[11] Over the past 40 years, Ventura County retained a strong agricultural tradition while accommodating a large amount of urban growth, driven, in large part, by its proximity to the city of Los Angeles and to the San Fernando Valley. Between 1960 and 2000, Ventura County's population grew at an overall annual rate of 7.0 percent, five times greater than the national average and more than twice the rate of the rest of Southern California (Los Angeles, Orange, San Bernardino, and Riverside Counties) and the state as a whole (Figure 1).[12] Thus, Ventura County is facing significant growth pressures, prompting grassroots support for increased growth-management efforts. More importantly, Ventura County should have the wealth and resources to successfully implement countywide planning if it chooses.

Figure 1: Average Annual Population Growth for the United States, California, Southern California, and Ventura County: 1960 to 2000



Source: U.S. Census Bureau, Census of Population (see Appendix A).

Not surprisingly, the amount of new housing built in Ventura County also increased dramatically. The number of units more than tripled between 1960 and 2000, increasing from 60,698 to 251,712 units (Table 1).

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The rate of growth, however, has declined notably over the last 20 years; housing growth fell from 85 percent during the 1960s to just 10 percent in the 1990s, a pattern mirroring growth trends in population. The absolute number of housing units added each decade also dropped dramatically, from 71,000 in the 1970s (the high point) to 23,000 in the 1990s.

Table 1: Change in Housing Units, 1960-2000

Year	Total Units	Addl. Units	Change
1960	60,698	—	—
1970	112,133	51,435	84.7%
1980	183,384	71,251	63.5%
1990	228,478	45,094	24.6%
2000	251,712	23,234	10.2%
Total	—	191,014	314.7%

Source: U.S. Census Bureau, Census of Housing (see Appendix A).

A. Growth Management in Ventura County

For more than 30 years, Ventura County has also been at the forefront of California's well-known movement to manage and control urban growth at the local level. Most important is the fact that between 1995 and 2000, voters in seven of the county's 10 cities and in the county itself passed a related series of growth control measures called the "Save Open-space and Agricultural Resources" measures, or SOAR. These measures lock in current land-use policies and require voter approval for conversion of additional agricultural or open space land to urban use.[13] They also mimic local-level strategies adopted as part of statewide growth-management programs in states such as Oregon and Washington State.[14] During the 1990s, SOAR-style initiatives also proliferated throughout California. Table 2 outlines when and how Ventura County's SOAR ordinances were adopted in each jurisdiction, and how long they will remain in effect.

Table 2: SOAR Measures by City and County, 1995-2000

	Census 2000 Population	Year SOAR Approved	Percent Approval	Sunset Year	Notes
Ventura County	753,197	1998	63%	2020	
Camarillo	57,077	1998	66%	2020	
Fillmore	13,643	N/A	—	—	57.1% 'No' vote in 2000, but city officials and SOAR proponents reached an agreement in October 2001 on a proposed growth boundary.
Moorpark	31,415	1999	67%	2020	
Ojai	7,862	N/A	—	—	Firm historic support for little or no growth
Oxnard	170,358	1998	70%	2020	
Port Hueneme	21,845	N/A	—	—	Fully bounded by Pacific Ocean and Oxnard
Santa Paula	28,598	2000	55%	2020	Failed in first 1998 vote
Simi Valley	111,351	1998	70%	2020	
Thousand Oaks	117,005	1998	71%	2030	
Ventura (city)	100,916	1995	52%	2025	Formal name is San Buenaventura

Note: The sunset year is the last year in which the initiative can be in effect.
Sources: www.ventura.org/election and U.S. Bureau of the Census (see Appendix A).

A recent brochure compiled by the Ventura County Planning Division summarizes the scope of the SOAR initiatives:

> *Generally, the cities' SOAR ordinances and initiatives establish 'City Urban Restriction Boundary' (CURB) lines around each city and requires city voter approval before any land located outside the CURB lines can be developed under the city's jurisdiction for urban purposes. The County SOAR ordinance requires countywide voter approval of any change to the County General Plan involving 'Agricultural,' 'Open Space' or 'Rural' land use map designations, or any change to a General Plan goal or policy related to those land use designations.*[15]

In effect, the supply of land planned and/or used for commercial, industrial, and residential development at the time of SOAR's enactment is "locked-in" through 2020 unless a majority of voters approves a change to an urban-growth boundary and/or conversion of non-urban land to urban use. Advocates emphasize that SOAR initiatives are not "no growth," arguing that current General Plans provide for approximately 60,000 additional housing units by 2020 (an increase of approximately 25 percent), which they argue "hardly equals no-growth."[16]

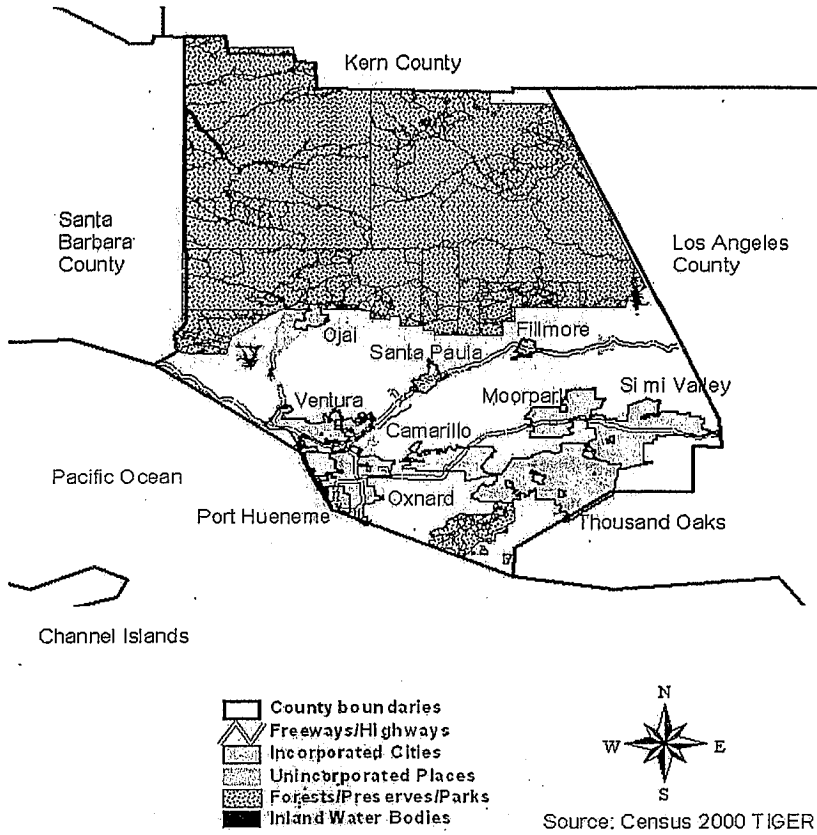
During the 1990s, SOAR-style initiatives also proliferated throughout California.

Based on 1996 California Farmland Mapping and Monitoring Program data, almost all urbanized areas were within urbanized growth boundaries at the time the SOAR initiatives were proposed. Sizeable pockets of agriculture were also located in Oxnard, Camarillo, and the city of Ventura (see Figure 2). Thousand Oaks and Simi Valley had the largest areas of undeveloped land that were neither wetlands nor over 25 percent slope. Ventura and Santa Paula have large undeveloped areas inside their boundaries, but these areas often have steep slopes of more than 25 percent. Of those cities that have undeveloped land inside their boundaries that is not affected by a slope issue, Thousand Oaks and Simi Valley have the most.

On the other hand, some community leaders, property owners, and developers have expressed concern that the existing inventory of vacant and underutilized land within already designated urban growth boundaries and/or already designated for urban uses will not likely keep pace with actual demand for new housing and commercial space and may already be having an impact on development. If these concerns are valid, the process for managing growth and land supply becomes critical to the success of the growth-management program.[17]

As in most fast-growth communities, growth and land development are geographically focused. Urbanization and agricultural cultivation are centered in the southern third of Ventura County between the Los Angeles County line and the Pacific Ocean (Figure 2). The northern two-thirds of the county is comprised almost entirely of the Los Padres National Forest, a rugged mountainous area with relatively few residents. Despite a population of three-quarters of a million people, agriculture is still strong in the county, with about 120,000 acres in production, mostly in the coastal areas. Ventura County agriculture production topped the $1 billion mark in 2000 for the second year in a row, maintaining its position as one of the top farm regions in the state. About 10 percent of the population lives in the northern section of the county while the remaining population is about evenly divided between the eastern and western sections. Freeways generally run east to west and along the coast. The Point Mugu Naval Air Station and Santa Monica Mountains form the southern edge of the county.

Figure 2: Map Of Ventura County



For the purposes of this analysis, the county is divided into three regions: North, East, and West. In the north, just south of the forests, are the three small cities of Fillmore, Ojai, and Santa Paula that remain largely agricultural in orientation. The western coastal plain includes the cities of Ventura (formally named San Buenaventura), Camarillo, and Oxnard, and each is continuing to add housing, office, and commercial development. The eastern part of the county includes the cities of Simi Valley, Thousand Oaks, and Moorpark. These emerged as middle and upper-income bedroom suburbs of Los Angeles beginning in the 1950s and are now adding employment centers as well as most of the additional housing during the 1990s. The section of Highway 101 near Thousand Oaks, for example, is an emerging "technology corridor" and home to high-tech firms such as Amgen, Inc.[18]

B. SOAR and Growth Management

California has a long history of growth management and growth control. While some aspects of its growth-management system make California unique (e.g., the California Environmental Quality Act), many of the issues and tools used to manage growth are common in other parts of the nation. California cities, for example, manage growth through general (or master) plans, and zoning laws are required to be consistent

with the General Plan. Cities are also allowed to use Specific Plans to facilitate the development of large integrated phased development projects in ways similar to Planned Unit Developments (PUDs).

More importantly, California's size and diversity provide an important backdrop for assessing various types of growth-management plans. For example, Petaluma, a community north of San Francisco, tested the waters of the state's growth-management laws when it imposed a cap on housing permits pegged at 500 per year in the early 1970s.[19] More recently, California cities were among the nation's leaders in adopting urban-growth boundaries and using initiative and referenda for planning purposes.[20] Ventura County was in the forefront of these growth-management efforts. In fact, SOAR is best seen as a continuation of a 30-year history of growth control in Ventura County that more closely resembles the activist approach taken by San Francisco Bay area cities and counties.[21]

In 1969, Ventura County, its cities, and the Local Agency Formation Commission (LAFCO) agreed on the *Guidelines for Orderly Development* to channel urban development away from unincorporated areas and inside city boundaries.[22] LAFCO placed a limit on the number and geographical arrangement of new cities and also strictly controlled the cities' "spheres of influence" (SOI)—adjacent territory cities will be permitted to eventually annex when developed.[23] In short, the county created urban-growth boundaries in an effort to establish distinct urban communities and distinguish between rural and urban land.

Between 1967 and 1986, the county and many cities also adopted five Greenbelt Agreements that were unenforceable but politically important policy statements designed to set aside agricultural "greenbelts" and physically separate the cities from one another. In the 1980s, most cities in the county also adopted annual numerical caps on the number of new housing permits.

The agricultural industry remains an important part of Ventura County's economy and identity and protecting agricultural resources has been an important part of Ventura County's policy history. The first move toward recognizing and protecting agricultural land was the Agricultural Land Protection Program (ALPP), which began in 1982. This program was responsible for adding an agricultural component that strictly tied urban growth on agricultural land to the county's General Plan.

As a result, 30 years of Ventura County growth controls have helped create a distinctive physical landscape in which:

- There are a limited number of cities;
- No city is dominant;
- Most cities have populations of between 50,000 and 150,000; and
- Each city retains a distinct geographical identity surrounded by agricultural and open-space land.

This physical landscape is well-suited to an analysis of the implementation issues surrounding growth management. The county's long history with growth management and small number of jurisdictions facilitate data gathering and analysis. In addition, given the most recent wave of growth-management laws driven at the ballot-box, the county is still small enough to investigate the nuances associated with development control and approval at the municipal and county levels.

Agricultural Land Planning in Ventura County

While several policies, forecasts, and plans were developed and updated between 1970 and 2000, there was no comprehensive, inter-jurisdictional review of county growth policies. This changed with the organization of the Beyond the Year 2000 Advisory Committee, established in 1988 by the Ventura County Board of Supervisors. The Committee's goal was to determine whether new growth-management policies should be considered. The Committee initiated several sub-projects to assess different aspects of land use in the county. One group, the Agricultural Land Trust Advisory Commission (ALTAC), was established in 1989 to focus on agriculture. ALTAC met for 16 months to try to determine ways to protect agricultural land more effectively. The three principal ALTAC recommendations were:

- Form a nonprofit agricultural land trust;
- Purchase (or transfer) development rights; and
- Allocate a percentage of sales tax to fund acquisition of farmlands.

The first recommendation was completed through the establishment of the Ventura Agricultural Land Trust (VALT), which started meeting in 1992 and is the only countywide conservancy. Neither of the other two tasks was implemented.

ALTAC served as a precursor to the Agricultural Policy Working Group (APWG) established by the Board of Supervisors in May 1997 to address the question: "How do we secure our agricultural lands?" Two events pushed this question to the forefront. First, Ventura city passed a voter-initiated SOAR ballot measure in 1995, and its success was pushing county officials to be more proactive about growth and agricultural issues. Second, the Hansen Trust (endowed by the last member of a long-time Santa Paula farming family) funded a report that discussed agriculture in Ventura County entitled *The Value of Agriculture to Ventura County: An Economic Analysis.* This report stimulated discussion about various aspects of the agricultural industry, and eventually moved the APWG to develop farmland preservation measures that were later endorsed through the approval of Measure A, an advisory growth-control law that was intended as an alternative to SOAR. Both Measure A and SOAR (Measure B) were on the November 1998 ballot, and both passed with about a two-thirds majority of the vote.

Part 3

Housing Capacity Analysis

As in other areas of the nation, housing is at the center of Ventura County's growth-management efforts. This is not surprising, since most local objections to growth in Ventura County and elsewhere are centered on housing development. Residential development constitutes the largest share of property valuation and urban acreage and generally has the largest impact on the physical landscape.[24] Thus, as population increases, changes in the physical environment are apparent, and these perceptions influence the planning process. Therefore, a first step toward assessing the impact of a growth-management plan or reform is to create a baseline for development trends, particularly in housing.

A. Estimating Population, Housing, and Permits

Census 2000 data provides an initial look at changes in Ventura County in the 1990s, a starting point for examining planned future housing capacity and development. With more than three-quarters of a million people, Ventura County ranks as the nation's sixty-fourth and California's twelfth most populous county.[25] During the past decade, more than 8,400 persons, 2,300 housing units, and 2,500 households were added to Ventura County each year, on average (Table 3). Population and households increased faster than housing units during the 1990s, suggesting on a general level that the demand for housing may be outstripping the supply.

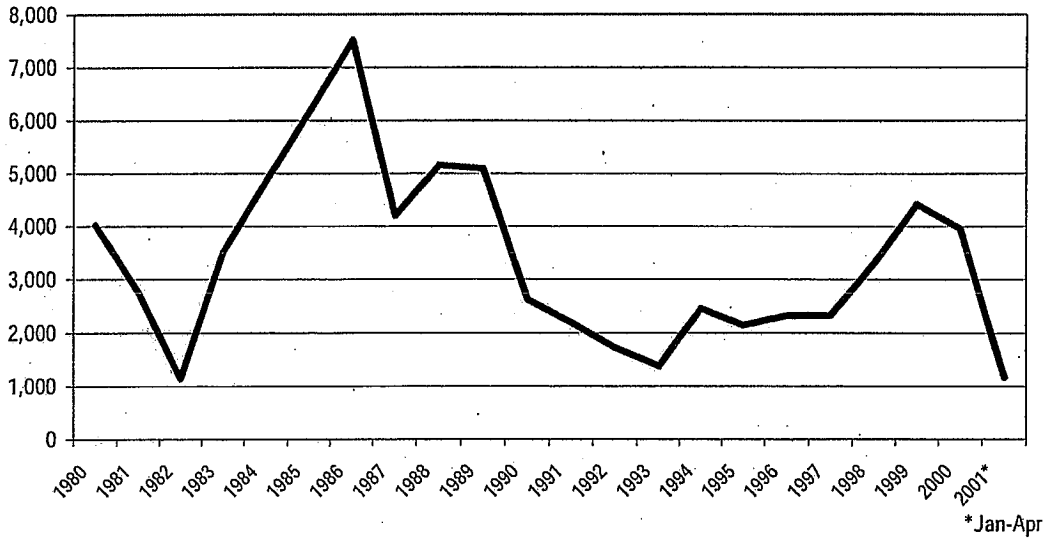
Table 3: Population, Housing Units, and Households in Ventura County, 1990-2000

Ventura County	1990	2000	Net Change	Percent
Population	669,016	753,197	84,181	12.6%
Housing Units	228,478	251,712	23,234	10.2%
Households	217,298	243,234	25,936	11.9%

Source: U.S. Census Bureau, Census of Population and Housing (see Appendix A).

Figure 3 shows the number of permits for housing units issued in Ventura County each year since 1980 through the first four months of 2001.[26] Between 1980 to 2001, almost 3,500 permits were issued annually, on average. During the 1990s, however, the average number of permits issued annually fell to 2,647. Housing permits rebounded somewhat in the late 1990s, increasing to an annual average of 3,280 between 1996 and 2001. To some extent, this variation can be explained by the economic cycle: the economic boom of the late 1980s was followed by a steep regional recession in the early 1990s. By 1995 building-permit activity had increased and peaked in 1999, dropping off in 2000 and 2001.

Figure 3: Building Permit Activity in Ventura County, 1980 to 2001



Source: U.S. Census Bureau, Survey of Construction & USA Counties 1998 (see Appendix A).

Unfortunately, city-specific permit data are only available from 1996 to 2001. Nevertheless, these data show that the county's three biggest cities—Oxnard, Simi Valley, and Thousand Oaks—accounted for two-thirds of all residential construction in Ventura County (Table 4) even though they represented only half of the county's population.

Table 4: Building Permits by County and City, 1996-2001

	Total Units	Annual Avg.	Mean Construction (Cost per Unit)
Ventura County	*17,493*	*3,280*	*$203,488*
Camarillo	2,150	403	$197,657
Fillmore	332	62	$185,048
Moorpark	895	168	$172,772
Ojai	35	7	$202,547
Oxnard	3,651	685	$155,125
Port Hueneme	41	8	$105,971
San Buenaventura	1,081	203	$184,666
Santa Paula	89	17	$156,746
Simi Valley	4,154	779	$213,063
Thousand Oaks	3,839	720	$229,184
Unincorporated	1,226	230	$295,520

Source: U.S. Census Bureau, Survey of Construction (see Appendix A).

B. Step One: Estimating Planned New Housing Capacity

Under the existing planning policies of the county and its 10 cities, Ventura County has a "buildout" capacity of approximately 293,400 housing units—an increase of 41,500 (16.5 percent) from the current total. If pending development proposals for Ahmanson Ranch and the Ventura Hillsides are included, this total capacity increases to 298,350 units, an increase of 46,450 (18.5 percent from the current total).

To determine the planned capacity for new housing construction, we reviewed two sets of documents for the county and for all 10 cities: the Land Use Elements of their existing General Plans, and their current or draft Housing Elements. The Land Use Element establishes broad categories of uses for all geographic areas (such as low-density housing, neighborhood commercial, open space) and is intended as a long-term policy statement (usually covering 20 years). The Housing Element has a five-year revision cycle and is supposed to include the vacant, infill, and underutilized land in each jurisdiction, thus providing the ability to estimate residential buildout beyond 2005.

The county is obligated by California law to calculate the potential housing legally allowed through zoning on all land, even if the parcel lacks utility service, is in a remote area, or is designated as open space or agriculture. This study assumes that residential development on this type of land is not likely to occur by 2020, and adjustments were made to the number of potential additional dwelling units in the unincorporated county (see Table 5).

Population and households increased faster than housing units during the 1990s, suggesting on a general level that the demand for housing may be outstripping the supply.

Table 5: Adjusted Unincorporated County Housing Capacity

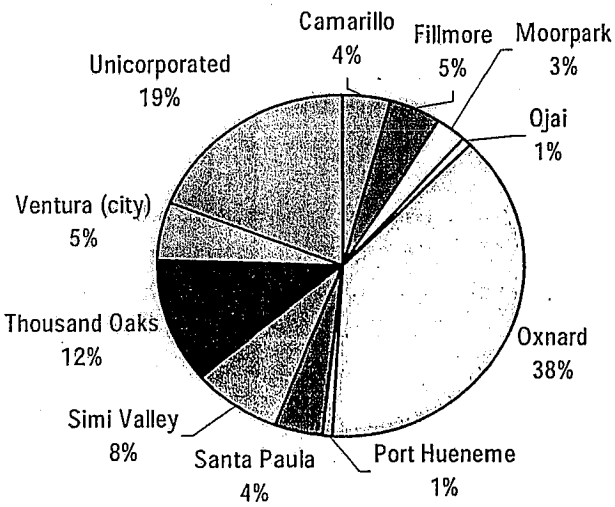
	Units
Unincorporated county	19,329
▪ Agricultural, open space and rural	(8,423)
▪ Ahmanson Ranch	(3,050)
Adjusted unincorporated county	7,856
Incorporated cities	33,623
Ventura County as a whole	41,479

Source: Ventura County and city of Ventura Housing Elements (see Appendix A).

Housing capacities are based on current zoning in which the allowed housing density is usually less than the General Plan designation. The Housing Elements for the cities and their spheres of influence list capacity for 33,623 units; the unincorporated county has an adjusted capacity for 7,856 units. Thus, total future additional residential development capacity is 41,479 housing units, or 63.4 percent of the General Plan capacity, based on the formally approved planning documents used by Ventura County governments when regulating land development. The Ahmanson Ranch Project could add another 3,050 units and Ventura Hillsides could add another 1,900 units. Neither of these projects was included in the Housing Elements. Thus, housing capacity could grow by an additional 4,950 units if the General Plans are modified and the projects are developed as proposed.[27]

Housing development and capacity are not evenly spread out among the county's cities. About 40 percent (almost 16,000 units) of the estimated housing capacity is located in the city of Oxnard and its sphere of influence (Figure 4). Almost 20 percent (7,800 units) is located in unincorporated county territory. The only other cities with considerable capacity are Thousand Oaks (4,991 units, or 12 percent of the total) and Simi Valley (3,266 units, or 8 percent) of the total.[28]

Figure 4: Distribution of Planned Additional Housing Capacity in Ventura County



Source: Various Housing Elements – See Appendix A

C. Step Two: Estimating Residential Demand

Planned capacity, however, is far below forecasted housing demand. The Southern California Association of Governments (SCAG) prepares population, housing, and employment projections in conjunction with the California Department of Finance using a range of demographic techniques and administrative data such as motor-vehicle registration and school-enrollment data. In May 2001, the Ventura Council of Governments (VCOG) adopted its version of the forecast. VCOG expects housing demand in Ventura County to grow by 60,483 units by 2020. An estimated 17,277 housing units will be needed by 2005, but the biggest surge in demand is expected between 2010 and 2020, when more than 27,000 additional housing units will be needed (Table 6).[29]

Table 6: VCOG Forecast 2000-2020 for Ventura County

	2000	2005	2010	2020	Net change
Additional Housing Units	-	17,277	15,611	27,595	-
Total Housing Units	252,191	269,468	285,079	312,674	60,483

Source: Ventura Council of Governments (see Appendix A).

At the capacity reported in the Housing Elements, the county is approximately 19,000 units short of meeting projected 2020 demand (or 14,000 short if Ahmanson Ranch and the "hillsides" are developed as proposed). Thus, VCOG expects that housing demand will generate a need for housing one-third higher than current planned capacities.[30] However, housing-unit capacity and demand varies greatly among the cities of Ventura County, and some cities will be able to meet demand with their capacity farther into the future. Thus, housing shortages are likely to appear at different times and in different degrees if VCOGs forecasts are accurate.

D. Step Three: Comparing Planned Capacity to Actual Development Trends

Planned capacities, however, often do not reflect the realities of the land development or the development approval (entitlement) process. Development projects are not always approved and built at the densities allowed by the General Plan (which are usually maximums) and zoning designations. Medium and large residential projects are also often subjected to environmental reviews that reduce the area or intensity of development to mitigate significant negative environmental impacts under the California Environmental Quality Act (CEQA) and other applicable state and federal regulations and laws. A developer will often meet with elected officials, community representatives, and/or planning staff in the early stages of designing a project and the formal entitlement application may be for less than the allowed number of units. The application-review process also often requires public hearings where opposition may lead to additional changes in the project. After a project is approved, an appeal opportunity exists, and the project may be legally challenged under a variety of causes of action (such as an inadequate environmental review).

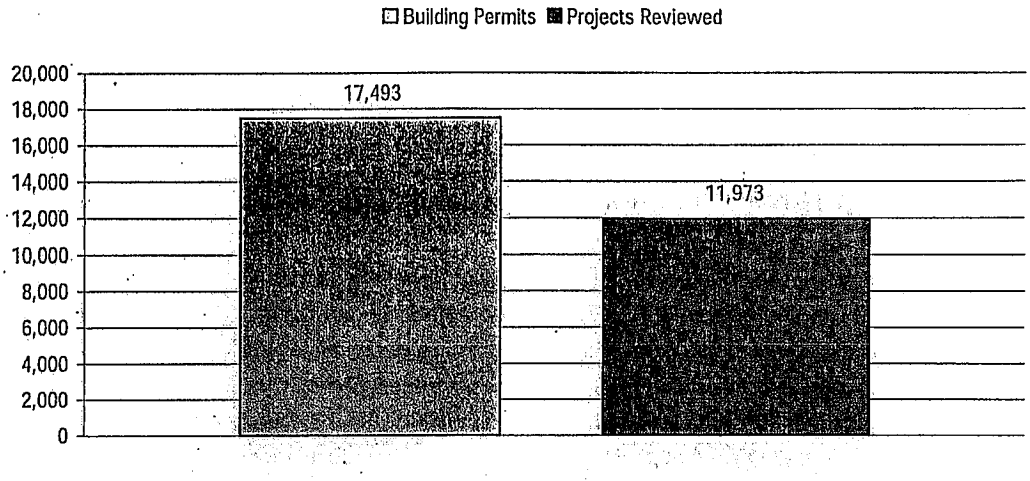
Given these considerations, it seems likely that the actual housing development projects will be smaller (i.e., have fewer units) than the General Plan and/or zoning permits. In short, real housing capacity may be substantially less than planned capacity.

E. Development Review in Ventura County

To more fully analyze this trend, the entitlement process was examined for 126 residential projects, totaling more than 11,900 units, approved between January 1996 and April 2001. All cities in Ventura County were included except for Moorpark, which insisted on charging a staff "screening" fee before allowing access to the project files. Countywide estimates were used for Moorpark.

The project-based data represents more than half of all building permits in the time period (Figure 5). In order to ensure a large enough sample and still meet the project's timetable, the review was limited to 30 in some cities. Project files were searched for the name, location, acreage, General Plan designation, zoning, and number of units approved. The resulting data were placed in a spreadsheet and sent to each jurisdiction's planning department requesting review. Six cities responded and the data were amended to reflect their comments (see Appendix A for a complete methodology and data description).

Figure 5: Projects Reviewed and Permits Issued 1996-2001



Source: Solimar Research Group and U.S. Census Bureau (see Appendix A).

The Specific Plan in California Planning

Specific Plans have emerged as an important element of the planning process in California. These provide specific guidelines and standards for developing land in geographically designated areas, giving "cities and developers the flexibility to create zoning standards appropriate to the site and the project in question."[31] Unlike the General Plan, which is a policy document, Specific Plans are designed as implementation tools and function similarly to planned-unit developments in other parts of the nation. According the Governor's Office of Planning and Research, more than 160 cities and counties have adopted Specific Plans, most of them initiatives by local governments.[32] They can cover land areas as large as tens of thousands of acres or less than one acre.[33]

Specific Plans have become popular in the private and public sectors because they can eliminate uncertainty in the plan-approval process. Local governments can use them to provide information to the private sector about what kinds of development are politically preferred in certain areas. By tailoring development plans to these criteria, project approval could be shorter and more certain. For the private sector, the Specific Plan creation process can help negotiate a more flexible and diverse development than would be allowed under existing zoning.

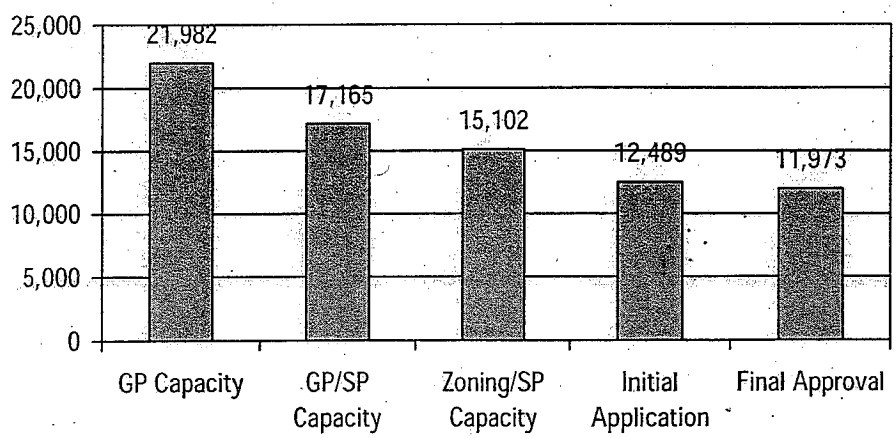
While some Specific Plans have focused primarily on setting goals and policy for areas, most involve regulation of specific land uses and types. In some cases, the Specific Plans can be very detailed. A 3,000 housing unit Specific Plan for a 865-acre area just east of downtown San Jose, for example, called for detailed breakdowns of land uses, including counts for specific lot sizes (e.g., 425 lots of 4,000 square feet), development standards for different size lots, an infrastructure and finance plan, an offsite traffic mitigation plan, and guidelines for amending the plan.[34]

The project-based analysis compared General Plan capacity, zoning capacity, and the size of the project as it was initially proposed and then at several points in the entitlement process to more fully understand how the projects were modified as a result of the planning process. Specific Plans were important in several cities—sometimes operating more like policy-oriented General Plans, sometimes more like zoning. Based on this analysis, three measurements of capacity were created: 1) the General Plan capacity, 2) the General Plan or Specific Plan capacity depending on which was binding, and 3) the zoning or Specific Plan capacity.[35]

The analysis yielded the seven conclusions presented below:

1. **Projects were approved at densities between 55 percent and 79 percent of planned capacity.** The total capacity of all the parcels of land involved in the 126 projects was somewhere between 15,100 and 22,000 units, depending on whether the General Plan, Specific Plan, or zoning in various combinations were used as the measurement. However, the number of units approved was just below 12,000 units—representing just 79 percent of the hybrid zoning/Specific Plan capacity, 70 percent of the hybrid Specific Plan/General Plan capacity, and 55 percent of the General Plan capacity (Figure 6).

Figure 6: Housing Units from Capacity to Approval in Ventura County



Source: Analysis by authors.

2. **Most of the reduction in capacity came at the time of the application; very little further reduction occurred in the approval process.** Most reduction in density occurred because the applicant chose to apply for fewer units, not because the applicant's density was reduced in the public-review process. Again, Figure 6 shows that despite capacity of between 15,000 and 22,000 units, applicants chose to submit applications totaling only 12,500 units. During Planning Commission and City Council review, the total approved was reduced to 11,973 units, a 4 percent decline. It would appear that in many projects, density reductions occurred at the pre-application stage, not during the entitlement and approval processes. It is possible that planners and/or consultants advised developers of what is "politically feasible" density. Unfortunately, available resources did not permit an extensive examination of the source of these pre-application density reductions and whether they were market-driven or planning-driven.

3. **Cities with a population of 50,000 or more approved projects closer to the General Plan capacity than in the cities under 50,000.** Projects in larger cities were approved at a rate 20 percent higher than those in smaller cities. Smaller cities experienced virtually no change in the percentage of housing units approved whether compared to General Plan, Specific Plan, or zoning densities. It appears smaller cities rarely use Specific Plans or reduced zoning densities to alter the General Plan.

4. **Projects that were 100 percent affordable were more likely to be approved at or close to zoning capacity.** Thirteen affordable housing projects with a total of 908 units were approved at 90 percent of zoning capacity. These projects were located in six cities, ranged in size from 14 to 190 units, and represent a small sample of projects. These projects are consistently closer to their maximum housing-unit allocations than are non-affordable housing projects. This may be the result of density bonuses mandated by state laws. The result also suggests that cities will reduce an affordable housing project's underlying allowed density to ensure that, even with a density bonus, the project is just at or under the maximum allowed capacity.

Projects in larger cities were approved at a rate 20 percent higher than those in smaller cities.

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5. **Multi-family project densities were reduced less than single-family project densities.** Multi-family projects were more likely to receive approval at or near their maximum densities than were single-family projects. Single-family projects were approved at 79 percent compared to 87 percent for multi-family projects. Generally, multi-family units "lost" during the approval process may be "recovered" with design changes since the final number of units was not as critical as the traffic generation and location and massing of the structure(s). Reductions to single-family projects, on the other hand, are not usually made up by smaller lots and/or units.[36]

6. **North county (Fillmore, Santa Paula, and Ojai) projects experienced a lower rate of approval than projects in the East or West County.** North county projects in Fillmore, Santa Paula, and Ojai were approved at about 61 percent of allowed zoning density compared to 89 percent in east county and 76 percent in west county cities. The increased use of Specific Plans with coordinated zoning in the east and west county cities may have played a role in the higher approval rate, and much of the east and west county development was by experienced large-scale merchant builders.

7. **Large projects were reduced less than small projects.** Large projects were reduced by 26 percent compared to 37 percent for medium-sized projects and 54 percent for small projects when comparing approved density to General Plan and Specific Plan densities. Large-scale merchant builders are experienced in the entitlement process while small-project developers may be somewhat more naïve. Small-scale infill projects would also tend to have increased community awareness and possible opposition. This suggests that smaller projects may experience planning commission-imposed "knockdowns" during the approval process rather than during the preapplication period.

8. **Specific Plan area projects were approved at close to Specific Plan densities while non-Specific Plan projects had larger reductions.** Cities adopt Specific Plans to create a more precise build-out program of a particular area. Not surprisingly, projects in Specific Plan areas have a higher density approval rate than projects not located in Specific Plan areas. Non-Specific Plan projects have a reduction rate that is 28 percent greater than projects in Specific Plan areas. Specific Plans are often proposed in cooperation with local business and community groups who then support the subsequent conforming projects. Specific Plans would have also had environmental review prior to adoption that would be reflected in their zoning, minimizing additional project-specific density reductions for environmental reasons.

F. Calculating Buildout

Given current policies and the past history of actual applications and approvals, a more realistic housing-capacity forecast for the county was developed. The sum of all units likely to be built in the county equals 33,257 units, which is 80.2 percent of the countywide planned capacity of 41,479 units, not including the Ahmanson Ranch and Ventura "hillsides" projects.[37] Some 27,000 units of the likely future capacity would be located inside cities and their spheres of influence and over 6,000 would be located in the remaining unincorporated county.

Current General Plans overstate future housing capacity by about 20 percent.

Table 7: Adjusted Housing Capacity based on Actual Residential Projects

	Census 2000 Housing Units	Planned Future Additional Capacity	Approval Rates	Likely Future Additional Capacity
Ventura County	*251,712*	*41,479*	*80.2%*	*33,257*
Camarillo	21,946	1,746	72.8%	1,271
Fillmore	3,852	1,936	58.6%	1,134
Moorpark[38]	9,094	1,184	89.3%	1,058
Ojai	3,229	320	77.3%	247
Oxnard	45,166	15,933	79.2%	12,620
Port Hueneme	7,908	273	62.1%	169
Santa Paula	8,341	1,726	70.7%	1,220
Simi Valley	37,272	3,266	85.4%	2,789
Thousand Oaks	42,958	4,991	99.3%	4,954
Ventura (city)	39,803	2,248	69.7%	1,567
Unincorporated	32,143	7,856	79.3%	6,228

Source: Analysis by authors.

Combining the realistic housing capacity with the 1996 to 2001 average annual permit rate creates a year-to-year buildout scenario, assuming the average annual number of permits issued were to continue unchanged (see Table 8). Buildout for each city and the unincorporated county is approximated in Table 8 by cumulatively adding the average annual permits until the total is close to the estimated buildout capacity.

Countywide, the supply of new residential units likely to be developed under current zoning and development approval rates will be exhausted in 2011. Most cities will run out sooner. If the Ahmanson Ranch and Ventura hillsides projects are developed as proposed at a combined total of 5,000 units, the buildout year would be extended by about two years, to 2013. Some cities, including Moorpark, Camarillo, Simi Valley, Thousand Oaks, and Ventura, will run out of capacity much sooner—between 2004 and 2008. Only three small cities and the unincorporated county are likely to have housing capacity remaining in 2020—the sunset year for most SOAR measures.

Table 8: Projected Buildout Year

Jurisdiction	Avg. Annual Permits	2001	2002	2003	2004	2007	2008	2010	2011	2019	2020	% of Capacity	Units likely to be built
Ventura County	3,282	2,165	5,445	8,723	11,738	13,838	19,344	21,372	22,380	30,258	30,520	91.8%	33,257
Camarillo	403	266	669	1,072	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	100.0%	1,271
Fillmore	62	41	103	166	228	290	477	601	664	Deficit	Deficit	100.0%	1,134
Moorpark	168	111	279	446	614	782	Deficit	Deficit	Deficit	Deficit	Deficit	100.0%	1,058
Ojai	7	4	11	17	24	31	50	63	70	122	129	52.2%	247
Oxnard	685	452	1,136	1,821	2,505	3,190	5,244	6,613	7,297	Deficit	Deficit	100.0%	12,620
Port Hueneme	8	5	13	20	28	36	59	74	82	143	151	89.3%	169
Ventura (city)	203	134	336	539	742	945	1,553	Deficit	Deficit	Deficit	Deficit	100.0%	1,567
Santa Paula	17	11	28	44	61	78	128	161	178	311	328	26.9%	1,220
Simi Valley	779	514	1,293	2,072	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	Deficit	100.0%	2,789
Thousand Oaks	720	475	1,195	1,915	2,635	3,355	Deficit	Deficit	Deficit	Deficit	Deficit	100.0%	4,954
Incorporated	3,052	2,013	5,063	8,112	10,897	12,767	17,583	19,151	19,930	25,969	26,001	96.2%	27,029
Unincorporated	230	152	382	611	841	1,071	1,761	2,221	2,450	4,289	4,519	72.6%	6,228

Source: Analysis by authors.

Another important aspect of this scenario is that each time a project is approved at a zoning density less than the maximum allowed under a General Plan, the increment of not-built housing units is permanently lost. Based on this study, housing development capacity based on the General Plan densities is usually unrealistic (with some exceptions). Based on a study of 126 project files and their actual approval rates, current General Plans overstate future housing capacity by about 20 percent. (As noted previously, this analysis does not take into account size, type, or cost of housing being developed, only a count of units.)

G. Housing Deficits

Table 9 compares the VCOG forecasted cumulative-housing demand to realistic housing development for 2005, the ending year of the current Housing Element revision cycle. Tables 10 and 11 look at the situation in the years 2010 and 2020, respectively. In these figures, once a city achieves buildout the cumulative new housing count remains constant although the cumulative demand continues to increase. A number in bold indicates capacity was reached, and no additional construction occurs in all remaining years to 2020. In other words, to enable further development each city would have to expand its sphere of influence to bring more land into its jurisdiction or increase planned and/or approved densities within current boundaries.

By 2005, the county as a whole has fallen behind forecasted demand by about 3,500 units, with only the cities of Moorpark, Oxnard, and Thousand Oaks having more cumulative new housing development than their 2005 demand. The 10 cities as a whole are close to meeting demand while the unincorporated county is significantly behind. By 2010, halfway through the 20-year planning forecast, demand has outstripped supply in Ventura County as a whole by 35 percent, and five cities have reached their buildout: Camarillo, Moorpark, Ventura, Simi Valley, and Thousand Oaks (Table 10). By 2020, demand will exceed supply by over 29,000 units, with only Thousand Oaks having a "surplus" of 800 units (Table 11). As shown in Table 8, the county as a whole has capacity for about 3,000 more units after 2020, mostly in Santa Paula (892 units) and the unincorporated county (1,709 units).

Table 9: Demand and Buildout 2005					
2005	Cumulative Demand	Final Build-out	Difference	Percent Difference	Meets Demand?
Ventura County	17,277	13,838	-3,439	-20%	No
Camarillo	1,484	1,271	-213	-14%	No
Fillmore	481	290	-191	-40%	No
Moorpark	205	782	577	281%	Yes
Ojai	163	31	-132	-81%	No
Oxnard	2,659	3,190	531	20%	Yes
Port Hueneme	210	36	-174	-83%	No
Ventura (city)	1,883	945	-938	-50%	No
Santa Paula	1,156	78	-1,078	-93%	No
Simi Valley	4,860	2,789	-2,071	-43%	No
Thousand Oaks	1,783	3,355	1,572	88%	Yes
Incorporated	*14,884*	*12,767*	*-2,117*	*-14%*	*No*
Unincorporated	2,393	1,071	-1,322	-55%	No

Source: Analysis by Authors.

By 2020, demand will exceed supply by over 27,000 units, with only Thousand Oaks having a "surplus" of 800 units

In summary, only slightly more than half of the cumulative future forecasted demand (60,483 units) is met with new development (33,257 units) under this buildout scenario. The full development of the Ahmanson Ranch and Ventura Hillsides projects would add 4,950 units, increasing the number of new additional units to 38,207, about 63 percent of the expected housing demand.

Table 10: Demand and Buildout 2010					
2010	Cumulative Demand	Final Build-out	Difference	Percent Difference	Meets Demand?
Ventura County	32,888	21,372	-11,516	-35%	No
Camarillo	3,304	1,271	-2,033	-62%	No
Fillmore	961	601	-360	-37%	No
Moorpark	409	1,058	649	159%	Yes
Ojai	364	63	-301	-83%	No
Oxnard	6,083	6,613	530	9%	Yes
Port Hueneme	210	74	-136	-65%	No
Ventura (city)	3,220	1,567	-1,653	-51%	No
Santa Paula	1,964	161	-1,803	-92%	No
Simi Valley	7,754	2,789	-4,965	-64%	No
Thousand Oaks	3,536	4,954	1,418	40%	Yes
Incorporated	*27,805*	*19,151*	*-8,654*	*-31%*	*No*
Unincorporated	5,083	2,221	-2,862	-56%	No

Source: Analysis by Authors.

Table 11: Demand and Buildout 2020

2020	Cumulative Demand	Final Build-out	Difference	Percent Difference	Meets Demand?
Ventura County	61,324	32,229	-29,095	-47%	No
Camarillo	5,705	1,271	-4,434	-78%	No
Fillmore	2,528	1,134	-1,394	-55%	No
Moorpark	3,272	1,058	-2,214	-68%	No
Ojai	830	129	-701	-84%	No
Oxnard	14,036	12,620	-1,416	-10%	No
Port Hueneme	210	151	-59	-28%	No
Ventura (city)	5,910	1,567	-4,343	-73%	No
Santa Paula	3,580	328	-3,252	-91%	No
Simi Valley	10,931	2,789	-8,142	-74%	No
Thousand Oaks	4,154	4,954	800	19%	Yes
Incorporated	*51,997*	*26,001*	*-25,996*	*-50%*	*No*
Unincorporated	9,327	6,228	-3,099	-33%	No

Source: Analysis by Authors.

Part 4

Policy Implications

The policy implications of this analysis for land-use planning and growth management in Ventura County are significant. SOAR, like most ballot-box initiatives, locks in place existing General Plans and requires that changes that would convert non-urban land uses and/or extensions of urban boundaries be approved by voters (countywide in unincorporated areas, citywide in each city with a SOAR). Yet the preceding analysis demonstrates that most cities and the county fall well short of meeting forecasted demand for additional housing units, even if the demand estimates were mistakenly high and/or demand were to decline. If all these conditions persist over the next few years, the conflict between housing demand and housing capacity under current plans and SOAR will escalate. As this situation evolves, policymakers in the county and its 10 cities will be faced with three possible housing and land-use policy choices.

A. Scenario One: Do Nothing

The first option policymakers can choose is to do nothing: retain the current General Plans and planning policies and the current SOAR boundaries, and assume housing projects will be approved at about the same reduction in density as in the past. If current trends continue and no policies or entitlement practices are changed, the following conditions and trends will likely result:

1. Housing Values and Rents Increase While Vacancies Decrease

"Tight" housing market effects are widely documented in housing literature and represent typical market responses to sustained strong demand for housing with little prospect for increasing supply. The effects are:

- Housing values and rents increase faster than the general cost of living. Low-and moderate-income households have fewer choices and/or pay more of their incomes for shelter, reducing available income for other expenditures such as consumer goods, entertainment, transportation, and health care.
- Vacancy rates decline from about 5 percent—a rate that gives consumers choices—to less than 1 percent.
- Equity-rich middle-class homeowners "cash-out" and move away, replaced with high-income households with fewer children, roommate groups, and/or extended families with several wage-earners.
- Residential development is diverted to other areas. In the case of Ventura County, development would move to Santa Barbara County, north Los Angeles County, the High Desert, or the Inland Empire.
- Construction of illegal housing, such as converting garages or adding small units, increases. The existing stock of low and moderate income housing units is upgraded to a higher value and rent (i.e., "gentrification"), squeezing out more low- and moderate-income households.

- Housing becomes more crowded as households double or triple. Crowding leads to potentially negative effects on family life and educational attainment, and demand for services exceeds the local infrastructure (i.e., water, waste treatment, parking, schools, parks, etc.).
- Pressure will increase for governments to provide and/or require housing subsidies and set-asides, especially in those areas where local industries employ low- and moderate-income workers who are either traveling farther to find affordable housing or leave the area, shrinking that segment of the labor market supply.

2. Redevelopment, Rehabilitation, and Infill Development Increases

As new housing development largely "shuts down" in each area because buildout is achieved, redevelopment and rehabilitation of existing units become the main means of providing additional housing, gradually using up infill sites and generating market demand to 'gentrify' older neighborhoods to their maximum zoning density.

3. Development Moves to Areas with Remaining Capacity

New housing development moves to areas where additional new development capacity remains, increasing competition for project approval, increasing the pace of development, and pushing other cities to premature buildout. This likely means, as time goes on, increased pressure in the smaller cities such as Fillmore and Santa Paula, as well as increased pressure on unincorporated areas even though the county has always pursued a policy goal of channeling most urban development inside the cities.

One possible way to increase housing production would be for applicants to apply for projects at closer to the planned densities, either on their own initiative or with the encouragement of local planning staffs.

B. Scenario Two: Seek to Increase Capacity under SOAR as Currently Enacted

Even if the SOAR measures are not changed around the county, there are still several ways in which both housing capacity and actual housing production could increase as the pressure builds. Two scenarios are likely.

1. Projects Are Applied for and Approved at Closer to Planned Densities

Our analysis indicated that projects were applied for and approved at a significantly lower density than planned capacity: 79 percent compared to zoning, 54 percent compared to General Plans. Almost all of this reduction occurred because applicants, for whatever reason, chose to apply at lower densities. One possible way to increase housing production would be for applicants to apply for projects at closer to the planned densities, either on their own initiative or with the encouragement of local planning staffs. Experience suggests that most projects are not reduced in size significantly from their applied-for densities. This, of

course, critically depends on the local political climate and willingness of communities to embrace the densities specified in their General Plans.

2. Housing Capacities Are Increased on Non-SOAR Property

SOAR applies only to properties that are currently zoned for agricultural or open-space use. It does not apply to parcels already designated for urban development. Thus, one possible response by policymakers at the local level would be to "upzone," or increase allowable densities, on parcels already zoned for residential use. Another possibility would be to change the zoning designation on commercial or industrial parcels to residential use even though this runs counter to current tax policy that encourages commercial development. This response would likely lead to more so-called "Smart Growth" or "sustainable" development that increases densities but in a manner generally considered desirable and of higher quality design with more efficient use of public services and infrastructure compared to typical sprawl development.

C. Scenario Three: Change SOAR Boundaries

The final option is to change SOAR boundaries. There would likely be three ways to do so. The first would be to propose changes in SOAR boundaries for individual properties, currently zoned for agricultural or open-space use, to accommodate specific new housing projects not currently contemplated in General Plans. The second would be a city-by-city amendment, most likely driven by Housing Element law. The third would be to propose a sweeping reform of SOAR on the same scale as the 1998 vote.

1. Parcel-by-parcel Changes to SOAR

SOAR proponents have always argued that SOAR does not suppress housing development but simply subjects changes in agricultural and open-space zoning to the additional step of voter approval. Anecdotal evidence, however, suggests that this outcome is unlikely. Ballot-box zoning increases uncertainty in the development approval process, and, as result, increases the transaction costs associated with housing development. As such, ballot-box zoning will likely have a dampening effect on housing development.[39]

There is, of course, little question that as the supply of land for housing becomes more constrained, some developers will go to the voters and seek rezoning of property for new housing projects. This is much more likely to occur in individual cities than in unincorporated territory since SOAR amendments in unincorporated territory require a countywide vote and election campaign.

Voters in Ventura County and its cities have expressed a willingness to amend SOAR when they believe the urban land use being requested is worthy. But, to date, the elections have been very specific, and nonresidential with little impact on land-use trends or patterns. The willingness of voters to approve SOAR amendments to accommodate housing is untested. Furthermore, the record statewide of developers seeking ballot approval for housing projects is not good. Most recently, a developer in Sacramento County seeking an amendment to that county's urban-growth boundary for a senior housing project was soundly trounced at the ballot box.

2. Amending SOAR City by City

Cities generally revise their General Plans every 10 to 15 years. In addition, they are required to update their Housing Elements every five years. The current round of Housing Elements updates will likely be certified by the state within the bounds of SOAR. However, the next round of Housing Elements—which will cover the period between 2005 and 2010—may trigger General Plan amendments or revisions in individual cities designed to increase housing capacity. These General Plan revisions may call for amendments to SOAR to convert agricultural or open space to urban use. Such revisions would require voter approval, but would likely be backed by each city's political leadership. The support of political leaders for more housing, however, is no guarantee of voter approval. As the January 1999 vote in Moorpark revealed, in many cases voters support SOAR and reject housing proposals as a way of expressing their displeasure with political leaders they regard as too "pro-growth." Moreover, growth controls themselves are often a reflection of broad-based resistance to further growth. Defeating a SOAR amendment to expand housing capacity would have few negative implications for current residents, particularly homeowners who might benefit from potentially higher housing prices.

Growth controls themselves are often a reflection of broad-based resistance to further growth.

3. Sweeping Reform of SOAR

As the land supply for housing becomes more constrained under SOAR—most likely after 2010—political pressure will probably increase among business interests to mount a campaign for a comprehensive reform of SOAR prior to 2020. Under this scenario, business interests and housing advocates would craft a package of measures in both the county and in the individual SOAR cities to expand the SOAR boundaries, thus bringing new land into the housing capacity picture. A sweeping reform of SOAR holds the advantage of being a countywide campaign with local implications, as the 1998 campaign was, and might also involve other provisions (such as permanent open-space preservation) designed to win the support (or blunt the opposition) of hard-core SOAR supporters.

Part 6

Conclusion

Cities, counties, and state legislatures across the nation are considering initiatives that would greatly increase the scope of land-use regulation at all levels of government. Many of these growth-management and planning reforms involve a significant increase of public participation in the development control process. Effective implementation of these reforms requires a practical understanding of the implementation issues surrounding growth-management reforms and development control.

This study suggests that significant deficiencies exist in the capacity of existing planning systems to accommodate rational planning goals. Despite passing a countywide growth-management initiative in 1998, most cities have not adjusted their plans to accommodate expected housing demand, creating conditions that are likely to lead to further housing-price escalation and increased political manipulation of the housing market.

Based on the analysis of Ventura County, a county with a long history of growth management and planning reform, most cities in that county will face significant housing shortages well before the end of the 20-year planning horizon anticipated during the public campaign to approve the far reaching growth-management initiative. Most cities in Ventura County have no more than 10 years of housing capacity left under current policies and entitlement practices. SOAR will begin to have a major effect on new housing development between 2005 and 2010 as planned housing capacity is used up—first in a few cities, then gradually countywide. Development pressure will increase within cities to "up-zone" and change General Plans to allow more housing, and possibly to redevelop and rehabilitate existing. Projects that do try for a SOAR-mandated voter approval in order to bring new land into housing development will need to be different in some manner compared to past development. Unless SOAR is changed or invalidated, the county and its cities are unlikely to meet estimated future demand for additional new housing and tight housing market effects will increase over time. The lessons learned from the "laboratory" of Ventura County, a county with substantial experience in growth management and planning reform, should be valuable for other cities and counties across the nation that are wrestling with growth management.

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Related RPPI Studies

Smart Growth and Housing Affordability: Lessons from Statewide Planning Laws, by Samuel R. Staley and Leonard C. Gilroy, Policy Study No. 287, December 2001, www.rppi.org/ps287.html

Urban Sprawl, Smart Growth, and Market-oriented Approaches to Growth Management, by Samuel R. Staley, Policy Brief 20, August 2001, www.rppi.org/pbrief20.html.

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Repairing the Ladder: Toward a New Housing Paradigm, by Howard Husock, Policy Study No. 207, July 1996, www.rppi.org/ps207.pdf.

Appendix A

Methodology and Data Collection

The research necessary to assess demand and capacity for new residential development in Ventura County followed a four-step process. The first step assessed regional, state, and federal data in order to derive an educated estimate of the future demand for housing. We relied heavily on the estimates provided by the Ventura County Council of Governments. The second step, determining the quantity and capacity of available land, required an in-depth review of each city's and the county's General Plan with a specific emphasis on the Housing Element section of each report. The third step of determining potential development limitations involved the on-site review of recently approved residential development projects in an effort to uncover the impact of city and county planning on approved developments. Finally, the fourth step—predicting capacity—involved analyzing the three previous steps jointly to arrive at the best possible forecast for residential development.

A. Future Development Needs

A variety of sources were referenced in the process of generating estimates for future development needs. The U.S. Census Bureau has begun releasing state, county, and place data on population, housing units, households, and persons per dwelling unit, current through the 2000 Census. This information was compiled into a spreadsheet and historical growth rates were calculated to ascertain trends for the United States, California, Ventura County, and each of its cities.

In addition, the authors researched building-permit information from the U.S. Census Bureau back to 1990. The information compiled is more detailed for 1996 through April of 2001, providing data on the number and cost of single-family and multifamily units issued building permits in each city and the unincorporated areas of the county.

Finally, forecasts for population, housing units, households, and persons per dwelling unit have been compiled by the Ventura County Council of Governments (VCOG) which is a member of the Southern California Association of Governments (SCAG). The council's projections for 2000, 2010, and 2020 were compared to the Census 2000 numbers to determine if the county and city projections are ahead or behind, and by how much.

B. Land Capacity

The quantity and capacity of land available for housing development was determined from the legal mandate for cities and counties to quantify the amount and capacity of vacant and under-utilized lands within their

control. Each jurisdiction is expected to accommodate a portion of the future residential growth for the entire county. Representatives from each city and the county were contacted and arrangements made to secure the General Plans which contain this data.

The Housing Elements for the 10 cities and the county contain charts and analyses that specify the number of acres available for development and corresponding dwelling unit projections based on the General Plan and zoning in place. The Housing Elements reviewed for this study, which are traditionally updated every five years to reflect changes in availability and capacity of land, cover the period from 1998 through 2005. The statistics contained within these Housing Elements also include the vacant and under-utilized land in each jurisdiction, thus providing the ability to estimate residential buildout under the current General Plan in the county.

The vacant and under-utilized acreage available for residential development within each of the cities and the county was broken out by three levels of density. "Low density" equates to 0-7 dwelling units per acre. "Medium density" comes in at 8-15 dwelling units per acre. Finally, "high density" equals anything greater than 16 dwelling units per acre. Although not specified in a majority of the Housing Elements reviewed, the acreage referred to is typically gross. A spreadsheet was designed that aggregates the acreage and dwelling units of all 10 cities and the county by vacant and under-utilized land in the city, sphere, and county for each density range.

C. Land Supply

By far the most intensive component of the research process was that pertaining to the limitations on the supply of land. This research, generally referred to as the "Record of Development Approvals," involved an in-depth review of residential projects approved since 1996. It should be noted that while the majority of development files reviewed were not sufficiently organized to easily locate data or often contained missing/inconsistent data, the various city planners proved informative and helpful in overcoming these barriers.

The researchers analyzed the data using the following approach:

Research parameters. To conduct a thorough and efficient study, it was necessary to lay out the parameters that would control the research. Each of the 10 primary cities within Ventura County would be included in the study. These cities vary in size and development activity. Four are smaller communities with very few residential developments: Fillmore, Ojai, Port Hueneme, and Santa Paula. Six larger cities that have experienced a great deal of development over the last decade are: Camarillo, Moorpark, Oxnard, San Buenaventura (city of Ventura), Simi Valley, and Thousand Oaks.

Next, the researchers set a timeframe for the development projects to be reviewed. The study covers residential projects approved for construction between January 1, 1996 and March 31, 2001. The selection of this five-year period took into account collection feasibility, contemporary relevance, and fluctuation in real-estate and economic activity.

Finally, the researchers defined the number of projects to review. Initially, they expected to evaluate all residential files in the specified timeframe. However, once cities began to send preliminary data on the projects within their jurisdiction, it became apparent that the number of applicable developments in the larger

communities would greatly exceed the study's resources, given budgetary and time constraints. Researchers decided to review no more than 30 projects in any given locality, thus assuring a significant sample while maintaining expectations to remain on schedule.

Data Collection. The second methodological component was deciding what information to gather from the selected residential development files. To simplify data collection, researchers designed an Excel spreadsheet to incorporate separate sections for each city along with input cells for the categories of information, using a laptop to insert the data directly into the spreadsheet at each site to save time and reduce transmission errors. The following list details the data critical to this project:

Table A1: Variables and Descriptions Used in Statistical Analysis

Variable	Description
City	Name of the city in which the project is located
APN	Assessor's Parcel Number designates specific land map location of proposed project;
Tract	Number identifying geographical land location of project
Name	Name of the development company
Project Name	Name of the project
Dev Type	Whether the development is a single family or multi-family project
Final Activity Date	Date of the most recent activity on the project
Level	Level of government that approved the project
Original GP	The original land-use category for the project area (low, medium or high density)
GPA	Whether or not the General Plan was amended
Amended Use	New General Plan land use designation if amended
Specific Plan	Whether a specific plan applies to the given project
GP Min du/ac	Minimum number of dwelling units per acre according to the General Plan
GP Max du/ac	Maximum number of dwelling units per acre according to the General Plan
Zoning Permitted Max	Maximum number of permitted dwelling units per acre as specified by zoning codes
Acreage	Gross or net site acreage on which the project is located
GP Max	Calculation of the maximum dwelling units allowed using GP and project acreage
Zoning Permitted Max	Maximum dwelling units allowed using zoning and project acreage
SP du	Maximum dwelling units allowed using Specific Plan and project acreage
Initial Application du	Number of dwelling units the proposed project initially applied for—this number is from the earliest application
Final App du	Number of dwelling units the proposed project finally applied for after negotiations with development staff
PC Approved du	Number of dwelling units that were approved for the project by the Planning Commission
CC Approved du	Number of dwelling units that were approved for the project by the City Council
100% Affordable Housing	The project met 100% affordable housing requirements
Density Bonus	A density bonus was awarded to affordable housing projects
Geography	Location within the county for the project (North, West, or East)
City Size	Size of the city within which the project is located (large or small)
Project Size	Size of the project based on the number of dwelling units: small (0-29 units), medium (30-99 units), or large (100+ units).

Source: Compiled by authors.

Implementation. The third step in methodology was implementing the research project. In preparation for on-site research at each city's planning/development department, researchers obtained lists of potential development projects. A majority of the cities sent internal department project lists, which were reviewed and screened prior to the site visit. In the cities where selection was required the following factors determined the projects evaluated: a) mixture of project sizes, types, and years; b) projects larger than three units in size; c) consultation with planning staff; and d) projects for which all research data was available.

A date was arranged ahead of time with each city for the visit so that planning staff knew of the research team's presence, could provide space to work in, and could ensure the requested files were accessible. Researchers gathered data from a variety of points in the development approval process, including initial and subsequent applications, planning commission approval, and city council approval. The smaller cities required only one day of research while the larger sites needed three to five days to complete. In sum, 126 residential development project files were individually reviewed and recorded in the study's spreadsheet. Nearly every city required follow-up through phone calls, faxes, or repeat visits in order to correct or compensate for initially inaccessible files and missing data. One city, Moorpark, insisted on charging fees for access to their development files; after numerous attempts over several weeks to solicit their cooperation, researchers decided to move the study forward without Moorpark's participation.

Analysis. The final step involved organizing and evaluating the raw data. Multiple spreadsheets were created to categorize, aggregate, and summarize the collected data. Table A1 contains summary data that are referred to frequently in the research section of this study. As a final precautionary measure, researchers sent copies of the projects reviewed to each corresponding city with a request for their comments or corrections on the data collected. Six of the nine participating cities responded and the research was amended to reflect their contributions.

D. Integration of Data Analysis

In the fourth and final phase of the research, researchers evaluated all research components together. In most instances, statistical results from one phase of the research was used in the other two phases in a series of tests designed to fine-tune the study's raw data. The assumptions behind the study's final forecasts for future residential development were also laid out. In the end, using analytical techniques to predict the impact of the SOAR ordinances on Ventura County's growth will require further research, but the existing research showed that ballot-box land-use measures change the economic landscape for development.

Appendix B

Regression Analysis and Results

Analysts used regression analysis to more fully assess the impact of Ventura County's growth-management laws on housing prices. Regression analysis is a statistical technique that allows researchers to examine the relationship between two variables while holding other factors constant. In this study, for example, the researchers were interested in what projects were most likely to be approved and at what densities in order to determine whether planning goals were met during plan implementation. A direct comparison of the average approved density with the planned or zoned density provided a general measure of how well planning actions conform to intentions, but other factors (e.g., the size of the project, type of housing, existing market conditions, etc.) may also influence a planning board or city council's decision to approve a project at a certain density. Regression analysis allows analysts to examine approved densities while considering these other factors.

The analysts in this study employed a specific type of regression analysis called "stepwise regression." Stepwise regression adds each variable (e.g., city size, project size, type, etc.) into the equation one at a time, estimating the impact of each (independent) variable on the variable they wanted to explain (the dependent variable), and then substitutes another variable into the equation to estimate the effect. In this case, the researchers wanted to know which factors were most significantly associated with the number of dwelling units approved compared to the amount allowed by the General Plan or zoning code. Thus, the dependent variable—the variable they wanted to explain—is the difference between the actual approved density and the amount allowed under planning or zoning. Thus, a larger number reflects a wider difference between the approved and allowed numbers.

The regression equations should be interpreted the following way. If multifamily projects are approved at densities consistently lower than the amount allowed in the General Plan, then the relationship would be negative: multifamily projects will be associated with a *larger* difference between the approved density and the actual density. If larger land projects are associated with higher densities, the relationship will be positive: larger projects have *smaller* differences between the approved and planned densities.[40]

The dependent variables were defined in the following ways:

GP = Percentage of actual number of residential units approved by the city council and the amount allowed under the General Plan. A higher rate indicates an approval rate closer to the maximum densities allowed in the General Plan.

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GPS = Difference between the actual number of residential units approved by the city council and the amount allowed by the General Plan or the Specific Plan, whichever was the controlling regulation for the property. A higher rate indicates an approval rate closer to the maximum densities allowed in the General Plan.

ZS = Difference between the actual number of residential units approved by the city council and the amount allowed under zoning or the specific plan, whichever was the controlling authority over the project and property. A higher rate indicates an approval rate closer to the maximum densities allowed in the General Plan.

A. General Plan Model

This model used GP as the dependent variable and the key independent variables explained 40 percent of the difference between approved and allowed densities under the General Plan. Only the variables that were statistically significant at the 95 percent level were included in the equation.

Based on the results of this analysis, we concluded the following:

- Multifamily housing projects were more likely than single-family projected to be approved at densities close to the General Plan maximums;
- Projects with more land are less likely to be approved at densities closer to the General Plan maximums;
- Projects with more units are more likely to be approved at higher densities;
- Simi Valley is more likely than Thousand Oaks (the reference city) to approve projects at higher densities;
- Affordable housing projects are more likely to be approved at a higher rate than non-affordable housing projects; and
- Ventura is less likely than Thousand Oaks to have higher approval rates.

Table B1: Estimates for General Plan Stepwise Regression

Variable	Beta Coefficient
MFD	0.1045
ACREAGE	-0.0038
CC_DU	0.0010
SIMIVAL	0.1104
AFFHGYES	0.1509
SANBUENA	-0.1223

Source: Authors' calculations.

B. Model II: General Plans Versus Specific Plans

The second model compared rates of approval based on whether the General Plan or a Specific Plan had controlling authority over densities. This model explained about 32 percent of the variation in density approval rates. These results suggest:

- Projects that are in jurisdictions with Specific Plans for project areas are more likely than those that do not to be approved at higher densities;
- Ventura city is less likely than Thousand Oaks to approve projects at higher densities;
- MFD are more likely than SFD to have higher approval rates.

Table B2: Estimates for General Plan Versus Specific Plan Stepwise Regression	
Variable	Coefficient
SP_YES	0.21485
SANBUENA	-0.28065
MFD	0.18109

Source: Authors' calculations.

C. Model III

The third model compared General Plan maximum densities to zoning or Specific Plan densities, whichever had controlling authority. This model had the least predictive power, explaining just 10 percent of the difference in density approvals. These results suggest:

- The East is more likely than the West to have higher approval rates; and
- Projects with more units are more likely to have higher approval rates than projects with fewer units.

Table B3: Estimates for General Plan Versus Specific Plan Stepwise Regression	
Variable	Beta Coefficient
EAST	0.12008
CC_DU	0.00046

Source: Authors' calculations.

Appendix C

Housing Elements 2005 and Compliance

Housing Elements are usually updated every five years, and the current 2005 deadline for cities in Ventura County and the County itself was December 31, 2000. The chart below shows which jurisdictions are in compliance as of July 3, 2001.

Status of Housing Elements July 4, 2001

City and county	Type	Reviewed	Compliance
Ventura County	Draft	03/26/2001	Out
Camarillo	Draft	10/27/2000	Out
Fillmore	Adopted		Due
Moorpark	Draft	11/16/2000	Out
Ojai	Draft	01/11/2001	Out
Oxnard	Adopted	05/10/2001	In
Port Hueneme	Adopted		In Review
San Buenaventura (City of Ventura	Adopted		Due
Santa Paula	Adopted		Due
Simi Valley	Adopted	02/9/2001	Out
Thousand Oaks	Adopted	03/30/2001	In

Source: housing.hcd.ca.gov/hpd/hrc/plan/he/status.htm.

As shown in the preceding table, two cities are in full compliance. If the jurisdiction has an adopted Housing Element found by HCD to comply with Housing Element law, its compliance status is "In." If HCD has determined that an adopted Housing Element does not comply, the jurisdiction is listed as "Out." If the jurisdiction has yet to submit an element for the current planning period, it is listed as "due." Jurisdictions that have submitted a draft element but have not formally adopted the element are listed as "out," regardless of whether HCD found the draft element "in" or "out" of compliance with state law. Regardless of their compliance status, the Housing Elements are a current public source for the existing housing stock and opportunities for housing development (or redevelopment) prepared in a consistent manner with a common ending period of 2005, and any revisions are not likely to significantly alter their estimates of demand.

Endnotes

1 Patricia E. Salkin, "Smart Growth: The State of the States," presentation to the Northeast State Planning Directors Meeting, March 2000. Salkin is Professor and Director of the Government Law Center at Albany Law School, Albany, New York. See also Patricia E. Salkin, "Smart Growth at Century's End: The State of the States," *Urban Lawyer*, Vol. 31, No. 3 (Summer 1999), pp. 601–648.

2 The first states were Hawaii and Vermont. Hawaii has a unique political environment shaped by its plantation past and island geography. Vermont is a small, mountainous state with a large tourist and natural resource-based economy, but no large urban areas.

3 See Deborah Howe, "Growth Management in Oregon," in *Growth Management: The Planning Challenge of the 1990s*, ed. Jay M. Stein (Newbury Park, California: Sage Publications, 1993) pp. 61–75; Gerrit Knaap and Arthur C. Nelson, *The Regulated Landscape: Lessons on State Land Use Planning from Oregon* (Cambridge, Massachusetts: Lincoln Institute for Land Policy, 1992).

4 Phyllis Myers, "Livability at the Ballot Box: State and Local Referenda on Parks, Conservation, and Smarter Growth, Election Day 1998," discussion paper prepared for The Brookings Institution, Center for Urban and Metropolitan Policy, January 1999.

5 Anthony Downs, "What Does 'Smart Growth' Really Mean?" *Planning* (April 2001), www.planning.org/pubs/plng01/april012.htm.

6 See the discussion in Samuel R. Staley, "Markets, Smart Growth, and the Limits of Policy," in *Smarter Growth: Market-based Strategies for Land-use Planning in the 21st Century*, eds. Randall G. Holcombe and Samuel R. Staley (Westport, Connecticut: Greenwood Press, 2001), pp. 201–218.

7 Rick Rosan, "'Smart Growth': It Sure Beats Ugly Urban Sprawl," *San Fernando Valley Business Journal*, August 9, 1999, p. 27.

8 Mary R. English, Jean H. Peretz, and Melissa Manderschied, *Smart Growth for Tennessee Towns and Counties: A Process Guide* (Knoxville, Tennessee: Energy, Environment and Resources Center, University of Tennessee, February 1999), eerc.ra.utk.edu/smart/title.htm.

9 Ibid.

10 Florida Department of Community Affairs, Division of Community Planning, August 2001. See also the discussion in Samuel R. Staley and Leonard C. Gilroy, *Smart Growth and Housing Affordability: Evidence from Statewide Planning Laws*, Policy Study No. 287 (Los Angeles, California: Reason Public Policy Institute, 2001).

11 The nation has 3,141 counties and Ventura County's population ranks sixty-second.

12 Recently released Census 2000 population data shows that between 1990 and 2000 the United States grew 13.2 percent and Ventura County grew 12.6 percent. However, most of Ventura County's growth occurred prior to 1980. Since 1980, growth in the county declined to rates comparable to the region and state, and during the 1990s matched the growth rate of the nation as a whole.

13 Ventura County's SOAR initiatives were based on growth-control measures used in the Napa Valley north of San Francisco that survived legal challenge (*DeVita v. County of Napa*, 9 Cal.4th 763 [1995]), so there is little likelihood they will be struck down in court, at least not in the short run.

14 Oregon, Washington, Florida, and other states, for example, have encouraged the use of growth boundaries and broad-based citizen participation in planning and land-use decisions.

[15] Ventura County Resource Management Agency, "Questions and Answers," *SOAR: Save Open-space and Agricultural Resources* (Ventura, California: Planning Division), PLN5128-2/99.

[16] smartgrowth.org/information/news/news_trends9-99.html.

[17] The long-term impact of this scale of voter-managed land-use planning is not well understood. Only three "SOAR override" elections have been held—two in the City of Ventura and one involving property in an unincorporated part of Ojai. While all three passed, none involved residential projects and their intended uses were relatively low impact. Rather, they concerned a proposed public park, a proposed church, and the proposed expansion of a convalescent home. It remains to be seen how developer-driven projects that require an override will be treated in the voting booth.

[18] Our division of the county differs from the traditional division into East and West. However, we believe that the Ojai and Santa Clara valleys are geographically discrete areas, and we further note that Fillmore and Moorpark are at approximately the same east/west parallel, so we chose to place the northern valleys in a separate category. Also, the northern valleys contain only small cities, whereas the east and the west each contain large cities.

[19] William Fulton, *Guide to California Planning*, second ed. (Point Arena, California: Solano Press, 1999), p. 189.

[20] Ibid., pp. 198-201. See also Samuel R. Staley, Jefferson G. Edgens, and Gerard C.S. Mildner, *A Line in the Land: Urban-growth Boundaries, Smart Growth, and Housing Affordability*, Policy Study No. 263 (Los Angeles, California: Reason Public Policy Institute, October 1999).

[21] Ned Levine, Madelyn Glickfeld, and William Fulton. *Home Rule Local Growth...Regional Consequences*, report prepared for Metropolitan Water District and SCAG, unpublished manuscript, April 1996.

[22] LAFCO is a state-mandated public agency that overseas annexation and city boundary changes as well as other responsibilities depending on the local jurisdiction. LAFCO in Ventura County is also directed to promote orderly growth and development, discourage urban sprawl while preserving open space and agricultural lands, and encourage efficient service areas for local governments.

[23] LAFCO is a state-mandated local agency for each county that is directed.

[24] For an examination of the role of residential property, see Dick Netzer, "Property Taxes: Their Past, Present, and Future Place in Government Finance," in *Urban Finance Under Siege*, eds. Thomas R. Swartz and Frank J. Bonello (Armonk, New York: M.E. Shapre, Inc., 1993), pp. 51–78.

[25] U.S. Bureau of the Census. The nation has 3,141 counties; California has 115.

[26] The Census Bureau collects monthly construction permit data in the Survey of Construction (SOC). The number of building permits issued between 1990 and 2000 (24,865) exceeds the number issued reported in the 2000 Census additional housing units (23,234) by 7 percent. The difference is housing unit loss due to natural disaster, condemnation, or other reasons.

[27] Ahmanson Ranch is located in unincorporated Ventura County and was approved by the county in 1992, prior to the SOAR initiatives, and remains controversial. The 5,900-acre Ventura Hillsides, one of the largest undeveloped areas inside any city's sphere of influence, is designated for 8,000 units in Ventura city's General Plan but includes no units under the housing element. Landowners are currently proposing 1,900 units, but have not formally applied for approval. Ventura voters will decide if the project will require voter approval at the polls in November 2001.

[28] There is likely some minor duplication in housing units between the cities' spheres of influence and the unincorporated county, resulting in even less actual capacity. Commercial development capacity was not examined in this study, but cities will likely find ways to open up sufficient land for desirable commercial development. California cities have strong fiscal incentives to promote commercial development. The same tax incentive discourages converting commercial land to residential.

[29] Appendix D contains selected documentation on how VCOG calculated housing need.

[30] A word of caution is needed concerning housing analyses. The basic statistic is the housing unit, which could vary in size from a one-room "single" to a sprawling 10-bedroom estate. Each of these is

considered one housing unit, although they clearly have different capacities and costs. This study did not focus on housing by economic level or size of unit.

[31] Fulton, *Guide to California Planning*, p. 204.

[32] Ibid., p. 205.

[33] Ibid.

[34] Ibid., pp. 208–209.

[35] The data were divided into eight categories and cross-tabulated with the three capacities. Categories with either GP (General Plan), SP (Specific Plan) and/or a Z (zoning) beside them showed some ability to predict approval rates for that respective type of capacity, based on stepwise regression analysis (see results in Appendix A, Table 9 and explanation in Appendix C). The categories were: City Size, Affordable Housing (GP), Development Type (GP, SP), General Plan Amendment, Geographic Location (Z), Project Size -by units and acreage (GP,Z), Pre v. Post-SOAR, and Specific Plan Area (SP).

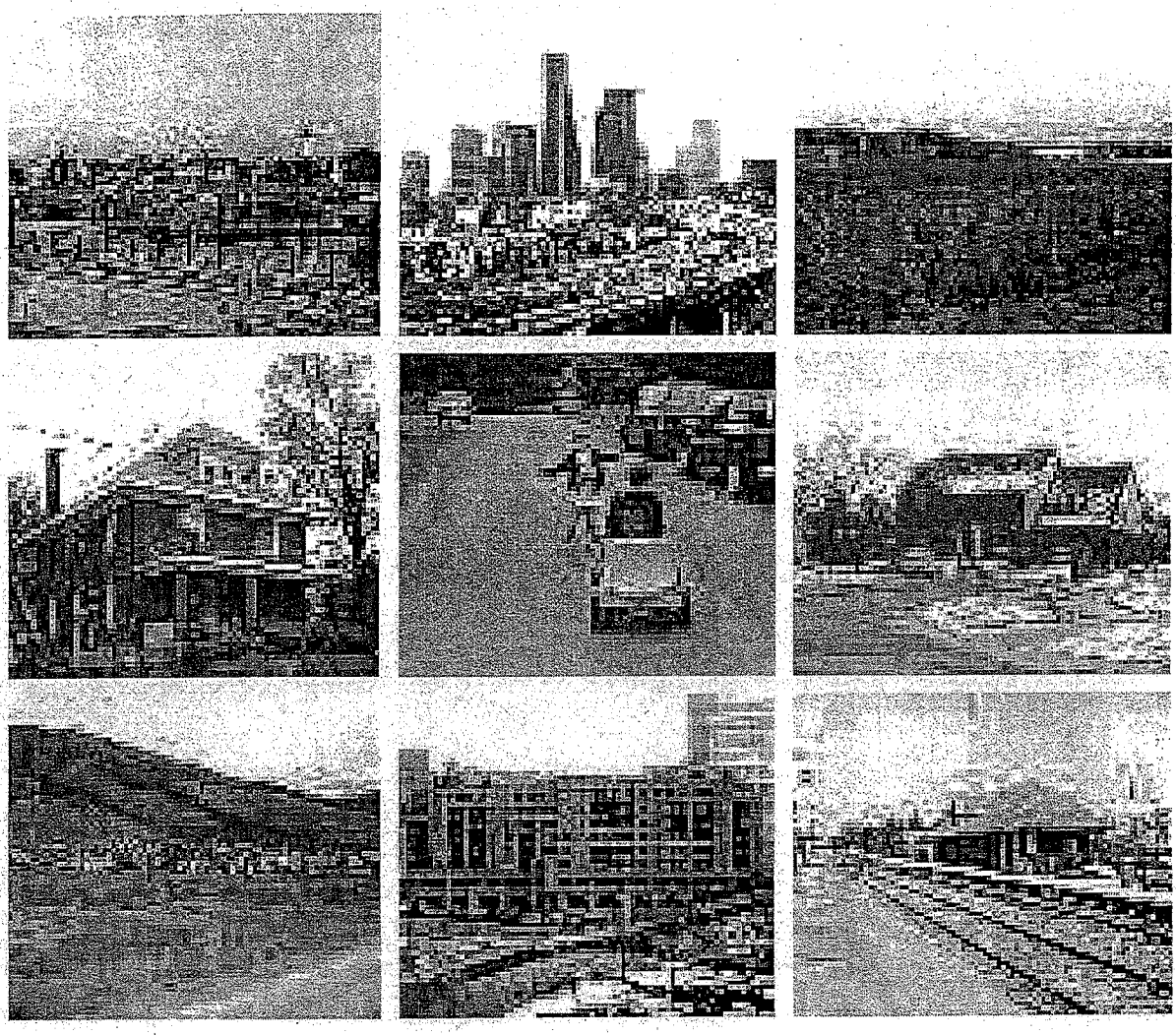
[36] Five projects were a mix of single family and multi-family units, four of which had Specific Plans in place.

[37] No actual projects were reviewed in Moorpark or the unincorporated county and approval rates are estimated for these two areas: Moorpark based on the average approval rate for East County cities and the unincorporated county based on the average approval rate of the 126 projects reviewed.

[38] The Moorpark Housing Element lists 13 "Approved/Planned" residential projects with a total of 3,098 units. It is not clear how many of these units will actually be completed nor if these units duplicate our estimates of building and planned capacity, which are much lower.

[39] Samuel R. Staley, "Ballot-box Zoning, Transactions Costs, and Urban Growth," *Journal of the American Planning Association*, Vol. 67, No. 1 (Winter 2001), pp. 25–37.

[40] One of the weaknesses of stepwise regression is that it lacks theoretical rigor. It is essentially an "ad hoc" procedure for determining which factors are statistically more important than others. As a result, many analysts, particularly economists, are reluctant to use stepwise regression because the effects are difficult to interpret. In this case, stepwise regression was used primarily to determine empirically which factors seemed to be most significantly related (statistically) to projects on average. Theoretical considerations—understanding "why" rather "how"—were less important to the analysis.



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May 2003

Smart Growth in Action, Part 2:

Case Studies in Housing Capacity and Development from Ventura County, California

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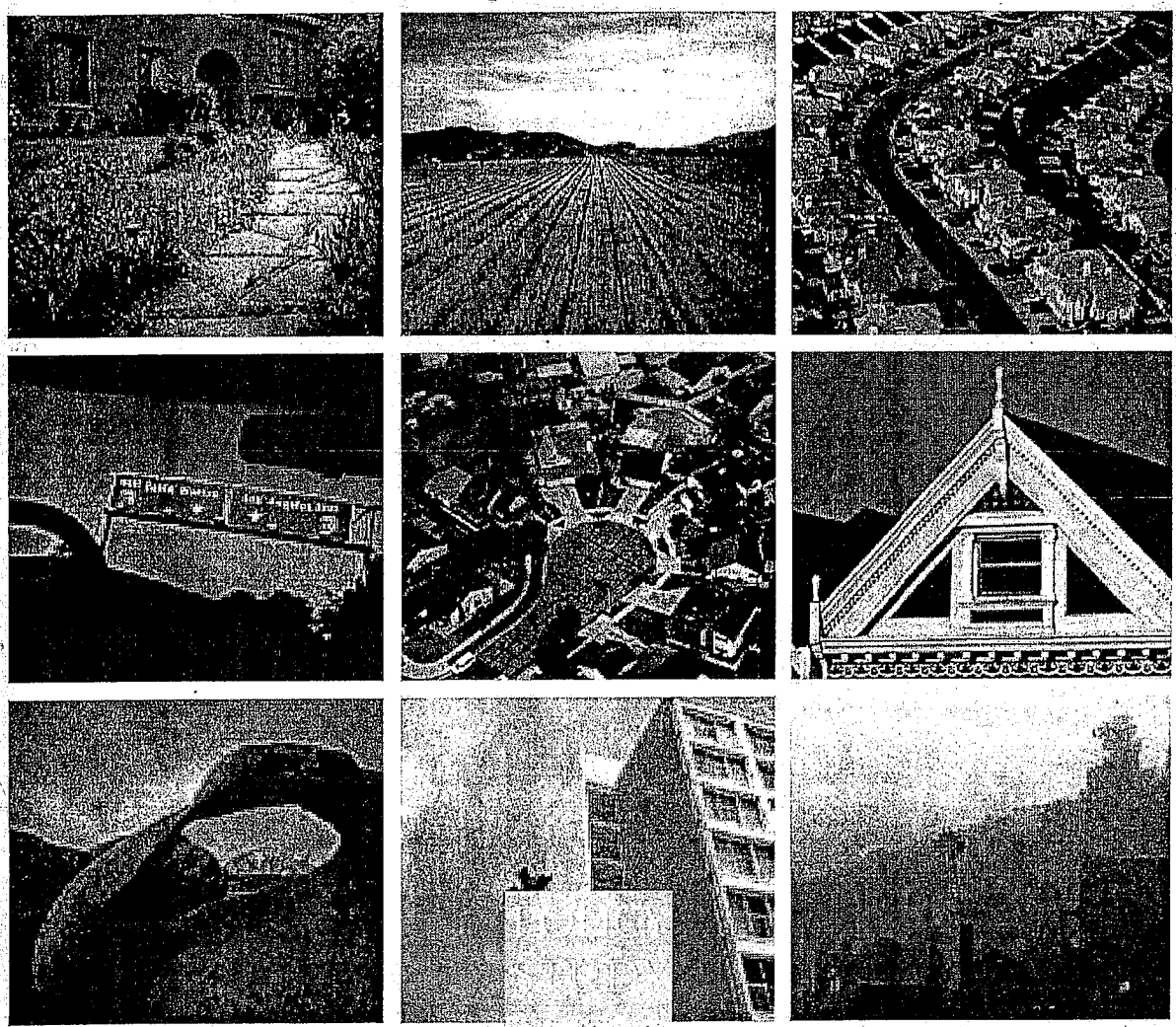

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Policy Study No. 311

Smart Growth in Action, Part 2:
Case Studies in Housing Capacity and Development from Ventura County, California

BY WILLIAM FULTON, SUSAN WEAVER, GEOFFREY F. SEGAL, AND LILY OKAMURA
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Executive Summary

The management of urban growth has emerged as one of the most important local policy issues in the nation. More than a dozen states have enacted some form of statewide growth management law, and most others are actively considering growth management legislation or planning reform laws that will directly affect the pace, pattern, and quality of land development. On the local level, growth management ordinances have become increasingly common, especially in the coastal states, with significant pressure for urbanization.

Despite the groundswell of activism and apparent public support for this new wave of growth management, remarkably little analysis has been done on whether local governments actually do, in fact, implement planning goals and visions. In part, the dearth of research is a result of the highly localized nature of growth management initiatives. Implementation issues, particularly assessments of the capacity of local communities to implement planning goals, are rarely addressed in the debate over "smart growth" or planning law reform.

This report is the second portion of a two-part study that attempts to help fill this void by examining the implementation of growth management techniques in Ventura County, California, a county of some 800,000 residents about 40 miles northwest of downtown Los Angeles and adjacent to Los Angeles County.

The first phase of this study was a quantitative analysis of residential development approvals in the county between 1996 and 2001. This second phase is a "case study" analysis examining six different residential development approvals in more detail.

We found that, despite the passage of Save Open Space and Agricultural Resources (SOAR) growth management initiatives, most cities in Ventura County had not amended their plans or their project approval processes to allow greater density within the boundaries of their municipalities. Quite the contrary, projects

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being approved in the cities were likely to have lower densities than the applicable general plans theoretically allowed. By failing to amend their plans or practices, cities were tacitly refusing to take any growth shunted from the SOAR-protected areas, in essence setting the stage for a crisis in housing supply to occur before SOAR's sunset date in 2020 and an exacerbated housing price escalation in the meantime.

Some of the study's findings specific to the mismatch between allowable and approved densities were these:

- Relative to the densities allowed by general plans, projects approved in the county on average provided less than 80 percent of planned capacity.[1]
- Multi-family projects were less likely to be scaled back severely than were single-family ones.
- Projects proposed within specific plan areas were subject to fewer reductions than those that were not.
- Projects in bigger cities were more likely to be approved at close to the plan densities than projects in smaller cities.
- Projects in the eastern part of the county were more likely to be approved at close to plan densities than in other parts of the county.
- The largest capacity reductions were more likely to occur prior to or at the time of application, not during public review of the project.

This last finding in particular engendered another series of questions that suggested pursuing the second phase of the study: What was happening in the so-called "pre-application" stage to spur the density reductions?

In examining the possible answers to this question, we posed five possible explanations for reductions in planned density during the pre-application stage. These were:

1. ***The Market.*** Developers know what is marketable in any given area at any given time and seek to provide a product that conforms to consumer demand; in some cases, this may mean reducing density. To remain competitive they must also bear in mind other current operating conditions—for example insurance availability, financing trends and tax incentives. Developers will make every reasonable effort to get their projects approved in the most cost- and time-efficient manner.
2. ***Politics.*** Planners have a good sense of what their elected officials expect to see and will vote to approve. They are loath to advance any project that promises to be highly controversial into the public forum unless they have support from their officials to do so.
3. ***"The Devil in the Details."*** In the transition from policy to implementation, the site specifics may drive a wedge between what is theoretically allowed under a general or specific plan and what is permissible under zoning regulations or other ordinances that set development standards.
4. ***Convenient Memory Loss or Myopia.*** The implication of the broad policy statements included in a general plan seldom hit home with residents until a specific development forced the issue. Even when neighbors have been involved in the general plan process, they may lose sight of the bigger picture when focusing on the vacant property adjacent to their own. Their perception of who was in control of the earlier general plan process—previous residents, developers, non-resident landowners—may erode their willingness to support the policies of the general plan.

5. *Aversion to Growth.* Density is still a dirty word for many residents of Southern California. And many planners working in Ventura County may also be growth-averse. The SOAR initiatives created the presumption of limited growth and made no density-tradeoff promises.

In applying this conceptual framework, we selected six case studies of residential development approvals, ranging in size from 75 to 404 units and in density from 3 to 18 units per acre. They were approved at densities ranging from 42 percent to 100 percent of planned density and averaged out to 68 percent. In assessing these six case studies, we found that, of our five possible explanations, no one explanation was the dominant factor in density reduction, and in some cases it was a combination of all five. We did find that market factors, politics, and "the devil is in the details" emerged most frequently as reasons for the reductions. Based on the case studies, however, we did reach four conclusions about the reasons for density reductions in residential development approvals.

First, developers sometimes do ask for lower densities in order to meet their perception of market demand or other non-regulatory considerations.

In some cases, developers will seek lower densities because they believe the market will accept single-family and lower-density housing types. Other issues not associated with local land use regulations, such as construction defect liability, may also play a role.

Second, the capacity in plans cannot always be politically sustained, especially under the pressure of neighborhood opposition.

Planning policies are not always the result of widespread political consensus. Often, they are brokered by a few interest groups with the motivation or desire to "play the game" at the plan level, including developers and citizen groups. Many stakeholders will sit out the comprehensive planning process and attempt to overturn policies when specific projects are proposed.

Third, the actual application of planning processes often drives the density down below the capacity contained in plans.

Project-specific review in California is largely, but not entirely, driven by the dictates of the California Environmental Quality Act, which identifies impacts that could be significant and strongly encourages local governments to take steps to mitigate those impacts. The net result is a system that often drives down the density or drives up the cost or both.

Fourth, specific plans appear to make a significant difference in creating plans that can be implemented "as-is".

A specific plan is a document that envisions the buildout of a specific part of a community, often under a separate set of planning policies and regulations. It is a hybrid document that includes planning policies, a buildout scenario, development regulations, and often a financial agreement between the developers and the city as well. Whereas general plans are "big picture" documents that both developers and citizens may have difficulty relating to, specific plans are often "real" enough to engage all parties in a meaningful way. Residents are less likely to stand outside the specific plan process than the general plan process because the issues are focused closer to home.

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Part 1

Introduction

The management of urban growth has emerged as one of the most important local policy issues in the nation. More than a dozen states have enacted some form of statewide growth management law, and most others are actively considering growth management legislation or planning reform laws that will directly affect the pace, pattern, and quality of land development. On the local level, growth management ordinances have become increasingly common, especially in the coastal states, with significant pressure for urbanization.

This pattern has been especially true in California, which does not have a state growth management law, but gives local governments great leeway in enacting local growth management ordinances. Not only have local elected officials in California been at the forefront in enacting such ordinances, but voters throughout the state have done the same. Since the 1980s, more than 600 local measures affecting land use policy and land use regulation have appeared on local ballots, mostly in coastal counties.[2]

Growth controls, however, are not implemented in a political vacuum. Once policies are adopted, local politics figure prominently in the question of whether planning goals will be realized. Particularly in the United States, where planning is explicitly local and must be adopted by locally elected officials, these political constraints are important elements of the planning process and should be incorporated into an evaluation of the success of the planning process and recommendations for further reform.

Despite the groundswell of activism and apparent public support for this new wave of growth management, remarkably little analysis has been done on whether local governments actually do, in fact, implement planning goals and visions. In part, the dearth of research is a result of the highly localized nature of growth management initiatives. Implementation issues, particularly assessments of the capacity of local communities to implement planning goals, are rarely addressed in the debate over "smart growth" or planning law reform.

This report is the second portion of a two-part study that attempts to help fill this void by examining the implementation of growth management techniques in Ventura County, California, a county of some 800,000 residents about 40 miles northwest of downtown Los Angeles and adjacent to Los Angeles County. Home to one of the most aggressive local approaches to growth management in the United States, Ventura County holds important lessons for all local governments attempting to plan development. The first phase of this study was a quantitative analysis of residential development approvals in the county between 1996 and 2001. This second phase is a case study analysis that examines six different residential development approvals in more detail.

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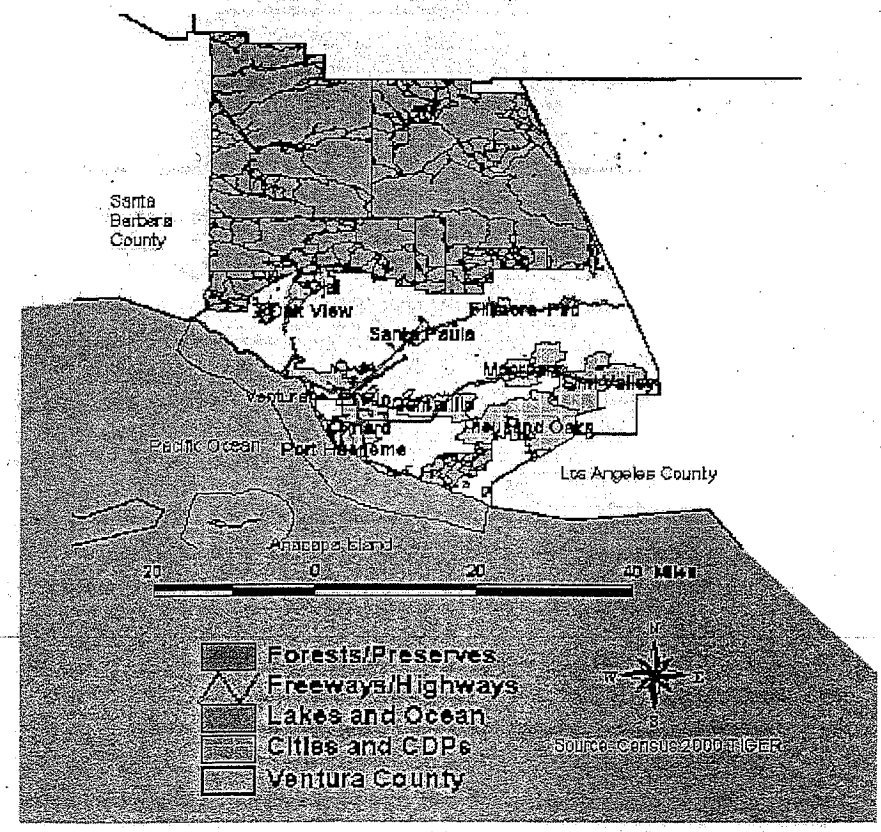
Part 2

Ventura County and its Growth Management System

With 1,864 square miles, Ventura is only average-sized among California counties, but with a Census 2000 population of 753,000 it ranks 11th in the state and among the largest in the nation. Its median household income in 2000 was just under $60,000—not only well above the state average, but above those of its neighboring counties, too.

Figure 1: Map of Ventura County



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Over the past 30 years, the county has engaged in a series of strong growth management and local government organization efforts seeking to preserve agricultural land and channel development into the county's cities. The result is a county with a unique spatial structure. The county still has more than 100,000 acres of irrigated agriculture. More than 90 percent of the population lives inside the county's 10 cities. But no one city is dominant. As Table 1 reveals, the county has four cities with populations of at least 100,000 but no city with a population of 200,000.

Table 1: Population of Ventura County and its Cities, 1990-2002

	1990 Census	2000 Census	% Increase, 1990-2000	2002 State Estimate	% Increase, 2000-2002
Camarillo	52,297	57,077	9.1%	59,500	4.2%
Fillmore	11,992	13,643	13.8%	14,400	5.5%
Moorpark	25,494	31,415	23.2%	33,050	5.2%
Ojai	7,613	7,862	3.3%	7,925	0.8%
Oxnard	142,560	170,358	19.5%	182,000	6.8%
Port Hueneme	20,322	21,845	7.5%	21,850	0.0%
San Buenaventura	92,557	100,916	9.0%	102,300	1.4%
Santa Paula	25,062	28,598	14.1%	28,750	0.5%
Simi Valley	100,218	111,351	11.1%	115,500	3.7%
Thousand Oaks	104,381	117,005	12.1%	121,000	3.4%
Unincorporated	86,520	93,127	7.6%	93,800	0.7%
Total	**669,016**	**753,197**	**12.6%**	**780,075**	**3.6%**

Source: California Department of Finance, Demographics Research Unit

The county's cities are geographically distinct from one another and maintain separate socio-economic identities as well. For example, six of the 10 cities have white populations of more than 70 percent, while three of the remaining four have Hispanic populations of 60 percent or more.[3] The county is separated into at least three areas that are experiencing pressure for urbanization. The first is the "East County," meaning cities such as Thousand Oaks, Moorpark, and Simi Valley, which are located close to the San Fernando Valley and at the top of the "Conejo Grade," a dramatic rise in the topography located along Highway 101 several miles inland from the ocean. The second is the "West County," meaning such cities as Oxnard, Ventura, and Camarillo, which are located below the grade, near the ocean, and along the rich agricultural soil of the Oxnard plain. The third is the Santa Clara Valley, another agricultural area along the Santa Clara River that is more remote from urbanization than the first two and consists mostly of the incorporated cities of Santa Paula and Fillmore.[4]

Most recently, the county's residents have passed a series of ballot-box zoning measures known as the Save Open Space and Agricultural Resources (SOAR) measures, which have been adopted in all but two of its cities.[5] These measures create urban growth boundaries around each city and require a public vote to change those boundaries. A SOAR measure was also adopted for unincorporated areas, and requires a countywide vote for land to be converted from agricultural or open space zoning to urban development. It is important to note that although the SOAR measures subjected future changes to a public vote, they did not substantially alter the growth management system already in place at the time.

There is no question that Ventura County's growth slowed during the 1990s. Between 1990 and 2000, the county's population grew by 12.6 percent, from approximately 669,000 to approximately 753,000, and the number of households grew by 11.9 percent, from approximately 217,000 to approximately 243,000. Despite

the county's strong legacy of growth control, these figures were typical of California generally and the metropolitan Los Angeles region in particular. The deep recession of the early 1990s appeared to depress population growth throughout California. Over the decade the population grew by 13.8 percent, from 29.8 million to 33.9 million, while households increased by 10.8 percent, from 10.3 million to 11.5 million.

Even though its population growth was below the statewide average, Ventura County did not produce enough housing to keep up with either population growth or household growth. During the 1990s, only about 23,000 units were added to the county's housing stock, a 10.2 percent increase, compared with 45,000 units in the 1980s and 77,000 units in the 1970s. Much of the additional population was accommodated by filling up vacant units (the vacancy rate dropped from 4.8 percent in 1990 to 3.3 percent in 2000) and by increasing household size (household size increased from 3.08 persons per household in 1990 to 3.10 persons per household in 2000.)[6]

Table 2: Population, Housing Units, and Households in Ventura County, 1990-2000

Ventura County	1990	2000	Net Change	Percent
Population	669,016	753,197	84,181	12.6%
Housing Units	228,478	251,712	23,234	10.2%
Households	217,298	243,234	25,936	11.9%

In the first phase of this study, *Smart Growth in Action: Housing Capacity and Development in Ventura County*,[7] we examined the effects of growth management policies at the county level in trying to understand why the level of housing production might have decreased. We took into account trends in population growth, demographics, and household formation, both before the imposition of these new controls and after they had been in place, to see what effect they had had on residential development and the general (or comprehensive) planning process.

We found that despite the passage of SOAR growth management initiatives, most cities in Ventura County had not amended their plans or their project approval processes to allow greater density within the boundaries of their municipalities. Quite the contrary, projects being approved in the cities were likely to have lower densities than the applicable general plans theoretically allowed. By failing to amend their plans or practices, cities were tacitly refusing to take any growth shunted from the SOAR-protected areas, in essence setting the stage for a crisis in housing supply to occur before SOAR's sunset date in 2020 and an exacerbated housing price escalation in the meantime.

Some of the study's findings specific to the mismatch between allowable and approved densities were these:

- Relative to the densities allowed by general plans, projects approved in the county on average provided less than 80 percent of planned capacity.[8]
- Multi-family projects were less likely to be scaled back severely than were single-family ones.
- Projects proposed within specific plan areas were subject to fewer reductions than those that were not.
- Projects in bigger cities were more likely to be approved at close to the plan densities than projects in smaller cities.
- Projects in the eastern part of the county were more likely to be approved at close to the plan densities than in other parts of the county.

The largest capacity reductions were more likely to occur prior to or at the time of application, not during public review of the project.

This last finding in particular engendered another series of questions that suggested pursuing the second phase of the study: What was happening in the so-called "pre-application" stage to spur the density reductions?

The pre-application stage is usually characterized by a series of private discussions—and informal negotiations—between the real estate developers applying for permit approvals and the government staff planners who process the permits. To our knowledge, no previous research had documented that the pre-application stage had such a profound impact on the final outcome of development approvals. And it was not clear from our quantitative analysis just exactly how the pre-application stage was reducing densities.

Was the story mainly about the developers' sense of what the market would buy, as many planners suggested? Or was it more a matter of planners imposing their ideas about good urban form or guiding developers to a better understanding of what the political climate in their community would support, as many developers suggested? This is the basic question that we sought to answer in this second phase of the research project.

Part 3

Framing the View: A Conceptual Framework of the Development Approval Process

The literature on development project approvals is thin. There is little literature on real estate development, for example, that describes the motivations of developers seeking lower densities; indeed, what literature exists focuses on how developers might increase densities during the project approval process.[9]

Meanwhile, literature on city planning offers little insight into the breach between comprehensive planning and implementation, but does speak to some of the political issues surrounding project approval—specifically public consensus and the influence planners exert at various points in the approval process.

If residential development projects are approved at lower densities than the underlying plans call for, this may reflect a lack of consensus in the community about the densities contained in the plan itself. Though a California jurisdiction's general plan may map out its future development through policy statements,[10] it is not always a consensus document. The formal adoption process—with its emphasis on public hearings—does not lend itself to the type of dialogue required to reach consensus[11] and the focus on the technical aspects of planning, including environmental impact reports, often deters the average citizen from participating in the process. As a consequence, the resulting plans are generally not considered by public officials to be indicative of the community's vision of itself because the most likely to participate are those associated with special interest groups.[12]

Even among those who do participate in the general planning process, few will stick around after the general principles have been adopted to hammer out the specifics that will guide implementation. Much like Captain Picard, of Star Trek fame, the public in effect waves its hands and declares, "make it so." The result is that what is adopted as policy is often expected by citizens to impinge only on someone else's choices. A survey taken in Wisconsin and reported on by the *Milwaukee Journal Sentinel* revealed that while more than three-fourths of those polled voiced support for compact, pedestrian-friendly development, two-thirds indicated they would not consider living in such a development because they themselves prefer lower-density neighborhoods.[13]

Public involvement in the general planning process provides no guarantee that implementation of the adopted plans will proceed smoothly. Many stakeholders do not participate in the plan-making process and enter the fray only when individual projects are presented for approval at the implementation level.

Furthermore, at such a late stage, they will often contest not only the specifics of the project but challenge the general plan principles as well.[14]

At the implementation level, planning is not as antiseptically technical an exercise as might be expected by those not involved in the development community. The entitlement process is often the vehicle used by elected and appointed officials to advance their own view of the community, no matter what the existing plans say. Their personal agendas are often implicitly promoted in the project approval process by staff members, for whom job security and career advancement may be more important than adhering to good planning principles.[15]

The dynamic tension between the various actors involved in real estate development is multi-layered, and an understanding of its local peculiarities is critical to political effectiveness. Even as local government planners seek to further the agendas of their elected officials, they also maintain close working relationships with developers who cultivate such relationships in order to facilitate approval of their projects, though, as public servants, planners are charged with serving in the public interest.[16]

Though planners may be active participants in the development approval process, their relationship with developers is not necessarily a simple, straightforward and trusting one. Planners may share a specialized set of tools with developers, but they generally are not similarly concerned with development economics. Manuals on planning practice advise that the policies, guidelines, and standards that will be applied "should be ironed out in the pre-app process...elements of the project get locked in fast because it is in early phases that projects are approved for financing by banks and other lenders."[17] But it is not uncommon for planners to use the financial value of time as a strategic tool to shape projects to match what they envision for particular sites. Simply put, the planners, unlike the developers, need not be concerned about the cost of money over time and the need to reach the marketplace with products quickly.

With planners as the gatekeepers to the project approval process, compliant developers will have help in expediting the approval process; others may find that inter-agency wrangling or other snags will subject them to expensive slow-downs.[18]

Since planners provide a link between adopted policies, elected officials, citizens, and developers, their role has also been described as facilitation. Working with developers, in the pre-application and application processes, planners convey what types of development are likely to receive community support or spark community opposition. Ethically, there is a limit to the amount of advice planners can give developers before they cross the line into advocacy. Frequently planners wind up conducting "shuttle diplomacy" between the various interested parties.[19]

Given all these factors, we constructed a conceptual framework suggesting five different possible reasons why densities might be reduced at the project approval stage. As we approached the case studies, we did not believe that the answer would always lie with only one of the five possibilities. Rather, given the fact that individual circumstances in real estate development vary widely across markets, communities, and land parcels, we believed that a different combination of reasons would exist in each case. However, we believed that, over six case studies in the same county, we would find consistent patterns.

Our five possible explanations for reduced densities at the project approval stage were as follows:

1. ***The Market.*** Developers know what is marketable in any given area at any given time and seek to provide a product that conforms to consumer demand; in some cases, this may mean reducing density. To remain competitive they must also bear in mind other current operating conditions, for example insurance availability, financing trends and tax incentives. Developers will make every reasonable effort to get their projects approved in the most cost- and time-efficient manner.

2. ***Politics.*** Planners have a good sense of what their elected officials expect to see and will vote to approve. They are loath to advance any project that promises to be highly controversial into the public forum unless they have support from their officials to do so.

3. ***The Devil in the Details.*** In the transition from policy to implementation, the site specifics may drive a wedge between what is theoretically allowed under a general or specific plan and what is permissible under zoning regulations or other ordinances that set development standards.

4. ***Convenient Memory Loss or Myopia.*** The implication of the broad policy statements included in a general plan seldom hit home with residents until a specific development forces the issue. Even when neighbors have been involved in the general plan process, they may lose sight of the bigger picture when focusing on the vacant property adjacent to their own. Their perception of who was in control of the earlier general plan process—previous residents, developers, non-resident landowners—may erode their willingness to support the policies of the general plan.

5. ***Aversion to Growth.*** Density is still a dirty word for many residents of Southern California. And many planners working in Ventura County may also be growth-averse. The SOAR initiatives created the presumption of limited growth and made no density-tradeoff promises.

Part 4

Methodology

To pry open the "black box" of the pre-application process, the case study approach was taken. The original study had considered 126 different residential projects in nine of the 10 cities in the county. While assembling our database on the 126 different projects, we identified approximately 30 projects that might be suitable for case studies based on their characteristics. In preparing for this phase of the study, we whittled these 30 projects down to six. These projects were chosen specifically because they represent a range of situations representative of the county as a whole. Among the considerations were the following:

- The six case studies include one each from six of the county's 10 cities.
- All six residential projects were approved and constructed in the late 1990s.
- The projects were approved at densities ranging from 42 percent to 100 percent of the densities called for in the city's planning documents.
- The projects range in size from 75 to 404 units.
- The projects range in density from 3 to 18 units per acre.
- Two of the six projects were multi-family projects and four were single-family projects.
- Five of the six projects were located within specific plan areas. One was in fact removed from a specific plan area, and another involves a transfer of density within a specific plan area.

The six projects included are:

- Meadows at Mission Oaks, a 221-unit detached condominium project in Camarillo.
- Riverwalk, a 144-unit single-family neighborhood in Fillmore.
- Vintage at the Rose, a 404-unit multi-family complex in Oxnard.
- Rancho Madera, a 75-unit single-family neighborhood in Simi Valley.
- Tract 5095 at Dos Vientos Ranch, a 168-home subdivision in a master planned community in Thousand Oaks.
- Nichols Ranch, a 198-unit single-family home subdivision in Ventura.

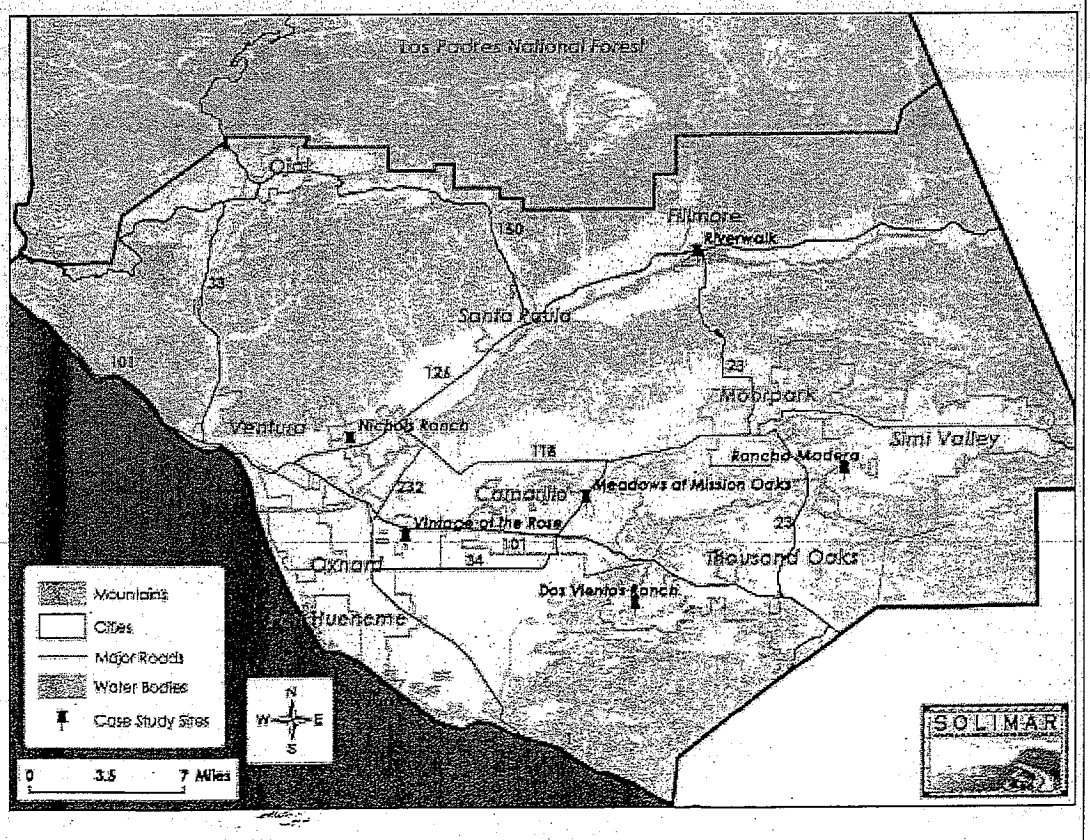
As shown in Table 3, the case studies were approved at densities that ranged from less than half the maximum assigned in the relevant general plans to nearly 100 percent (in the case of Vintage at the Rose). Taken as a group, the projects were approved at about 70 percent of maximum density. Compared to specific plans or zoning minimums, Vintage at the Rose, Dos Vientos and Nichols Ranch were all approved at

greater densities. The average for the six was still only 85 percent, largely because Riverwalk was approved at only 45.5 percent of the minimum indicated by zoning. The approval rates for the six case studies are higher than those for the total 126 projects included in our previous study, where the overall approval rates were 55 percent of general plan density and 79 percent specific plan/zoning minimum capacity.

Table 3: Approved Capacity as Percent of Planned Capacity

	General Plan Maximum Density	Specific Plan/ Zoning Minimum Density	Initial Application Density	% of General Plan Density	% of Specific Plan/ Zoning Density	Final Approval Density	% of General Plan Density	% of Specific Plan/ Zoning Density
Meadows at Mission Oaks	10.0	10.0	11.1	111%	111%	8.2	82.0%	82.0%
Riverwalk	11.0	11.0	5.9	54%	54%	5.0	45.5%	45.5%
Vintage at the Rose	18.0	18.0	22.0	122%	122%	18.0	99.8%	100.0%
Rancho Madera	7.0	3.3	3.2	46%	97%	3.1	44.3%	93.9%
Dos Vientos	4.5	3.1	3.4	76%	110%	3.2	71.1%	103.2%
Nichols Ranch	12.0	6.0	7.1	59%	118%	6.2	51.7%	103.3%
Average for Case Studies	10.4	8.6	8.8	84%	103%	7.3	69.9%	85.0%

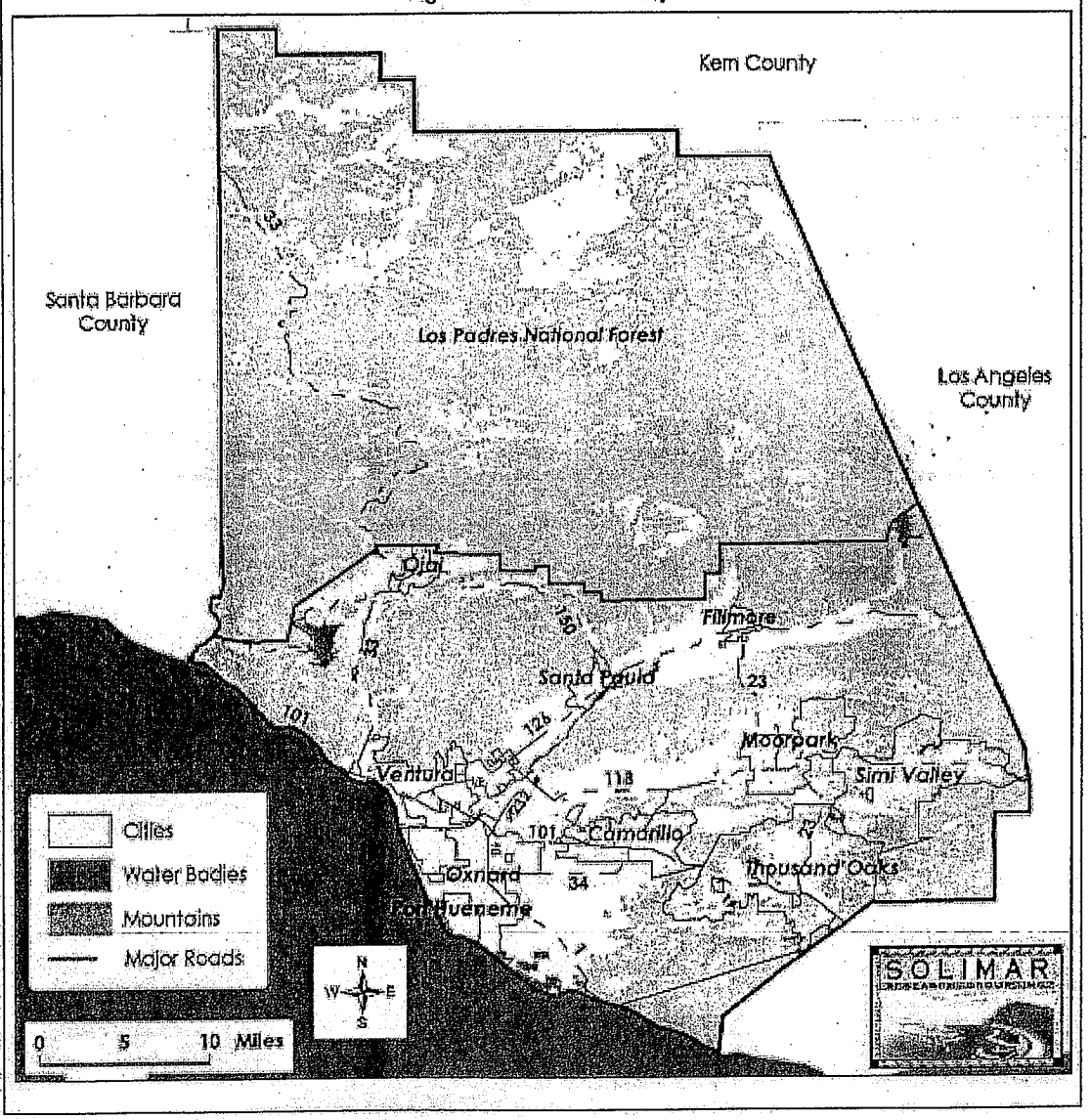
Figure 2: Six Cases



Once the six case studies were identified, the researchers took a qualitative approach to the actual research. Specifically, we:

1. Reviewed the project file available at each city planning department;
2. Assembled a preliminary chronology telling "the story" of the project approval;
3. Interviewed between two and five participants in each project approval, including the developer applicants, the city's case planner, and in some cases elected officials and planning commissioners; and
4. Revised the chronology based on the interview, thereby fleshing out the case study.

Figure 3: Reference Map



Part 5

Camarillo: Meadows at Mission Oaks

Meadows at Mission Oaks, a 221-unit detached condominium project in Camarillo, was approved at 82 percent of the density called for in both the city's general plan and in the Pitts Ranch Specific Plan. Though the project was a long time in the making, its approval process was remarkably uncontroversial. Market conditions may have been a major factor in lowering the density, but the devil was definitely in the details.

Camarillo, a mid-sized city located amidst the farmland of the Oxnard plain, has been growing in both size and importance because of its advantageous location along Highway 101 in the very center of the county. The Meadows at Mission Oaks was a project typical of Camarillo in the 90s—a "greenfield" development at the eastern edge of the city that reflected the shift away from single-family residences that occurred in some parts of the city.

Throughout the decade of the 1990s, Camarillo was adding population more slowly than most cities in the county, but it was adding housing at an unsurpassed rate. Despite the real estate downturn in the early nineties, the city increased its housing stock by 7.9 percent between 1990 and 1994, and by 8.5 percent between then and the end of the decade. When the housing price bubble burst, the real median home price in Camarillo plummeted by more than 30 percent, slightly more than the county average of 28.2 percent.[20]

It was in this climate that the Meadows at Mission Oaks project was proposed in 1990. By the time the project was built almost a decade later, the real estate market had rebounded and the real median home price had risen by 27 percent over its 1995 level, but still was nearly 12 percent below its 1990 high.[21]

That it took so long to build the Meadows project has more to do with the real estate market than with the city's review and approval processes. In fact the city's stance during that time has been characterized as moderately growth-promoting.[22] With a jobs-to-housing ratio of 1.6, it is on a par with Thousand Oaks.[23] Though the city established a maximum build-out population in 1986, it has distributed the housing unit allocations using a consistent set of standards that, unlike Ventura's process (described later), lays out a predictable path-to-development-entitlements.

The Meadows at Mission Oaks project occupies the northwest portion of the area comprising the 211-acre Pitts Ranch Specific Plan (PRSP) in the city of Camarillo. Lying to the south of Upland Road, it is also bounded by Flynn Road on the east, the Southern Pacific Railroad tracks and Lewis Road to the west. To the south, there is a landscaped buffer dividing it from an area designated for industrial development. Until development began, Pitts Ranch was a lemon grove. It adjoined St. John's Seminary, which is located on the

north side of Upland Road. When the Pitts Ranch Specific Plan was drawn up, both the Pitts Ranch and land belonging to St. John's were included. The Meadows was built on a portion of the latter property.

The area occupied by the Meadows is shown in the Pitts Ranch Specific Plan as a 33.8-acre parcel carrying a Residential-Low Medium (R-LM) designation of 10 dwelling units per acre. Another 8-acre parcel was set aside for R-LM in the southern portion of the plan area. Theoretically, the Meadows project could have accommodated 338 homes, or 80 percent of the total set aside for R-LM in the specific plan area. The amount of acreage that comprises the site was a continuing matter of discussion, however, and was revised several times prior to project approval. But up until late in the project's history, its developers consistently adjusted their plans to conform to the 10 units per acre density specified by the specific plan.

When Village Properties first submitted project plans to the city in December 1990, the company had estimated the site at 29.4 acres and designed a 299-unit attached condominium project.[24] In May of 1991, surveyors re-calculated the size of the parcel and then determined that it was only 28 acres. Accordingly, revised plans were drawn showing 280 units in clustered 2- to 6-unit buildings, still right on the mark of 10 dwelling units per acre. These plans were approved, but carried a condition that the tract map could not be recorded nor construction started until a final plan for Calleguas Creek had been submitted. The applicant also requested that the development allotments necessary under the city's growth management ordinance be awarded to him from the 1992 allotments.

In early 1992, approved plans and allotments in hand, Village filed for a modification that would allow it to record its map and develop the site prior to the completion of the Calleguas Creek Study. The study was being managed by Pardee, another developer in the specific plan area whose property was adjacent to the creek. A dispute between the city and Pardee regarding a mobile home site was holding up the study's finalization. Since its condominium project was not near the creek, Village Properties asked for relief from the condition. No action was taken on the issue, however, and in March of 1993, the developer requested a one-year time extension on that basis. It was approved, and in August the city council finally approved the deletion of the condition of approval related to the Calleguas Creek Study, clearing the way for Village Properties to record its map and begin construction.

In December 1993, the developer once again requested a plan modification. Yet another site survey had determined the parcel to be only 26.9 acres. It is unclear what the problems were in accurately determining the size of the parcel. Contributing factors may have been the proximity of rights-of-way for the future widening of Upland Road and for the Southern Pacific Railroad tracks. In order to mitigate the noise of the railway, a sound-attenuating wall of block, earth and plants was designed. The width of this structure may have reduced the useable space.[25] Whatever the reason for the corrected acreage, Village adjusted the number of units, reducing them from 280 to 266. Despite the approval of these changes, the developers still did not break ground. With the difficulties in complying with ordinances resolved, "the market" now entered the picture.

Changes in real estate market conditions and in construction liability laws prompted Village to apply for yet another modification in late 1995. Based on its experience with another attached condominium project, which was suffering from lagging sales, Village had deduced that current buyer demand was for detached units. This, coupled with its concerns about its ability to get construction liability insurance for attached units, prompted Village to ask permission to build 221 detached condominium units rather than the 266 attached ones for which it had entitlements.[26] With only 221 units on 26.9 acres, the density was now reduced to 8 units per acre and the Village once again had a set of approved plans.

This was the critical decision in determining the final density, and it was apparently made by the developer for solely market-based reasons. Had Village pursued a single-family scenario on the property, it almost certainly would have occurred at an even lower density, because—even with detached units—a condominium project still did not need to meet single-family setback requirements. As it was, however, the decision to "pull apart" the units reduced the project's density by some 1.5 units per acre.

Five years later, the project still had not been built. Village continued to apply for time extensions, apparently trying to weather the dismal real estate market conditions. Prior to construction, Village sold the property to Pardee, which finally built the units in 2000. Asking prices for the units ranged from approximately $300,000 upward.[27]

Though the number of units steadily decreased through the development history of the Meadows project, density was not reduced until late in the game. Even then, it wasn't city staff or adjacent property owners who drove the process. Rather, the density decline occurred for two reasons. First was the "devil in the details." Repeated property surveys steadily diminished the developable area of the parcel. Second was the role of "the market," or at least the developer's concerns about construction defect liability and product type, which were not a local land-use regulatory issue. Village Properties is defunct, and those who worked for it and might have explained why it took so long to get the details right are apparently no longer in the industry. Tony Bowden, who was the Development Director at the time and had an encyclopedic knowledge of development in Camarillo, is deceased. It is clear, however, in the memories of others involved and from the published public record that in this instance the density reductions were made solely at the behest of the developer in response to a market experience he interpreted as a consumer preference for single-family detached units.

Part 6

Fillmore: Riverwalk

By far the largest differential between theoretical and approved density found in these case studies existed in the Riverwalk project in Fillmore. The initial application represented about 54 percent of the maximum allowable density; the plans finally approved were at 45 percent. As is often the case in highly political circumstances, the reductions were a result of a complex mélange of all five possible explanations.

With an area of three square miles and a year 2000 population of 13,643, Fillmore is by far the smallest city in the study and one of the fastest growing. Traditionally, Fillmore was a citrus packing town in the Santa Clara Valley, far from most urbanization. It is perhaps best known for its picturesque 1920s downtown, and a majority of its residents are Hispanic. Much of its recent growth is attributable to its increasing role as a bedroom community for Ventura, which is located 20 miles to the west. Continued population and job growth in Santa Clarita (20 miles to the east) has also created more urbanization pressure.

Through the 1990s, population growth outstripped housing production. While its population was growing at a double digit pace during the decade (13.8 percent), housing expanded by only 4.4 percent from 1990 to 1994 and by an even lower rate of 3.4 percent between 1995 and 2000. Meanwhile, the median house price increased by nearly 35 percent—the second-highest rate of increase in the county.[28] To some extent this increase was certainly fueled by the competition of buyers for homes in this relatively affordable community, but it was also affected by the conscious effort of the city council to move the city up-market. While Fillmore did not adopt SOAR boundaries at the ballot box (but rather at the city council level after seven other cities had voted to impose them)[29] and does not have any other growth management policy,[30] neither does it give free rein to development. Rather it relies on its general plan and zoning ordinances to control growth and direct developers into the markets the city wants to see developed, as the Riverwalk project illustrates.

The 28.95-acre area that would become Riverwalk was the mish-mash remainder of agricultural acreage held by multiple owners, who had carved up their individual properties over the years to accommodate the surrounding development. It butted up against State Route 23 to the east. River Street and existing single-family residential development lay to the north, to the west lay undeveloped land and the city's sewage treatment plant, and to the south the Santa Clara River. The parcel was not an economically viable agricultural property, and was not in an agricultural preserve. Though it lay alongside the river, the property was not included in the floodplain on FEMA maps. The Fillmore general plan designated the area as Residential Medium, which provides for 7 to 11 dwelling units per acre and, theoretically, between 200 and 318 units could have been developed on the parcel.

These attributes suggested to Lynn Jacobs, president of Ventura Affordable Homes, Inc., that the site would be a perfect place for an affordable housing project much like one she had developed recently in Ventura.[31] She undertook to acquire the property, and in late 1996 she approached the city with a plan that would have put approximately 7 affordable single-family houses per acre on the site. The project that was ultimately approved provided 4.97 units per acre, barely more than 70 percent of Jacobs' original proposal and the low-end of the density range assigned in the general plan. No affordable units were included.

Opinions among the participants on what led to the knockdown in density differ. From the developer's standpoint, the city made it impossible to develop within the 7 to 11 units per acre density range provided for in the general plan, and in so doing priced the homes that could be built there out of the affordable range. But in the city's view, expressed by City Planner Kevin McSweeney, it was the developer who drove the density reduction by requesting to build single-family homes in an area that theoretically could have been developed with multi-family residences.[32]

McSweeney had expected that apartments would be proposed for the property. The rationale he recalls Jacobs giving for proposing the single-family development was "that is what sells." Though the city was grappling with the housing targets assigned by Southern California Association of Governments, McSweeney indicates that city officials were not in all respects disappointed that multi-family housing was not being proposed for this particular location.[33] They suspected the local political environment would not have supported it. When Jacobs came in with her single-family proposal, the city planning commission played its "devil-in-the-detail" card and noted that the zoning ordinance set minimum lot size in single-family residential at 6,000 square feet.

Still intent on building affordable housing but knowing that the 6,000-square-foot lot size would preclude this, Jacobs argued in the pre-application process in early 1997 that the city's development permit allowed the city to relax its minimum lot size in return for design concessions. In September 1997, she submitted plans for 162 units, or 5.6 per gross acre, but as negotiations continued and the city laid out the mitigations it would require, she became convinced that the city had no intention of allowing affordable units at that location. The amenities package initially requested included a 2.86-acre linear park, a horse trail, improvements to the adjacent sewer treatment facility, a grid-patterned street design, parkways, neo-traditional architectural features and utility line undergrounding that extended beyond the borders of the project. These, Jacobs believes, indicated that the city was consciously pricing the property out of the affordable range. From the city's perspective, these pointed strictly to its desire to apply "new urbanist" design principles.

Jacobs regrouped and joined with Kaufman and Broad to redesign the development to include 162 homes, upgrading the architectural details and incorporating the neo-traditional designs features that city council and staff had suggested. Pressing her point that the city's ordinances allowed for lots of less than 6,000 square feet with the approval of a development permit, Jacobs continued to negotiate with city staff over lot size. When the application was deemed complete in March 1998, staff and developers had compromised—the number of units being proposed had been reduced from 162 to 152, or 5.25 units per gross acre; the average lot size was 5,265 square feet But at estimated selling prices of $175,000 to $250,000, the homes were no longer priced in the "affordable" range.[34] Nevertheless, the applicant's name—Ventura Affordable Housing—generated substantial and persistent opposition to the project among adjacent property owners.

At the July 1998 planning commission hearing on the 152-unit plan, Jacobs responded to the staff report by pointing out that the lot sizes included in her plan were substantially larger than those of surrounding

developments. The commission reiterated its desire to see standard 6,000 square foot lots. One commissioner went so far as to suggest that the developer acquire more land south of the levee in order to increase lot sizes. Several area residents spoke against the project, citing the substandard lot size and their concern that houses on small lots would likely become HUD rental units. The hearing was continued and the applicant advised that the commission wanted, among other things, to see larger lots. That desire was restated at the subsequent continued hearings in August.

At the September 3, 1998, meeting, Jacobs presented new site plans to the planning commission, apologizing that they had not been available earlier.[35] The developers had eliminated all lots under 5,000 square feet, which along with a street change had eliminated two lots. Staff asked that the site plan and footprints be submitted to staff rather than be reviewed by the commission on the spot, and the commission agreed. But following public comments, the commission indicated that the applicant had not sufficiently addressed their concern about lot size. During commissioners' comments, it was suggested that the applicant reduce the number of units—this time to 140 (4.8 units per acre)—and redesign the project so that the minimum lot size would be 6,000 square feet. The hearing was continued for two weeks, and when that hearing was concluded, the commission validated the 5,000-square-foot minimum lot size, but required that the median lot size be 5,800 square feet. As explained later by McSweeney, who was the case planner at that time, this continued insistence was based on the planning commissioner's belief—one shared by the city council—that buyers came to Fillmore looking for larger lots than were available in the more urban settings of Santa Clarita or Ventura County's coastal cities.

Jacobs reworked the plans, and in October 1998 she returned to the commission with a plan for 144 units, or 4.97 units per gross acre—62 percent of low end of the density range shown in the general plan. The average lot size was now 5,500 square feet but the median was 5,200 square feet, not the 5,800 square feet the commission has requested. Despite this, city planning staff supported the plan, citing the design and infrastructure concessions as justification for allowing the smaller lot sizes. Though several members still pressed for 5,800-square-foot median lot size, after two failed motions, the commission finally recommended approval of the project to the city council, but not without reiterating its desire to have larger lot sizes.

In December 1998, the city council approved the development with the median 5,200 square foot lots, finding that the design of the project warranted the deviation from the 6,000-square-foot standard established in the zoning ordinance for single-family homes. Among the mitigating benefits were:

1. A new levee designed not only for safety but also for aesthetics;
2. A park nearly twice the size that would have been required by the city's park and recreation land dedication ordinance;
3. Payment of half of the fees that would have been assessed in lieu of park provision;
4. Incorporation of traditional neighborhood design features;
5. Street lighting upgraded to the nostalgic "Fillmorean" poles used in the civic center;
6. Rubberized asphalt paving on subdivision streets;
7. Landscaped parkways between the street and the sidewalks; and
8. An odor attenuation system for the city's sewage treatment plant.

Though Ventura Affordable Housing had acquired the necessary approvals, the company did not go on to build the project, but sold the entitlements to Greystone Homes in mid-1999.[36] Greystone then joined with Western Pacific Housing to form Grewes LLC, and in February of 2000 briefly floated a proposal to modify the plan to include 103 duplex housing units and 71 single-family homes. This would have increased the number of units per acre to 6, but the officials' response to the revision prompted Grewes, to withdraw the proposal from further consideration.[37] Instead, the partnership later applied for and received approval of a plan modification that allowed the inclusion of more single-story homes than had been proposed by Jacobs' firm, but did not increase the number of units. Hence the density remained at 4.97 units per gross acre.

The homes eventually sold for prices ranging upwards of $200,000.[38] Though city officials had expected buyers to come from northern Los Angeles County, as it turned out the majority came from Ventura County, specifically Ventura, Camarillo and Santa Paula.[39]

It is arguable that the density reduction in the case of Riverwalk was introduced by the developer, but only to the extent that she opened a window of opportunity for the city by requesting single-family homes in an area zoned to accommodate multi-family residences—a proposal based in part on her reading of the marketplace. Jacobs had accurately gauged the city's reluctance to develop single-family projects at the high end of the MDR range of 7-11 units. It is doubtful, though, that a multi-family project of any size would have been approved on the site. It was clear from the outset of this case that the adjacent community favored lower-density development, and the concerns raised in public hearings about HUD rental units indicate there would have been vociferous opposition to a multi-family project. While City Planner Kevin McSweeney indicates that he had waged an ongoing campaign to have the planning commission relax their focus on density in favor of neighborhood design, they remained intent on increasing lot sizes in this project even as they handed the project off to the city council.

In the case of Riverwalk, then, the density reductions came at every point along the path to approval, and all possible explanations played a role. The developer, taking the market into account and using staff's input to gauge the city's mood (politics), proposed a single-family project at the low end of the density range allowed; planning staff and city officials decreased the density in the pre-application stages by requiring neo-traditional amenities (politics and devil in the details); the city planning commission in the public hearing process (myopia and growth aversion) ratcheted the density down further, though not as far as some commissioners might have liked.

Part 7

Oxnard: Vintage at the Rose (Tierra Vista)

Vintage at the Rose offers a rare example of a city's adopting a general plan and adhering faithfully to it. In this case politics trumped the market. Despite the developer's argument that consumers would prefer single-family residences to the multi-family residences that were called for in the Northeast Community Specific Plan, the city staff's resolve to stick to its plan was unwavering.

Located in the heart of the Oxnard plain, Oxnard is the largest city in Ventura County (182,000 residents) and, during the 1990s, it was the second-fastest growing, behind only Moorpark. It is heavily Hispanic and has a younger population than the county on average. It is also more crowded, with more than 30 percent of housing units having more than one person per room.[40] With an area of 24 square miles, it is far from the largest of the study cities in terms of geographical size, but it is the most hospitable to a variety of housing types. Despite this, Oxnard's housing production is not keeping up with population growth. While the population grew by 19.8 percent over the last decade, housing units increased by slightly less than 11 percent. The majority of this growth occurred between 1995 and 2000.[41]

Vintage at the Rose, which would later be renamed Tierra Vista, was proposed and built in this latter time frame. The property is located in the northeast section of the Oxnard's Northeast Community Specific Plan (NECSP) area, an area just south of the emerging retail corridor along Highway 101 in Oxnard, a few miles west of Camarillo. The project is bounded by Graves Road on the east and Wankel Way to the north. A greenbelt lies to the west, providing a visual buffer between the property and similarly zoned property to the west. Socorro Way forms the southern boundary and beyond it a Low Medium Residential (LMR) area.

The NECSP was adopted in 1993 "to provide a guide for orderly growth and development of a portion of the Northeast Community..."[42] It covered an area of 856 acres, which originally comprised 21 parcels. As part of the adoption process, a General Plan Advisory Committee was formed and drafted a preferred alternate land use pattern, which was compared to that proffered by specific plan area property owners among others. Neighboring communities of Rio Linda and La Colonia also were consulted. As a result of the public input process, it was agreed that 3,411 dwelling units would be appropriate for the area. Of these, 1,427 (41.8 percent) were allocated to Low Density zones, 940 (27.6 percent) to Low Medium Residential, 908 (26.6 percent) to Medium Density and 136 (4.0 percent) to Manufactured Housing.

The site on which Vintage at the Rose was eventually built was assigned a Medium Density Residential (MDR) designation, which allowed 12-18 dwelling units per acre. Covering approximately 23 acres, the site

was allocated 405 units—the maximum 18 dwelling units per acre—or nearly half of the total allotted for the MDR designation. The property immediately to the south of the Vintage at the Rose site (and bounded north and south by Socorro Way and a greenbelt respectively) was designated as Low Medium Residential (LMR) and given a limit of 92 dwelling units.

In January of 1998, SIA, Inc. submitted a site plan for review that largely ignored the NECSP. It proposed apartments on 36 acres—the 23 acres that carried the MDR designation and approximately 13 that carried a LMR designation. With an average density of 11 units per acre, the density would have fallen between the allowances for the LMR (7-10 du/ac) and MDR (12-18 du/ac) zones. The 384 units proposed represented less than 80 percent of the 497 units allotted to the two areas by the NECSP. The city council was unimpressed with the proposal, and indicated that the developers should familiarize themselves with "...the design intent of the NECSP as well as the city's vision for a more livable community" before redrawing and resubmitting.[43]

Subsequently, the developers submitted new plans showing 496 units on the 36 acres, which increased proposed density to 14 units per acre, and they asked the city council for further design direction. When the project was reviewed by the city council in April of 1998, the fact that a portion of the project was within the LMR zone became an issue. The applicant was advised to go back to the drawing board and confine the apartments to the MDR portion of the property.[44]

Matthew Winegar, the city's development department director, relates that there was very little negotiation over density going on anywhere in the city during the 1980s and 1990s. Particularly within the confines of the NECSP boundaries, there was no incentive to propose something that didn't conform to the plan and the EIR. The city, in adopting the NECSP, intended to provide housing for the city's industrial workers and for employees they expected to work in adjacent high capacity office districts. Its intent was to provide a variety of housing opportunities while maximizing housing capacity and creating a critical mass to support local retail. Planning well in advance had allowed them to avoid neighbor disputes in the NECSP area.[45]

While the SIA project was more than one-half mile away from the nearest residential development (which was south of Camino Del Sol), it was not consistent with the NECSP. This meant that SIA could not rely on the Environmental Impact Report that had been adopted as part of the plan approval process but would have to prepare a supplemental EIR, at the minimum. Additionally SIA would have had to initiate a plan amendment and take on the substantial costs and risks that effort would involve. With both of the communities involved in the adoption of the NECSP on record as favoring lower density development, vocal opposition was to be expected.[46]

The project SIA subsequently submitted in the summer of 1998 was confined to the MDR zone and proposed 404 units on a 22.5-acre parcel, exactly the density allowed under the NECSP. Plans consisted of two- to three-story apartment buildings, a single-story community building, 2 pool and spa areas, and accessory buildings. As proposed the project was strictly market rate, but the NECSP called for a 10 percent set aside for low- and very-low income housing. Pressed by the city to include the affordable units, SIA proposed to work with another developer to provide the units off-site. That proposal was rejected.

When the project went before the planning commission in October of 1998, it included 40 affordable units on-site and evenly dispersed throughout the project. The project as proposed was exactly what the commission expected to see and was willing to approve. There was no opposition to the project. It was the first apartment complex with more than 100 units to be proposed and approved in Oxnard in 20 years.[47]

SIA decided in late 1998 to pursue bond financing for the project. That entailed no changes in the plans, but would have included 81 affordable units. The bond issue was approved by the city council in January of 1999, but was never used for the project. SIA sold the project to Essex in 2000 and, according to Oxnard Housing Director Sal Gonzales, Essex wasn't interested in using the public financing.[48] Instead they reduced the number of affordable units to the 40 required by the inclusionary housing provisions of the NECSP and renamed the project Tierra Vista.

The remaining 13 acres of SIA's original proposal are currently being developed by SIA in partnership with another developer as a 90-unit single-family housing tract. Under the NECSP that property had been allocated 92 units. In terms of density, the property was restricted to seven units per acre, on the low end of the range allowed by the LDR designation.

Vintage at the Rose was built to the highest density allowed by the NECSP, but the density range was less meaningful here than the number of housing units assigned to the site. SIA could have proposed to build as few as 276 units and still have been in compliance with the NECSP range assigned to the parcel. But given the city's determination to implement the NECSP, it is unlikely the city would have been encouraged to build less than 12 units per acre. In contrast, the cap of 92 units imposed on the LDR property immediately to the south restricted density there to the low end of the range allowed by the NECSP. If only the density range had applied, as many as 130 units might have been developed there.

Within the NECSP in Oxnard, the negotiations on density were hammered out in the specific plan approval process when the total number of housing units was divvied up among the various sites. The EIR predicated on those allocations served as a strong disincentive to requesting use changes or increased density. It would have presented less of a barrier to density decreases. Staff, however, was firm in demanding a plan that squared with the NECSP. As noted above, the city council was not open to negotiations concerning changes in density, and the staff was aware of this political situation. The staff also felt there was sufficient demand for multi-family units to warrant its insistence on building to the full density allowed. Though not all developers may have agreed with the staff's reading of the market at the time, experience has supported the staff's view. Tierra Vista, as Vintage at the Rose is now known, has occupancy rates that routinely range between 93 percent and 95 percent[49] and full-market rents that ranged from $1,140 to $1,910 per month in March, 2003.[50]

Part 8

Simi Valley: Rancho Madera

In Rancho Madera, we once again saw an interplay between the market and the "devil in the details." Viewed in light of the general plan, the density reduction was severe, but what was approved was in line with the Rancho Madera Specific Plan. Topography played a large part in the knock-down, as we will see.

At 115,000 people, Simi Valley is the third-largest city in Ventura County and one of two cities adjacent to Los Angeles. It is located along Highway 118 just a few miles west of the San Fernando Valley (part of the city of Los Angeles). During the 1990s, Simi Valley's population grew by 11 percent, and the city produced more housing than any other city in the county except for Thousand Oaks (4,662 units or a 14.2 percent increase).

Simi Valley is geographically large (39 square miles) and contains a wide variety of suburban-era neighborhoods, from 1950s and '60s subdivisions featuring large lots but modest homes to high-end master-planned communities such as Wood Ranch, which is located in the southern portion of the city near the border of Thousand Oaks. It is in this more upscale part of the city that the Ronald Reagan Presidential Library is located—and Rancho Madera, the subject of the Simi Valley case study, is positioned just down the hill from the library along Olsen Road, a major arterial.

In its 1988 general plan update, the city of Simi Valley dedicated the 43-acre-plus Rancho Madera area almost exclusively to senior citizen-serving uses, with about 5.5 acres reserved for general commercial uses targeted to senior needs. Requiring a specific plan to be prepared prior to development, the general plan explicitly called for development "to offer senior citizens a variety of residential and residential/care life styles."

While the general plan indicated preliminary projections of the number of units, it also noted that the Hillside Performance Standards (HPS) would determine the actual number of units that would be allowed. Potential densities ranged from a maximum of 50 dwelling units per acre in the 7.5-acrea area designated for very high density to a minimum of 10 units per acre in the 30.2 acres shown as high density, but the "appropriate" number cited for the area was 404 units plus 59 beds in a skilled nursing center.

When project planning began for the parcel in 1989-90, the real estate market was still quite strong. The Rancho Madera Specific Plan was designed as a senior-oriented neighborhood, but it had far fewer units than had been envisioned in the general plan. With the Hillside Performance Standards taken into account, total dwelling units were reduced to 201, or half of the number cited in the general plan. But the skilled nursing/continuing care facility, now planned with 99 beds, had been nearly doubled in size.

By the time the specific plan was approved in 1991, the real estate market had begun to slump. Both housing prices and rents dropped in the area and weak demand for senior housing delayed the start of the project. Not until 1996 did the market begin to rebound, but even then developers were still leery of building so large a project aimed solely at seniors. Kaufman and Broad (K&B), which had acquired rights to the property and submitted a preliminary application for the parcel in 1997, noted that, based on its assessment, a large market rate senior complex was not economically viable.[51] Consequently K&B proposed amendments to both the general plan and the valley floor map that would remove Hillside Performance Standards from certain portions of the property and would reduce the seniors-only portion of the project to 3.5 acres. The intention was to build single family homes for unrestricted sale on approximately 24 acres. The commercial portion of the property would be retained if the city so desired.

By the time the project was to be heard on October 27, 1997, it was clear to K&B that city staff was not supportive of any bid to amend the valley floor map, and would not recommend approval of the project as configured in the proposal. Consequently, at the planning commission hearing K&B expressed its "willingness and commitment to work with the City to create a project that is consistent with its wishes and requirements."[52] The request to amend the valley floor map was withdrawn, but K&B asked for immediate consideration of the GPA request since without it K&B would not be able to include market-rate detached housing. Because this product would be necessary to pay for the majority of the development's infrastructure, K&B was anxious to nail down the change, but it would have to wait for the GPA approval.

Apart from market considerations, K&B was particularly eager to finalize project plans and move the approval process ahead quickly because it already had $10.7 million in federal tax credit allocations in hand to provide financing for the affordable senior housing component of the plan. These allocations were not renewable or transferable, and would expire if, within 24 months of their award, the qualifying apartments had not been constructed. Since the allocations would leverage an additional $7 million, losing them would be extremely costly for K&B. City staff was sensitive to these timing issues, but also used the additional leverage to press their desire to have active senior apartments included in the project and negotiated the project design with the developer.[53]

With guidance from city staff, K& B revised its plans and, in early November 1997, submitted a proposal that increased the senior-oriented uses to 8.6 acres and reduced the density on the single family portions to match that of the HPS Residential Moderate designation. This configuration, by K&B's calculations, would have permitted construction of 79 single-family units and more than 250 units of senior apartments and assisted living space.[54] In a follow-up letter, K&B acknowledged the city's desire to retain zoning standard control over the project, control that might be ceded if the specific plan requirement was dropped. In answer to this concern, K&B proposed to submit a vesting tentative tract map and a planned development permit.

In mid-November, the city council authorized K&B to file for the necessary approvals. The proposal that went forward to the planning commission for review included 75 single-family homes and 136 senior-only apartments. Sixty-seven apartments were to be reserved as affordable units. The number was chosen to avoid the condition imposed by Article 34 of the state Constitution, which would have required voter approval before the affordable units could be constructed.[55] Also included was a 97-bed residential care facility site, which K&B intended to offer to other developers.

Table 4: Land Use Designation			
Land Use Designation	**Units**	**Acres**	**Units / Acre**
Simi Valley 1988 General Plan			
▪ High Density / Seniors	364	22.69	16.04
▪ Assisted Living / Seniors	99	7.53	13.15
▪ Very High Density / Senior Care	150	7.51	19.97
▪ Commercial Center	0	5.64	--
▪ Total Units	613	43.37	14.13
Rancho Madera Specific Plan			
▪ High Density / Seniors	201	21.78	9.23
▪ Continuing Care / Seniors	99	2.06	48.06
▪ Open Space	0	16.25	--
▪ Commercial Center	0	3.45	--
▪ Total Units Including Congregate Care	300	43.54	6.89
November 1997 GPA Proposal			
▪ Very High Density / Seniors	129	8.63	14.95
▪ Moderate Density	79	23.86	3.31
▪ Open Space	0	11.05	--
▪ Total Units	208	43.54	4.78
June 1998 GPA Proposal			
▪ Residential Moderate	75	23.87	3.14
▪ Residential Very High	136	5.48	24.82
▪ Residential High	97	4.08	23.77
▪ Open Space	0	10.11	--
▪ Total Residential Units	211	43.54	4.85
▪ Including Congregate Care	308	43.54	7.07

The major reduction in permissible density on the Rancho Madera parcel was imposed during the HPS review when the slope analysis was conducted. Approximately 50 percent of the site was found to have slopes in excess of 15 percent, and hence restricted severely in the number of units allowed per acre[56]. The slope analysis was used with the 1988 general plan zoning designations to determine that a maximum of 251.6 units could be constructed—149.9 in high density areas and 101.7 in very high density areas—for an overall density of 5.77 units per acre. The reduction from 79 to 75 units that occurred in the final stages of design was a result of working with the setback, parking, and open space design constraints.[57] Tom Preece of Simi Valley's Environmental Services Department suggests it is appropriate to omit assisted living, continuing and congregate care facilities from density calculations, as these are considered commercial uses and are allowed in residential zones only by special use permit. If this is done, the residential density approved for the tract was 4.85 dwelling units per acre. While this is only 84 percent of the HPS allowable density, it is 101 percent of the density proposed in the 1997 general plan amendment. When congregate care facilities are considered, the units-per-acre figure rises to 7.07, which is 103 percent of the total density including congregate care allowed by the Rancho Madera Specific Plan.

The density decisions in this case were driven primarily by the "devil in the details" of the inflexible Hillside Performance Standards. Once the maximum number of units was established by that process, the developer and city staff worked to fine-tune the development to meet their respective needs. Here both the market and politics came into play, with city staff using market knowledge to their political advantage with respect to the

ticking time-bomb tied to the federal tax allocation credits. By all accounts, both sides took design constraints and market analysis into consideration in deciding how the allowed number of units would be allocated between single-family detached, active senior housing and assisted senior living facilities. Here, the forecasts were not uniformly accurate. The first two residential types have been built as planned, but the demand for congregate care facilities has remained sluggish and the area designated for this use has not yet been developed.

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Part 9

Thousand Oaks: Tract 5095 within Dos Vientos Ranch

Though we found evidence of many of our potential explanations of density reduction in the case of Tract 5095 in Dos Vientos Ranch in Thousand Oaks, most actors had long since exited the scene because the knockdown had occurred as part of the specific plan approval process well before the tract was designed. In the tract approval process itself, the city officials stood firm to defend the density allowed by the Dos Vientos Specific Plan No. 8/9, and a factor not found in the other case studies proved to be the most influential.

Thousand Oaks occupies a unique position in Ventura County. Originally developed as an executive suburb for the San Fernando Valley, it is now the county's most affluent city as well as one of its most important job centers, thanks largely to Amgen Corporation, a leading biotech company headquartered in Thousand Oaks. Many of the early Thousand Oaks neighborhoods—such as Westlake Village, which actually straddles the county line between Ventura and Los Angeles Counties—were pioneering high-quality suburban developments in the 1960s. Furthermore, Thousand Oaks is unusual in the sense that the city laid out a forward-looking general plan in 1970 and has, generally speaking, stuck with it ever since.

For this reason, Thousand Oaks has continued to deliver housing production despite a slow-growth reputation and the fact that it is rapidly approaching buildout. At 121,000 residents it is the second-largest city in the county after Oxnard, and between 1990 and 2000 its population grew by 12 percent. More than 5,000 housing units were added during that time for a 13.3 percent increase.

The area known as Dos Vientos Ranch is situated on the far southwestern side of the city, and stretches across the rolling savannah that lies south of the US 101 freeway. It butts up against the ruggedly scenic Western Plateau area. The1970 general plan initially proposed 2,900 housing units for this area, but when the Dos Vientos Specific Plan No. 8/9 was approved in April of 1988, the total number of units had been reduced to 2,350 units, of which 225 were to meet affordability criteria and 125 were to be seniors-only, market-rate units. Attachments to the city council resolution recording that decision noted that these "density reductions have been imposed as a means to mitigate to acceptable levels potentially adverse cumulative effects including traffic, noise, schools and air quality impacts identified in the Final EIR dated February 9, 1987. Therefore, approval of these Specific Plans does not permit the maximum number of residential units identified below (2,350) to be exceeded..."[58] At the same time, the council amended the general plan to reflect the change.

By the time that tentative tract 5095 and the related residential planned development (RPD) permit applications were submitted by Courtly Homes, a decade had passed. The tract had originally been planned for 175 homes and, as a general condition imposed by the community development department, this number was set as the maximum density for the development.[59] But as the project went through the formal pre-application process, minor refinements were made to the plans. The plans that went forward included a site for a daycare center, and the number of homes was reduced to 168. That change reduced the density of the tract from 3.54 to 3.40 units per net acre; however this was still in the range (2.0 to 4.5) and above the average of 3.25 units per net acre designated for the area in the Thousand Oaks General Plan.

Since the specific plan approval and general plan amendment in 1987, a subsequent EIR (FSEIR 301, dated June 27, 1994) had been certified as having fully analyzed the environmental effects of 2,350 new residential units. The planning commission resolution approving tract 5095, its RPD, and several other tentative tract maps referenced this certification and stated assertively:

> *...the City has made a commitment to specific land uses, residential densities and the number of new residents generated by the project.* Therefore, the question of new development is not a consideration. *(Resolution No. 98-167) (emphasis added)*

Perhaps this was meant to quiet opposition to the developments, as the size and scope of the Dos Vientos Specific Plan had made its approval process a fairly contentious one, but the strategy was successful only to the extent that it narrowed the debates. While none of the individual tract approvals generated specific opposition to their design or mix of land uses, they were still individually contested on the basis of cumulative noise and traffic impacts. These concerns are often raised as reasons to rein in growth. Tract 5095 generated relatively moderate attention on these grounds during its approval process.[60] In response to these concerns, the tract's developers were assessed nearly $500,000 in fees to mitigate the projected traffic impacts, but mitigation of noise impacts was deemed infeasible. Despite these and other unavoidable impacts, the planning commission found that the benefits to be derived by the city from the project were sufficient to warrant adoption of a statement of overriding considerations as they approved the tract map on a split vote on June 22, 1998.[61]

Within two weeks, the community development director appealed the planning commission's June 22nd decision. While the policy and procedure for density transfers within the Dos Vientos plan area was a major issue, the grounds for appeal hinged on the reduction in the amount of commercial acreage shown in tract 5096 and the impact this would have on surrounding tracts, tract 5095 included. Previously 9.2 acres had been determined as the minimum area required for an economically viable neighborhood shopping center. As approved, the commercial acreage was now only 7.3 acres. Coupled with density increases and transfers in tract 5094 and tract 5095, this prompted the community development director to point out that sufficient provisions for local shopping opportunities had been identified in both final EIRs associated with Dos Vientos as a mitigation measure to reduce off-site traffic impacts and to lessen traffic-related adverse air quality impacts. With the reduction in size, he contended the commercial acreage was no longer sufficient to serve as mitigation. The city council upheld the planning commission's decision regarding the density transfers, but seemed to acknowledge that increased off-site traffic impacts would result from the smaller commercial site.[62] In partially granting the appeal, the council established the tract's pro rata share for a future bridge-widening project on Wendy Drive and so amended the conditions attached to the tract in ratifying its approval.[63] At the same time, the council also ratified, without changes, the accompanying RPD 917-517, which gave Courtly Homes permission to construct 168 single-family detached dwellings.[64]

While construction had already begun in many phases of tract 5095, the daycare center site was still vacant in February 2002 when the Western Plateau Preservation Plan was heard by the city. As part of that plan, an application was made to re-subdivide that 3.83-acre site into seven lots. Entitlements for seven single-family residences were also requested. Both requests were granted as part of a 17-application package that amended the city's general plan and the Dos Vientos Specific Plan by adding 191 acres to the city's inventory of permanently protected open space. The compound result of the council's actions on the Western Plateau Preservation Plan was to reduce the maximum number of housing units that could be built in the Specific Plan 8/9 area by four units, to 2,346.[65] It also lifted age and affordability restrictions on housing built there.[66] Starting prices on houses in the most recent phase of the Villa Encanto subdivision within tract 5095 were advertised as being in "the low $500,000's."[67] Prices in adjacent subdivisions currently start at $650,000.[68]

With the additional seven-unit entitlement, the density of tract 5095 is once again at 3.54, solidly in the middle of the density range established in 1988. In protecting 191 acres of Western Plateau land from development, the city reduced the total number of units allowed in Specific Plan 7 by 128, but in Specific Plan 8/9 they were reduced by only four.

The city has generally maintained the density established for the Specific Plan 8/9 area by allowing density to be transferred between tracts. The city's resolve to stand firm against residents' growth-averse assaults on Specific Plan 8/9 stems, at the least in part, from development agreements with the area's master developers—a factor not present in our other case studies. These stipulate the minimum number of residential unit entitlements will be equal to the maximum number of units permitted by the specific plan.[69]

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Part 10

Ventura: Nichols Ranch

The Nichols Ranch case offers an example of growth-resistant myopia. The Juanamaria Specific Plan, which had been adopted in 1989, was not embraced by current residents. They strongly opposed the initial project proposed for the parcel in conformance with the Juanamaria plan. This opposition finally led to the city's bringing in professional mediators to preside over a consensual planning process.

Commonly known as Ventura, the city of San Buenaventura is the county seat, stretching from the ocean inland along the Highway 126 corridor for some nine miles. Comprising 21 square miles, it had a population in 2000 of about 101,000—a 9 percent increase over its 1990 population. The 2000 median house price of $233,800 represented a 33.6 percent increase in real terms over the 1995 median house price. This rapid rise, third fastest in the county, was due almost exclusively to the interplay of increased demand and an insufficient supply of housing rather than to a change in the type or quality of housing being built. Housing stock in the Ventura metropolitan area increased by only 3.9 percent from 1990 to 1994, and by a mere 1.9 percent from 1995 to 2000.[70]

Ventura has had a slow-growth reputation since the 1970s. The city's comprehensive plan sets a maximum population limit of approximately 116,000 persons by the year 2010, and residential growth toward that target is controlled by an implementation system known as the Residential Growth Management Plan. Under the RGMP, the city doles out a limited number of "housing allocations" (permissions to move forward in the planning process) every two years.[71] In 1995 an additional brake on growth was imposed when voters passed the Save Open-space and Agricultural Resources (SOAR) initiative. SOAR requires a vote to convert any land in the city's sphere of influence that is zoned for agriculture.[72]

SOAR's passage may have fixed in some residents' minds the notion that any property still under cultivation within the city limits would remain so unless and until citizens voted for a change. This was especially true in the eastern Ventura neighborhoods where pro-SOAR sentiment was high. Leapfrog development dating back to the 1960s has resulted in a patchwork of urbanization in east Ventura, with neighborhoods and agricultural land intermixed.

However, not all of the land under cultivation in 1995 was zoned for agriculture. When the city adopted the comprehensive plan in 1989, it also approved a specific plan for the so-called Juanamaria area and designated some agricultural parcels for urban development. Hence, these parcels were not subject to SOAR.

Nichols Ranch was one such parcel.

Situated along Kimball Road near Route 126 in Ventura, Nichols Ranch was a lemon orchard of slightly more than 42 acres that had been surrounded by urban development. Included in the Juanamaria community, it had carried an urban use designation in the city's comprehensive plan prior even to the 1989 update. Residential areas had already been developed on three sides of the site, and the 126 Freeway abutted it to the south.

In the comprehensive plan, the site was assigned a planned residential designation with density to range between 6 and12 units per net acre. According to the CP, the assignment had been made because the site "...provide[d] the best opportunity in the Community for a mixed density residential development." The plan went on to describe the preferred arrangement of uses on the property—low-density development to face existing single-family residences stepping up to higher density on the perimeter adjacent to Kimball Road and the freeway[73].

Beazer Homes had been working to design a project for the site for a number of years, and had acquired housing allocations through the RGMP process in August of 1994, more than a year before SOAR's passage. The allocations allowed Beazer to build as many as 227 additional units on the property (there was an existing house on the property), subject to entering a development agreement with the city and obtaining the requisite planning approvals. Mark Stephens, who was then a Ventura city planner assigned to the case, recalls there was very little public input during the RGMP allocation process and early stages of the approval process.[74] A portion of the property was in the city's sphere of influence but outside the city's boundary, so, in addition to a zone change request and planned development permit application, annexation proceedings had to be initiated. In November 1994, Beazer submitted the applications for these with the intent to build 227 single-family homes ranging in size from 1,998 square feet to 2,622 square feet. Ninety-three lots would be 5,500 square feet or larger, 133 smaller parcels would be 3,900 square feet or larger.

In July of 1995, the city council approved a mitigated negative declaration for the project, but the project didn't reach the planning commission until November of that year, the same month that the SOAR initiative was voted on. At that commission meeting, commission members raised concerns about the design of the subdivision, and appointed a three-member subcommittee to work with city staff and the applicant to redesign the project. That effort took the better part of eight months.

The plans presented to the planning commission on March 5, 1996, included a reconfigured street pattern and design changes intended to soften the differences between the proposed development and the existing one. Though the developers had met with residents of the neighboring homes, they had, in Commissioner Lynn Jacobs's view, engaged in a mediocre public relations job that had done more to fuel neighbor opposition to the project than to garner support for it.[75] Based on the commission's continuing concerns about project design, the case was continued for a week. At the subsequent meeting, the opposition was out in full force; more than 200 people attended the hearing. The commission, because of what then-Planning Commissioner Sandy Smith described as "a disconnect between staff and the Planning Commission,"[76] was still not satisfied that design changes sufficiently addressed community concerns. The commission denied the project. Surprisingly, even some of the members of the sub-committee, which had overseen the revisions, voted to deny.

Beazer, however, was not ready to give up the fight. With support from members of the city council, at the following planning commission meeting it asked for and got reconsideration. In granting this, the commission continued the project and recommended the developer not only retain outside design assistance in reconfiguring the project but engage a professional facilitator to solicit neighbor participation in the

process. The commission was specifically interested in seeing "new urbanist" ideas incorporated into the plans.

The consulting team of John Cahill, a process facilitator, and David Sargent, an architect with the firm of Civitas Town Planning, were hired to guide the consensus planning project. Two residents of the Ventura East tract, which is adjacent to the project site, were chosen to represent that community. Then Cahill and Sargent set to work, meeting with the planning commission committee and city staff, Beazer staff and the project property owners, and the community representatives. In March of 1997, nearly a full year after the reconsideration had been granted, they held their first public workshop at Juanamaria School. About 100 people attended. In the course of the workshop, general concerns about the city's growth were aired. But when the focus was narrowed to the Beazer project, the paramount concerns voiced were about traffic, pedestrian access, and the adequacy of public safety services—not the number or density of units.

The result of the public consensus process was the decrease in the number of units planned from 228 to 198. Though density had decreased from 6.98 dwelling units per net acre to 6.06, it was ostensibly the desired street configuration and not resistance to the proposed density that spurred the change. Vehicular and pedestrian circulation issues had been hashed out, and in Sandy Smith's view, solving an existing traffic problem for the Ventura East neighborhood was important in building support for the redesigned project.[77] Mark Stephens recalls that prohibiting two-story units on lots adjacent to the Ventura East neighborhood and reaching an agreement on boundary and streetscape landscaping that would help retain the feeling of space once the orchard was gone were also important.[78] Architectural design standards were established to make the development more visually compatible with the existing neighborhood. The end result was that the redesigned project reflected the preference of its neighbors for something they were comfortable with—something very similar to their own low-density subdivision. Though much of the neighbors' concerns were voiced in terms of traffic and circulation issues, the crux of their fear was that an adjacent, higher density project would diminish their properties' values. As noted by David Sargent, reducing the size of the project by 30 homes had a negligible effect on circulation between the two neighborhoods, but the increase in lot size this accommodated made the project much more palatable to the residents of Ventura East.[79]

Toward the end of March 1997, Beazer submitted its revised plans to the city. For the next few months they were reviewed by various city departments, and in May received staff level approvals from the environmental impact review committee and the subdivision committee. In early June, Cahill and Sargent issued the Consensus Planning Process Final Report; the project had been placed on the June 17th planning commission agenda. Sandy Smith recalls that perhaps four or five members of the public showed up for that final planning commission hearing. The commission voted to recommend the approval of the revised project to the city council. The project received final approval from the city council on July 21, 1997. When the homes were marketed in 1998, Beazer's asking prices started at $350,000.[80]

Under the Residential Growth Management Plan (RGMP), the planned densities shown in the comprehensive plan only give the broadest idea of what may eventually be developed. The developer's timing and Ventura's RGMP allocation process turn out to be major factors. The number of units a developer can hope for is determined by the number available for distribution, the other projects vying for allotments at the same time, and the design merits of the projects. The number of units assigned to the Nichols Ranch project restricted the density of the project to approximately seven units per net acre, or the lower end of the range allowed by the property's comprehensive plan (CP) designation (6-12 units), but they might well have been assigned more or fewer units. So, relative to the CP designation, the first reduction came in the political "black box" of the RGMP process. The developers did not of their own volition reduce project density. The

remaining reduction resulted from the public process where the Juanamaria Specific Plan was attacked (myopia) and concerns about traffic and infrastructure adequacy betrayed neighbors' growth-averse tendencies. Though the "D" word may not have been bandied about in the public workshops or hearings, the result of the process was to reduce the project's density to six units per net acre as average lot sizes were increased and neighbors molded the new subdivision into an image of their own.

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Part 11

Conclusion

In the first phase of this study, we found—to our surprise—that most reductions in density occurred not during the public approval process, but in the pre-application stage. As a result, we concluded that the real horsetrading over density occurred during these pre-application negotiations, though we could only guess why. In reviewing the first phase of the study, government planners often told us that developers proposed the density reductions based on market conditions, while developers often told us that planners proposed the density reductions based on political feasibility. As we searched the literature for studies dealing with the project negotiations, we found some dealing with the public side, but nothing that helped explain the process from the developers' side of the table.

In constructing our hypothesis, we were somewhat hampered by the paucity of information presented from the developers' point of view. As a consequence, the myriad reasons that might prompt density reduction requests were condensed into the "Market" category. Reductions emanating from the public agency side were placed in two categories—Politics, which encompasses staff interactions with elected officials and other departments, and "devil in the details," which accounts for technical difficulties imposed by codes and ordinances on the translating of broad policy statements into practical projects. The remaining categories—Myopia and Growth Aversion—include sources found not only in the general public, but among public officials, too.

We expected that if reductions did occur mainly at the pre-application stage, that they would come mainly from the market, politics, or the "devil in the details." In fact they did, but we also found evidence of the other two. We also hoped to determine whether the planners' actions or the developers' requests were most often responsible for the reductions. But the case study analysis examined here reveals a truth that is somewhat more complicated. What we found was that seldom was only one source responsible for driving density down. Instead, there were generally several reasons intermingled in each case.

Overall, based on our case study approach, we found at least four common reasons why densities are reduced.

First, developers sometimes do ask for lower densities in order to meet their perception of market demand or other non-regulatory considerations.

This factor came into play in several case studies, including Riverwalk in Fillmore and Rancho Madera in Simi Valley, but it was most dominant in the case of The Meadows in Camarillo.

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Camarillo's planning policies permitted a density of 10 units per acre at The Meadows. The area was still developing, neighborhood opposition was minimal, and city officials were supportive of higher-density products. But the project was originally proposed at the beginning of a "down" market, at a time when California was beginning to see a steep decline in the construction of attached condominium projects.

The project was delayed for several years because of market considerations, and eventually the developers sought and obtained a density decrease of approximately 1.5 units per acre in order to build detached, rather than attached, condominium units. This approach was not uncommon in the mid-'90s; indeed, a number of other detached condo projects were built in Camarillo and Oxnard during this time.[81]

It is important to note that the switch to detached condos was also motivated by an economic consideration not related to the city's land use regulatory structure: the difficulty in obtaining insurance for attached condominium projects, which appears to be related to the state's liberal construction defect liability laws. Even those outside of the building industry have come to accept that the construction defect liability issue is a legitimate concern, and recent state legislation is designed to reduce the liability and therefore encourage insurance carriers back into the marketplace.[82] Thus, in that one case, a state-level legal issue completely unrelated to land use regulation was a major factor in driving down the density.

Second, the capacity in plans cannot always be politically sustained, especially under the pressure of neighborhood opposition.

The fact that existing plans do not have strong political support came out most obviously in the case of Riverwalk in Fillmore and Nichols Ranch in Ventura. In both cases, existing plans anticipated development and called for a particular density range. Yet in both cases, it was clear neither neighboring residents nor the community's political leadership was deeply "invested" enough in those plans to make them stick. Sometimes this came out in the pre-application stage; other times it didn't become an issue until the public hearing process began.

In the case of Fillmore, we heard somewhat conflicting stories from the developer and the city over who made the actual decision to propose single-family, rather than multi-family, units. But there is no question that both sides recognized that multi-family units were not politically palatable, and this was factored into the pre-application process. Furthermore, when confronted with conflicting policy directives—a general plan permitting up to 11 units per acre and a zoning ordinance requiring 6,000-square-foot lots—the city stuck strongly to the policy directive that would force a lower density.

In the case of Ventura, neighborhood opposition took a somewhat different form. In the wake of SOAR's passage, the surrounding residents simply did not believe that Nichols Ranch could be developed because it was still in agricultural cultivation. The lengthy process of facilitation and consensus-building was only partly about the design and size of the project. In large part, it simply served to allow the neighbors to become familiar with the reality of the city policy they had voted on, which still permitted development on agricultural land that was slated for urban development in the comprehensive plan.

Third, actual application of planning processes often drives the density down below the capacity contained in plans.

When we discussed the results of the first phase of this report with planners throughout Ventura County, they were not surprised by the results because, they argued, project-level review inevitably reveals site-

specific situations that will cause the project to be reduced in size. Although we were somewhat surprised by this perspective (Why would planners believe that the plan could not be implemented as written?) it turned out to be true in some cases.

Project-specific review is largely, but not entirely, driven by the dictates of the California Environmental Quality Act, which identifies impacts that could be significant and strongly encourages local governments to take steps to mitigate those impacts. The net result is a system that often drives down the density and drives up the cost or both. Such site-specific considerations played some role in reducing the density in the Simi Valley, Ventura, and Fillmore projects.

In Simi Valley, both the 1988 general plan and the 1990 specific plan proposals called for relatively high densities (somewhere between 10 and 16 units per acre). But the Rancho Madera property is extremely hilly. Once the city's hillside review was conducted, the project declined considerably in size and density.

In Fillmore and Ventura, project-specific review did not simply identify impacts and mitigations; it also "opened the door" for a negotiation between the neighborhood and the developer over the amenities to be provided, which in turn affected the density. In Fillmore, a residential development proposal originally designed as affordable eventually had to bear the cost of a wide range of community amenities, including a new levee and a park that exceeded city standards. In Ventura, project-specific review created the opportunity to discuss traffic patterns and alternate traffic scenarios, which in turn appeared to decrease the density as well.

It is worth noting as well that in one case project-specific review revealed deficient information about the parcel itself, which in turn affected the size of the project. In the case of The Meadows in Camarillo, neither the city nor the developer had accurate information about the size of the parcel even though a specific plan for the area had already been adopted.

Practicing planners often argue that project-level review will always reveal site-specific conditions that cannot be anticipated at the plan level, and therefore the actual density of a project will inevitably be lower than the plan calls for. To them, this is simply part of the implementation of their planning policies. As Ventura County continues to mature, this consideration will likely become more important, because more development will occur on small, difficult, or leftover parcels adjacent to existing neighborhoods—as was the case in Simi Valley, Fillmore, and Ventura.

Fourth, specific plans appear to make a significant difference in creating plans that can be implemented "as-is".

In the first phase of the study we found that residential development projects located inside specific plan areas were much more likely to be approved at the densities envisioned in planning policies. In general, the case studies—especially those in Thousand Oaks and Oxnard—bore out this conclusion.

In California, the "specific plan" provides an intermediate step between a citywide general plan and actual project approval. A specific plan is a document that envisions the buildout of a specific part of a community, often under a separate set of planning policies and regulations. It is a hybrid document that includes planning policies, a buildout scenario, development regulations, and often a financial agreement between the developers and the city as well.[83] Whereas general plans are "big picture" documents that both developers and citizens may have difficulty relating to, specific plans are often "real" enough to engage all parties in a

meaningful way. Residents are less likely to stand outside the specific plan process than the general plan process because the issues are focused closer to home.

In both Oxnard and Thousand Oaks, the specific plans were major community undertakings that focused community attention on the buildout of important sections of the city. This is not to say that they were without controversy. The Dos Vientos Specific Plan in Thousand Oaks has been the subject of a great deal of controversy and even litigation over the years. But in both cases, the battles had been waged at the specific plan level, so that the actual projects could be proposed and approved more or less as envisioned at the plan level.

In the case of Dos Vientos, it is possible that when the Western Plateau Preservation Plan was being considered, the community might have reneged on commitments made in the specific plan if not for the accompanying development agreement. It is to be expected that over the course of time, community priorities may change. And technically, plans may be amended. But where development agreements are in place, and developers are resolved to defend them, the legal ramifications of plan amendments may dissuade the community from changing its mind.

The Nichols Ranch project in Ventura offers a different cautionary note about specific plans. Nichols Ranch was contained in the Juanamaria Specific Plan area, which envisioned a fairly specific buildout and also contained a financial plan for infrastructure improvements. This did not prevent intense community opposition at the project level. But in the case of Nichols Ranch, the community consensus around the Juanamaria Specific Plan—if consensus ever existed—had already been undermined by the passage of time and the adoption of SOAR.[84]

One final important note about specific plans. In the two case studies where specific plans were successfully implemented at the project level, they involved large tracts of undeveloped land that could be developed together, almost as a master-planned community. In the future, however, it will be far more likely that development in Ventura County will occur on smaller parcels previously passed over, as was the case with Nichols Ranch. So, to be successful in the future, specific plans will have to address the question of how to continue to build out partially completed communities that already have residents and vested interests.

In the world of real estate development, translating plans into on-the-ground projects is never easy. Land use plans always represent an uneasy truce between the market reality of development, driven by the needs and preferences of consumers not yet in residence, and the political reality of communities, which are driven by the views of homeowners who already live there. No matter how carefully they are drawn, it may not be possible to implement plans as they are written because political and economic conditions are subject to change.

About the Authors

William Fulton is president of Solimar Research Group Inc., a public policy research firm dealing with metropolitan growth, urban planning, and economic development issues throughout California and nationwide. He was one of the principal authors of *Smart Growth In Action*, released by Reason Public Policy Institute in 2001. Mr. Fulton is also editor and publisher of *California Planning & Development Report*, a monthly newsletter, and the author of four books, including *The Reluctant Metropolis: The Politics of Urban Growth* in Los Angeles, which was an *L.A. Times* best-seller. Mr. Fulton earned his B.A. in Mass Communications from St. Bonaventure University, an M.A. in Journalism/Public Affairs from The American University in Washington, D.C., and an M.A. in Urban Planning from the University of California, Los Angeles.

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Mr. Segal has presented his research at numerous conferences around the world. He has appeared in front of the cities of Phoenix, San Diego, and Stockton city councils as well as submitted testimony to the State of California. Furthermore, he has advised numerous government officials on privatization, efficiency, transparency, and accountability.

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Related Reason Foundation Studies

William Fulton, Chris Williamson, Kathleen Mallory, and Jeff Jones, *Smart Growth in Action: Housing Capacity and Development in Ventura County*, Reason Foundation Policy Study No.288, December 2001.

Samuel Staley, *Line in the Land: Urban-Growth Boundaries, Smart Growth, and Housing Affordability*, Reason Foundation Policy Study No.263, November 1999.

Randall O'Toole, *Urban Transit Myths*, Reason Foundation Policy Study No.345, September 1998.

James V. DeLong, *Myths of Light Rail Transit*, Reason Foundation Policy Study No. 244, September 1998.

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Endnotes

1 Compared to general plan capacity, only 55 percent of the maximum number of dwelling units permissible were approved. When compared to more restrictive zoning ordinances, the entitlement rose to 80 percent.

2 William Fulton, Mai Nguyen, et al., *Growth Management Ballot Measure in California* (Ventura, CA, Solimar Research Group, Inc., 2002).

3 U.S. Census Bureau, Census 2000, http://www.census.gov/main/www/cen2000.html.

4 In local parlance, the Santa Clara Valley is typically lumped together with the West County, but we separated it out as the "North County" in phase one of this report.

5 The only two cities without SOAR measures in place are Ojai, which permits little growth as a matter of course, and Port Hueneme, which is completely surrounded by the city of Oxnard and the Pacific Ocean.

6 Similarly on the state level, housing units increased by 9.2 percent, more slowly than the population increase of 13.8 percent, and the vacancy rate decreased from 7.2 percent to 5.8 percent.

7 William Fulton, Chris Williamson, et al., Smart Growth in Action: Housing Capacity and Development in Ventura County (Los Angeles, CA: Reason Public Policy Institute, 2001).

8 Compared to general plan capacity, only 55 percent of the maximum number of dwelling units permissible were approved. When compared to more restrictive zoning ordinances, the entitlement rose to 80 percent.

9 Steven Fader, *Density by Design: New Directions in Residential Development* (Washington, D.C., Urban Land Institute, 2000).

10 William Fulton, *Guide to California Planning* (Point Arena, CA, Solano Press, 1999).

11 Charles J. Hoch, ed., *The Practice of Local Government Planning* (Washington, D.C., International City/County Management Association, 2000).

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13 Jerry Taylor and Peter VanDoren, *Sprawl for Me, But Not for Thee* (Washington, D.C.: Cato Institute, 2003).

14 James Innes, "Planning through consensus building." *Journal of the American Planning Association* (62(4), 1996), pp. 460-472.

15 Steven A. Bollens, "Urban Planning and Intergroup Conflict: Confronting a Fracture Public Interest," *Journal of the American Planning Association* (68(1), 2002), pp. 22-42.

16 John Forester, "Planning in the Face of Conflict: Negotiation and Mediation Strategies in Local Land Use Regulation," *Journal of the American Planning Association* (53(3), 1987), pp. 303-314.

[17] Albert Solnit, Carl Reed, et al., *The Job of the Practicing Planner* (Washington, D.C., Planners Press, 1988).

[18] John Forester, "Planning in the Face of Conflict: Negotiation and Mediation Strategies in Local Land Use Regulation," *Journal of the American Planning Association* (53(3), 1987), pp. 303-314.

[19] John Forester, "Planning in the Face of Conflict: Negotiation and Mediation Strategies in Local Land Use Regulation."

[20] Ventura County Workforce Investment Board, *State of the Workforce 2002*, November 2002, www.wib.ventura.org

[21] Ibid.

[22] Madelyn Glickfeld, William Fulton, et al., Growth Governance in Southern California (Claremont, CA: Claremont Graduate University Research Institute, 1999).

[23] Ventura County Workforce Investment Board, *State of the Workforce 2002*, November 2002. www.wib.ventura.org

[24] Ed Burns and Bob Burrow, city of Camarillio, in October 25, 2002, interview.

[25] Ed Burns, city of Camarillo planner, in October 25, 2002, interview.

[26] Camarillo Development Director Bob Burrow in November 13, 2002, interview.

[27] Ventura County Houses and Homes for Sale. http://www.signonvc.com/findhomemain.htm

[28] Ventura County Workforce Investment Board, *State of the Workforce 2002*, November 2002.

[29] William Fulton, et al., *Smart Growth in Action: Housing Capacity and Development in Ventura County.*

[30] Governor's Office of Planning and Research, California Planners' Book of Lists 2001, Sacramento, California, 2001.

[31] Lynn Jacobs in October 31, 2002, interview.

[32] Fillmore City Planner Kevin McSweeney in October 23, 2002, interview.

[33] Under the state law governing Housing Elements (Section §65583), SCAG, the Southern California Association of Governments, as regional planning agency, is responsible for developing the Regional Housing Need Allocation (RHNA) plan for Ventura County in consultation with the state's Departments of Housing and Community Development (HCD) and Finance (DOF). In an iterative process based on the population growth projected by DOF, HCD estimates the housing needs by income level for the county, and the local council of government—SCAG in the case of Ventura County—predicts how the need will be distributed among the cities and unincorporated areas of the county. Once a RHNA plan has been agreed to by HCD, DOF, and the affected Council of Governments, the housing needs allocations are incorporated into the county and city Housing Elements. RHNA allocations are distinct from allocations made by cities, though the latter should reflect RHNA allocations. By way of differentiation, allocations made under the city of San Buenaventura's Residential Growth Management Plan (RGMP) attempt to regulate the pace of housing development so that it doesn't outstrip infrastructure and resource capacity. Allocations made by the city of Oxnard and the city of Camarillo in their specific plan approval processes stipulate where projected growth will go within specific plan boundaries.

[34] City of Fillmore Planning Department Staff Report to Planning Commission dated July 23, 1998.

[35] Fillmore Planning Commission Special Meeting Minutes, September 3, 1998.

[36] Lynn Jacobs in October 31, 2002, interview.

[37] City of Fillmore Planning Department Staff Report to Planning Commission dated February 17, 2000.

[38] Home Buyers' Guide http://www.hbg.com/ven.html

[39] Fillmore City Planner Kevin McSweeney in October 23, 2002, interview.

[40] Ventura County Workforce Investment Board, *State of the Workforce 2002*, November 2002. www.wib.ventura.org

[41] Ibid.

[42] City of Oxnard, "Northeast Community Specific Plan," December 1993, p. 1-1.

[43] Undated city of Oxnard Planning & Environmental Services memo from Joyce Parker-Bozylinski, Planning Manager, to Edmund F. Sotelo, City Manager.

[44] Ibid.

[45] City of Oxnard Development Services Director Matthew Winegar in October 24, 2002, interview.

[46] City of Oxnard, "Northeast Community Specific Plan," December 1993, pp. 1-7 and 1-8.

[47] Ibid.

[48] City of Oxnard Housing Department Director, Sal Gonzales in October 22, 2002, interview.

[49] Debra Baccari, Tierra Vista leasing agent, interview with authors 2003.

[50] Inside Ventura County Rentals. http://www.insidevcrentals.com/communities/tierra_vista/

[51] Gary Gorian for Kaufman and Broad in letter dated 8/29/97 addressed to city of Simi Valley Mayor and city council members contained in the city's File No. 703-2-2, PR-451 Kaufman & Broad Home Corporation.

[52] Gary Gorian for Kaufman and Broad in letter dated 10/27/97 addressed to city of Simi Valley Mayor and city council members contained in the city's File No. 703-2-2, PR-451 Kaufman & Broad Home Corporation.

[53] Eric Lieberman, formerly with Kaufman and Broad, in February 3, 2002, interview.

[54] Eric Lieberman for Kaufman & Broad in letter dated 11/7/97 addressed to Sam Freed, Senior Planner, city of Simi Valley contained in the city's File No. 703-2-2, PR-451 Kaufman & Broad Home Corporation.

[55] Amendment 34 requires voter approval prior to construction of publicly funded rental complexes when 50 percent or more of the units are reserved for low and very-low income residents.

[56] Sites with slopes of 15-20 percent are restricted to 0.25 units/acre; those with slopes greater than 20 percent are restricted to 0.025 units/acre.

[57] Eric Lieberman, formerly with Kaufman and Broad, in February 3, 2002, interview.

[58] City of Thousand Oaks, *Resolution No. 88-69, Exhibit B, III.B. Maximum Number of Permitted Residential Units* (1988), p. 1.

[59] City of Thousand Oaks, *Resolution No. 51-98PC* (1998), p. 11.

[60] John Prescott, Planning Division Manager, city of Thousand Oaks, interview with G. Segal.

[61] City of Thousand Oaks, *Resolution No. 51-98PC* (1998), p. 2.

[62] City of Thousand Oaks Community Development Department, *Appeal Application for Tract Map and Land Division Permit No. TR. 5095,* 1998.

[63] City of Thousand Oaks, *Resolution No. 98-167* (1998), p. 6.

[64] City of Thousand Oaks, *Resolution No. 98-168* (1998).

[65] City of Thousand Oaks, *Western Plateau Preservation Plan Supplemental Environmental Impact Report,* 2002, p. 2-1.

[66] This was contingent upon payment to the city's affordable housing assistance fund by the Miller Brothers, owners of the property, of $500,000, and construction of 50 affordable units at a site to be chosen later by the city.

[67] Standard Pacific Homes. http://www.hbg.com/xstandardpac.html

[68] Trimark Pacific. *Concerto at Dos Vientos Ranch.* Advertisement in the *Los Angeles Times* New Homes Advertising Supplement, January 18, 2003, p. Y5.

[69] City of Thousand Oaks Community Development Department Memo to Planning Commission dated June 22, 1998, p. 11.

[70] Ventura County Workforce Investment Board, *State of the Workforce 2002,* November 2002. www.wib.ventura.org

[71] City of San Buenaventura Comprehensive Plan Draft 2002-2005 Housing Element, May 2002.

[72] LAFCO, or the Local Agency Formation Commission, is a special agency in each of California's counties, and is responsible for drawing boundaries for nearly all local governments—the sole exception being redevelopment agencies. In addition to establishing incorporation limits for cities, LAFCOs also establish spheres of influence. A city's sphere of influence may extend beyond its incorporation lines to encompass the area the city is expected to ultimately annex. In drawing up its general plans, a city can chose to include all the area in its spheres.

[73] Planning Commission Community Services Staff Report, action date June 17, 1997.

[74] Mark Stephens, formerly a planner for the city of San Buenaventura, in November 1, 2002, interview.

[75] Lynn Jacobs was a Ventura Planning Commissioner at the same time that she was attempting to develop Riverwalk in Fillmore.

[76] Ventura City Councilman Sandy Smith in November 4, 2002, interview.

[77] Ibid.

[78] Mark Stephens, formerly a planner for the city of San Buenaventura, in November 1, 2002, interview.

[79] David Sargent in November 15, 2002, interview.

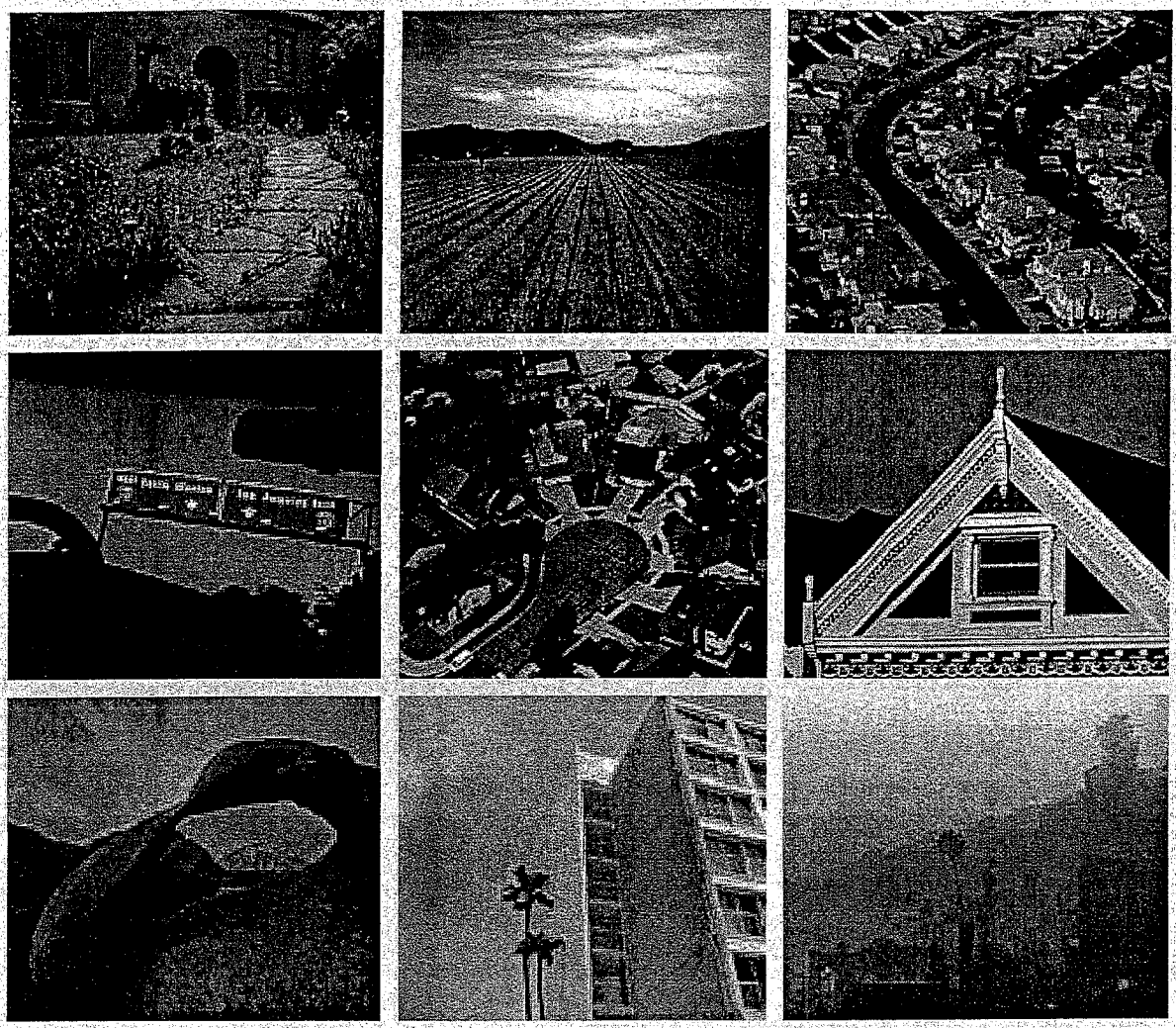
[80] Inside Ventura New Homes http://www.insidevcnewhomes.com/newhomes/newhomesinfo/index.cfm?action=listmodels&DevelopmentsID=105

81 Ed Burns, city of Camarillo planner, in October 25, 2002, interview with William Fulton and Lily Okamura, and Lynn Jacobs in October 31, 2002, interview.

82 Paul Shigley, "Construction Defect Rules May Change: Building Industry Says Litigation Depresses Condo, Townhouse Development", *California Planning & Development Report* (17(8)), August 2002.

83 Fulton, *Guide to California Planning, 2nd Edition.*

84 The lack of consensus was reflected in the vote on the adoption of the development agreement for Juanamaria, which took place in January 1988. It guaranteed developers 721 building permits in exchange for funding for a freeway overpass and interchange to serve the area. The agreement was adopted with the slimmest of margins (4 ayes, 3 noes). The council members voting "no" had just recently been elected (2) or re-elected (1) primarily on the strength of their slow-growth advocacy. "Ventura: Juanamaria Development Agreement", *California Planning & Development Report*, *Vo. 3, No.4,* April 1988, p. 6.



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Policy Summary No. 288

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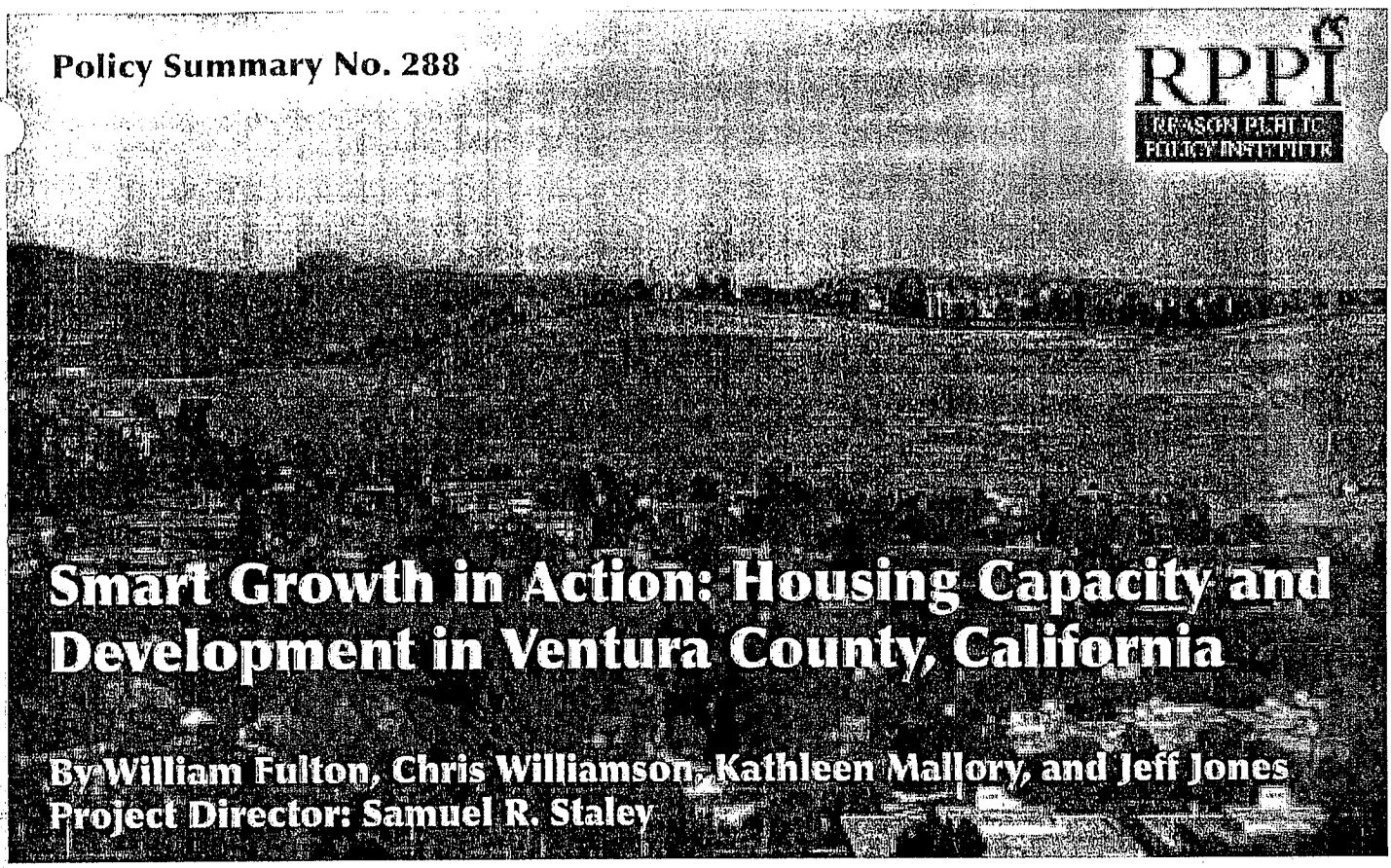

Smart Growth in Action: Housing Capacity and Development in Ventura County, California

By William Fulton, Chris Williamson, Kathleen Mallory, and Jeff Jones
Project Director: Samuel R. Staley

Urban growth has emerged as a touchstone policy issue, particularly on the state and local levels, ushering in an unprecedented new wave of growth-management and growth-control legislation. More than a dozen states have enacted some form of statewide growth-management law, and 37 others are actively considering growth-management legislation or planning reform laws that will directly impact the pace, pattern, and quality of land development. On the local level, hundreds of growth-management initiatives make it to local and statewide ballots each election cycle. One of the more salient trends in this movement is toward "ballot-box zoning"- the process of passing growth-management legislation and mandates through popular vote. Ballot-box zoning has been particularly prevalent in California, where dozens of cities and counties have adopted urban-growth boundaries and other growth controls to limit new land development.

Growth controls, however, are not implemented in a political vacuum. Once policies are adopted, local politics figure prominently into whether planning goals will be realized. Particularly in the United States, where planning is explicitly local and must be adopted by locally elected officials, these constraints are important elements of the planning process and should be incorporated into an evaluation of their success and recommendations for further reform.

Despite the groundswell of activism and apparent public support for this new wave of growth management, remarkably little analysis has been done on whether local governments actually can, in fact, implement planning goals and visions. In part, the dearth of research is a result of the highly localized nature of growth-management initiatives. Few have yet seen the benefit of analyzing growth-management policies that are targeted toward local prob-

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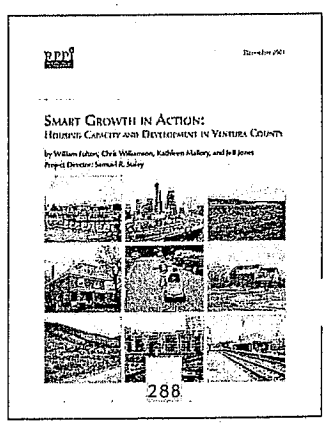

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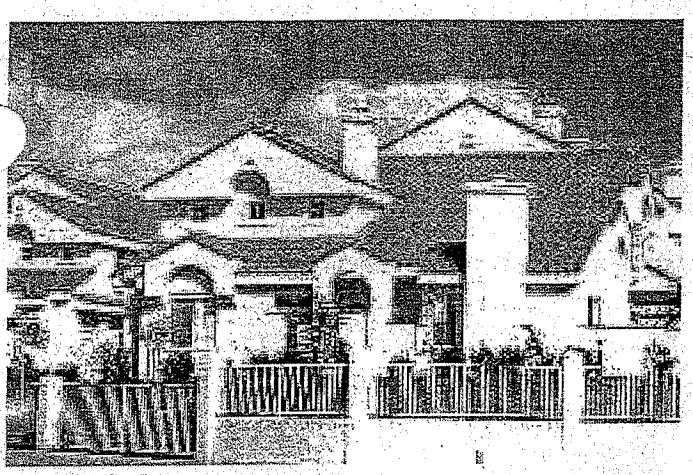


lems and framed by local values and issues. While the specifics of local growth-management policies may vary, however, the implementation issues are applicable to other cities in California and in other states.

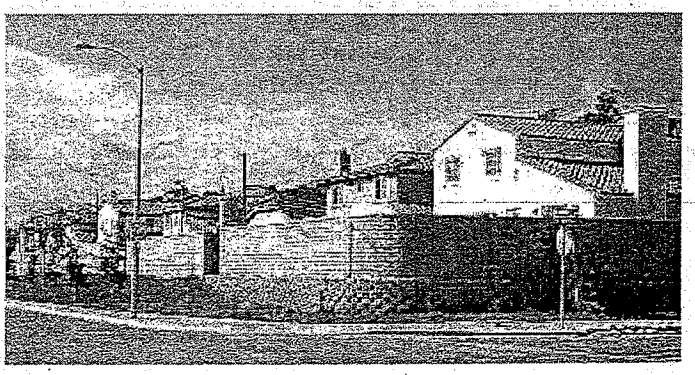
Implementation issues, particularly assessments of the capacity of local communities to implement planning goals, are rarely addressed in the debate over Smart Growth or planning-law reform. This study begins to fill this void by examining the case study of Ventura County, California, a county of some 700,000 residents about 40 miles northwest of downtown Los Angeles and adjacent to Los Angeles County. Home to one of the most aggressive local approaches to growth management in the United Sates, Ventura County's experience has important lessons for all local governments that attempt to plan development. This study also provides a general framework for citizens and policymakers in other communities to assess their own capacity for accommodating future growth through their local plans and evaluating the potential implications.

VENTURA COUNTY'S HOUSING SHORTFALL

Between 1995 and 2000, Ventura County voters passed a series of growth-control measures (the "Save Open Space and Agricultural Resources," or SOAR, initiatives,) that attempted to lock in existing land-use policies and require voter approval for conversion of agricultural, open space, or rural land to urban use. During the political campaign supporting the SOAR initiatives, proponents argued that the county, based on its current comprehensive plan, had the capacity to accommodate more than 60,000 new housing units before SOAR would expire in 2020. (A community's comprehensive plan is the primary policy document for guiding urban development, and typically outlines where, what kinds, and at what densities new development will take place.) The existence of a suitable planned capacity was a key argument, because opposition to the ballot initiative centered on whether Ventura County could adequately plan for and accommodate new housing in sufficient quantities. No one during the campaign, however, conducted an analysis of housing capacity to verify the advocates' claims.

To assess the ability and willingness of local governments to accommodate new growth, the researchers of this study reviewed housing trends, planning applications, and project approvals for all 10 cities in Ventura County. More than 120 projects, encompassing almost 12,000 approved housing units (covering more than two-thirds of the approved permits issued), were analyzed. After reviewing these projects as well as current planning policies and forecasted future demand, the authors concluded that the county is unlikely to be able to meet future housing demand, and that a crisis in housing supply will occur prior to SOAR's expiration in 2020.

Ventura County will likely need at least 312,000 housing units by 2020-a project increase of 60,000 units (24 percent) over the 2000 housing stock of 252,000 units. This is close to the estimate that advocates of SOAR used as they urged citizens to pass the initiative. Yet, under current policies, the planned capacity of the county is targeted at somewhere between only 293,500 and 298,500 housing units-an increase of between just 41,500 and 46,500 units, or 16.5 percent and 18.5 percent over the existing housing stock. This, however, is the highest number that might be approved. Since 1996, cities in Ventura County have approved development projects at densities much lower than planned capacities, generally falling 20 percent below zoned capacities and 45 percent below General (Comprehensive) Plan capacities (see figure). Thus, the likely future housing development in the county under current



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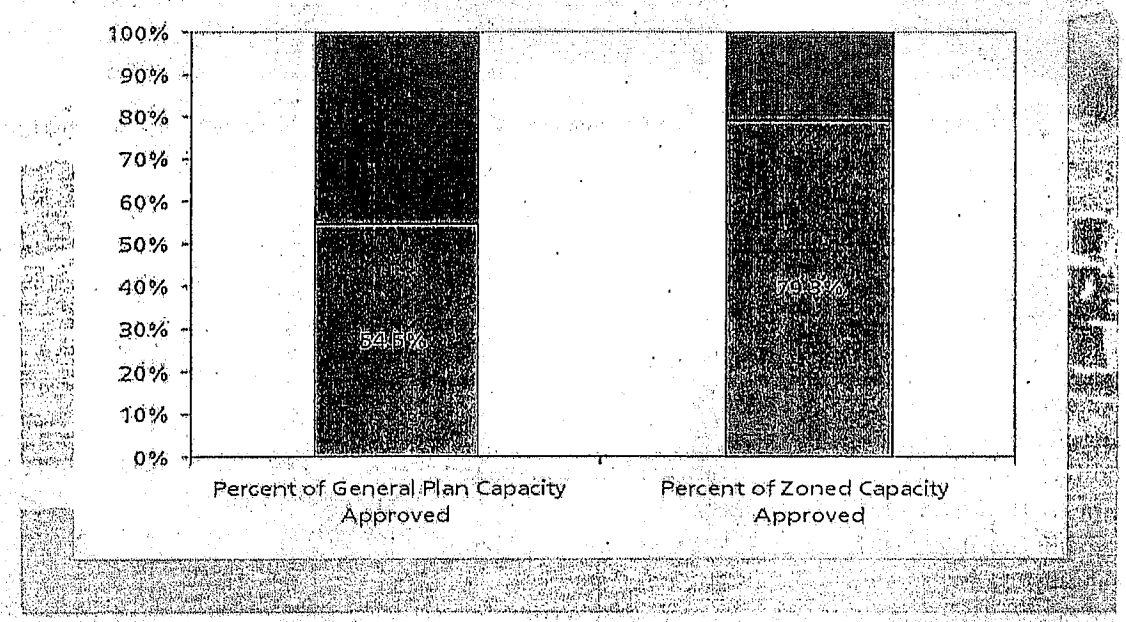
planning policies and entitlement practices will generate about 3,000 units: 55 percent below the regional planning agency's housing target for 2020.

Research also found that the density of most projects was likely reduced during the pre-application stage of the project-approval process. Applications sought considerably fewer housing units than allowed under the Comprehensive Plan. Then planning commissions and city councils reduced these densities by another 4 percent on average. Not all projects received equal treatment either. Affordable housing projects, multi-family projects, larger projects, and projects with plans tied to specific parcels of land were more likely to be approved at or near the capacity designated by planning policies, while smaller projects and projects in smaller cities tended to apply for and be approved at housing densities much lower than the capacities designated by planning policies.

FIGURE 1: Actual Approvals Compared to Planned and Zoned Capacity in Ventura County

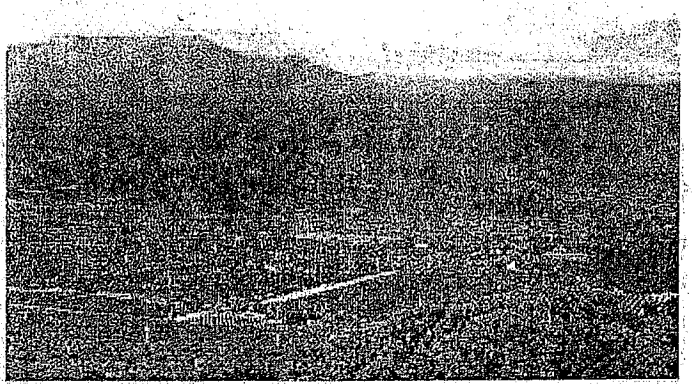


This study suggests that there are significant deficiencies in the capacity of existing planning systems to accommodate rational planning goals. Despite passing a countywide growth-management initiative in 1998, most cities in Ventura County have not adjusted their plans or their development-approval processes to accommodate expected housing demand, creating conditions that are likely to lead to further housing-price escalation and increased political manipulation of the housing market.

The analysis of Ventura County shows that most of its cities will face significant housing shortages well before the end of the county's 25-year planning horizon. In fact, most cities in Ventura County have no more than 10 years of housing capacity left under current policies and entitlement practices.

POLICY IMPLICATIONS FOR BOTH VENTURA AND THE NATION

Cities, counties, and state legislatures across the nation are considering initiatives that will greatly increase the scope of land-use regulation at all levels of government-reforms that closely resemble the policies implemented in Ventura County. Many of these growth-management and planning reforms involve a significant increase of public participation during the development-control process. Effective implementation of these reforms requires a practical understanding of the implementation issues surrounding growth-management reforms and development control, especially the capacity of local communities to meet their planning goals and objectives.



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SOAR will begin to have a major effect on new housing development between 2005 and 2010 as planned housing capacity is used up-first in a few cities, then gradually countywide. Development pressure will increase within cities to increase zooming densities, change general plans to allow more housing, and possibly redevelopment and rehabilitation. Projects that try to bring new land inside the growth boundaries for voter approval will need to be different from those approved in the past for development. Unless SOAR is changed or invalidated, the county and its cities are unlikely to meet estimated future demand for additional new housing, and tight housing market effects will increase over time. The lessons learned from the "laboratory" of Ventura County, a county with substantial experience in growth management and planning reform, could be valuable for other cities and counties across the U.S. that are wrestling with growth management.

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Jeff Jones is a research assistant in SRG's Ventura office analyzing residential development trends and projections for Ventura County in order to assess the impact of recent land-use initiatives.

Kathleen Mallory is a private planning consultant specializing in urban and regional planning and development.

OTHER RELATED RPPI STUDIES

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Urban Sprawl, Smart Growth, and Market-oriented Approaches to Growth Management by Samuel R. Staley, Policy Brief 20, August 2001, http://www.rppi.org/pbrief20.html.

Line in the Land: Urban-Growth Boundaries, Smart Growth, and Housing Affordability. By Samuel Staley, Jefferson G. Edgens, and Gerard C.S. Mildner, Policy Study No. 263, November 1999, http://www.rppi.org/ps263.html.

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Hydrological Responses from Low Impact Development comparing with Conventional Development

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ABSTRACT

In November of 2000, Prince George's County, Maryland initiated a field monitoring program to compare the stormwater hydrologic and water quality responses between a Low Impact Development (LID) design and the conventional development design at Somerset Heights Subdivision. In the Subdivision, two small watersheds are located side-by side: one was developed using a few LID concepts (grassed swales, bioretention areas, etc) with drainage area of 11.84 acres and another was developed entirely using a conventional stormwater conveyance system (a curb, gutter and pipe stormwater conveyance system) with drain area of 8.43 acres. The monitoring program, including one rain gage, two stream gages and two water quality automatic samplers, is capable of collecting continuous data in a 2-minute time interval. So far, more than two years of continuous flow and water quality data have been collected at both sites. The program is now moving into the third year of operation. This paper presents a data summary and analysis for the first two years of the monitoring program.

Although there are only two years of data, analysis of this data seems to reach a few general conclusions. When compared to the conventional site, the LID site had considerably lower event runoff volumes and peak flow rates as well as lower annual flow. In addition, most event runoff hydrographs started later, including peak time, in the LID site. The LID site showed a higher frequency of smaller flow rates while the conventional site showed a higher frequency of larger flow rates. As expected, the peak flow rate or runoff volume reduction at the LID site decrease as the event rainfall depth increased because the ground is saturated after certain rainfall depth. The annual pollutant loads for the LID site were lower for most constituents measured but not significant. The major reason is that the LID site is just recently completed and the soil conditions are still not stabilized yet. It is expected that, after the site is stabilized, the better water quality benefits will show-up.

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Keywords: Stormwater, Runoff, Bioretention, BMP, Low Impact Development (LID)

INTRODUCTION

Urban stormwater runoff has been identified as a significant source of pollution for many water bodies. Washing off road surfaces, parking areas, vehicles, and building materials, this precipitation and surface runoff contain a broad spectrum of pollutants. Proper control and management of runoff from impervious urban sources can provide for significant improvements to the quality of water entering local waterways. Concern for urban water quality improvements has spawned interest in natural-based treatment processes, such as bioretention and vegetated swales. These practices are part of an integrated paradigm known as Low Impact Development (LID—Department of Environmental Resources, 1999), which employs vegetated techniques to hold and treat run off water at the source, maximize infiltration, and reduce both quality and quantity impacts on local ecology.

Bioretention facilities are an integral part of stormwater management in the Prince George's County (Maryland) low-impact development program. Several systems have been designed and constructed in the county. However, not much performance data has been collected on their treatment efficiency, especially their advantage comparing to the conventional piping system; this paper represents the work in this regard. Detailed monitoring of the characteristics and performance of bioretention systems have been performed. The removals of several heavy metals and nutrients from both LID development and conventional development were evaluated.

The Somerset Heights monitoring program was developed to quantify the storm water hydrology and water quality benefits of LID. This evaluation is based on a comparison of the hydrologic and water quality differences between a watershed developed using LID practices and another watershed developed entirely using a conventional stormwater conveyance system. The two watersheds selected for the study are completely developed small, urban watersheds with uniform land uses and stormwater conveyance systems. Construction in the LID watershed was completed during 1999-2000. The stormwater management system for the LID watershed consists of grassed swales, Bioretention areas and disconnected impervious areas. Only a few LID techniques were used since the site was designed three years prior to the release of the County's LID design manual and very early in the County's development of the technologies. The conventional watershed was developed in 1990 and uses a curb, gutter and pipe stormwater conveyance system. The monitoring program was started in November of 2000 when the LID site was just completed and has been in continuous operation since that time.

It should be noted that the LID site is not developed in a typical and full-scale LID manner and is County's first attempt of using non-conventional approaches to reduce stormwater flows. This LID-like development includes grass swales, disconnection

of impervious areas, and non-typical bioretention facilities. Although the site did not follow the LID sizing and design criteria and was not stabilized during the monitoring period, the sampling results are very encouraging because it works better than what was expected.

METHODOLOGY

Watershed Characteristics

Landscape features for the two watersheds, while not identical, are in almost all respects similar. Land use within each watershed is comprised entirely of single family detached housing (1/4 acre lot size). The watersheds are geographically located adjacent to each other and drain approximately the same area. Housing and road density are different slightly (Table 1). Figure 1 shows the geographic location of the two sites.

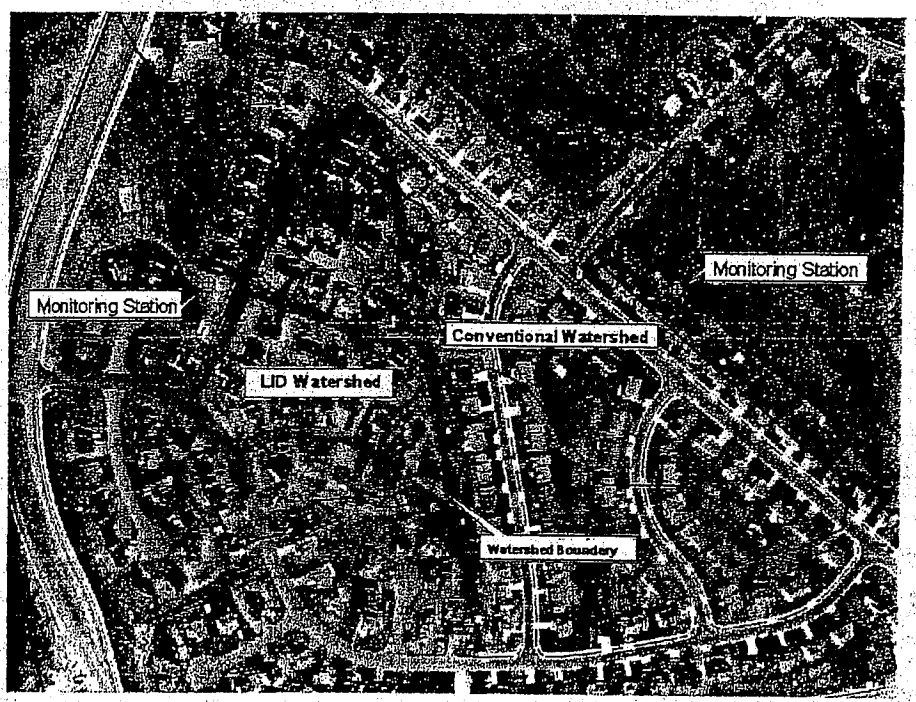

Figure 1. Project site

Table 1. Watershed Features

Watershed	Drainage Area (acres)	Number of Houses	Houses/acre	Road Length (ft/acre)	Road Width (ft)	Percent Impervious
Low Impact Development (S2 LID)	11.84	40	3.37 houses per acre	187	36	36 %
Conventional Development (S3 CONV)	8.43	28	3.33 houses per acre	189	24	30 %

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The conventional site's stormwater conveyance system consists entirely of a curb, gutter and pipe system. The LID site consists of a curb-less road drained by a grassed swale network; but did not follow today's LID sizing and design criteria. It was County's first attempt of using non-conventional approaches to reduce stormwater flow. Bioretention areas are located both on individual lots and along grassed swales. Typically, pipes are used only to convey stormwater under driveways and roads, however, when flows become too concentrated drop inlet structures and pipes are used to convey stormwater flows to an outfall point. In some cases, inverts for the drop inlets are slightly higher then the inverts for the bioretention area or swale and provide additional stormwater flow attenuation (see Figure 2).



Figure 2. Drop Inlet Structure Located in Bioretention Area

Monitoring Program

In addition to the careful selection of the two watersheds, a well-designed monitored program is also essential to the evaluation of differences in hydrology and water quality. Each watershed's outfall was instrumented with automated level and water quality sampling equipment. A rain gage was also located at the outfall point for the conventional watershed. A second rain gage, located about 0.5 miles from the monitored watersheds and maintained as part of county's flood warning system, was used as a data quality check.

A 2-foot H flume is used at each site to determine the flow rate and volume at each watershed's outfall point (Figure 3). The water levels in each flume are continuously monitored using an ISCO water level sensor, with level data recorded every two minutes. Conversion of water levels to flow rate is based on standard rating curves for H type flumes. Rainfall data are also collected using a two-minute interval.

Water quality sampling at each site is based on volume-weighted composite sampling procedure. This sampling method results in a 250-ml storm water sample being collected for each 250 cf (cubic feet) of runoff for small storms (less than 1.0 inches).

While for larger storms, the programming is changed to collect a water sample for each 500 cf. of runoff. These 250-ml samples are combined into a single water quality sample that is then sub-sampled and submitted to a laboratory for chemical analyses. This sample represents a volume-weighted event mean concentration for each sampled storm. The chemical analyses completed include measurements for lead, zinc, copper, total nitrogen, total phosphorus and total suspended solids. The sampling equipment is also illustrated graphically in Figure 3.

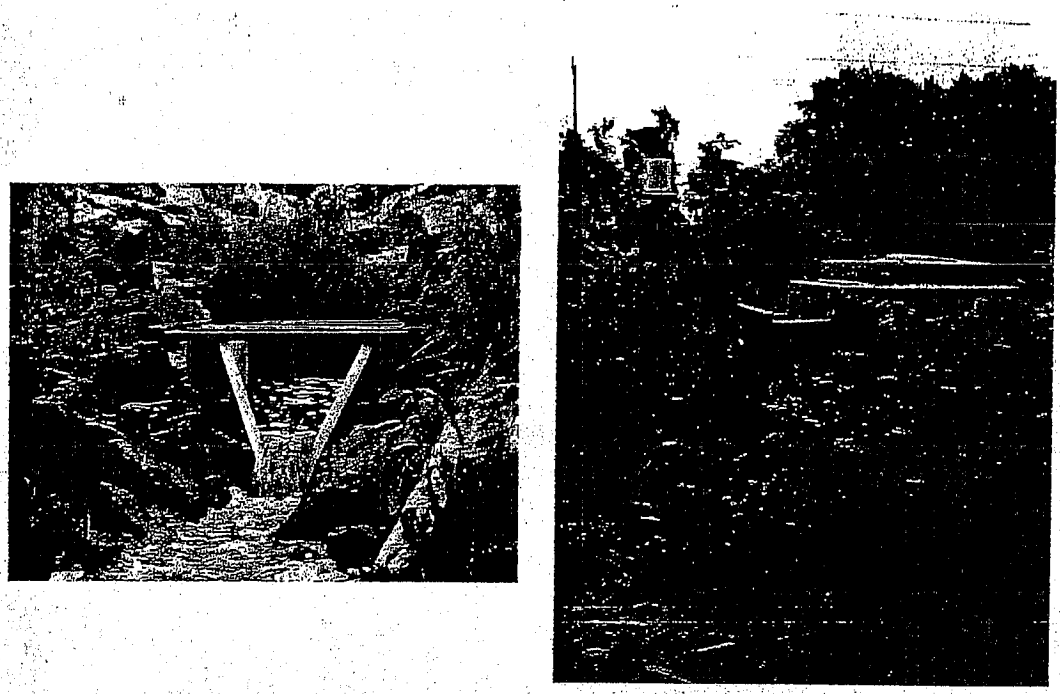


Figure 3. Flow and Water Quality Sampling Equipment at the Project sites

RESULTS AND DISCUSSIONS

General Climate

The results of any monitoring program are always affected by the large-scale weather patterns that occur during the course of monitoring. On an annual basis, rainfalls during the first and the second years of monitoring were slightly less than the long-term average of 42.3 inches reported by National Resources Conservation Service for Upper Marlboro (NRCS, 1995). Using a combined rainfall data set based from the Somerset monitoring station and County's rain gage, a rainfall total of 35.5 inches was measured from November 1, 2000 to October 31, 2001. For the period from November 1, 2001 to October 31, 2002, the total rainfall was 26.4 inches which is only 75% of the first year's value and only about 63% of the long term average. Figure 4 shows a comparison of monthly rainfall for these two years.

Hydrology

The flow sampling devices used in this project automatically record information at a two-minute interval. When measured on an annual basis, significant differences between the two watersheds were observed in the number of runoff events, the total runoff volumes and in peak event flow rates (Table 2). For the period, the LID watershed had 20% fewer runoff events. The LID watershed also had 20% less runoff volume per acre than did the conventional watershed. Peak flow rates during the period also had a tremendous reduction in flow rates on a per acre basis of about 44%. A change in the distribution of peak event flow rates was also observed and is illustrated in Figure 5. As shown in Figure 5 the event peak flow rates are generally lower and less frequent for LID sites than those observed at the conventional site. These results appear very encouraging. Even better, because of the location of the LID outfall (about 30 feet below the ground surface), the measured flow volume include both surface runoff and groundwater. Therefore, the actual annual surface runoff volume is even much smaller than the sampling results show.

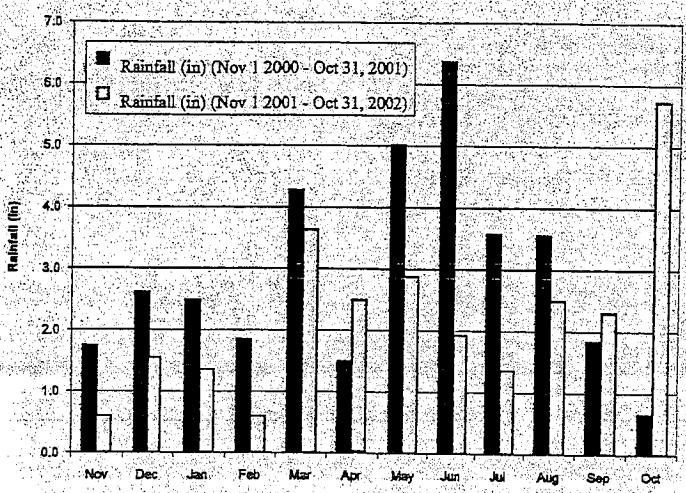


Figure 4. Month Rainfall Totals Nov 2000 to Oct 2002

Table 2. 2-Year Hydrologic Summary

Measurement	Watershed	
	Conventional	LID
Number of Events with Measurable Runoff > 100 cubic feet*	104	83
Total Runoff Volume (cubic feet/acre)*	41,403	33,391
Percent of Rainfall converted to Total Runoff*	19.0%	15.3%

* Difference is significant at the 95% confidence interval

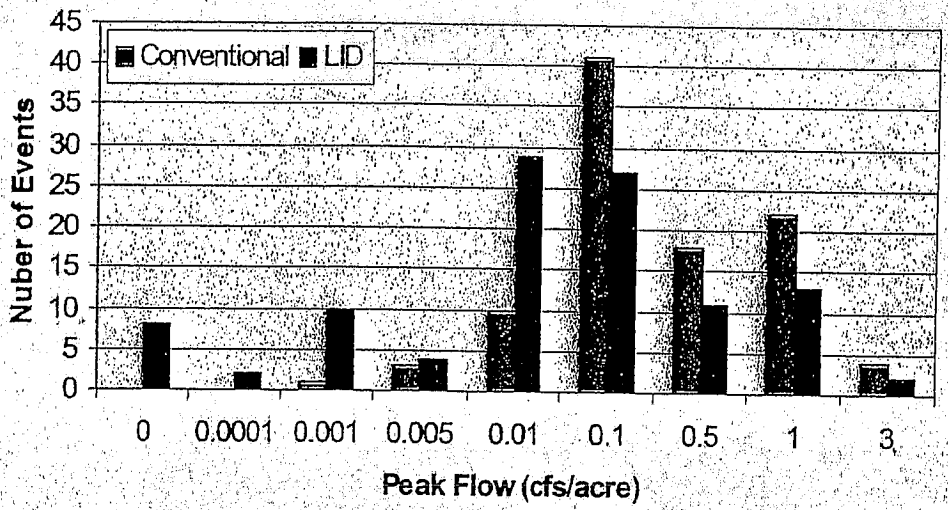


Figure 5. Comparison of Peak Event Flows at Conventional and LID Sites (November 2000 – October 2002)

On an event basis, reductions in an event's peak flow rate were also observed to increase in proportion to the inter-event time period between storms. Conversely, for very short inter-event time periods, a much smaller reduction in event peak flow rates was observed. A minimum inter-event period of about 24 hours appeared to be sufficient for the recovery of the LID watershed's storage and infiltration capacity. This recovery period is longer in duration during the non-growing season or nonexistent in the case of frozen soils. The responses of the LID and conventional site to a short event time period are illustrated in Figure 6. While the LID site effectively reduces the peak flow rate and volume for the first event, the following storm is not as effectively managed. In total thirty-six percent or 1/3 of the storms monitored at Somerset had a prior storm event that occurred within the previous 24- hour period. The main reason for this result is because of the location of the storm drain outfalls. For the conventional site, the storm drain outfall is located only a couple feet from the ground surface; while the outfall for the LID site is approximately 30 feet below the ground surface. Consequently, the measured peak and flow volume at LID site includes not only the surface runoff but also the ground water flow. This situation is very obvious because the outfall at LID site still releases flows even days after the storm events.

This annual groundwater volume needs to be estimated. A similar monitoring station, with a drainage area of 50 acres, is located a few miles away from this site. 38% of the total flow volume is measured to be groundwater. By carefully examining the flow data, the groundwater contribution is estimated at 25.5%. This separation between surface runoff and groundwater is estimated based on the storm hydrograph at a point which the flow is 150% of the pre-storm event.

It is also difficult to accurately measure runoff volume from short and intense storms at the conventional site. These storms produced rapid changes in flow that, even with the use of a 2-minute interval sampling, from which it was difficult to get accurate runoff volume estimates. Conversely, the slow and more gradual response of the LID site resulted in more accurate volume estimates for these types of storms.

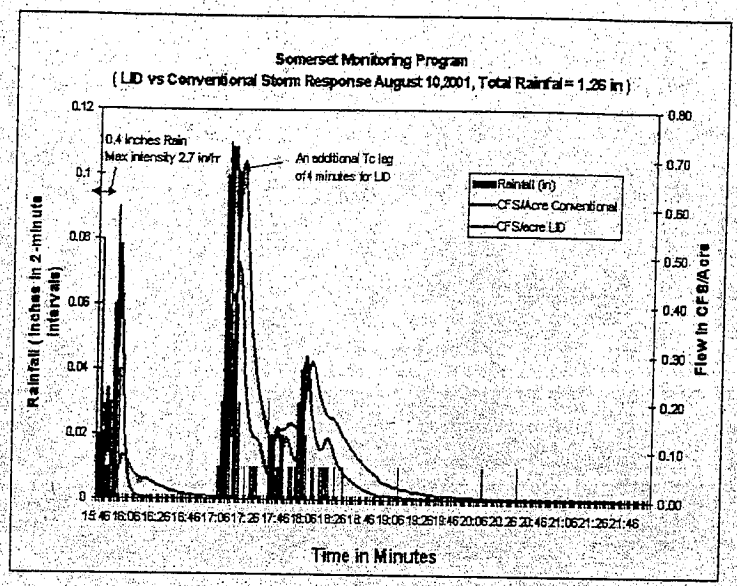


Figure 6. Peak flows comparison for Consecutive Storm Events

Even with these two disadvantages, the overall hydrological performance at the LID is still very impressive. The average peak flow rate for the two-year period at LID site is only 56% of the conventional site. The total flow volume, including groundwater / interflow volume at LID site is approximately 80 % of the conventional site. Since groundwater / interflow is 25.5% of the measured flow volume, the surface runoff volume at LID site is only approximately 60% of the conventional site. (see Figure 7).

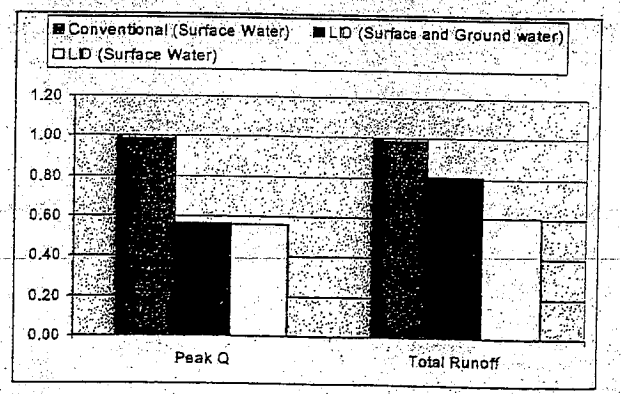


Figure 7. Two Years Hydrologic Performance Chart

Water Quality

The sampling program to compare the water quality benefits of the two stormwater conveyance systems consisted of a monthly sampling program for subset of the parameters normally monitored as part of the County's NPDES permit (Table 3). All the samples collected were volume-weighted composite samples. A total of ten storms were monitored every year.

Table 3. Water Quality Sampling Parameters

Parameters	Method	Reporting Limit (mg/L)
Nitrate/Nitrite	EPA 353.2	0.05
Total Kjeldahl Nitrogen	EPA 351.3	1.00
Total Phosphorus	SM 4500 P B+E	0.01
Total Suspended Solids	EPA 160.2	2.5
Total Copper	EPA 200.8	0.002
Total Lead	EPA 200.8	0.005
Total Zinc	EPA 200.8	0.020

For comparative purposes, water quality samples were required from both sites for the same storm. Since runoff from the LID watershed occurred less frequently then at the conventional site, the sizes of storms from which water quality samples were submitted were mostly larger storms (>0.5 inches). Overall, this resulted in a large percent of the total annual runoff volume from both sites being sampled for water quality (Table 3). For the conventional site, 66% of the annual runoff volume was sampled for water quality while 69% of the annual runoff volume was sampled for water quality measured at the LID site.

Event mean concentrations (EMC) and loading values were measured for both watersheds. The annual EMCs are calculated based on the total measured load for all ten storms divided by the total runoff for these storms. From the two-year average annual EMC values the LID site had lower loading rates for nitrate, total suspended solids (TSS) and zinc, and slightly higher loading rates for total Kjeldahl nitrogen and total phosphorus (see Table 4 and Figure 8).

This is a very in-consistent sampling result. After a careful reviewing of the site conditions, it is concluded that the major reason for this in-consistency is that the LID site is just recently completed and the vegetation and soil conditions are still not stabilized yet; while the conventional site was constructed in early 1990's. It is therefore expected that, after the site is stabilized, the better water quality benefits will show-up.

Table 4. Two-Year Average Loading

Parameter	Conventional Loading (lb./acre)	LID Loading (lb./acre)	% Difference
Total N	6.57	6.39	2.74%
Nitrate/Nitrite	1.64	1.07	34.76%
TKN	4.92	5.33	-8.33%
Total P	1.11	1.55	-39.64%
TSS	121.86	104.45	14.29%
Copper	0.0184	0.0117	36.41%
Lead	0.0057	0.0045	21.05%
Zinc	0.0682	0.0433	36.51%

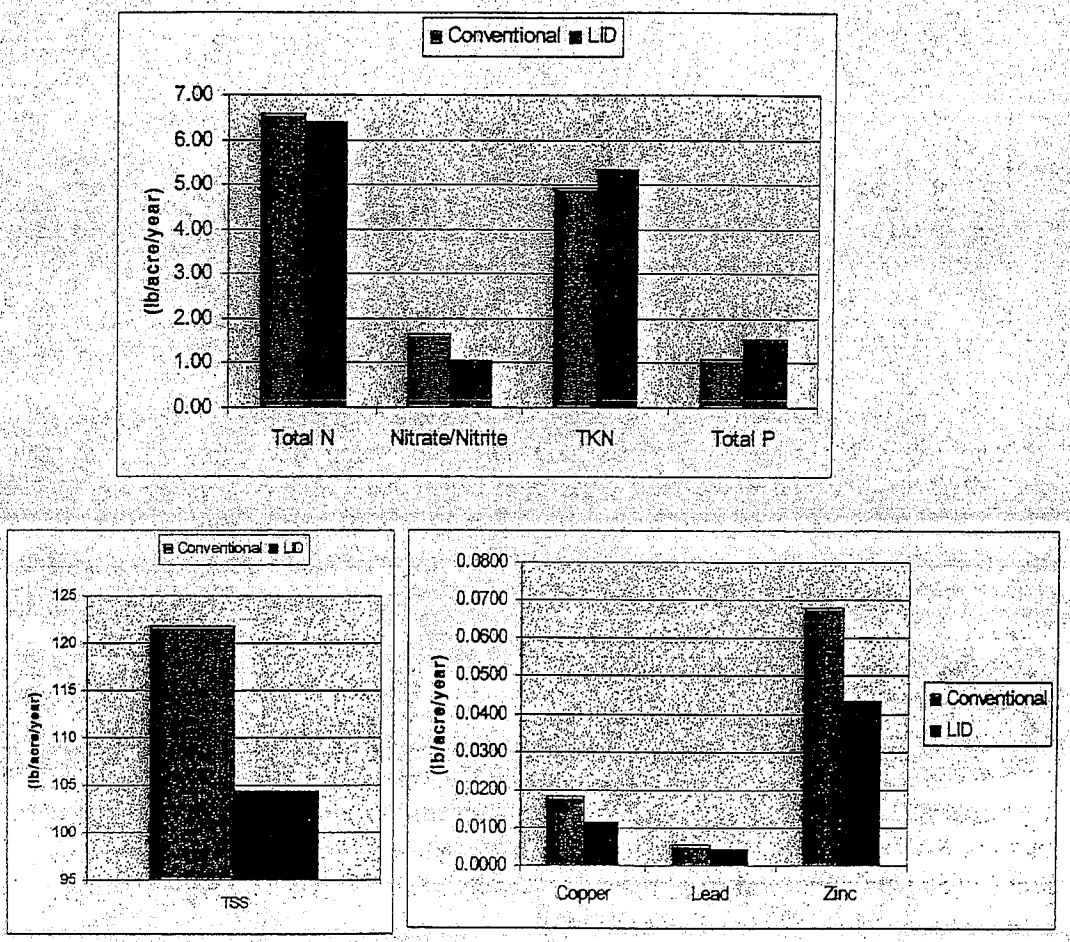


Figure 8. Comparison of Annual Pollutant Loadings between Two Sites.

SUMMARY AND CONCLUSIONS

Although the LID site did not utilize the typical and full-scaled LID approaches and was simply a first attempt of using non-conventional approaches to reduce stormwater flows, when compared to the conventional site, the LID site had considerably lower runoff volumes and event peak flow rates per unit area. The LID site also had fewer runoff producing events. Over the two years, percent of rainfall converted to runoff was 19% for the conventional site and 15% for the LID site. Accordingly, the average annual runoff volume per unit area was smaller at the LID site by 20%. Event runoff hydrographs started later in the LID site. The LID site showed a higher frequency of smaller flow rates (including no runoff events) while the conventional site showed a higher frequency of larger flow rates.

LID site also had a smaller peak flow per unit area. The ratio of the LID to Conventional peak flow per unit areas showed a general positive trend with event rainfall depth. Any peak flow rate or runoff volume saving of the LID practices seem to decrease as the event rainfall depth increases. The magnitude of the differences between the two sites did not appear to be affected by seasonal differences in rainfall intensity and infiltration rates. However, it is impacted by the time period between rainfall events.

The Total Nitrogen loading per unit area was similar at the two sites while the Total Phosphorus loadings were higher by about 40% at the LID site. The average annual loading per unit area for suspended sediment was lower at the LID site by 14.3%. For copper, lead, and zinc, the LID site had lower EMCs and annual loadings. The annual loadings per unit area were 36%, 21%, and 37% lower for Copper, Lead, and Zinc respectively at the LID site than the conventional site. This difference is a result of removal mechanisms in the grassed channels and/or bioretention areas. Another factor to remember is that the LID site is just recently completed and the site and soil conditions are still not stabilized yet. It is expected that, after the site is stabilized, the better water quality benefits will show-up.

It is beneficial to keep in mind that this monitoring period was a rather dry period when the annual rainfall was only about 84% of the long-term average for the first year, and 63% for the second year. Data from dry years may not be a good representative of normal or average years. Two other issues are also important to remember. For a drainage area as small as 10 acres, two-minute sampling time interval may not short enough for a conventional development site. One-minute time interval is more appropriate. To address the issue of consecutive storm events, more storage for the LID measures is recommended.

Finally, because the LID site was not developed according to today's LID sizing and design criteria, an EPA 319 grant was provided to the County to retrofit this residential development. When the project is completed, a better performance is expected.

References

Department of Environmental Resources, 1999, Low Impact Development Design Strategies – An Integrated Design Approach, Prince George's County Government, Largo, Maryland.

NRCS (National Resources Conservation Service), 1995, Water and Climate Center, Portland, Oregon.

EPA
United States
Environmental Protection
Agency

The Watershed Academy

The Watershed Academy Presents....

Low Impact Development Strategies, Tools and Techniques for Sustainable Watersheds

A Webcast Learning Session

Wednesday, October 19, 2005 Two-hour audio Web broadcast

Eastern: *1:00 pm – 3:00 pm* Central: *12:00 pm – 2:00 pm* Mountain: *11:00 am – 1:00 pm* Pacific: *10:00 a.m. – 12:00 pm*

Session Description:

Low Impact Development Strategies, Tools, and Techniques for Sustainable Watersheds: Low Impact Development (LID) is a decentralized or source control approach to stormwater management that focuses on maintaining or restoring the hydrologic cycle functions in a watershed. This approach is causing many communities and organizations to reevaluate their stormwater programs to see how LID can be used as part of a comprehensive watershed protection and restoration strategy. This Webcast will focus on how communities and institutions are using LID techniques to meet a wide range of water resource protection and community development objectives. It will feature Haymount, a large-scale Traditional Neighborhood Design community in Virginia that incorporates many LID techniques, and highlight other examples of LID designs and projects from throughout the country.



Instructor:
Neil Weinstein, Executive Director
Low Impact Development Center, Inc.

Neil directs the Low Impact Development Center, Inc., a non-profit water resource research organization based in Beltsville, Maryland. With over 20 years of experience in environmental planning, research, and design, much of his work has focused on how to effectively and efficiently use the landscape and built environment to create a sustainable infrastructure that protects natural resources and enhances the aesthetics and quality of life in urban areas. Neil is one of the pioneers of LID and helped create the initial planning, design, and analysis tools that are the basis of LID strategies. He has worked to develop stormwater policies and strategies at the national and local levels through research, development, and policy analysis.

The Watershed Academy

The Watershed Academy is a focal point in EPA's Office of Water for providing training and information on implementing watershed approaches. The Academy sponsors live classroom training, online distance learning modules through the Watershed Academy Web at www.epa.gov/watertrain/, and most recently, Webcasts on various watershed planning and restoration topics. EPA plans to offer additional Webcasts in 2005. For more information, visit www.epa.gov/owow/watershed/wacademy/.

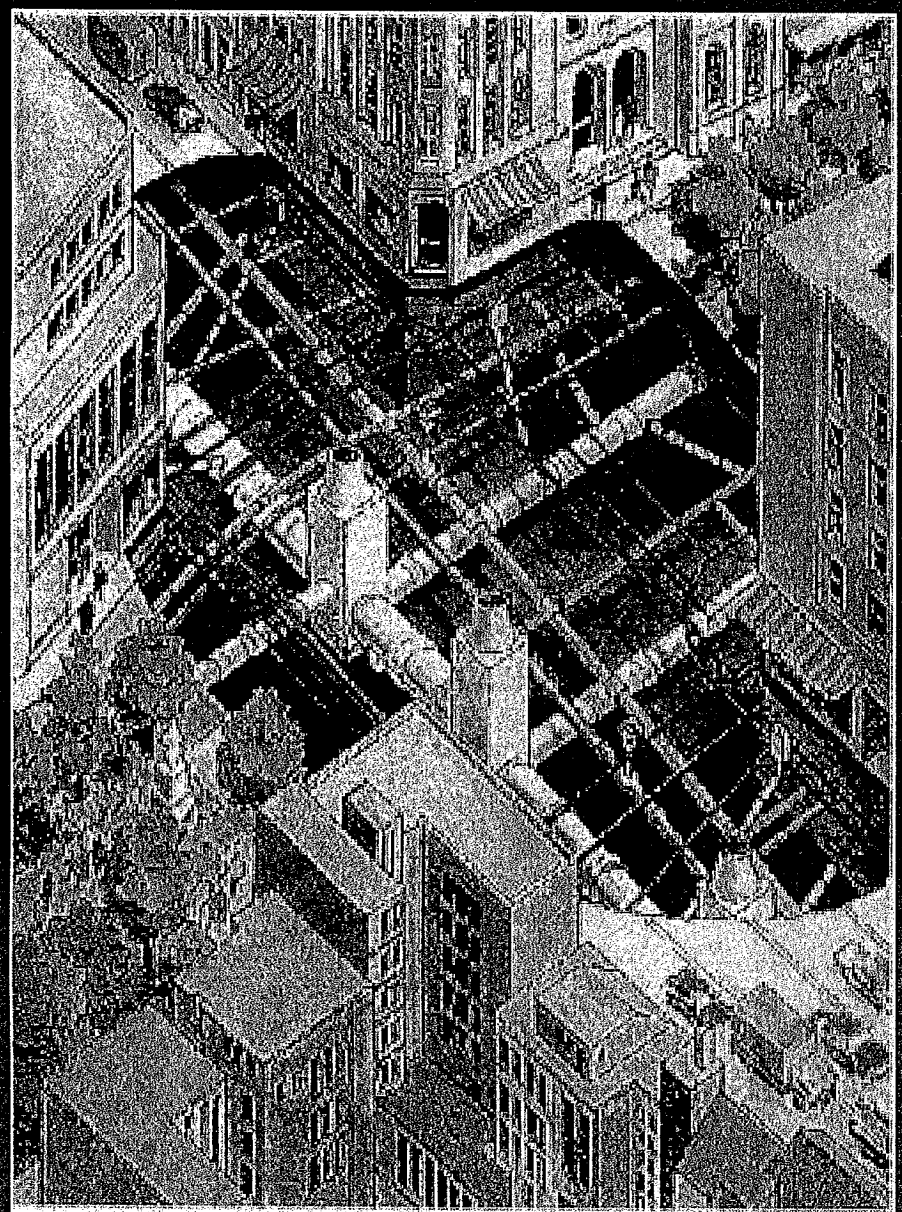
Registration

You must register in advance to participate in the Webcast. To register, visit www.clu-in.org/live. The Webcast will be a Web-based slide presentation with a companion audio portion. There are two options for accessing the audio portion of the Webcast: by phone OR streaming audio broadcast (not both). By selecting one registration option at the registration page, you will be registering to view the Web-based slides and the audio method of your choice. If you choose the streaming audio option, you will not be able to participate by telephone. However, you will be able to submit questions online for the presenters to answer during the Webcast. Closed-captioning is available. Upon registration you will receive complete participation instructions. **Please note that there are a limited number of toll-free phone lines available, so register early to guarantee your spot. Because of the growing popularity of these Webcasts and the limited number of available spaces, we strongly encourage you to reserve a conference room and invite your colleagues and other partners to participate.** If you register after that limit is reached, you will be added to a waiting list. After the Webcast is over, an audio version of the Webcast will be available—visit www.epa.gov/watershedwebcasts/ for more information.

Questions?

- If you have questions about the Webcast, visit the Web site at www.clu-in.org/live or contact Melissa DeSantis at melissa.desantis@tetratech-ffx.com.

The materials in this Webcast have been reviewed by EPA staff for technical accuracy. However, the views of the speakers and the speaker's organization are their own and do not necessarily reflect those of the EPA. Mention of any commercial enterprise, product, or publication does not mean that EPA endorses them.



Underground Congestion.

Low Impact Development:

Sustainable Solutions for Watershed Development

A096921



The Low Impact Development Center, Inc.

Balancing Growth and Environmental Integrity

Who we are and what we do

- 501 c 3
- Innovative and sustainable solutions for development/ redevelopment
- Focus on pilot projects, institutional development, manuals of practice
- Small, but partner alot

226984

New Stuff!

- LID for NPDES Phase II
- WERF Decentralized Study
- NCHRP Stormwater Report
- EPA HQ
- Navy/EPA Region 3 Partnership
- LID for Big Box Retailers

A006923

Chip In

- ASCE Database
- EWRI LID Committee

ASCE/EWRI

Today's Goals

- Introduction to LID
- Background
- Importance for Watershed Planning
- Some Case Studies
- Where are we going?

AR096925

Low Impact Development (LID)

Stormwater Management

Ecosystem Based Functional Design

"Uniformly Distributed Small-scale Controls"

"Integration of Controls with Sites, Streets and Architecture "

Hydrologic Cycle Based Approach

"Centralized versus Decentralized Controls"

Prince George's County, MD

Prince George's County Manual 1997

LID National Design Manual 1999

926926

What is LID?

- A Storm Water Management Strategy Concerned With:
  - Maintaining or Restoring the Natural Hydrologic Functions of a Site
    - Helps Meet Construction (New & Retrofit) Storm Water Management Goals
  - Fulfilling Environmental Regulatory Requirements
    - Helps Reach NPDES Permit Limits & TMDL Goals
  - Meeting Natural Resource Protection Objectives
    - Using Low Maintenance & Native Vegetation
    - Protection of Watersheds
- LID Employs Natural & Built Features that:
  - Reduce Runoff
  - Filter Out Pollutants
  - Facilitate Water Infiltration

Thanks, Larry Coffman

A966927

What is better?
Smart Growth or LID?

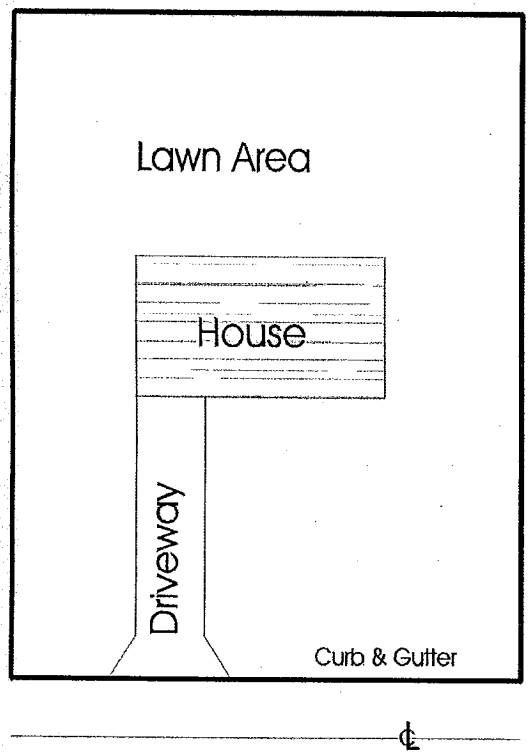
HUH?

LID is a site planning and design strategy that uses decentralized controls to manage stormwater!

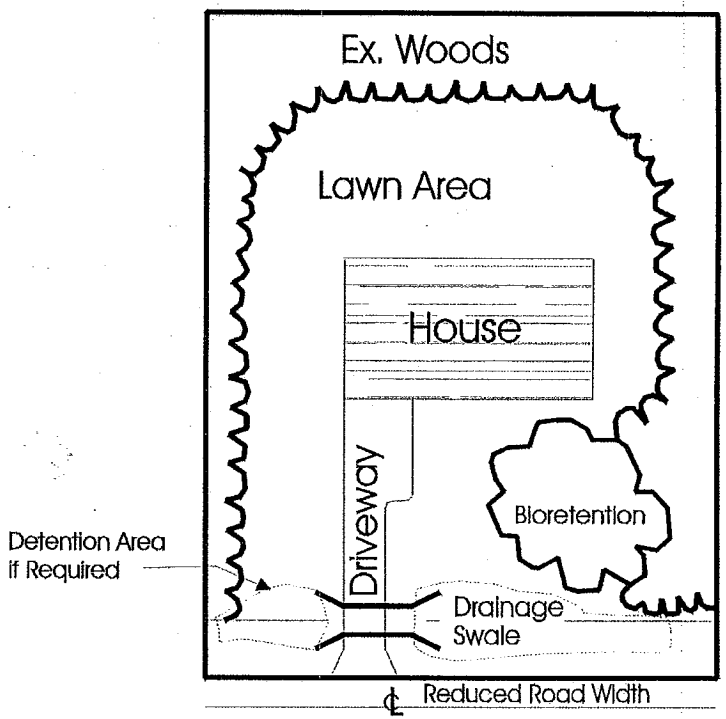
NOT LAND USE it's Technology !!!!!

4866928

Comparison of Conventional and LID Site Conditions

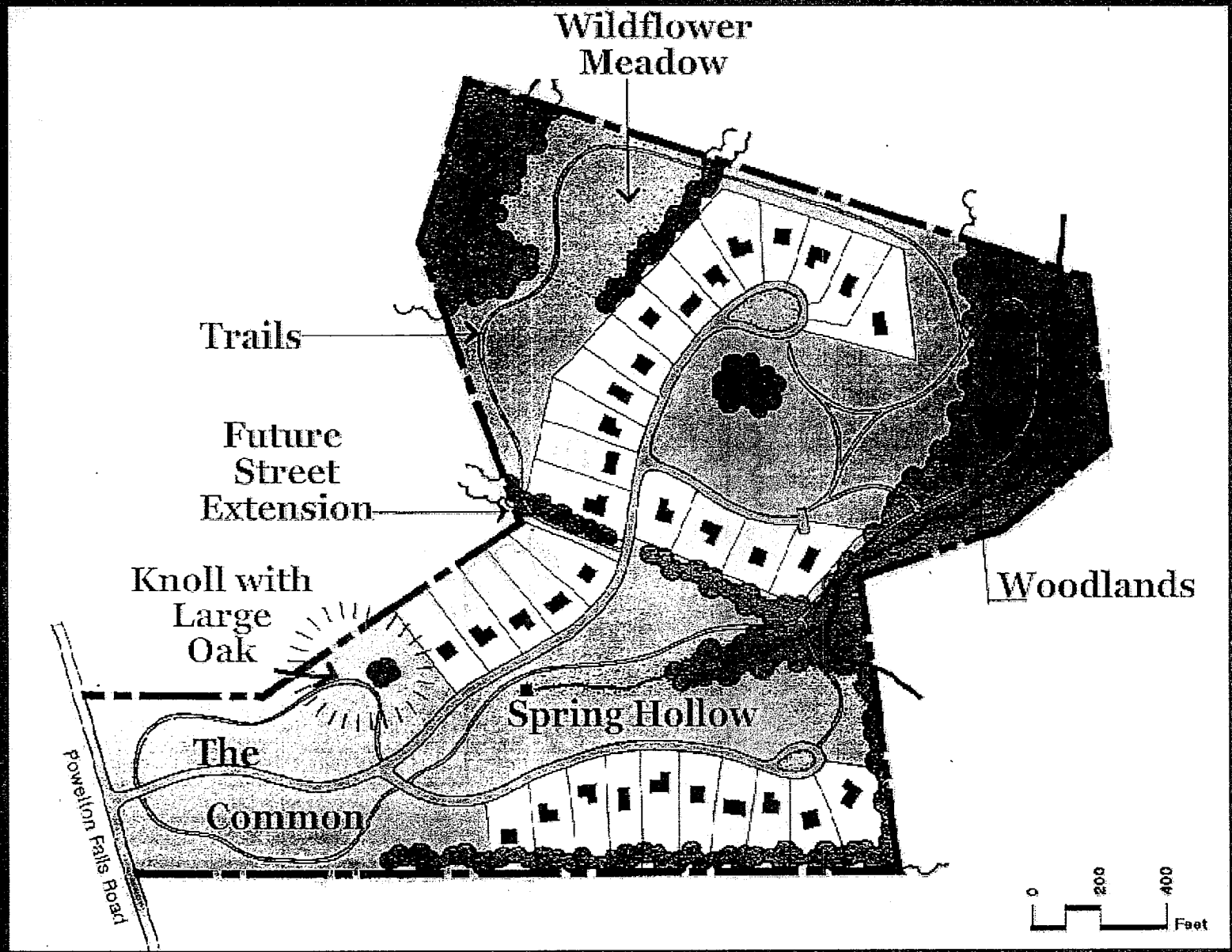


Conventional CN
for 1-Acre Lot
(Table 2.2a TR-55)
N.T.S.



Typical Low-Impact
Development Lot
N.T.S.

A006929



Courtesy Arendt

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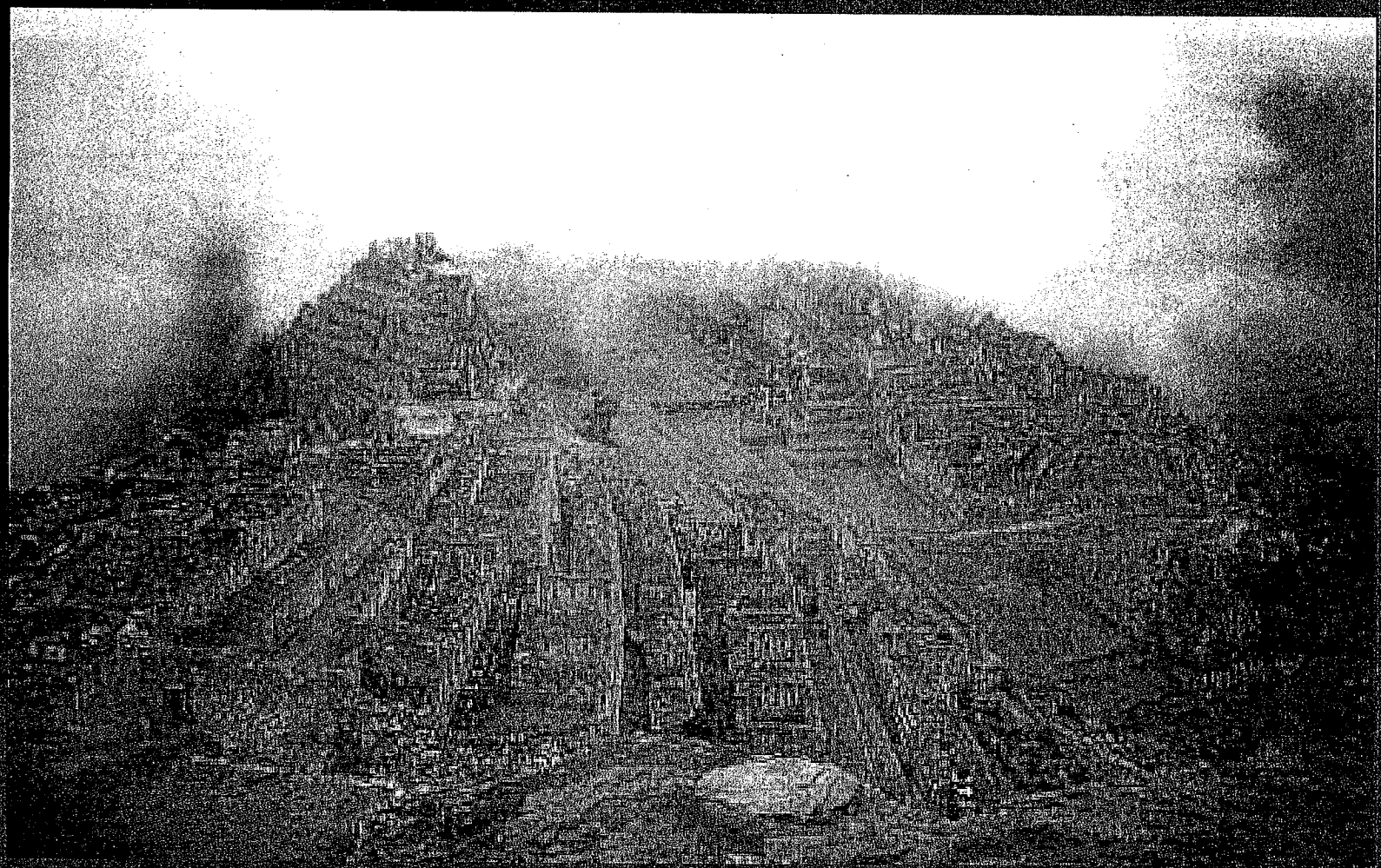
How this all started!



1200 Years and Still Working !!!

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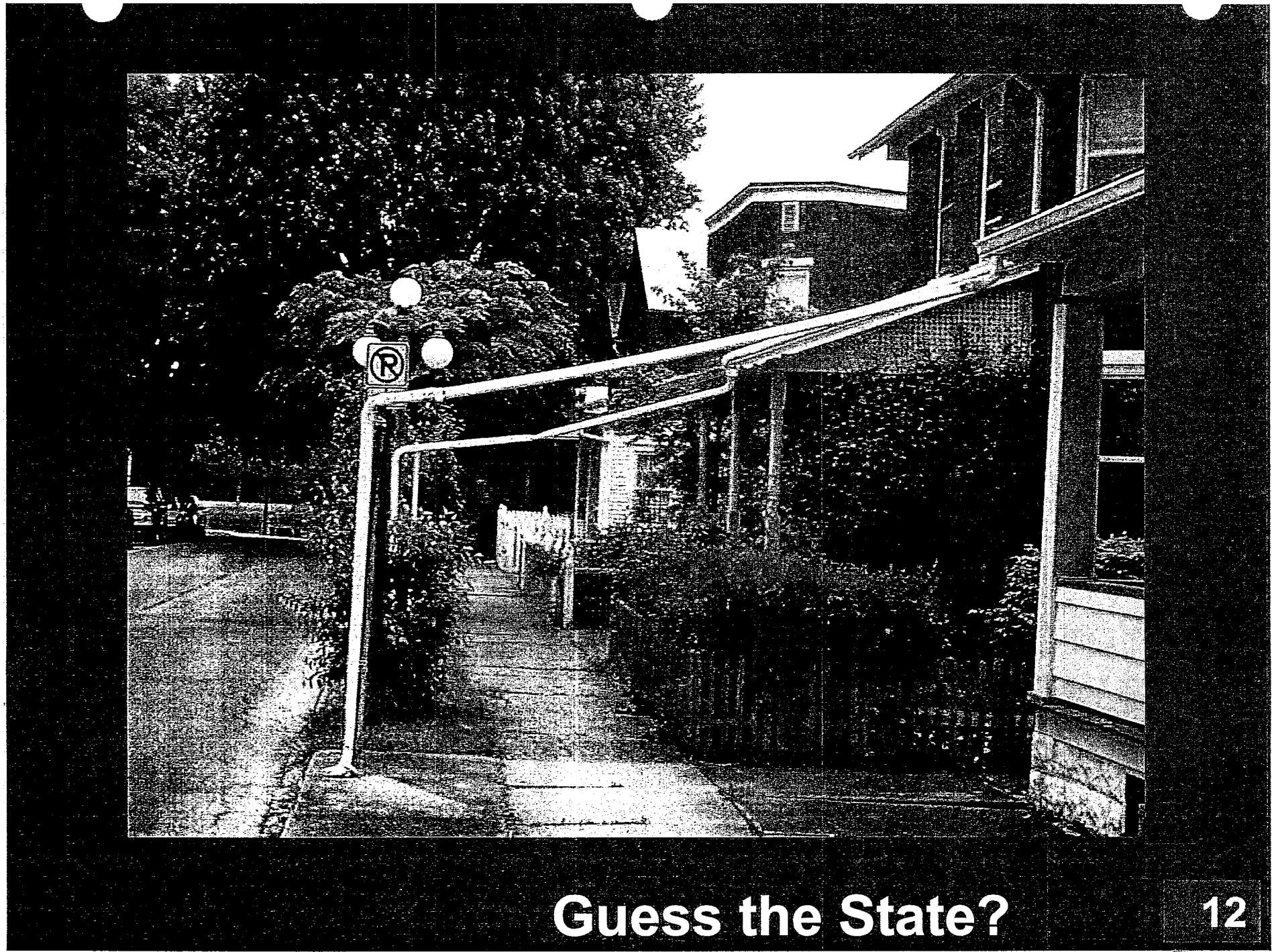

Guess the State?

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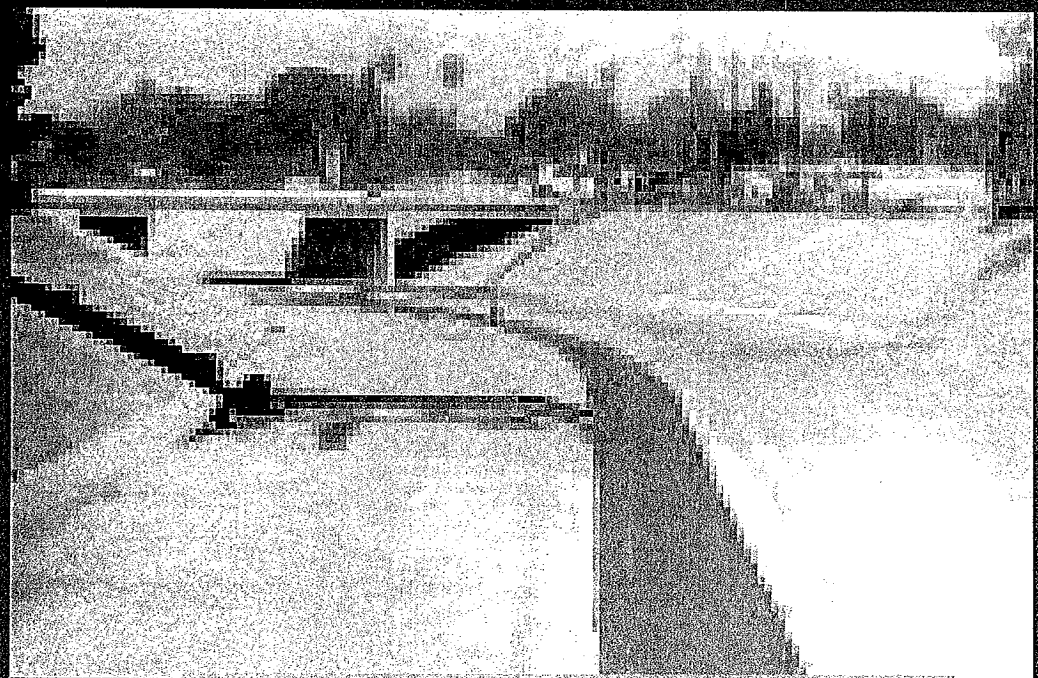
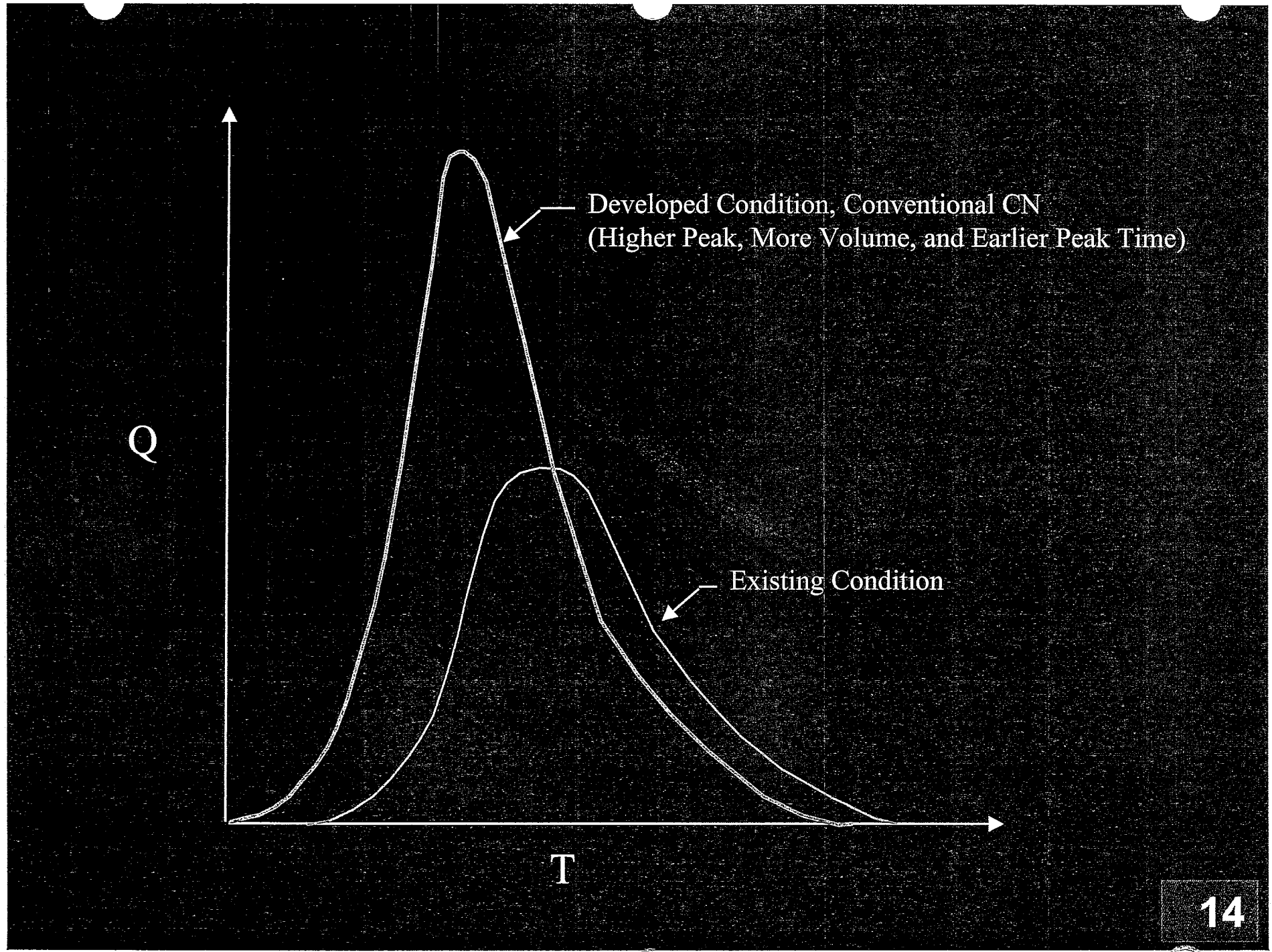
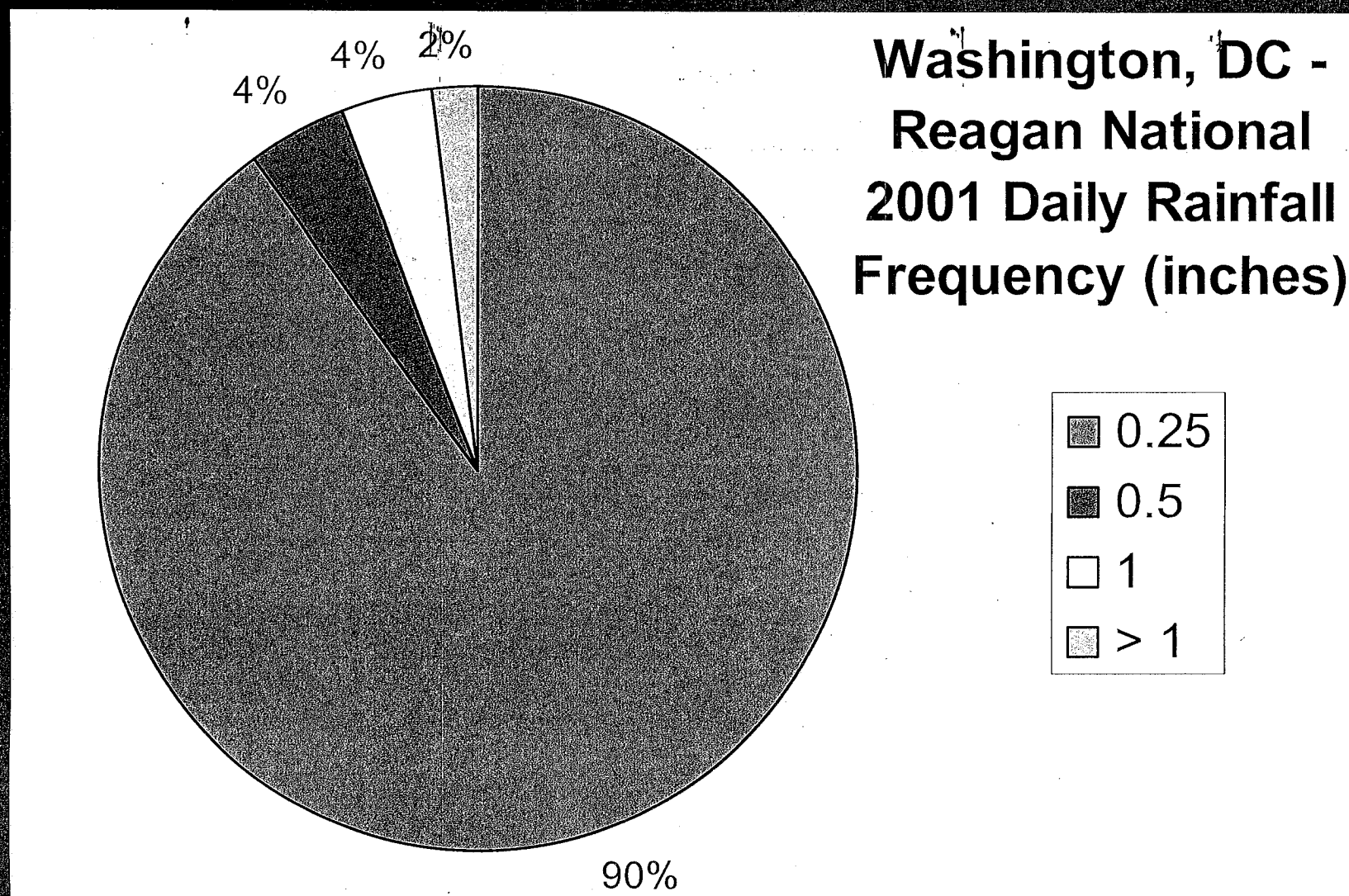
Early Stormwater



$$K = \frac{\beta}{n} AR^{2/3}$$

ADOBE


Developed Condition, Conventional CN
(Higher Peak, More Volume, and Earlier Peak Time)
Existing Condition
Q
T



Volume/Frequency

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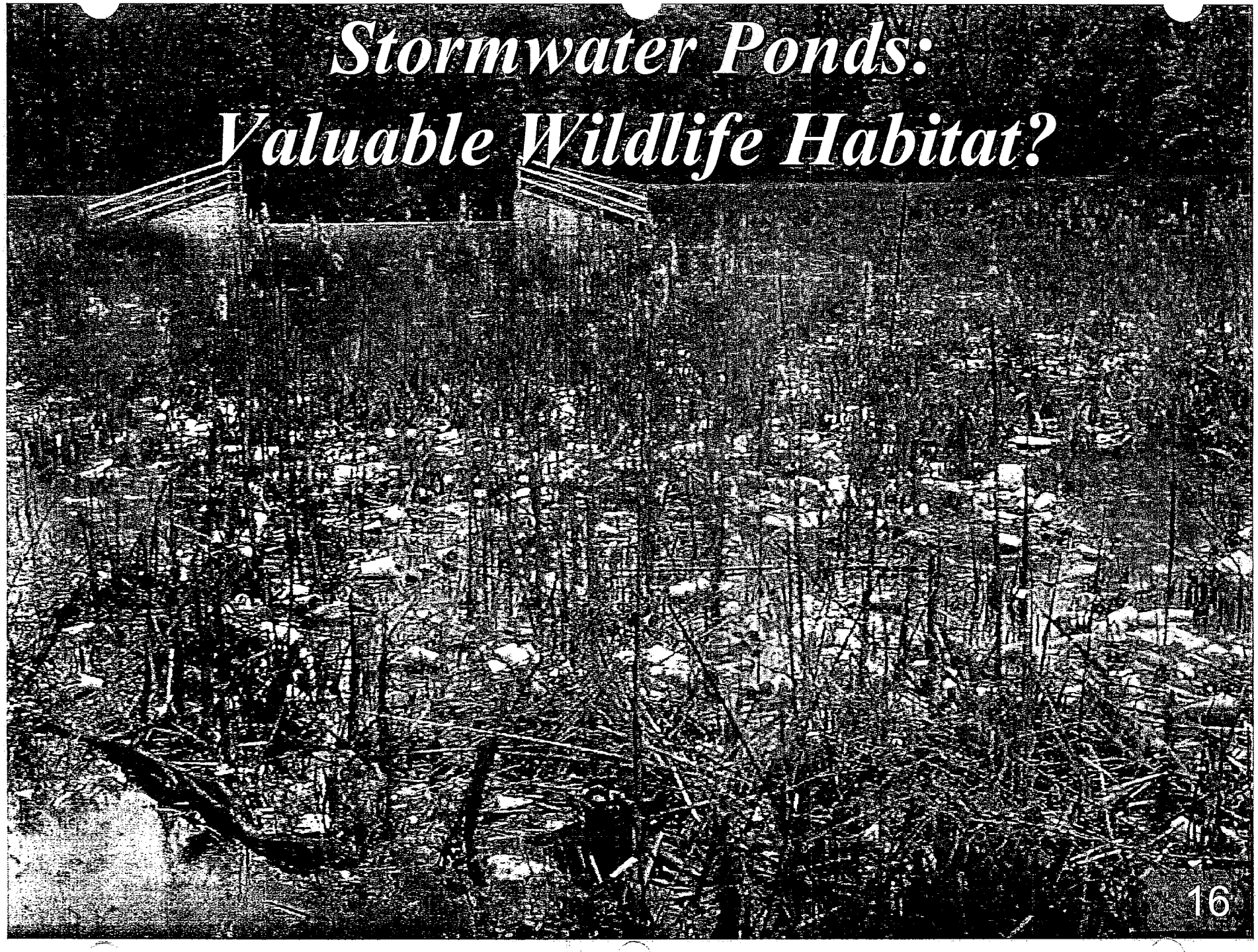

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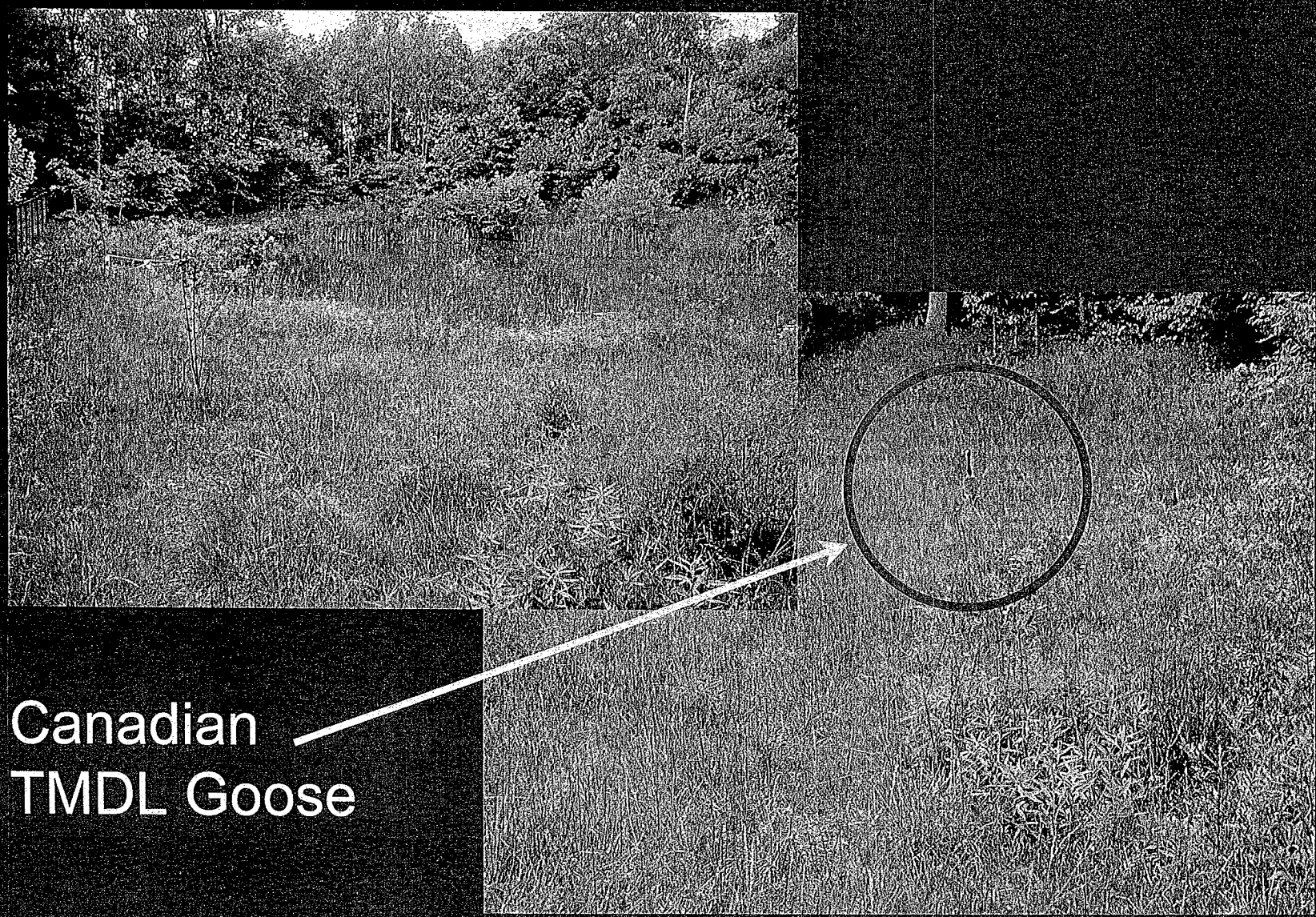

Canadian
TMDL Goose

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Buttermilk off North Shore

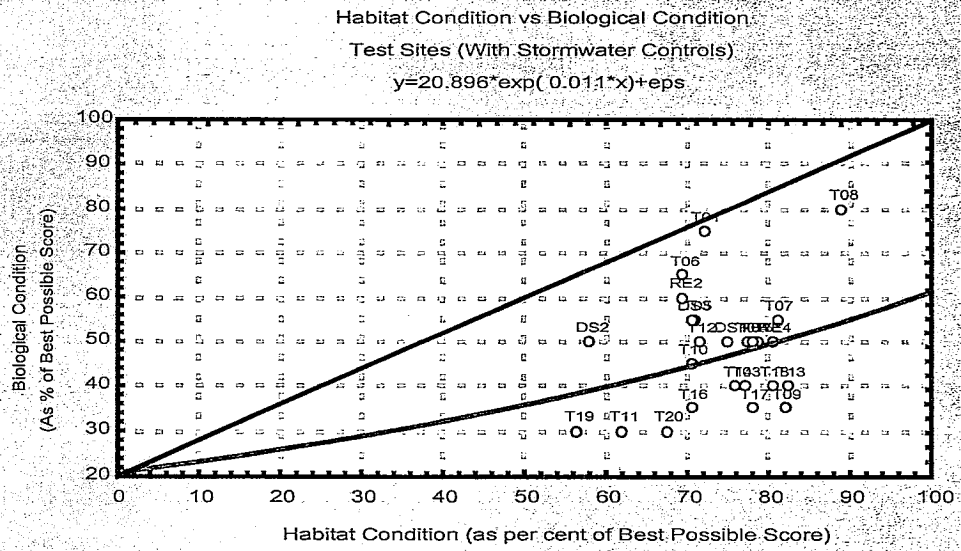


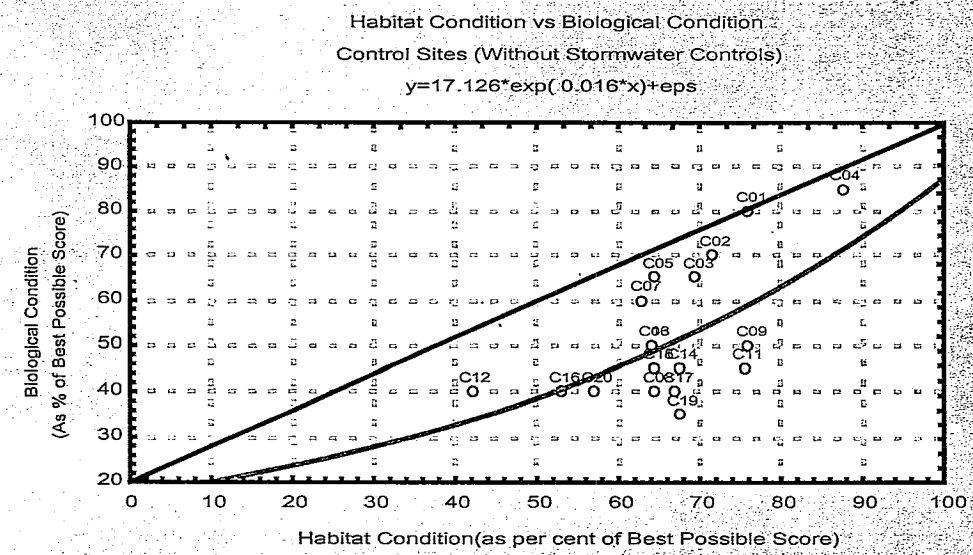
Buttermilk off Ring Road



A006941

Figure 1. Comparison of Habitat Condition and Biological Condition for Sites With and Without SWM





Montgomery County, MD

Both of the datasets plot mainly below the line (Figure 1). Almost all test sites do, and while 6-7 of the control sites plot along the line, the remainder plot below the line.

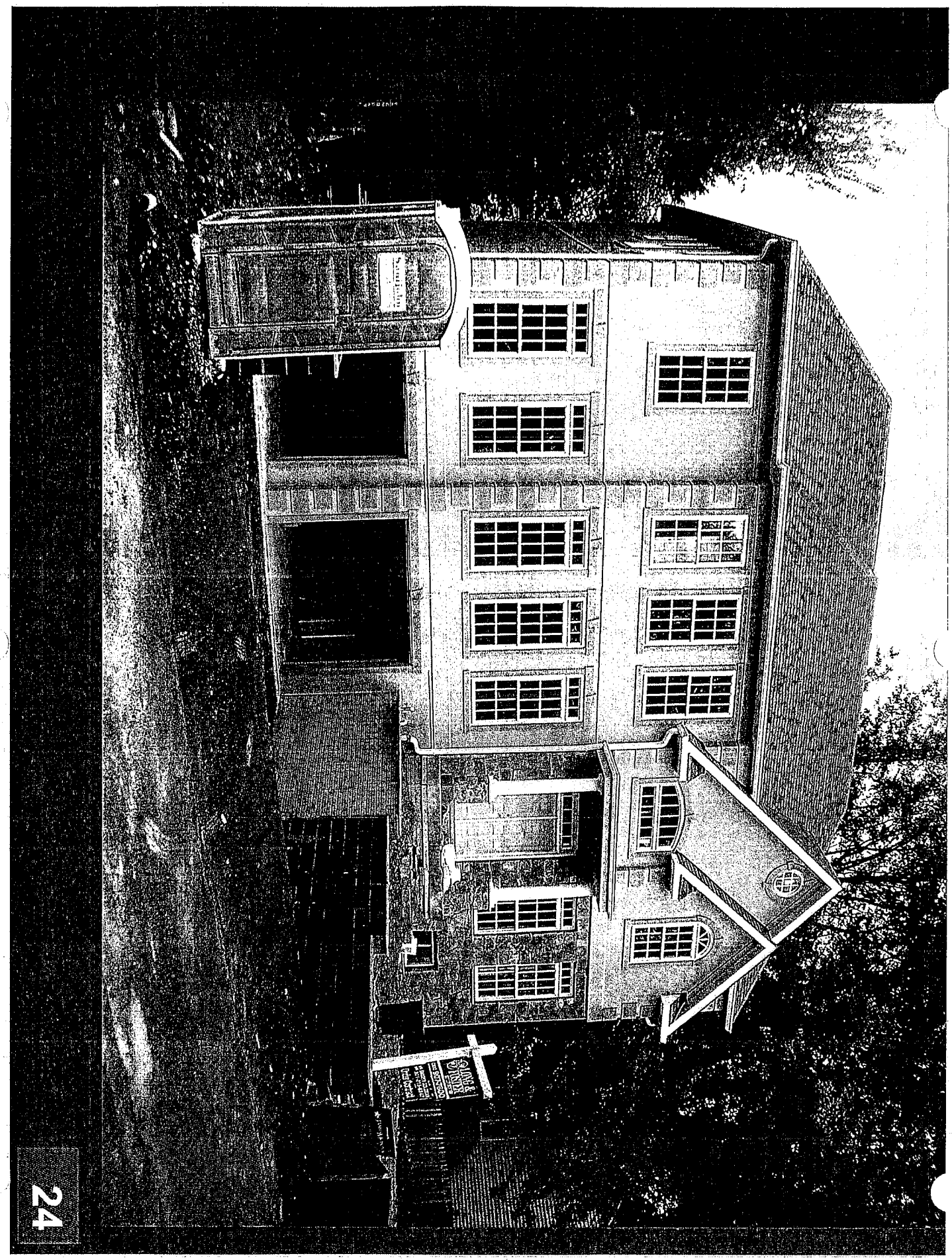
Stream embedding

Riffle areas

Flow regime

ARCHIVE

23



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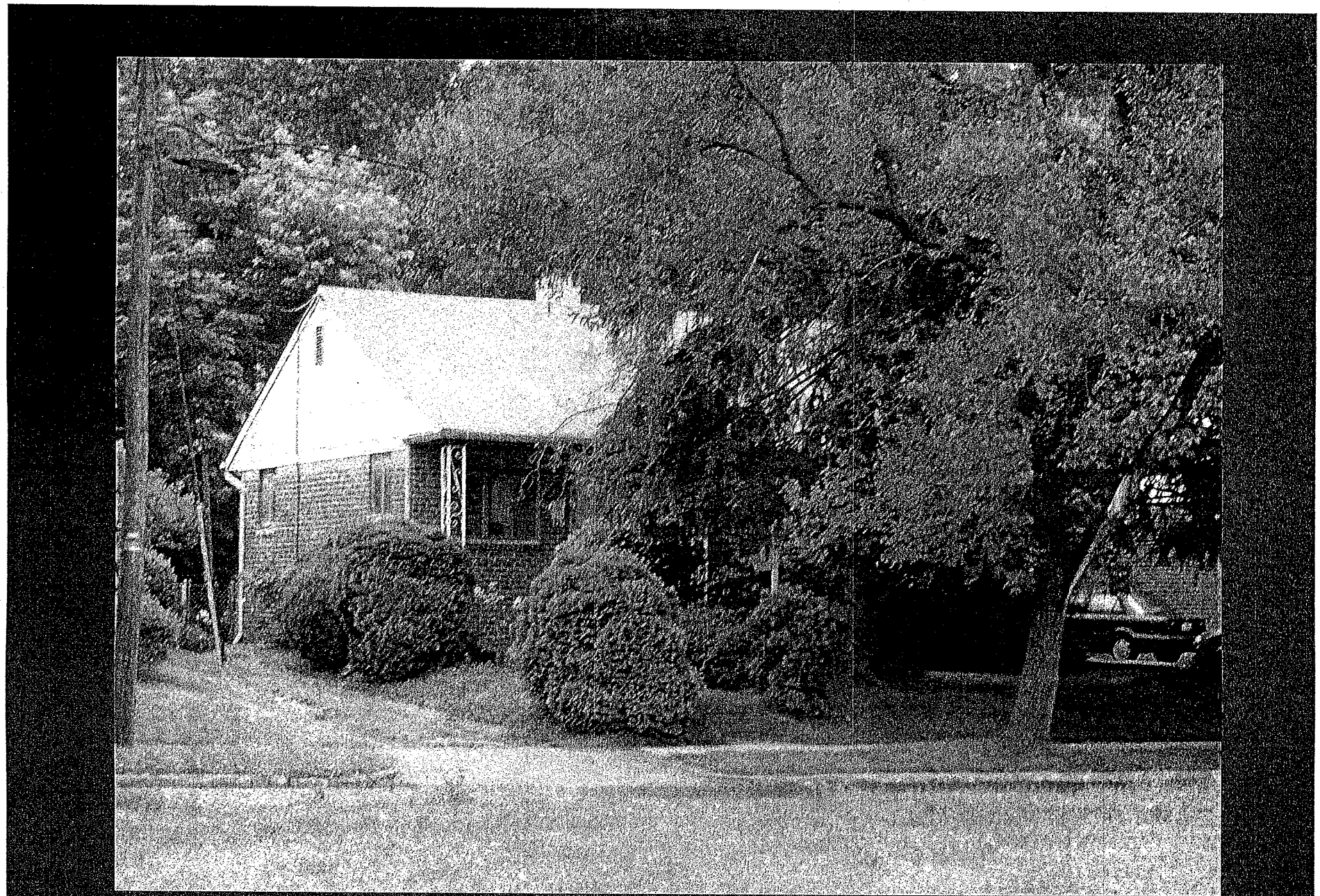
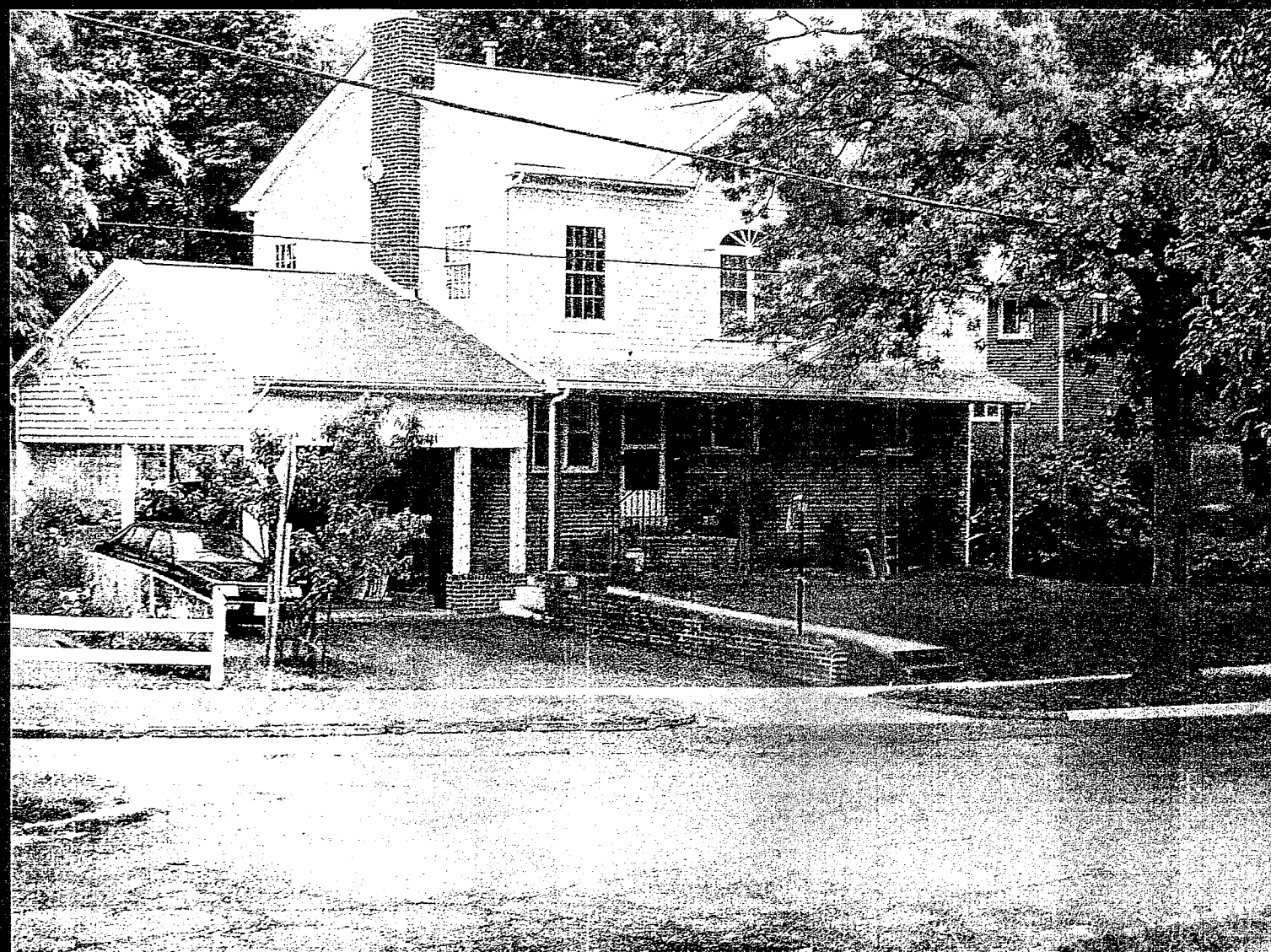


The Future of the Urban America

ARCHIVE
http://Archivebeta.Sakhrit.com



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Smart Growth/LID Hydrology

- Control Runoff at Microwatershed Level
- Consider Hydrologic Process in Microwatershed Layout
- Maintain First Order Receiving Streams
- Maintain Vegetated Buffer Zones
- Control Spatial Pattern of Hydrologic Storage
- Control Upland Flow Velocities
- Control Temporal Characteristics of Runoff

McQuen, 2004

A006947

What we know about codes and ordinances

- We're stuck!
- Site development BMPs don't protect watersheds (Energy Balance and Ranking and Prioritization of Projects is critical)
- Policies of Segregation don't work
- Land use planning/codes/and ordinances are the critical element to watershed based planning
- Requirements must be functional and not "accounting" based
- We really need adaptive management approach for regulations due to our lack of knowledge and training! The lag time is to long for responses to development
- The watershed concept is critical !

A006948

Questions ????



A006949

Defining LID Technology

Major Components

1. Conservation (Watershed and Site Level)
2. Minimization (Site Level)
3. Strategic Timing (Watershed and Site Level)
4. Integrated Management Practices (Site Level)
   Retain / Detain / Filter / Recharge / Use
5. Pollution Prevention
   Traditional Approaches

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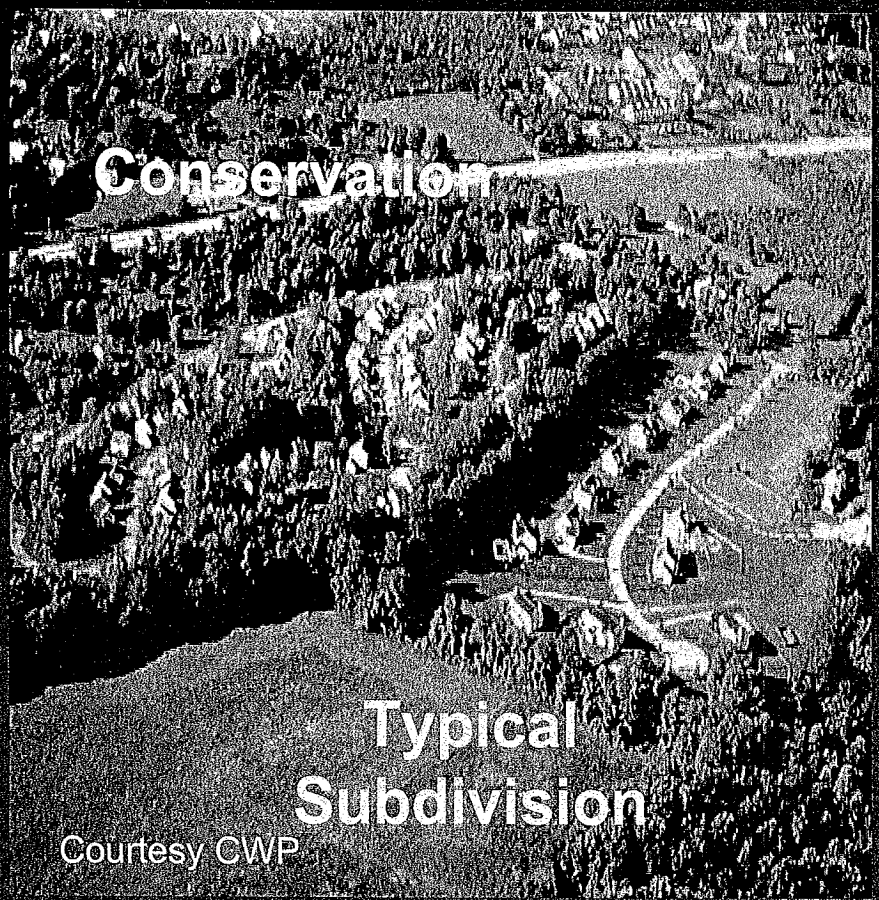
Conserve Natural Areas



Courtesy CWP

- **FUNCTIONAL!!** Conservation of drainages, trees & vegetation
- Land use planning
- Watershed planning
- Habitat conservation plans
- Stream & wetland buffers

155904

Site Fingerprinting



A00952

A006953

LID Key Element

Direct Runoff - Maintain Time of Concentration

- Open Drainage
- Use green space
- Flatten slopes
- Disperse drainage
- Lengthen flow paths
- Save headwater areas
- Vegetative swales
- Maintain natural flow paths
- Increase distance from streams
- Maximize sheet flow



A006954

LID Practices (No Limit!)

"Creative Techniques to Treat,Use, Store, Retain, Detain and Recharge"

- Bioretention / Rain Gardens
- Strategic Grading
- Site Finger Printing
- Resource Conservation
- Flatter Wider Swales
- Flatter Slopes
- Long Flow Paths
- Tree / Shrub Depression
- Turf Depression
- Landscape Island Storage
- Rooftop Detention /Retention
- Roof Leader Disconnection
- Parking Lot / Street Storage
- Smaller Culverts, Pipes & Inlets
- Alternative Surfaces
- Reduce Impervious Surface
- Surface Roughness Technology
- Rain Barrels / Cisterns / Water Use
- Catch Basins / Seepage Pits
- Sidewalk Storage
- Vegetative Swales, Buffers & Strips
- Infiltration Swales & Trenches
- Eliminate Curb and Gutter
- Shoulder Vegetation
- Maximize Sheet flow
- Maintain Drainage Patterns
- Reforestation.....
- Pollution Prevention.....

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Chicago City Hall after 6 months
Rooftscapes inc.
Green Technology for the Urban Environment
36

A026956

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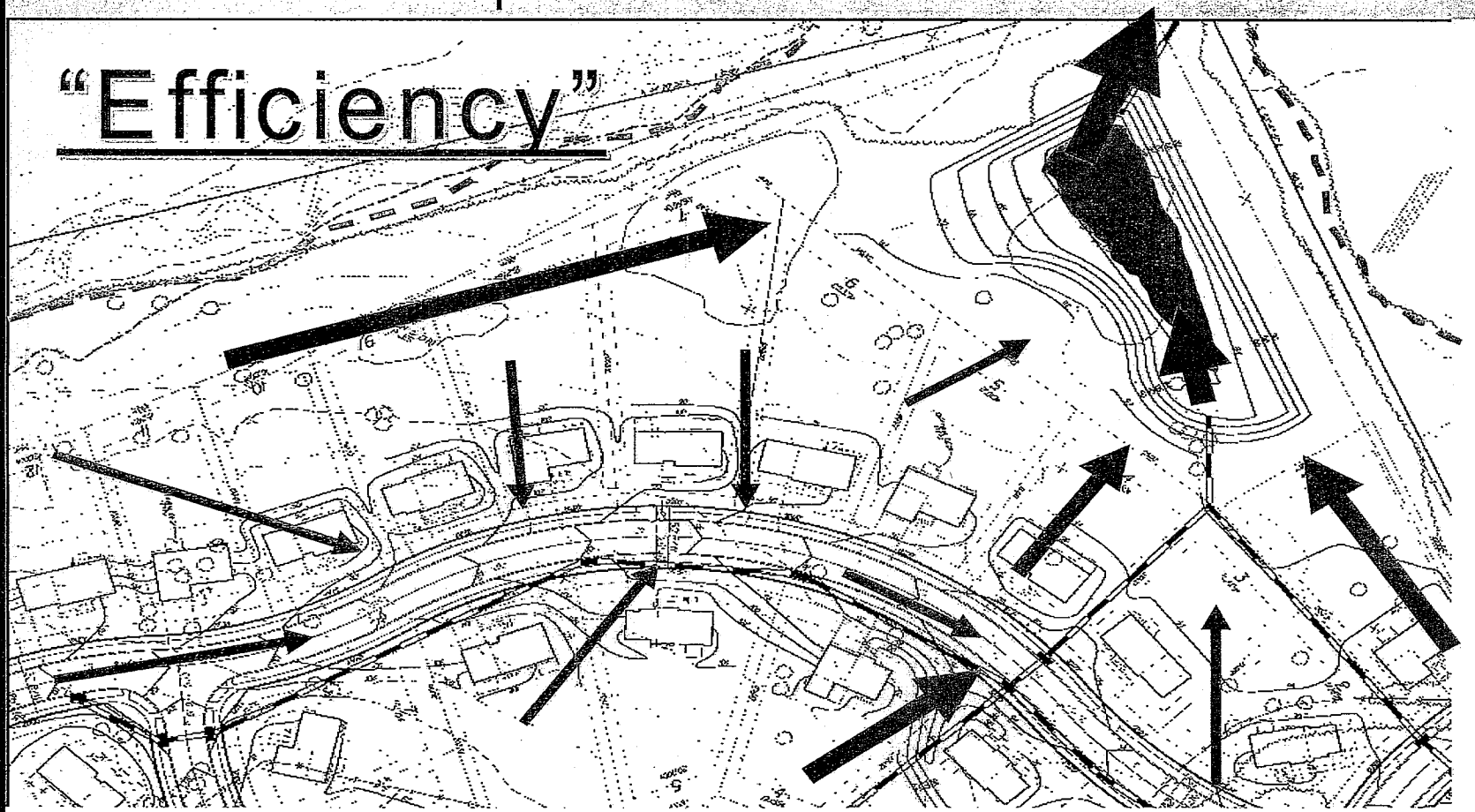
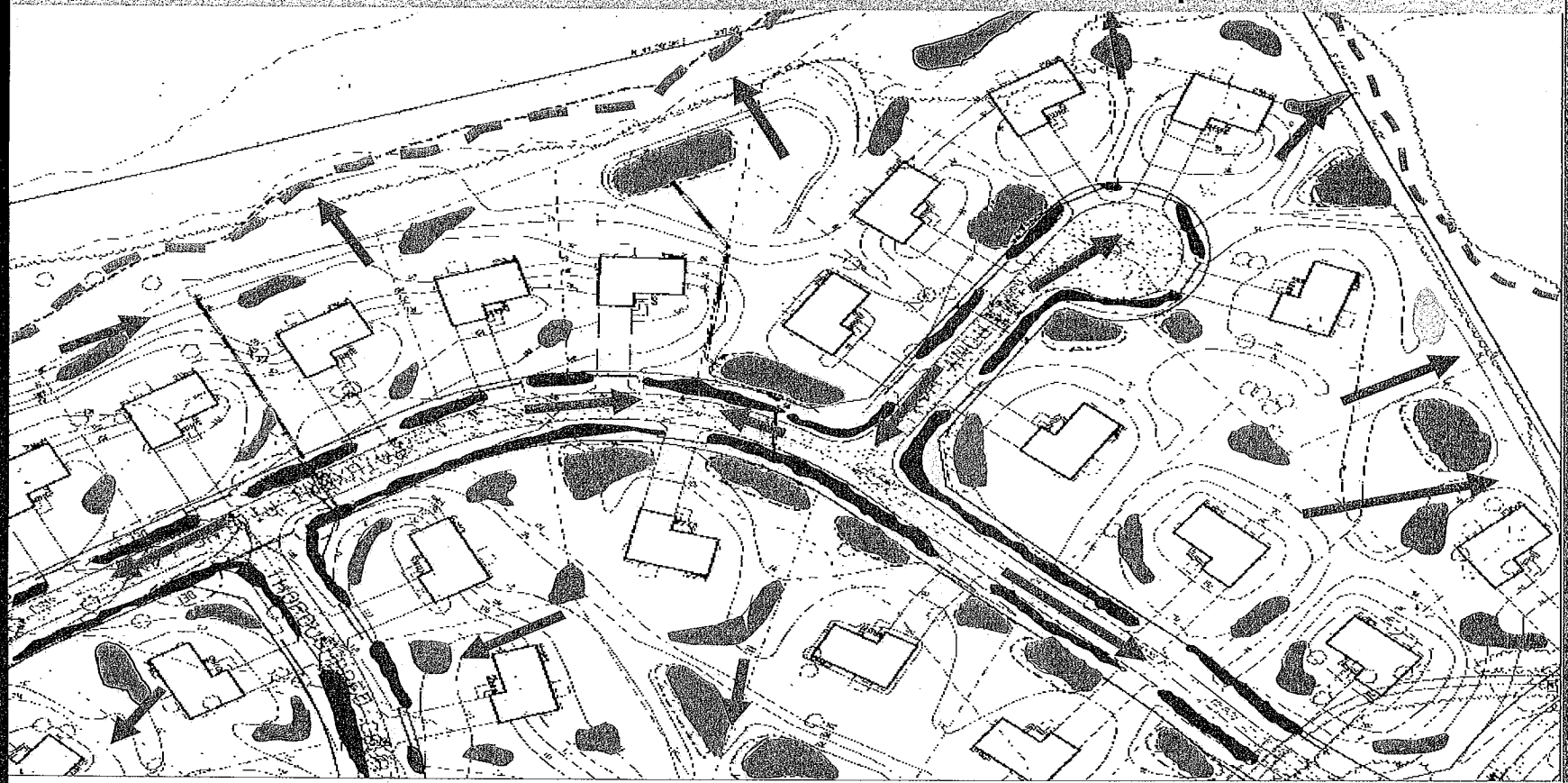
Conventional Pipe and Pond Centralized Control



LID Uniform Distribution of Micro Controls – Residential Example



LID Center Examples

- Institutional
- Compliance
- CSO
- Green Highways
- Technology Demonstration

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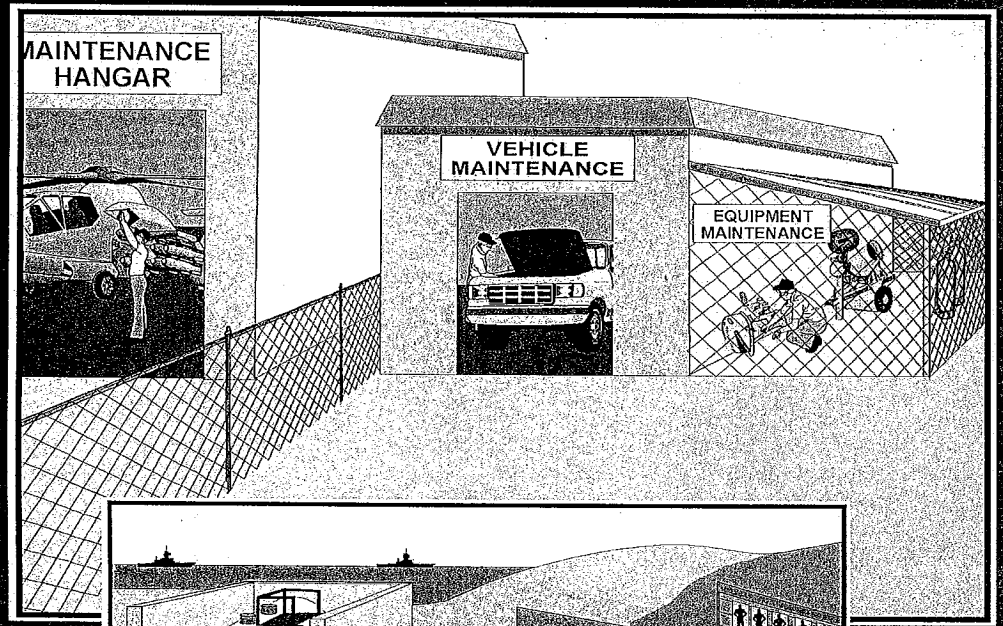
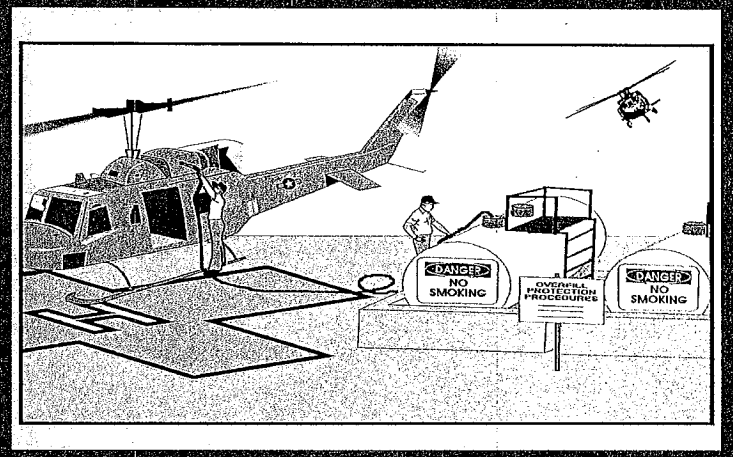
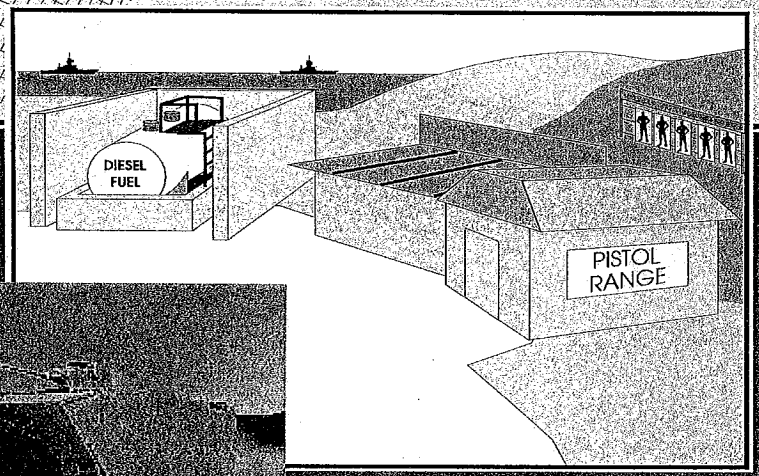
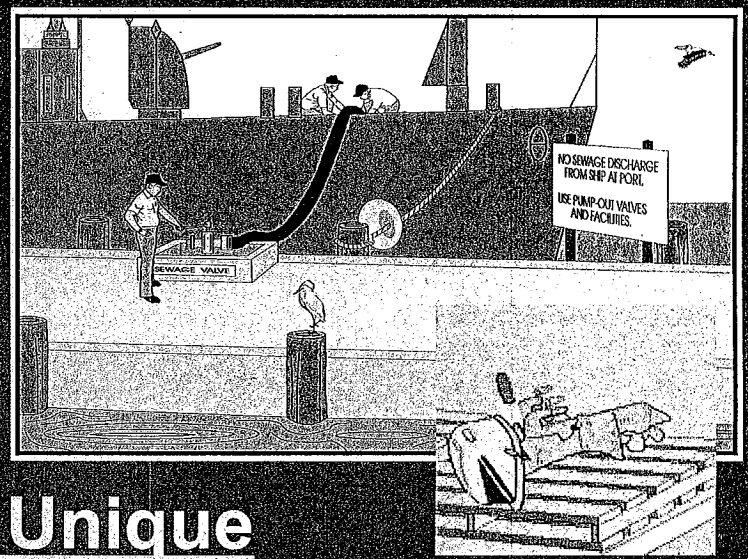
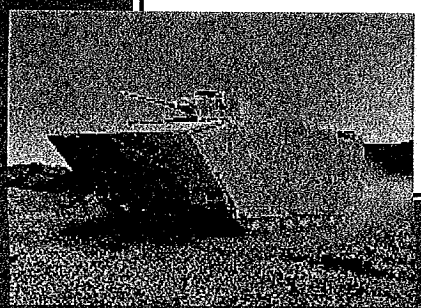
Partnership Approach











Identify Navy Unique Requirements/Solutions

199691

A006962

A Sustainable Ecosystem Approach

- Conservation of biological diversity
- Maintenance of productive capacity of forest ecosystems
- Maintenance of forest ecosystem health and vitality
- Conservation and maintenance of soil and water resources
- Maintenance and enhancement of long-term multiple socioeconomic benefits



HAYMOUNT

WEG
WILLIAMSBURG ENVIRONMENTAL GROUP, INC.

A006963

Stormwater Management Objectives

- Treatment at all major outfalls
- Preserve/improve runoff quality
- Preserve, enhance or restore resources
- Incorporate innovative treatment approaches
- Use a "treatment train" including interior management practices, stormwater mgmt. facilities, and resource restoration
- Incorporate bioengineered techniques that act as community amenities

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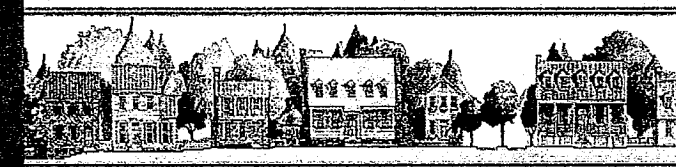
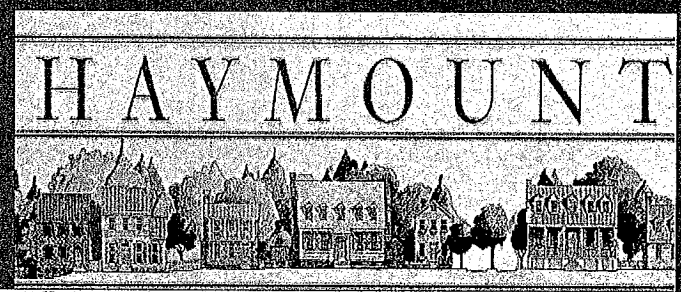


A006964

LID – Site Design Techniques

- Concentrated Development with Preserved Corridors
- Limited Impacts – Maintain Stream Corridors
- Biofiltration in Open Space Settings
- Enhanced Outfall Protection & Open Bottom Crossings
- Stream Restoration
- Restore Degraded Riparian Corridors

- Focus development on existing ag. fields to limit clearing.
- Preservation of about 2/3 of the site
- Use of IMPs to minimize impervious cover
- Reuse of on-site wastewater



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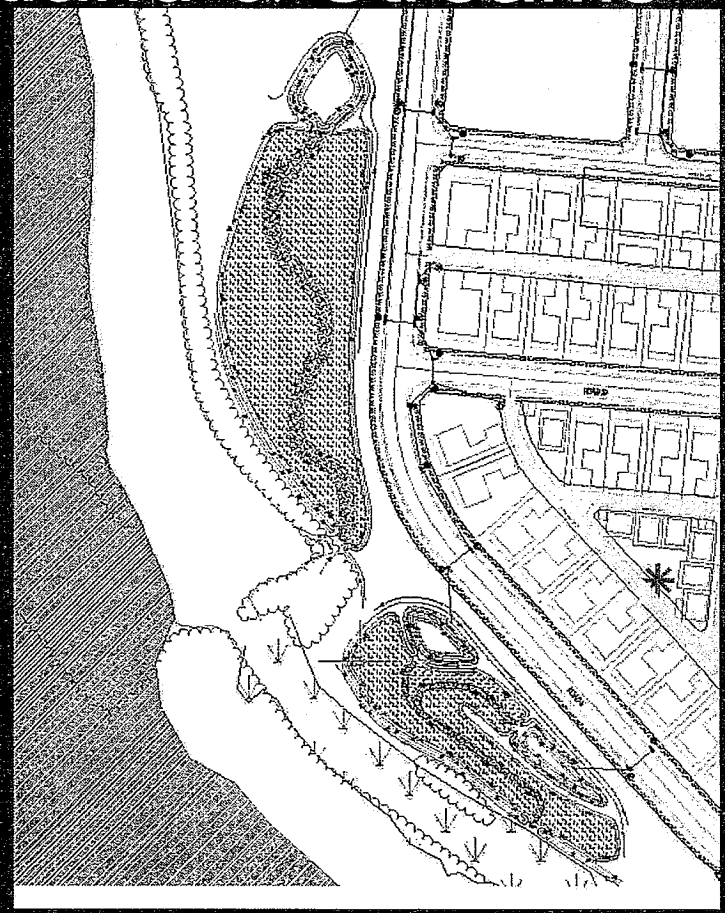
BIOENGINEERING – Wetland & Streams

- Constructed Stormwater Wetlands
- Multiple Teirs/Stages of Vegetation
- Hydraulic Connection to Existing Riparian Corridor
- Natural Channel Design
  - Channel Shaping
  - Instream Structures
  - Floodplain Connection
  - Stabilization with native species



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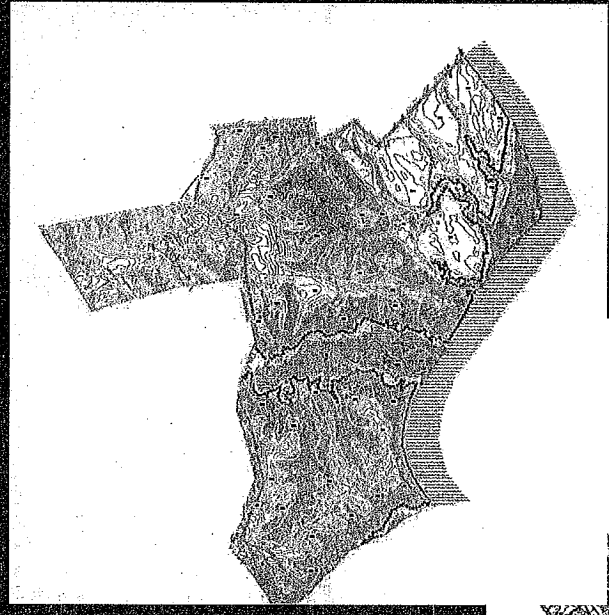
INTEGRATED PRACTICES – Suitability Screening

- Natural Resource Mapping & Analysis
  - Soils (Infiltration)
  - Slopes (Stability)
  - Floodplains (Limits)
- Pre-Development Hydrology
  - Maintain Flow Patterns
- LID Feasibility Analysis
  - Yields Suitable Areas





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A006957

DRAFT UFC X-XXX-XX
11 July 2003

UNIFIED FACILITIES CRITERIA (UFC)

DRAFT
DESIGN: LOW IMPACT DEVELOPMENT MANUAL



APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

NAVAC Low Impact Development Manual

Randy Jackson, P.E.
Engineering Innovation and Criteria Office
Naval Facilities Engineering Command

Neil Weinstein, P.E.,R.L.A.,AICP Executive Director

The Low Impact Development Center, Inc.

Emil Dzuray

Logistics Management Institute

43

AD66966

Sustainability Program Elements

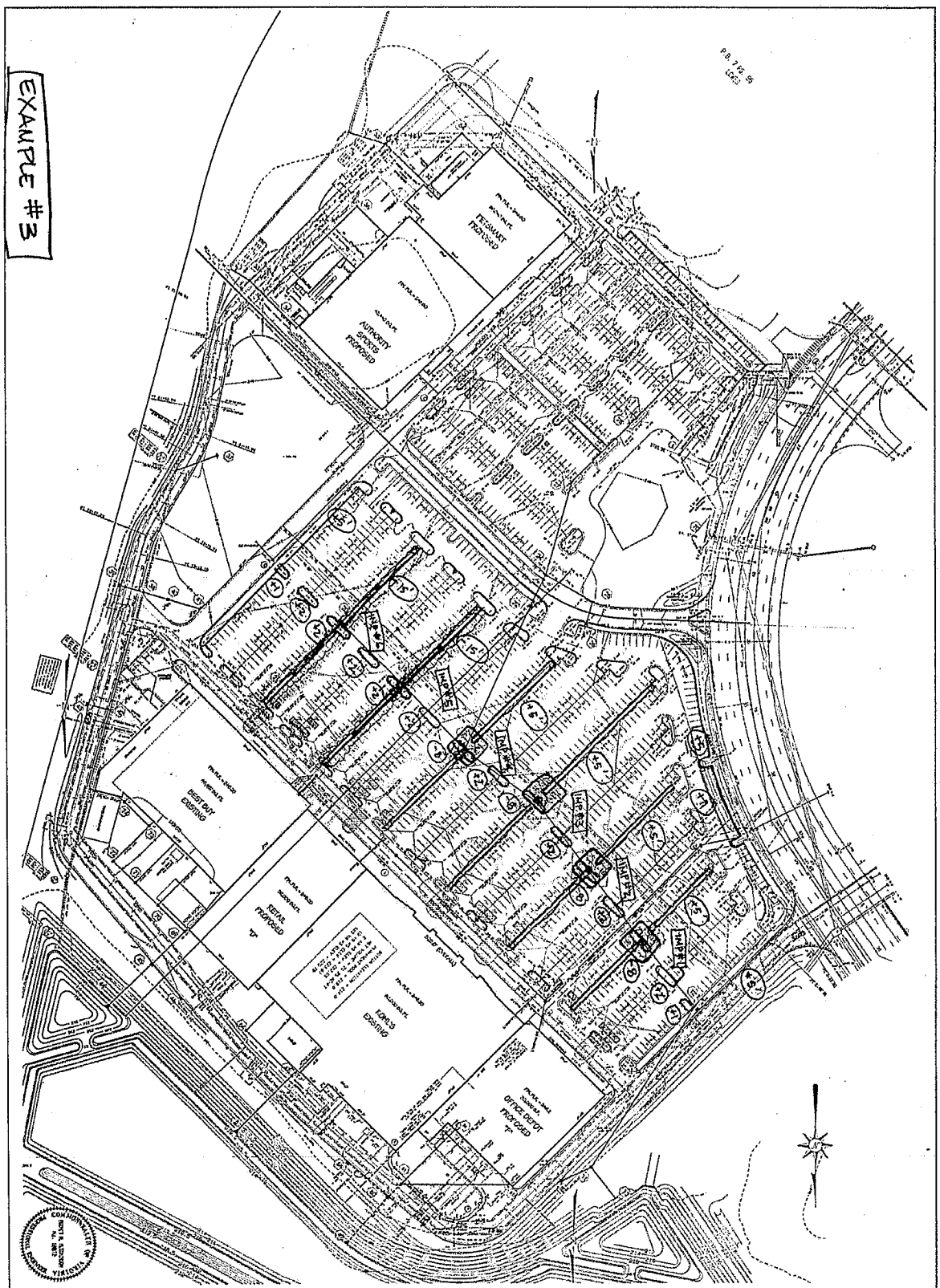


EPA Region 3 / Naval District Washington Partnership

Estornell.paula@epa.gov Parrish.Reginald@epa.gov

A006969

EXAMPLE #3



OVERALL SITE PLAN

OFFICE DEPOT

CENTRAL PARK

FREDERICKSBURG, VIRGINIA

No.	REVISION	Date	By
1	CHANGE WATER LINES INTO BUILDING	[illegible]	[illegible]
2	CHANGE SITE CENTER	[illegible]	[illegible]

Design By: MJK
Drawn By: ACT
Checked By:
Date: 8/01/97
Scale: 1"=60'
Sheet 2 of 4
File Number 6727

ENGINEERS * PLANNERS * LANDSCAPE ARCHITECTS * SURVEYORS

GREENHORNE & O'MARA, INC.

5444 JEFFERSON DAVIS HIGHWAY
SUITE 100
FREDERICKSBURG, VA 22407

(540) 891-1600
FAX (540) 891-1650

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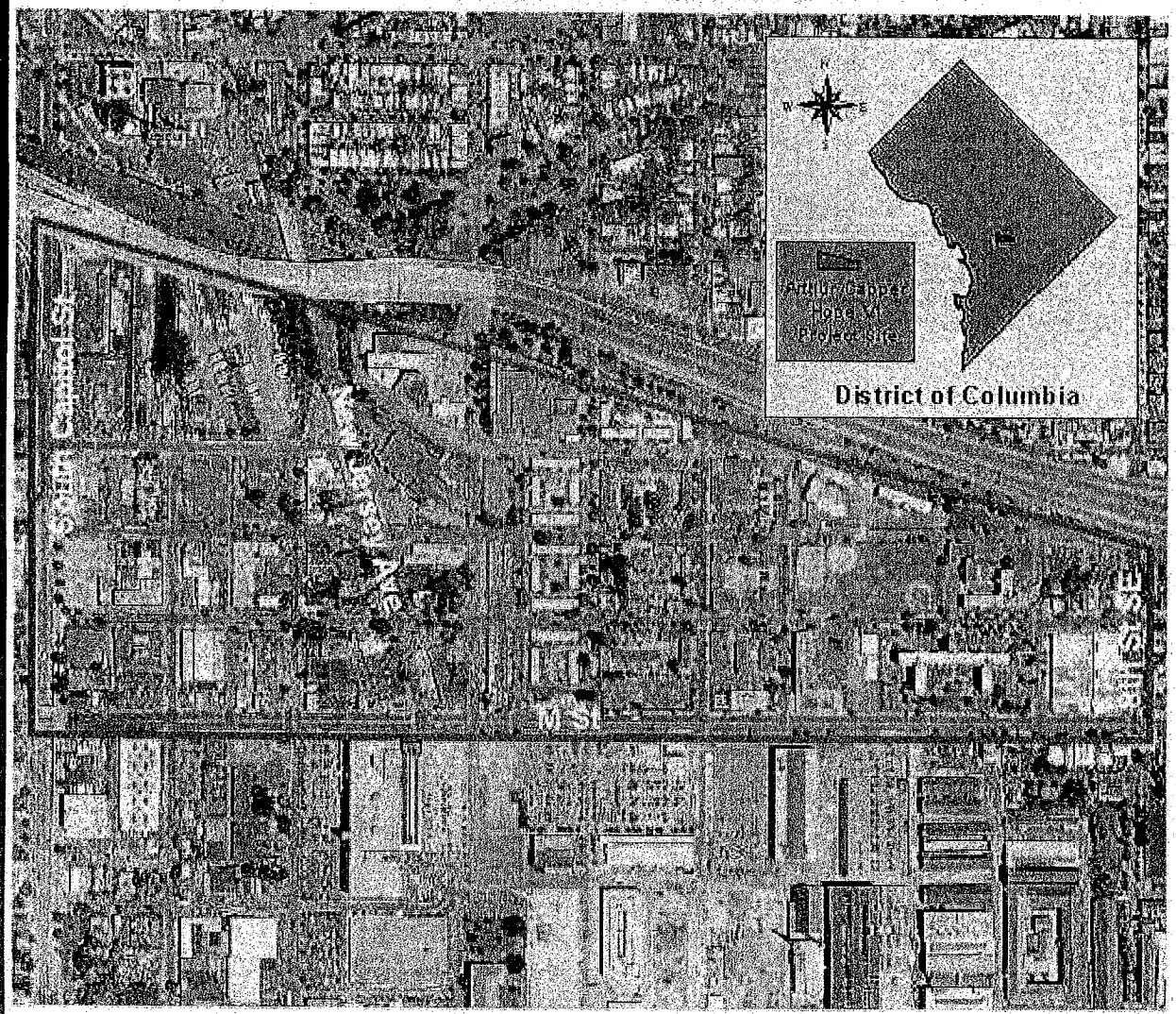
A006970

TARGET
TARGET
TARGET

A006972



30 0 30 60 90 Meters

Data provided by: DC Office of Planning
Created by: Low Impact Development Center
January 23, 2002

A66973

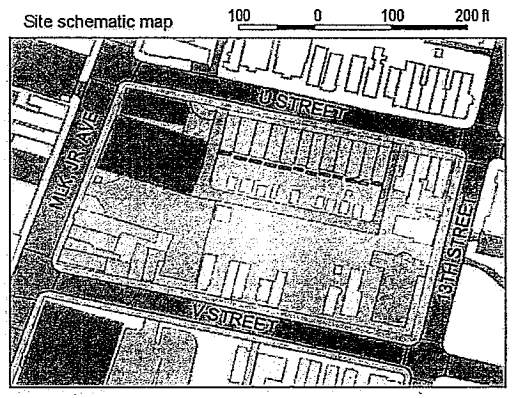
U Street Results

U Street block

Land uses	Land areas			Areas draining to BMPs			
	ft^2	ac.	% of site	ft^2	ac	% of site	% of LU
Entire site	137864.8	3.165					
Commercial Impervious	25597.6	0.588	18.6%	13653.1	0.313	9.9%	53.3%
High Density Res. Impervious	-	-	-	-	-	-	-
Med. Density Res. Impervious	25150.61	0.577	18.2%	11467.6	0.263	8.3%	45.6%
Paved roads or walks	38762.2	0.890	28.1%	19385.3	0.445	14.1%	50.0%
Open / permeable area	48354.4	1.110	35.1%	-	-	-	-

BMPs	BMP areas			Areas treated by BMPs			
	ft^2	ac.	% of site	ft^2	ac	% of site	% of IMPA
Green roofs	13653.1	0.313	9.9%	13653.1	0.313	9.9%	15.3%
Bioretention	891.4	0.020	0.6%	11467.6	0.263	8.3%	12.8%
Permeable pavement	19385.31	0.445	14.1%	19385.3	0.445	14.1%	21.7%
Total for BMPs	33929.7	0.8	24.6%	44506.0	1.022	32.3%	49.7%

Site schematic map



Yearly results

Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/yr	77.6	66.3	15%
Sediment	Tons/yr	12.6	6.4	50%
BOD_5	lb/yr	138.4	114.2	18%
Total N	lb/yr	25.7	17.5	32%
Total P	lb/yr	3.1	2.2	29%
Total Zinc	lb/yr	2.3	1.4	41%

Week report 1 — Week of 7/19; Total rain 1.83"; i_{rain} max 0.83 in/hr

Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/wk	3.3	3.1	8%
Sediment	tons/wk	0.4	0.2	48%
BOD_5	lb/week	1.8	1.1	40%
Total N	lb/week	0.7	0.4	37%
Total P	lb/week	0.1	0.05	36%
Total Zinc	lb/week	0.1	0.04	43%
Peak Q	cfs	1.6	1.3	23%

Week report 2 — Week of 1/18; Total rain 1.28"; i_{rain} max 0.73 in/hr

Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/wk	3.1	2.8	10%
Sediment	tons/wk	0.3	0.2	40%
BOD_5	lb/week	10.9	10.4	5%
Total N	lb/week	1.1	0.9	17%
Total P	lb/week	0.1	0.13	14%
Total Zinc	lb/week	0.1	0.05	30%
Peak Q	cfs	1.8	1.4	23%

Week report 3 — Week of 5/20; Total rain 0.75"; i_{rain} max 0.57 in/hr

Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/wk	1.4	1.2	10%
Sediment	tons/wk	0.3	0.1	49%
BOD_5	lb/week	1.3	0.8	38%
Total N	lb/week	0.4	0.3	38%
Total P	lb/week	0.0	0.03	37%
Total Zinc	lb/week	0.04	0.02	44%
Peak Q	cfs	0.9	0.6	34%

Week report 4 — Week of 3/4; Total rain 2.07"; i_{rain} max 0.34 in/hr

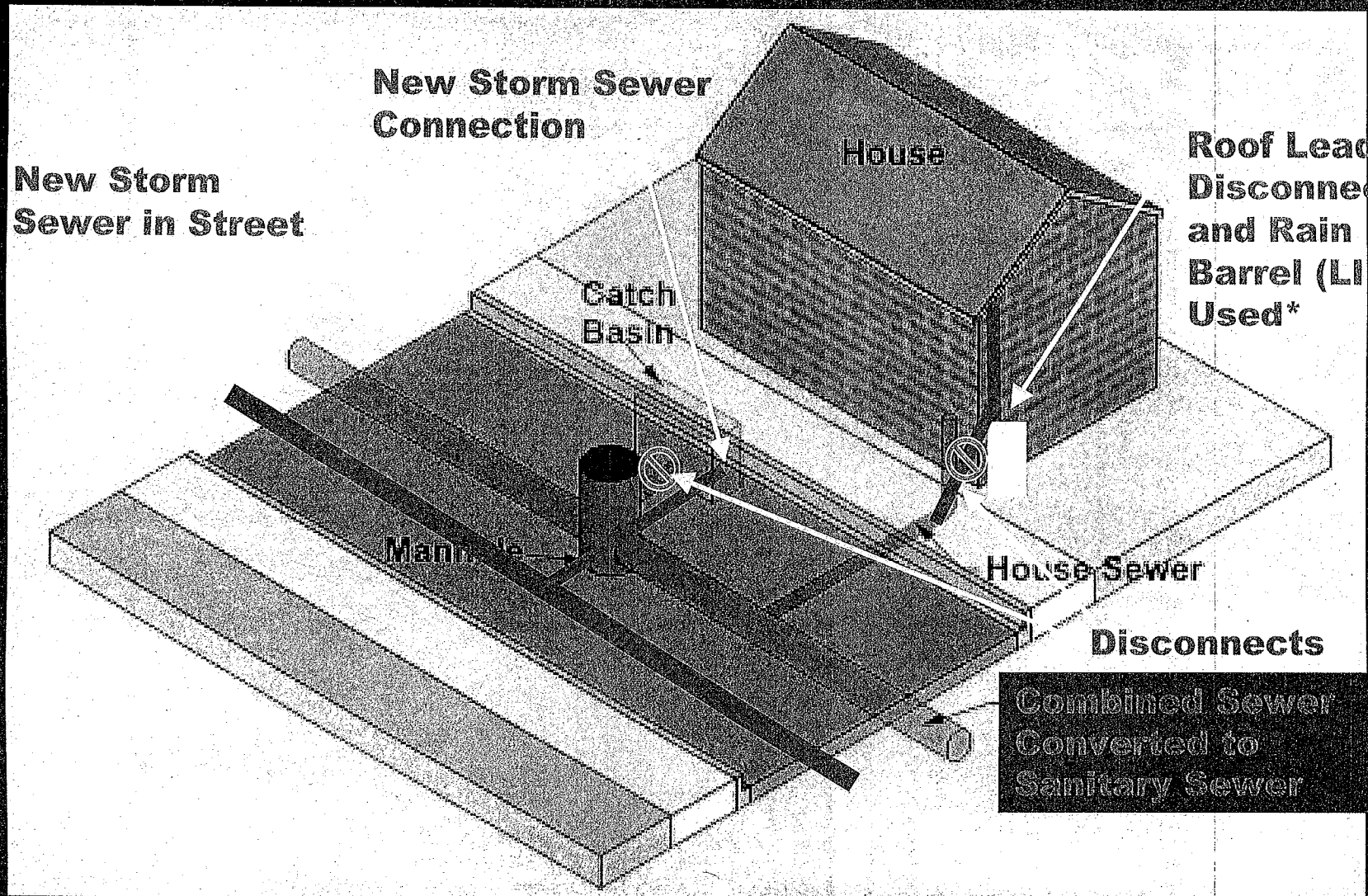
Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/wk	4.6	4.0	12%
Sediment	tons/wk	0.4	0.2	45%
BOD_5	lb/week	12.1	11.5	6%
Total N	lb/week	1.3	1.1	18%
Total P	lb/week	0.2	0.15	15%
Total Zinc	lb/week	0.1	0.06	32%
Peak Q	cfs	0.8	0.6	27%

Week report 5 — Week of 9/14; Total rain 1.17"; i_{rain} max 0.18 in/hr

Indicator	Units	No LID	LID retrofit	% red.
Outflow	acre-in/wk	2.3	1.9	17%
Sediment	tons/wk	0.3	0.1	54%
BOD_5	lb/week	1.4	0.7	47%
Total N	lb/week	0.5	0.3	44%
Total P	lb/week	0.1	0.03	41%
Total Zinc	lb/week	0.1	0.03	46%
Peak Q	cfs	0.3	0.2	31%

Outflow includes both direct, untreated runoff, and discharges from BMPs. LU = land use IMPA = impervious area

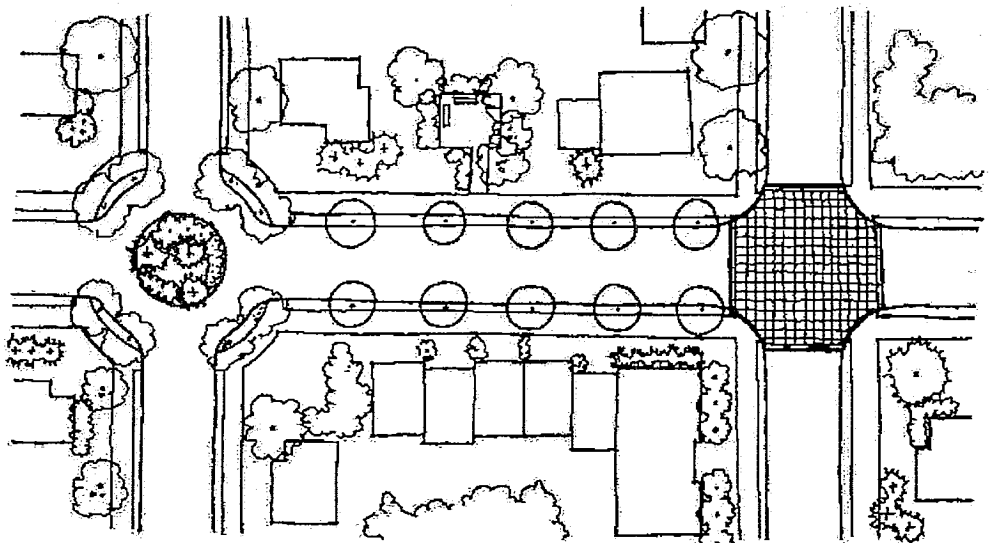
Separation Plan in CSO 006 Area (Est. Cost = $3,900/private property)



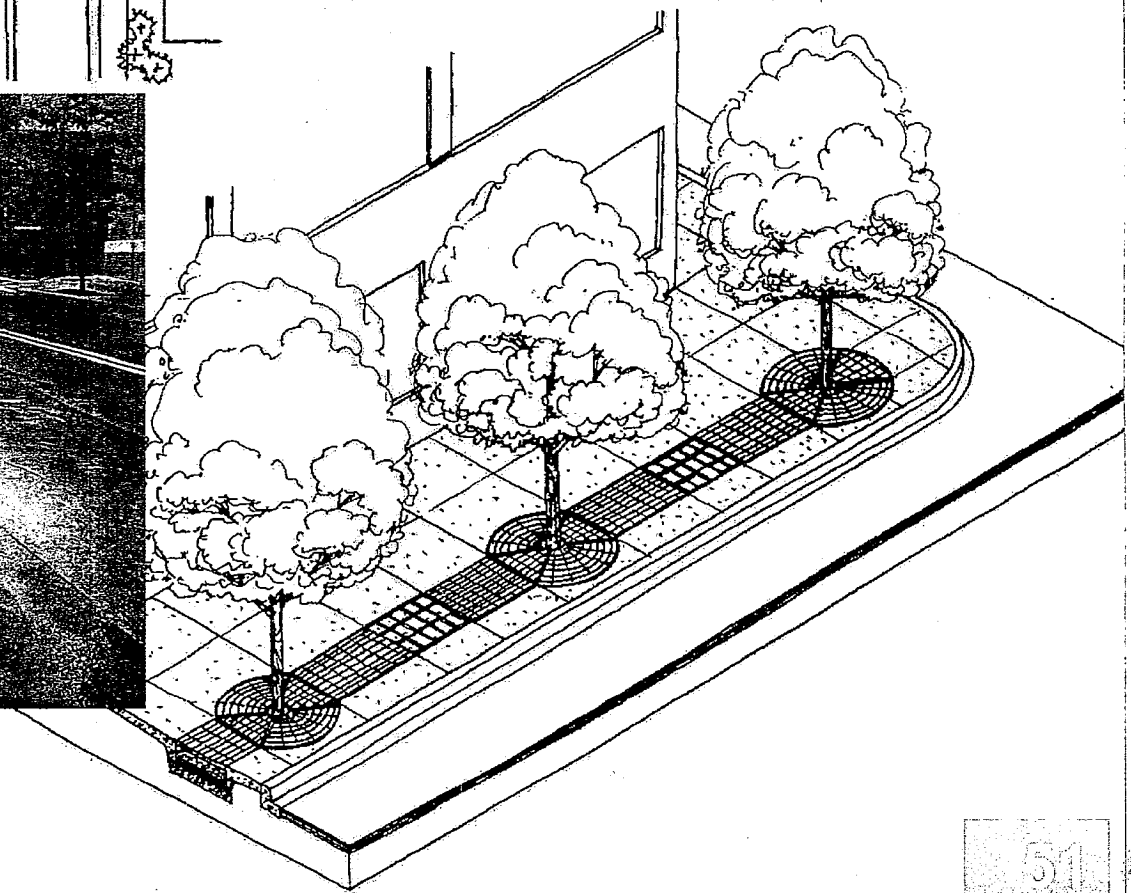
*No Extension on Private Property Required (May Result in 10-50% savings).

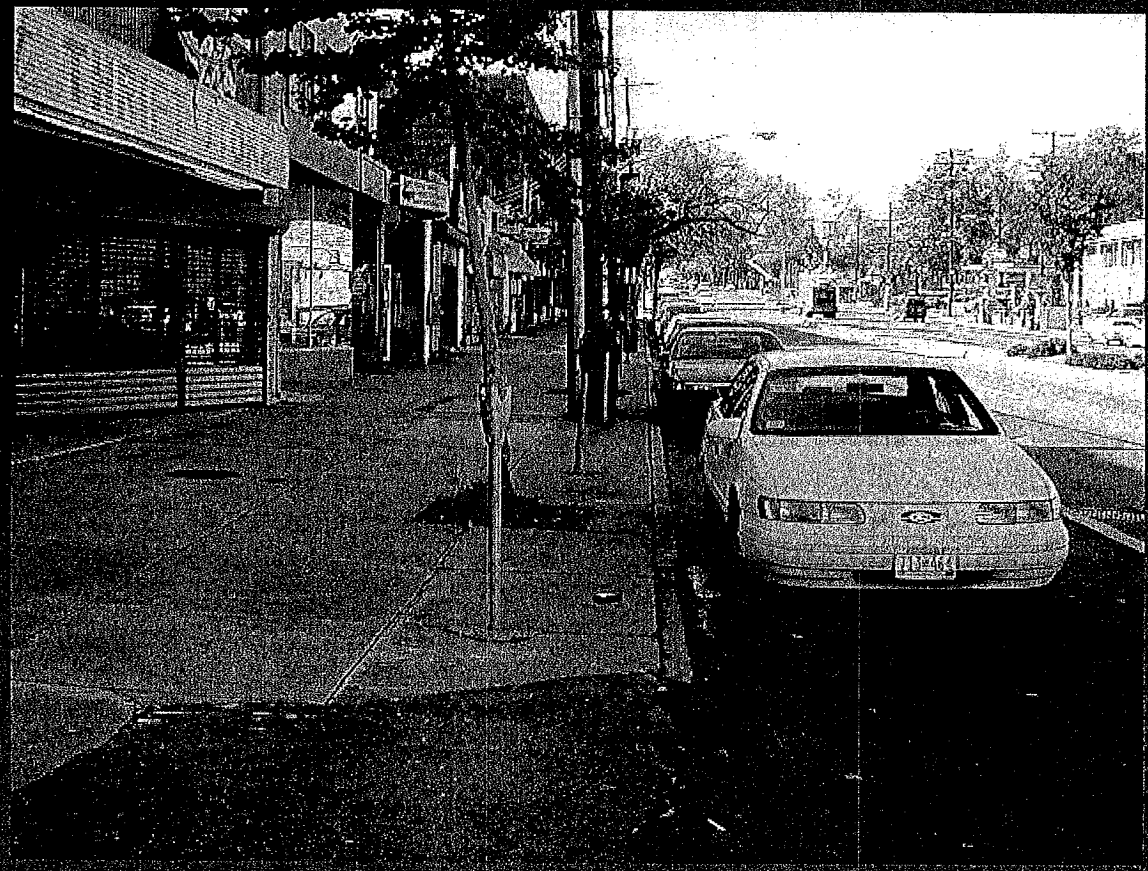
A006975

Sustainable Transportation





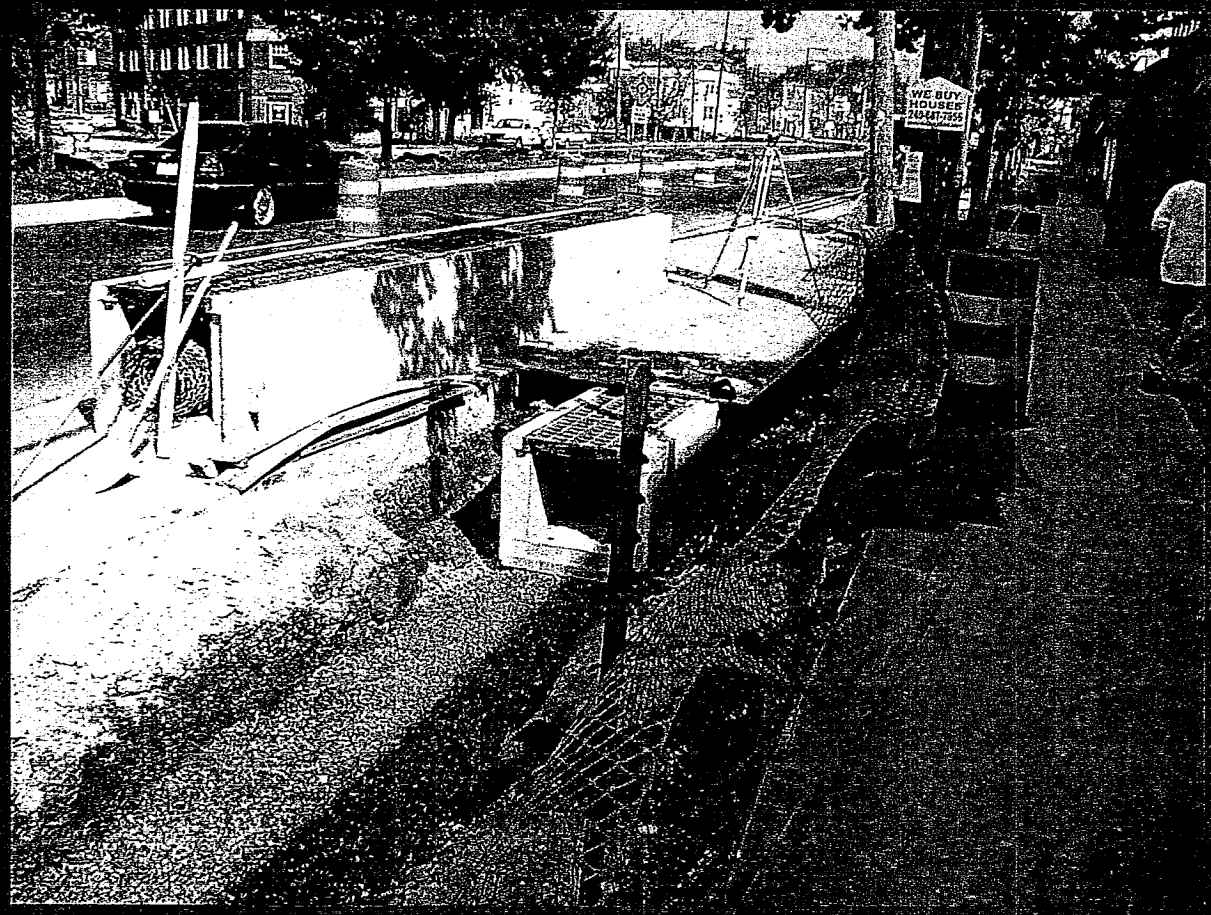




Maryland State Highway Administration -

Mount Ranier Demonstration Project

A006977



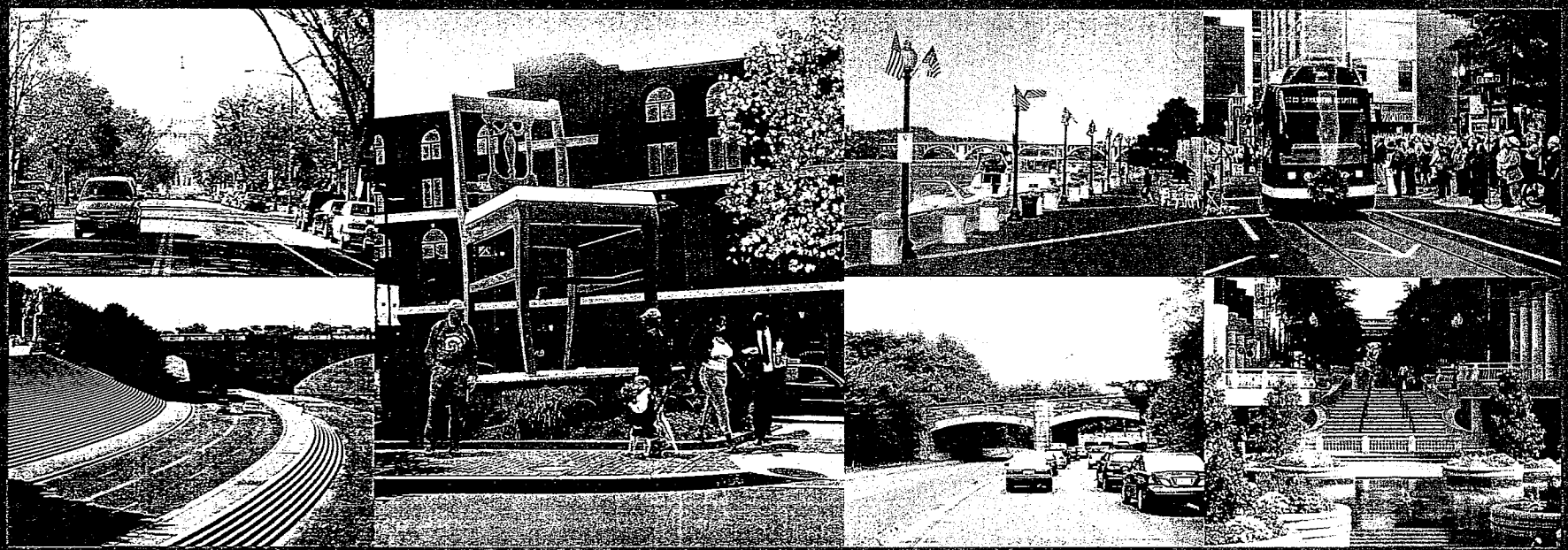
SHA Mt. Ranier Gutter Filters Integrated into Streetscape

A96978

A006979

Anacostia Waterfront

Transportation Architecture Design Standards

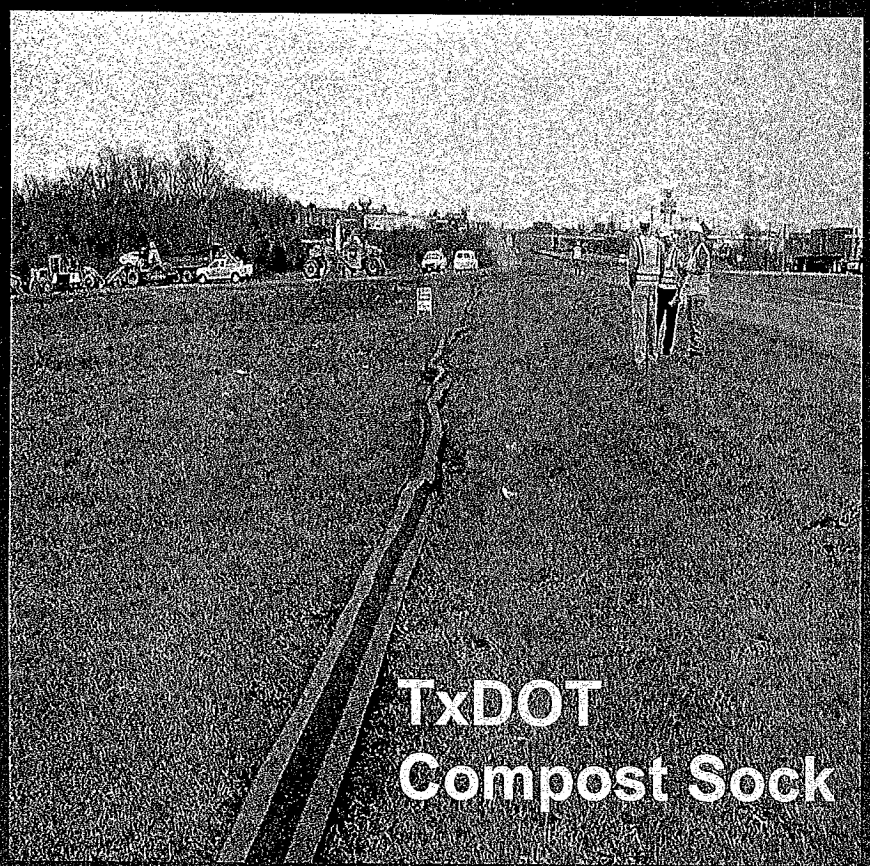


District of Columbia
District Department of Transportation

Infrastructure Project Management Administration

A006980

Construction and Temporary Uses



TxDOT
Compost Sock



Southeast
Federal Center

Maybe Construction Messed it up?

A0006931

Green Highways Initiative

- Region 3/FHWA/Private Public Partnership
- Sustainable Market Driven Goals
- Applied Research for Decision Makers
- Watershed Approach

http://www.greenhighways.org

A66982

WERF Decentralized Controls

Research Objectives

The main focus of this project was to evaluate the practicability of incorporating decentralized stormwater controls into urban CSO control plans. Six specific research objectives were identified to guide the project.

Research Objectives (cont.)

- Research decentralized methods
- Analyze technical issues and practicability
- Evaluate implementation strategies, incentives, and disincentives
- Evaluate implementation costs
- Identify ancillary benefits
- Develop guidance and protocols

A006984

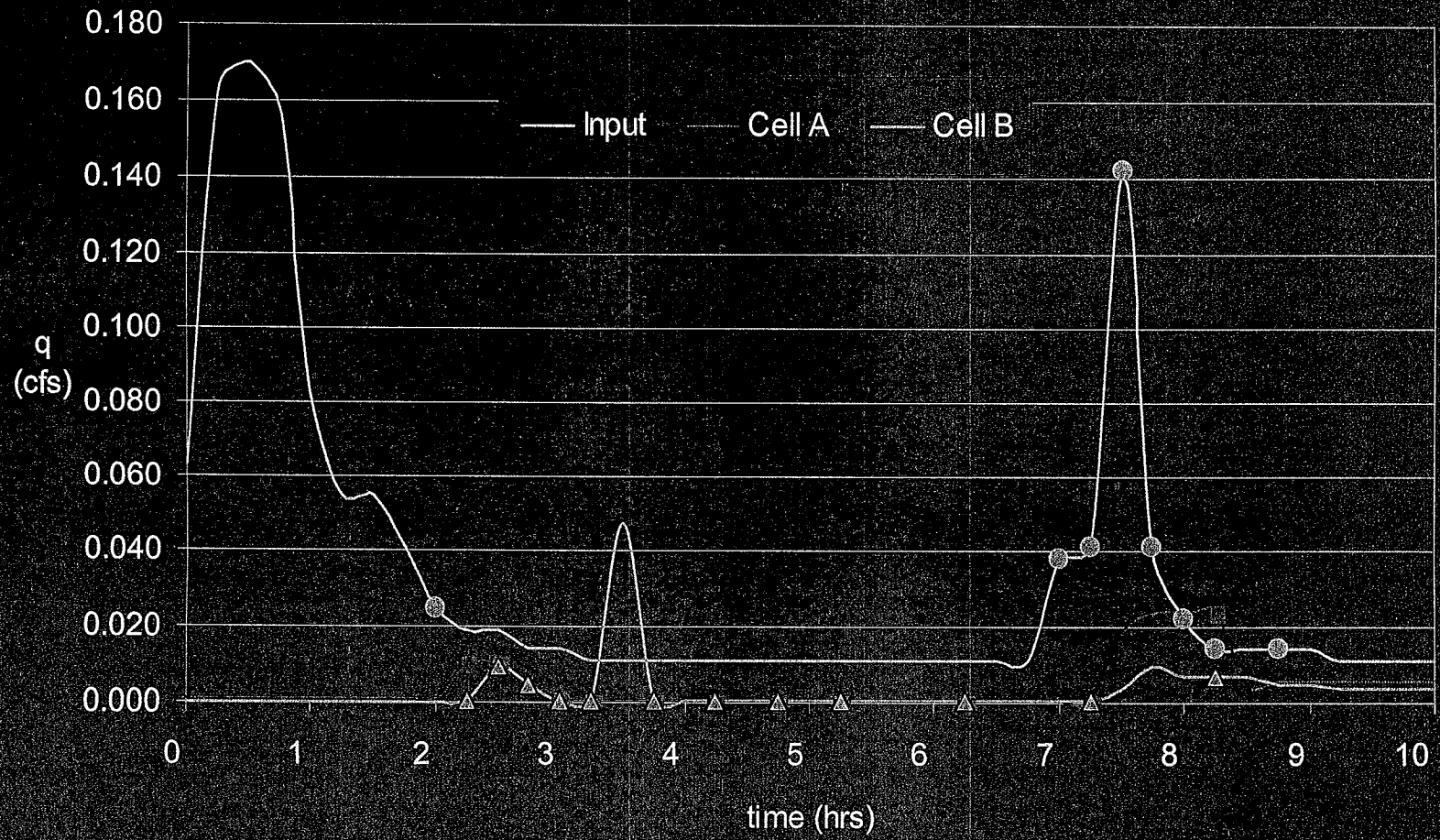
Overhead View of the Site



A005985

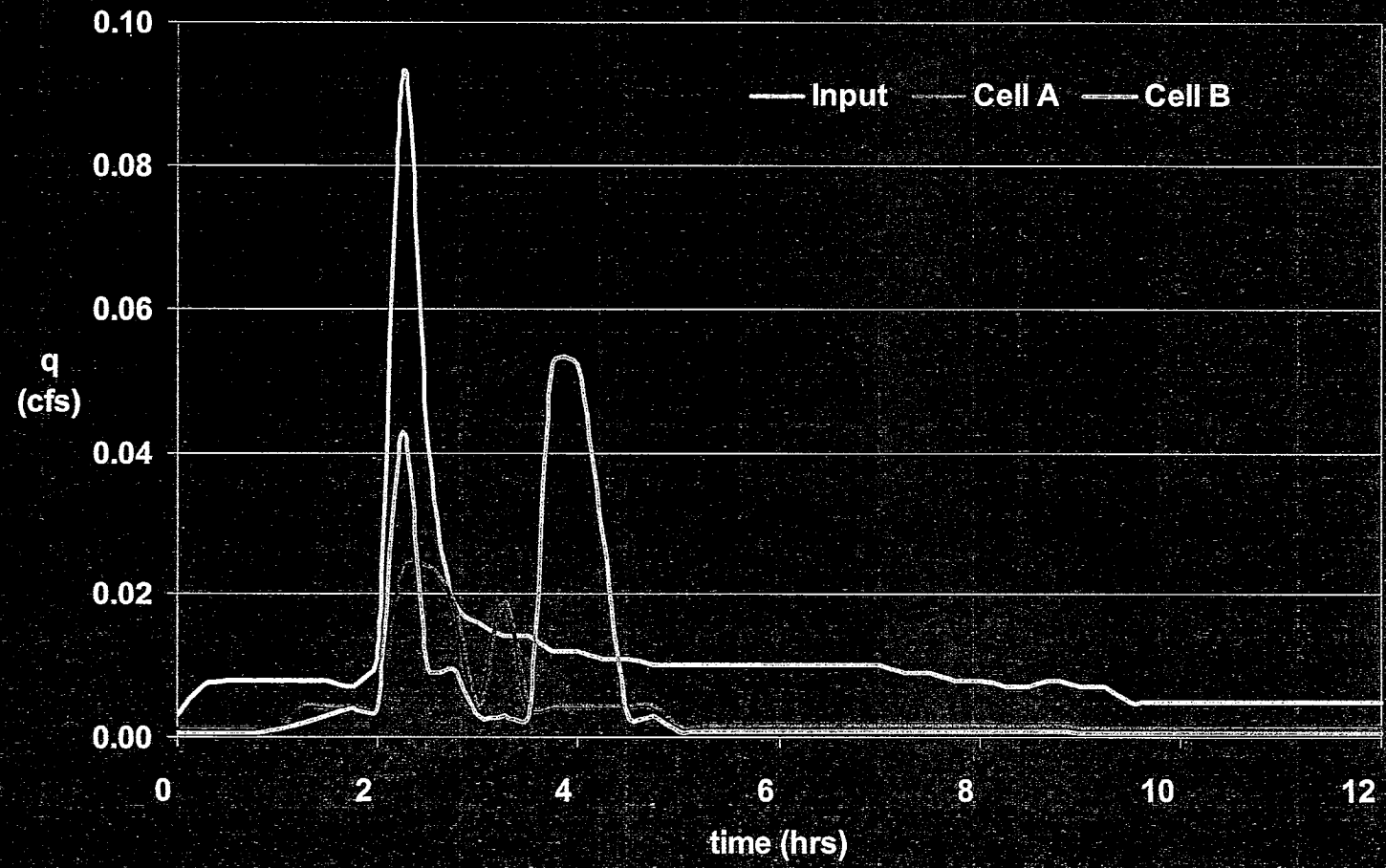
A006986

UMD Bioretention Hydrograph, July 28-29, 2003



A0069871

Hydrograph, August 1, 2003, UMD



Questions ???



A006989

Regional Applications

- Virginia (Haymount)
- California
- Puget Sound
- Seattle
- Massachusetts
- Alabama
- Minnesota

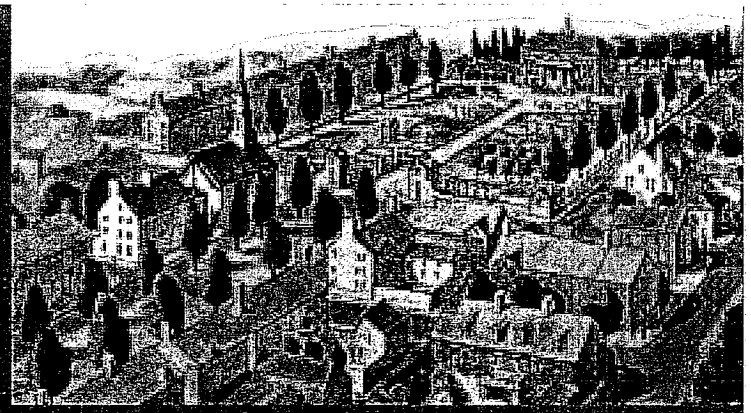
Development Examples

W. Douglas Beisch, Jr., P.E
Sr. Water Resource Engineer

Williamsburg Environmental Group, Inc.

A066991

Project Background
Haymount Development





- Located in Caroline County, VA just outside of Fredericksburg
- 1800+ acre development
- Located on 3 miles of Rappahannock River Shoreline
- 4000 Planned Housing Units
- Planning since 1990
- New Urbanism Style Development
- Responsible land use planning and Development

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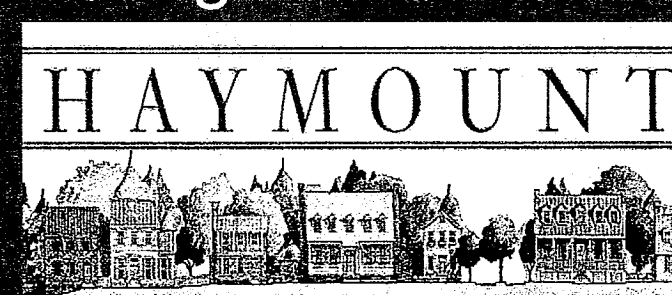


A006992

Ecosystem Management

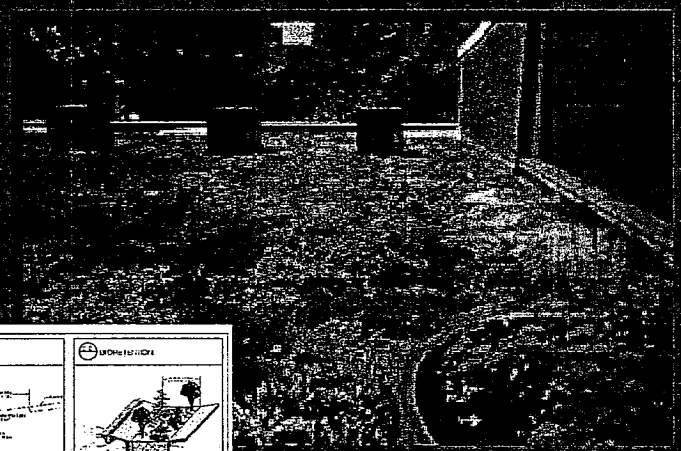
- Water Quality Management
- Nutrient Management
- Waste Water Reuse
- Wildlife Habitat Management
- Forestry Management

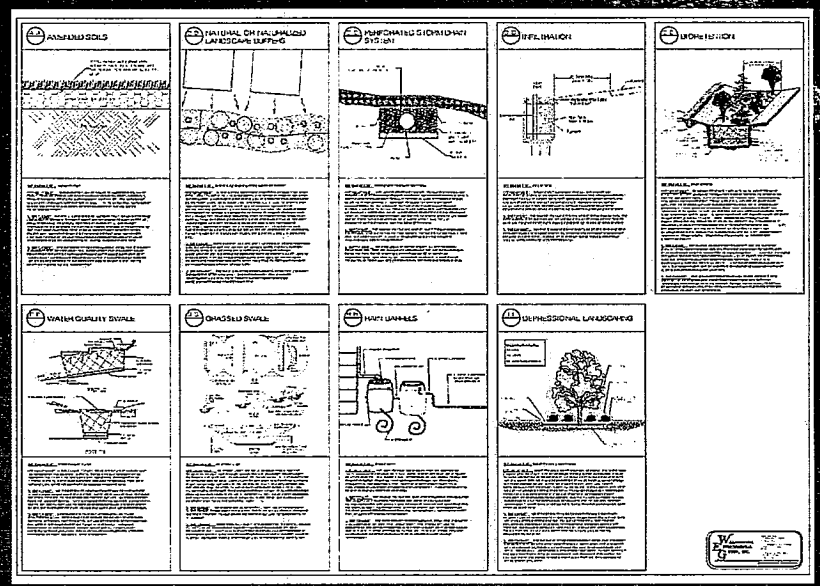


ADC553

INTEGRATED PRACTICES – Menu of IMPS

- Bioretention / Biofiltration
- Soil Amendments
- Permeable Pavements
- Green Roof Applications





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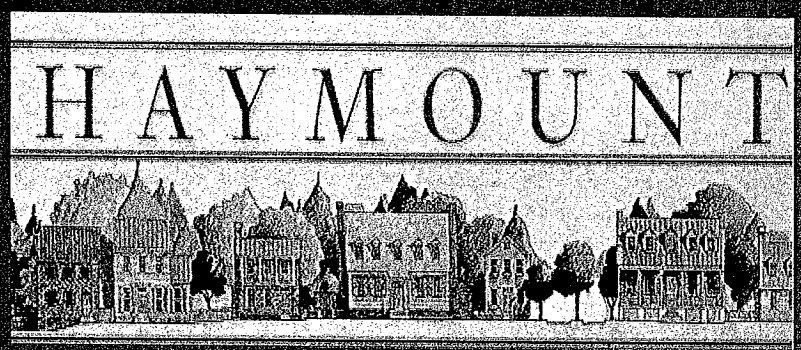
LID Education Program

Friends of the Rappahannock
Advocacy • Restoration • Education

Virginia Environmental Endowment

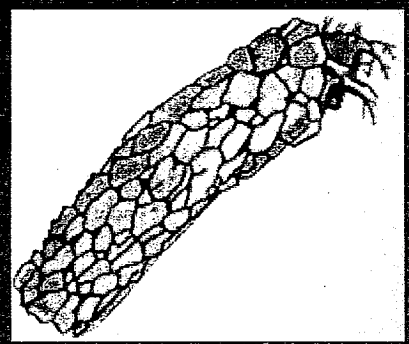


- Haymount has begun an LID Education Program with Friends of the Rappahannock
- The project is being funded through grant money awarded by Virginia Environmental Endowment
- The focus of the project is to educate high school students on the benefits and how to implement LID

A006995

Water Quality Monitoring Program

- Chemical and Biological Water Quality Monitoring to assess water quality



- Real time data collection posted on Haymount's environmental website

A005996

Wastewater Treatment Plant

- SBR Technology
- Aerobic and Anerobic process for nutrient reduction
- Energy efficient pumps and design

Earth Tech's LEED™ accredited architects, engineers and environmental scientists are working with Haymount to create an energy-efficient and environmentally sound Waste Water Treatment Plant

EarthTech
A tyco International Ltd. Company

Clean water is the lifeblood of a community.
AND WE'RE THE LIFELINE.

166997

Water Reuse



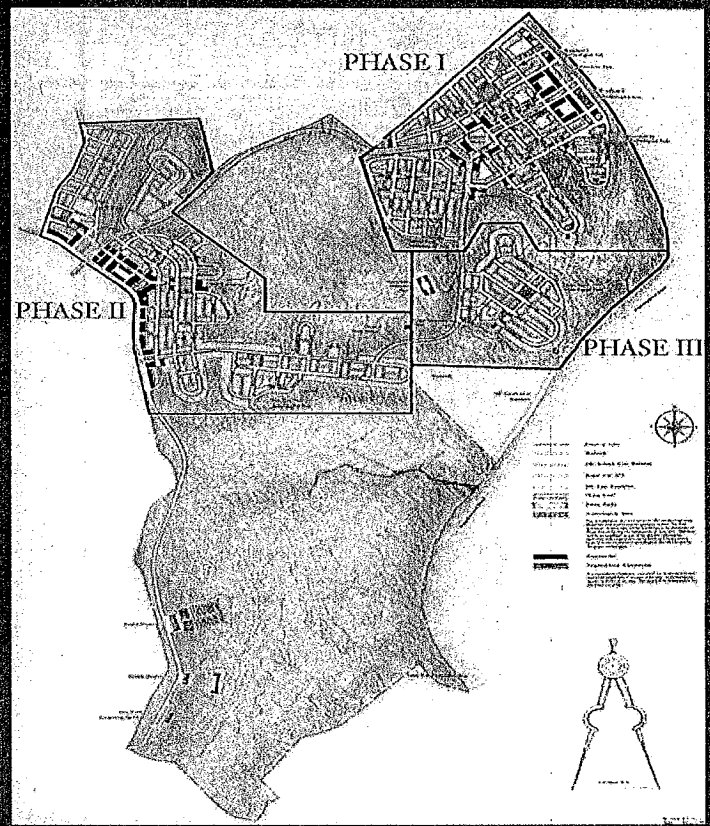
- Street Tree Irrigation
- Stream Augmentation
- Wetland Enhancement
- Commercial Building Heating/Cooling
- Car Wash



A666998

The Reason and the Vision for Sustainability at Haymount

- Design with humility & acknowledge the complexity of nature
- Accept environmental responsibility
- Nurture the connection between nature and the human spirit
- Design with sustainability to allow for environmental technology and advancements



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John Clark & Shelly May
(804) 742-5142
smay@jaclarkco.com

Williamsburg Environmental Group
Doug Beisch, P.E. & Scott Blossom
(757) 220-6869
dbeisch@wegnet.com

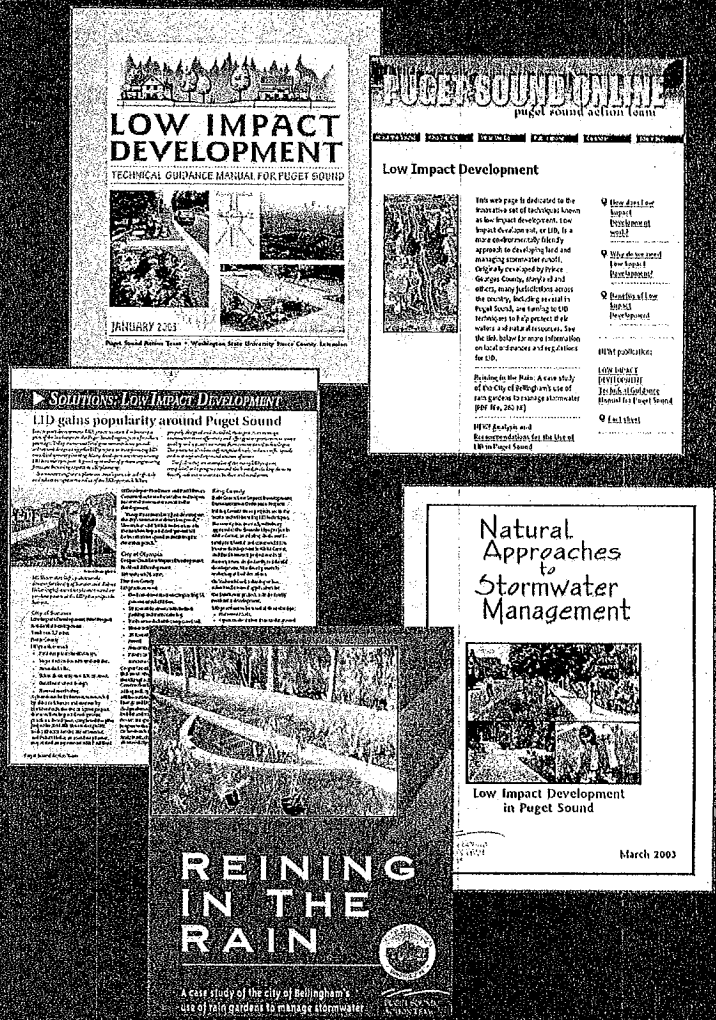
666904

Questions ???



Puget Sound Action Team Efforts to Promote LID

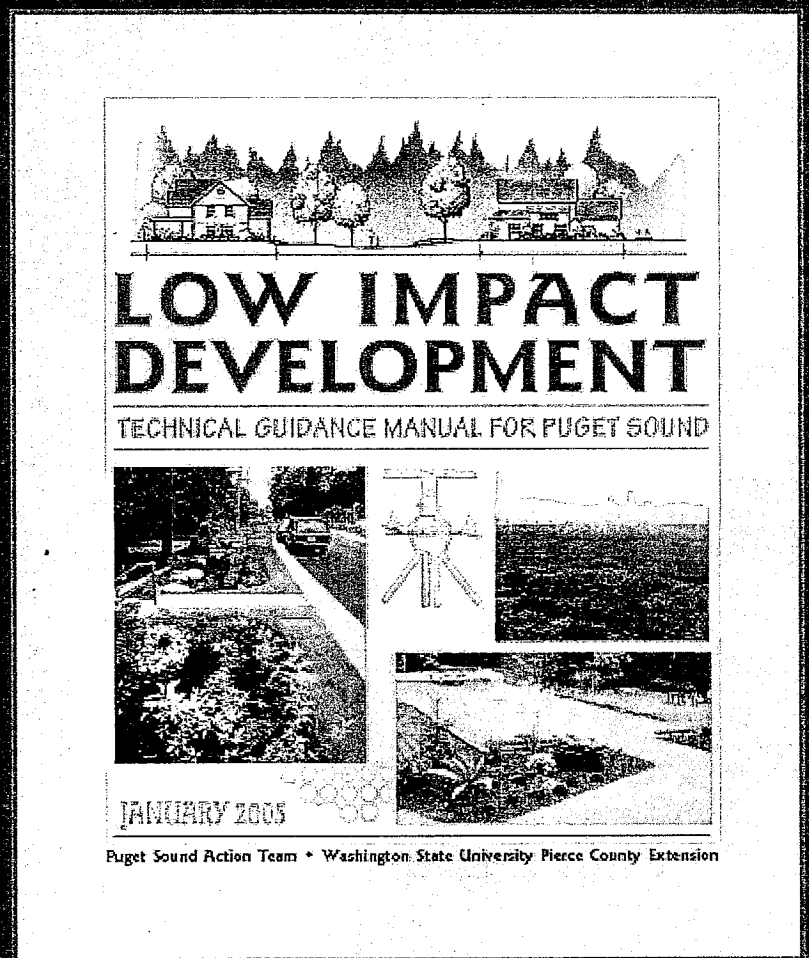
- Library of educational, technical publications & web site.
- All on the web at: http://www.psat.wa.gov/Programs/LID.htm
- Convened conference, workshops, provides ongoing assistance



A69761

Action Team/WSU LID Technical Manual

- Region's 1st LID manual
- Partnership – Action Team, WSU, Ecology, regional experts
- Guidance only
- Complements state stormwater manual
- Objectives, process, specifications, research



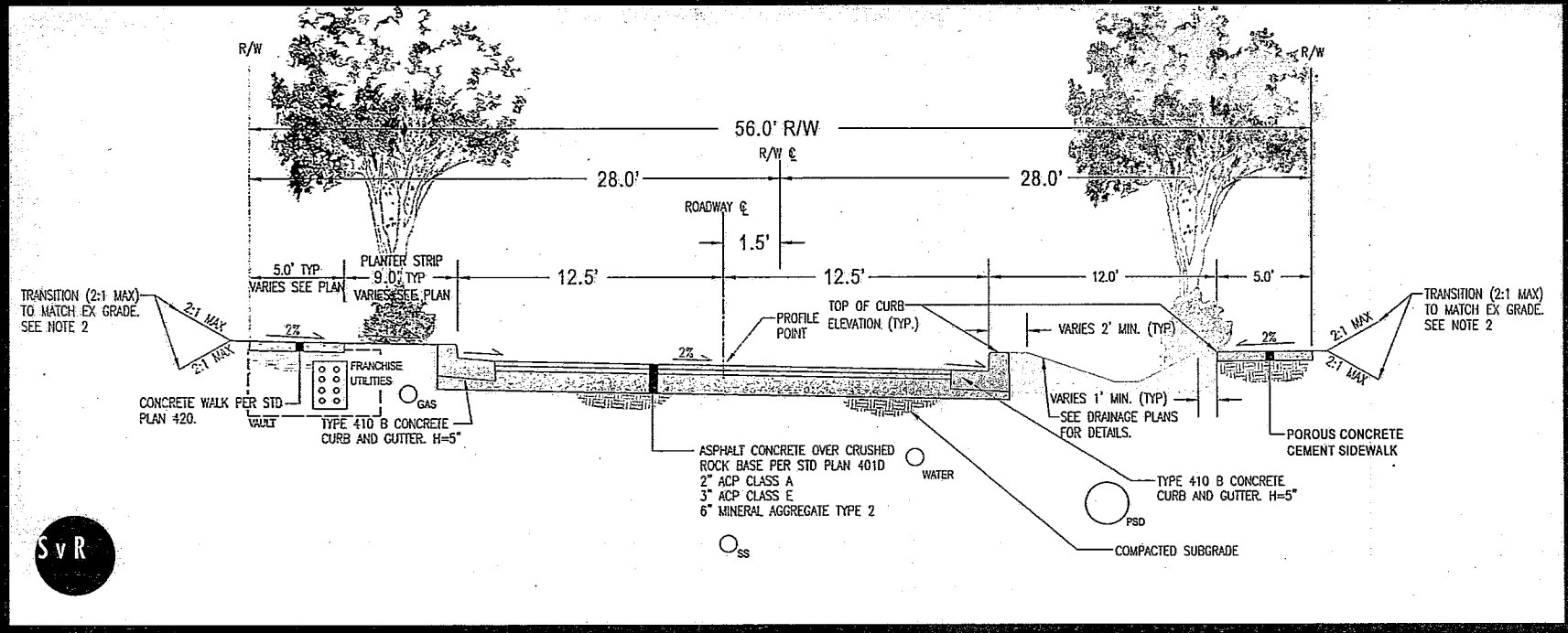
AR017992

Action Team Local Regulation Assistance

- Helping 5 cities and 6 counties revise regulations to allow for, encourage or require LID
- Draft products due 12/05
- Action Team will help local staff present to electeds
- State & federally funded
- Another round of assistance in '06

A007003

Developing Cross Section & Swale Length



- The cross sections for the NDS swales were developed through discussions with various City of Seattle departments (decisions by inches)
- Street widths: 25 feet/56 right of way; 28 feet/56 ft rw; 32 feet/60 ft rw
- Curb height, swale width, street tree locations, berm locations, side slopes, bottom width, etc. were established
- Porous sidewalks on the swale side

4007004

32nd Avenue - Porous Pavement Street





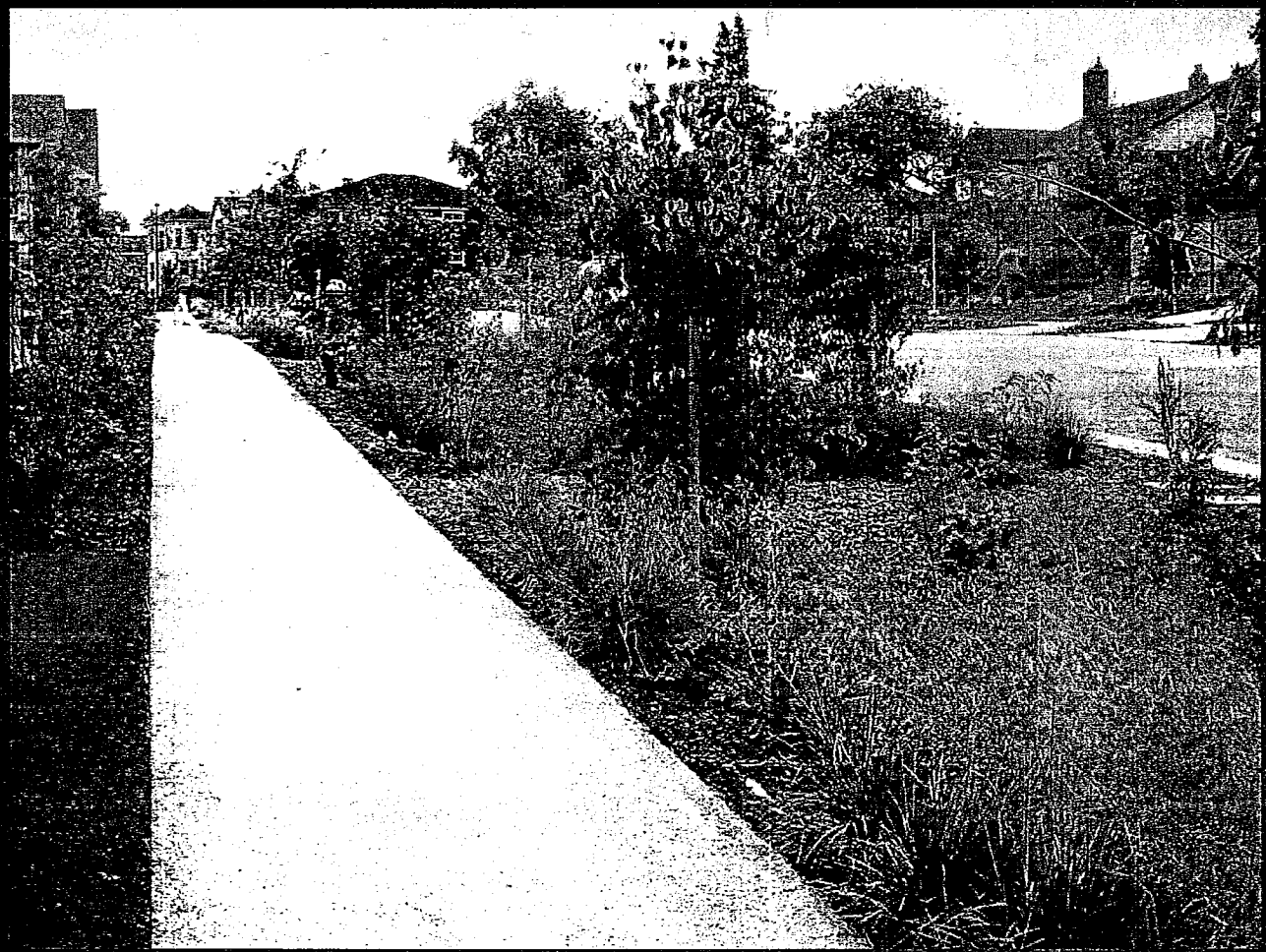


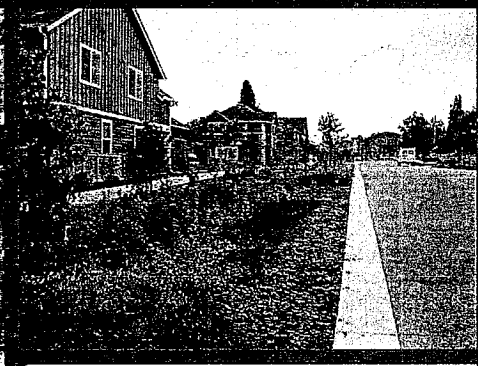


Courtesy SVR

A007965

32nd Avenue - Porous Pavement Street & Sidewalks



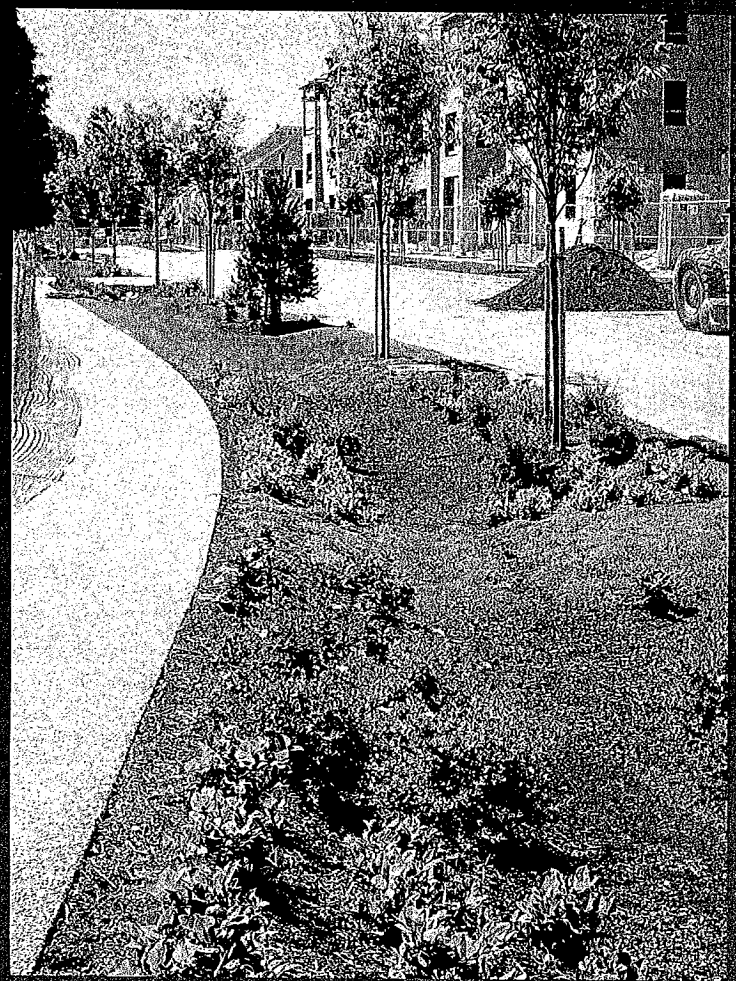


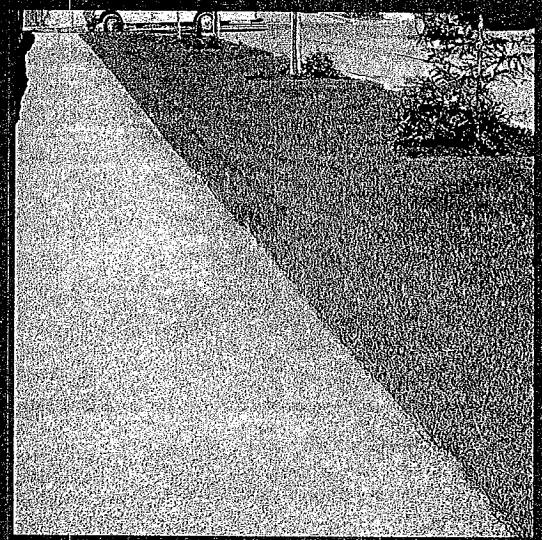


Courtesy SVR

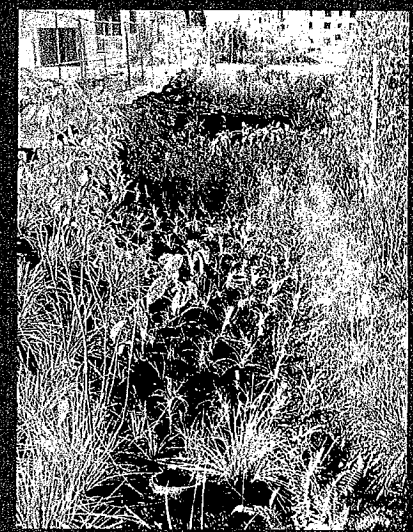
A007005

Porous Pavement Sidewalks and Swales







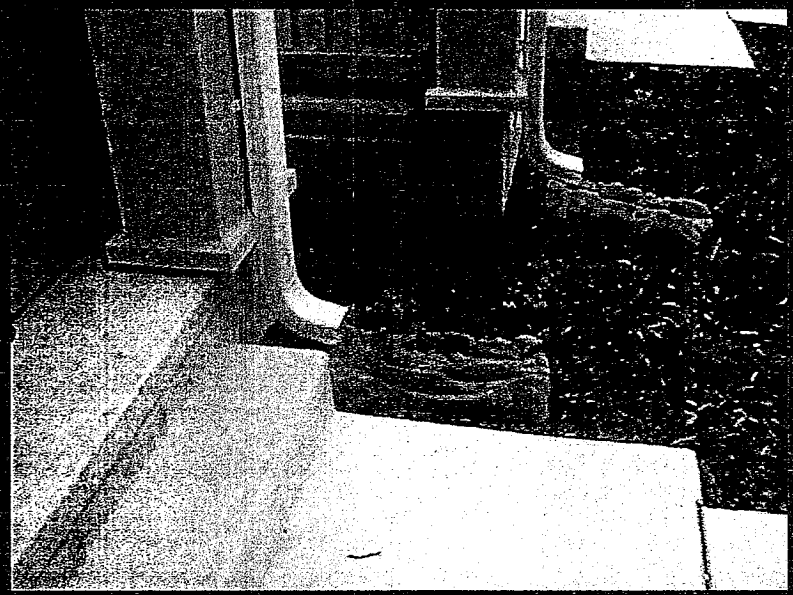


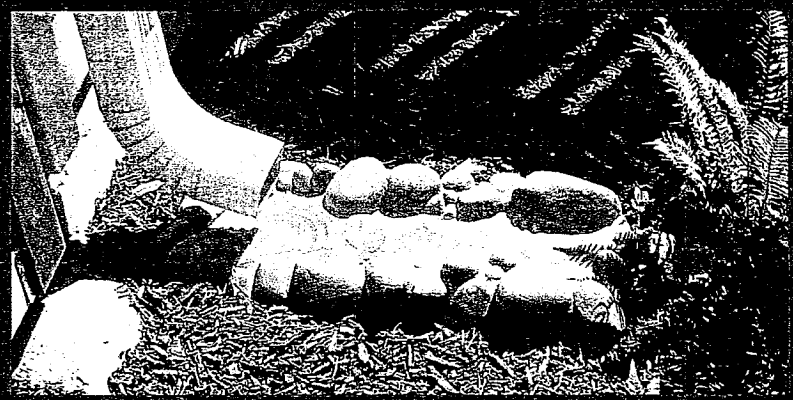
Courtesy SVR

ADOT007

Splash Blocks by Myersculpture







ADOBE



Fat Street

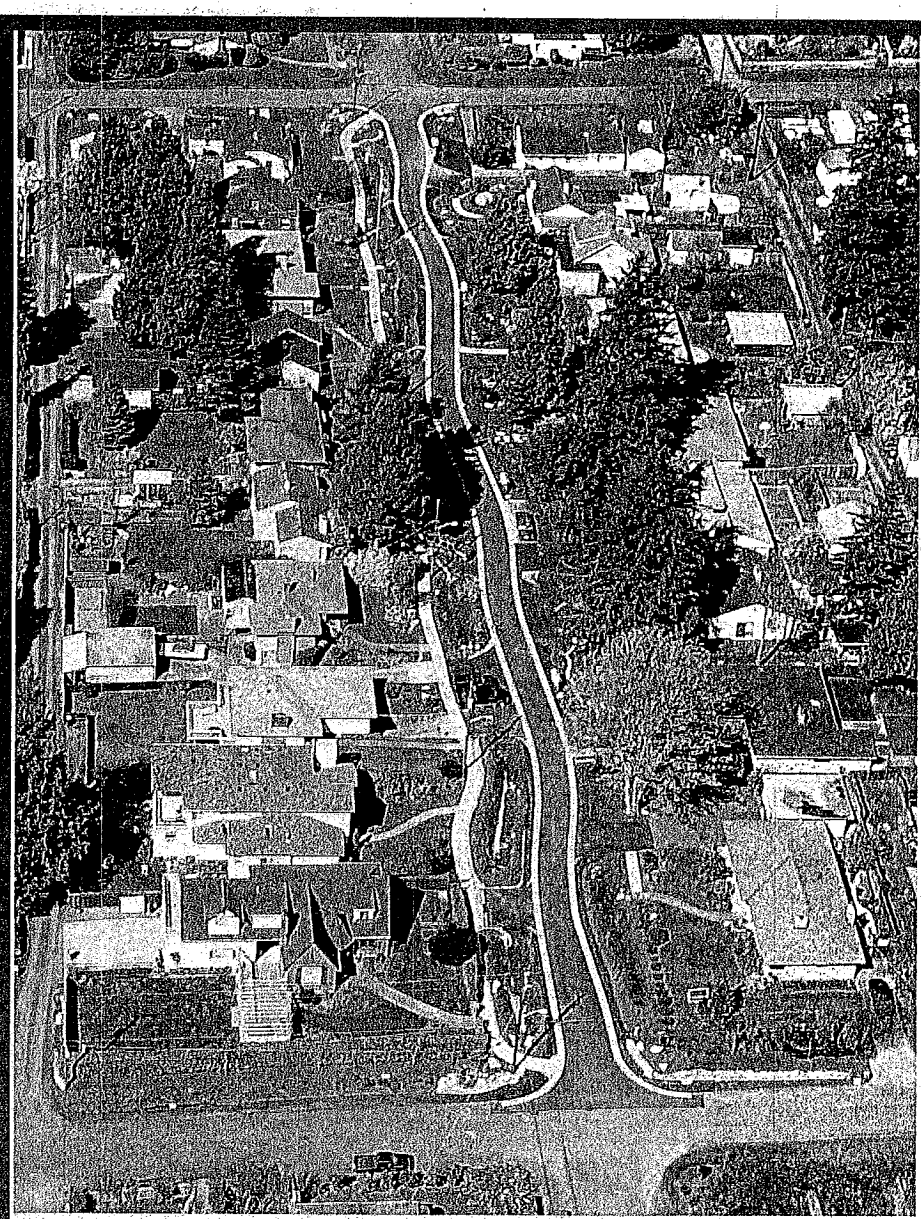
A007009

Skinny Street with Horizontally Challenged Person

90

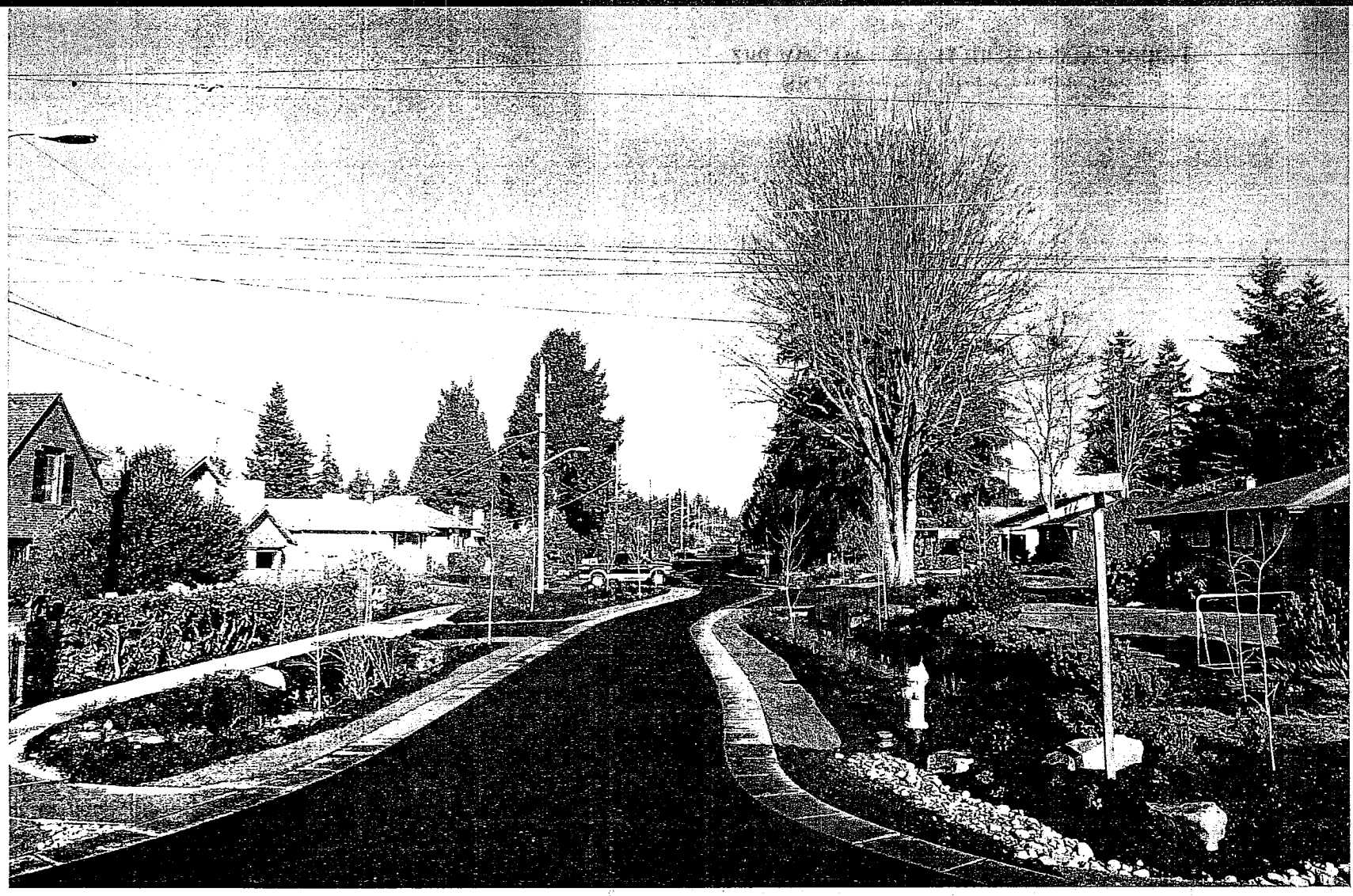
Reduced Impervious Area

- 11% less impervious area than standard street improvement
- 98% Reduction in Volume



SEA Streets - After Construction
2nd Ave NW - NW 117th St to NW 120th St

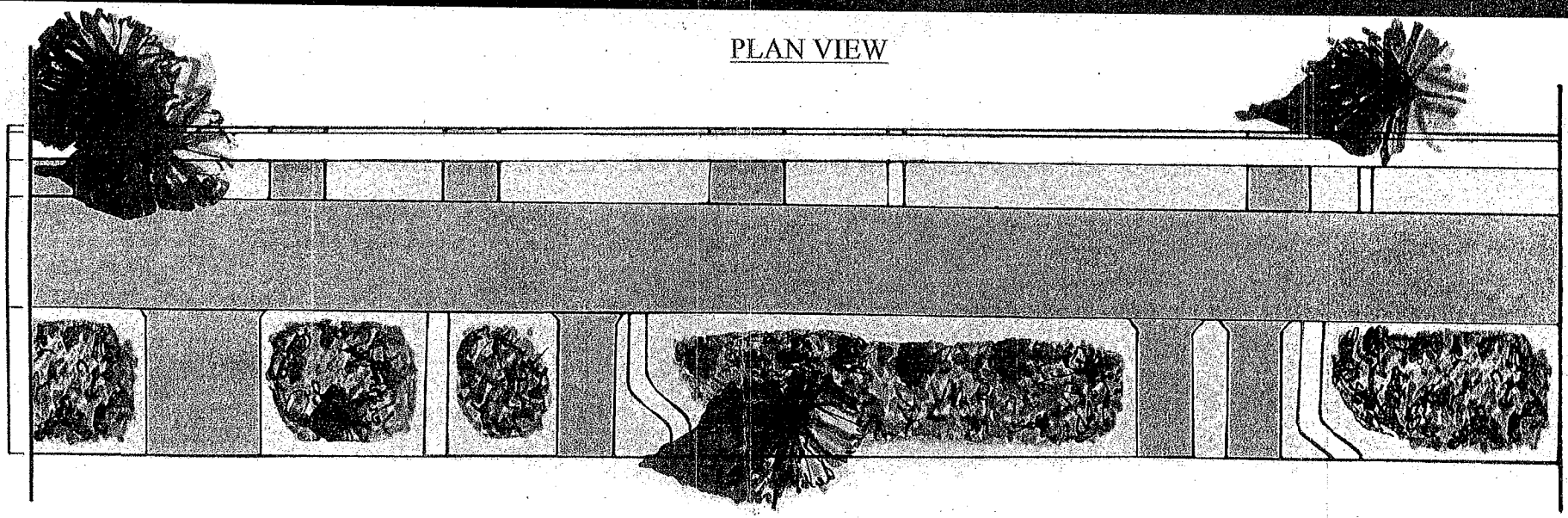
Appendix

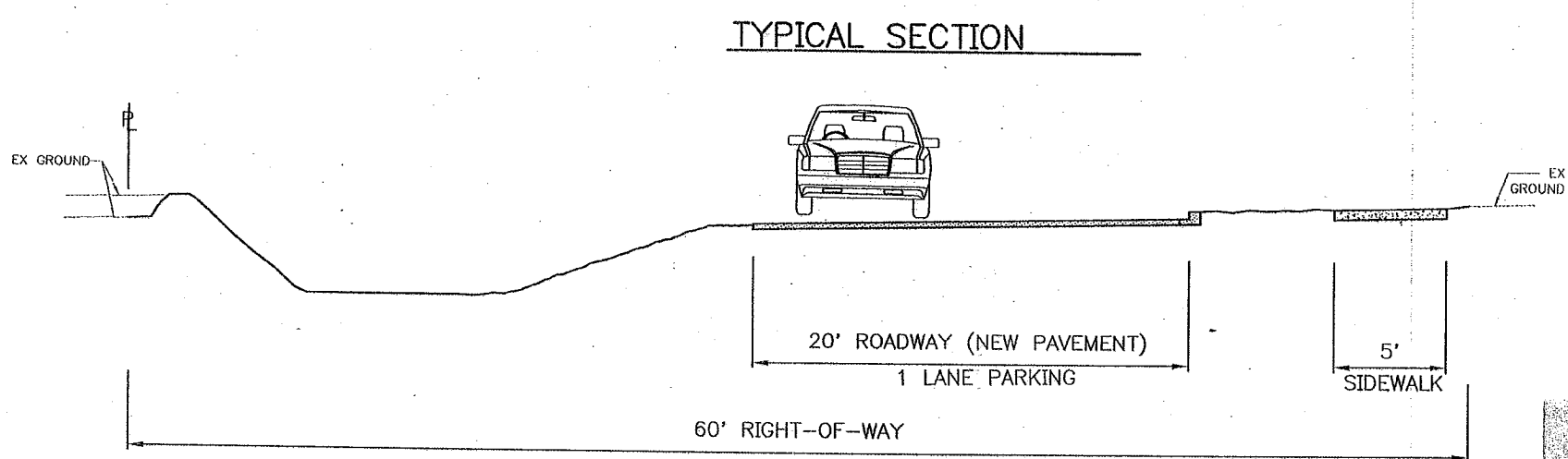


After Completion - January 2001

4007012

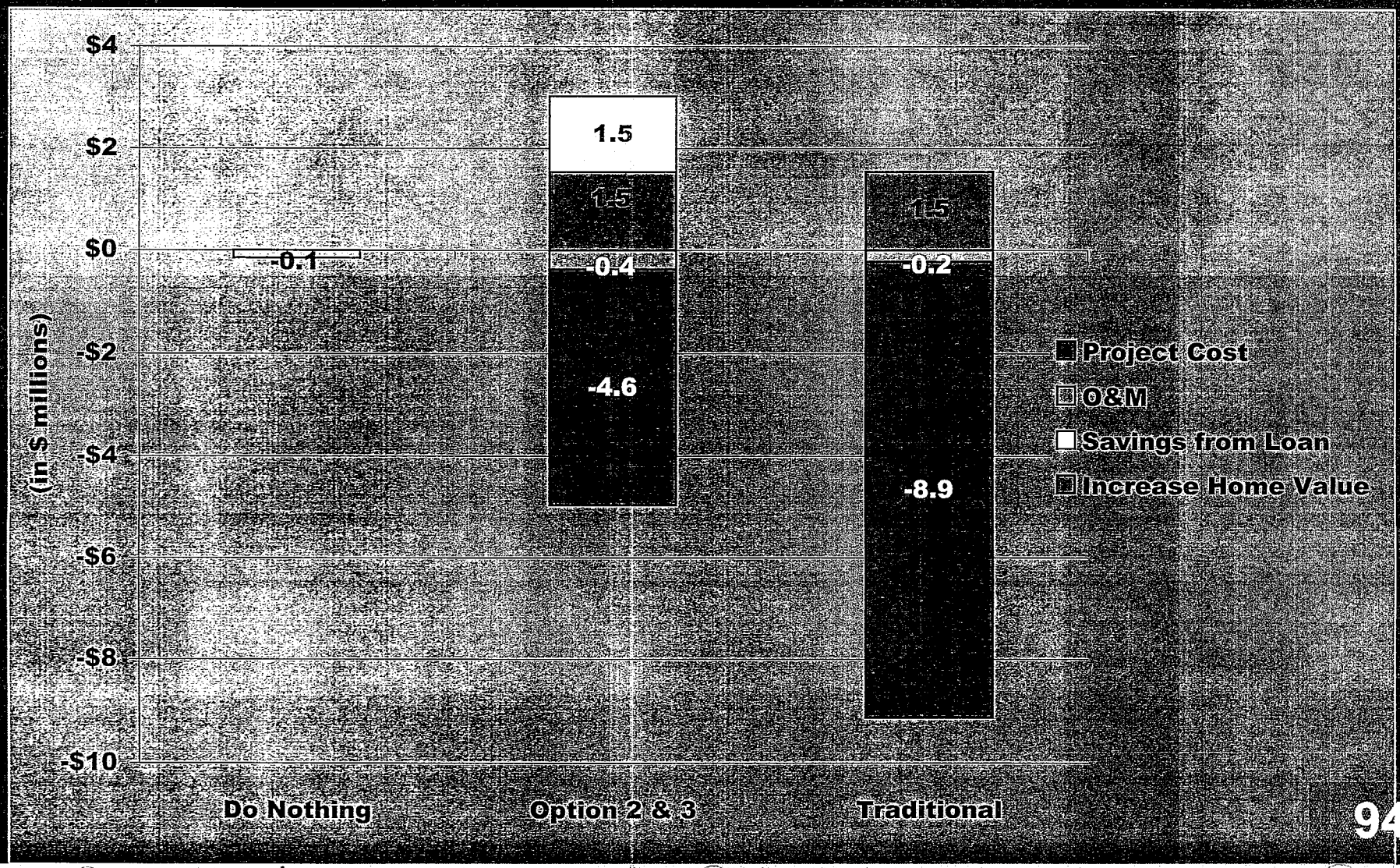
Offset Template





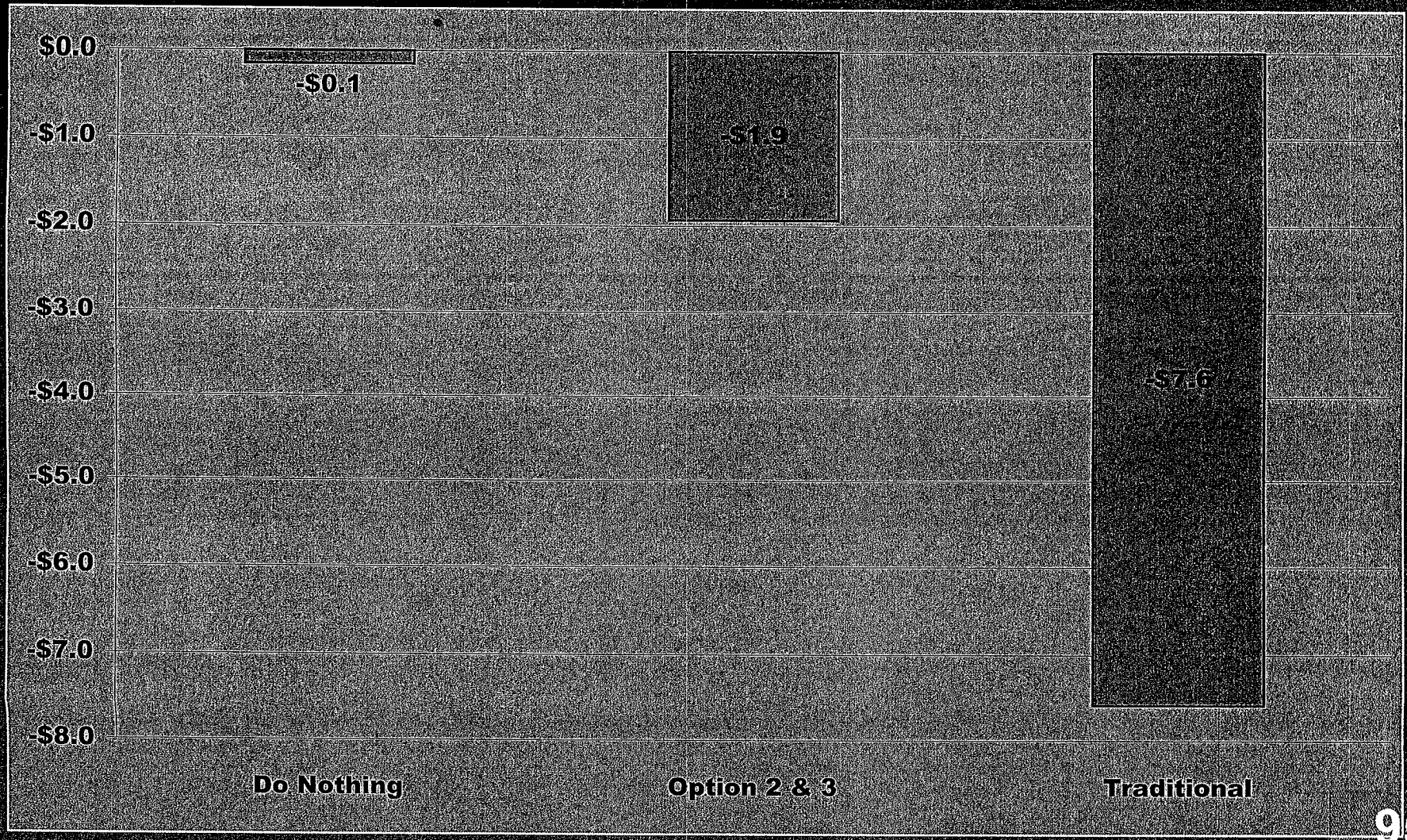
A007013

Quantifiable Costs and Benefits



4007014

Net Present Value
(in millions)

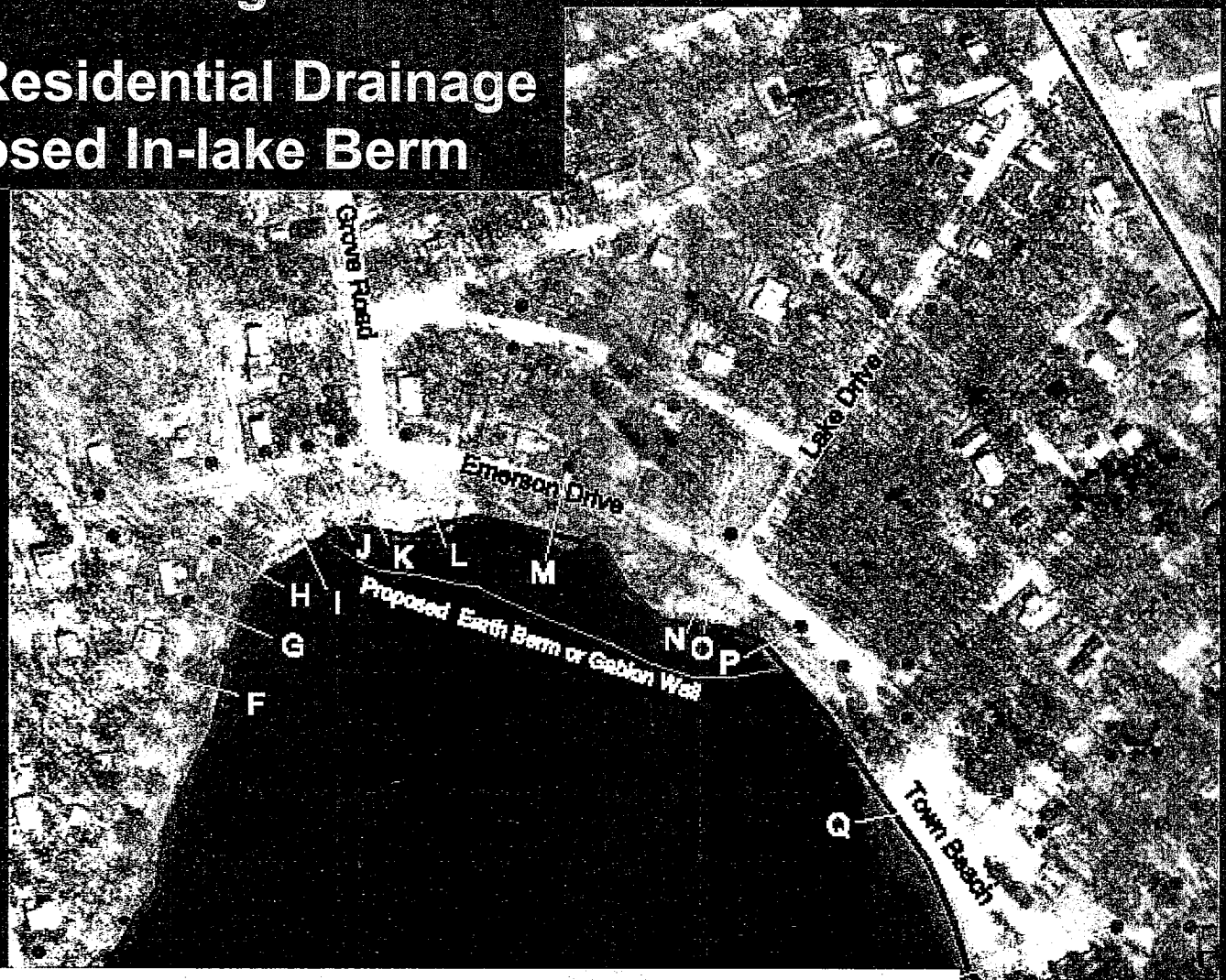


4997015

18 Stormwater Discharges

175 Acres of Residential Drainage

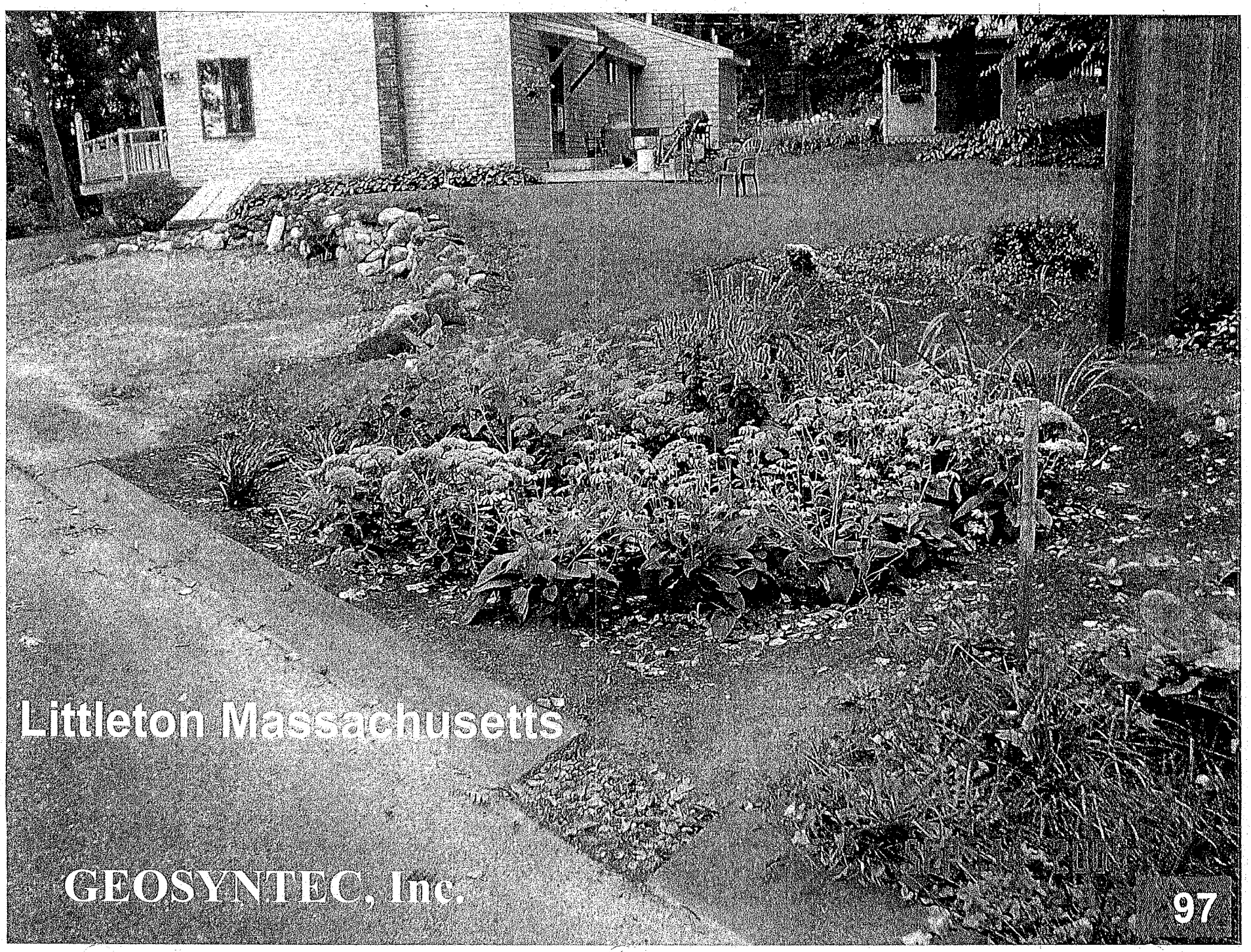
Original Proposed In-lake Berm



Long Lake LID Retrofit

Courtesy Geosyntec

4007016



4007017

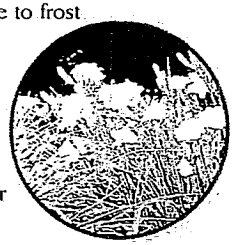
86



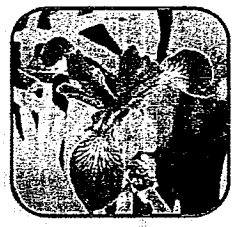
Burnsville Minnesota Courtesy
JRiggs Dakota SWCD

A007019

10 Happy Returns Daylily
(Hemerocallis 'Happy Returns')
Height: 18 inches
Space: 12 inches
Blooms : June to frost



1 Blue Flag Iris
(Iris versicolor)
Height: 2 feet
Space: 1 foot
Blooms: May - June



2 Johnson's Blue Geranium
(Geranium X 'Johnson's Blue')
Height: 15-18 inches
Space: 12 inches
Blooms: May to frost



3 White Coneflower
(Echinacea purpurea alba)
Height: 2-3 ft
Space: 18 inches
Blooms: June to frost

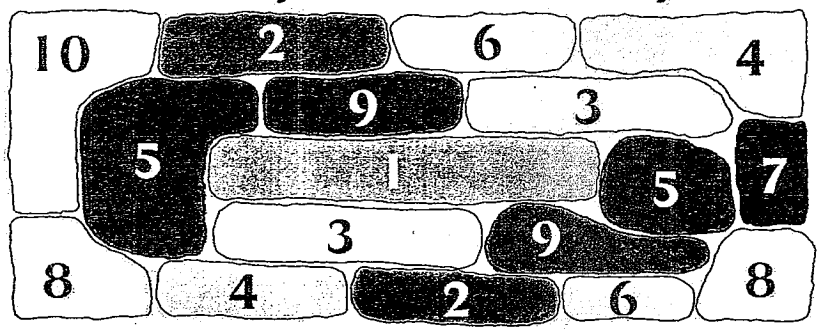


Bonestroo
Rosene
Anderlik &
Associates
Engineers & Architects
Garden & Brochure Design

9 New England Aster
(Aster Novae-Angliae)
Height: 4-5 Feet
Space: 2 Feet
Blooms: Midsummer to frost



The Sunny Border Garden Layout

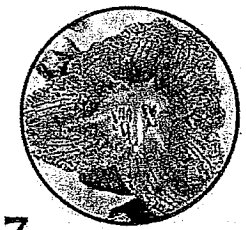




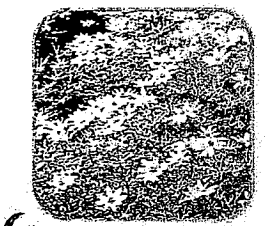
4 Purple Leaf Sedum
(Sedum x 'Vera Jameson')
Height: 12 inches
Space: 12 inches
Blooms: June to frost



8 Lambs Ears
(Stachys lanata)
Height: 12 inches
Space: 12 inches
Blooms: May to June with interesting foliage all Summer



7 Little Grapette Daylily
(Hemerocallis 'Little Grapette')
Height: 18 inches
Space: 12 inches
Blooms: June to frost



6 Moonbeam Coreopsis
(Coreopsis verticillata 'Moonbeam')
Height: 12 inches
Space: 12 inches
Blooms: All Summer



MAPLEWOOD
Together We Can

5 Great Blue Lobelia
(Lobelia Siphilitica)
Height: 2 feet
Space: 1 foot
Blooms: August - September

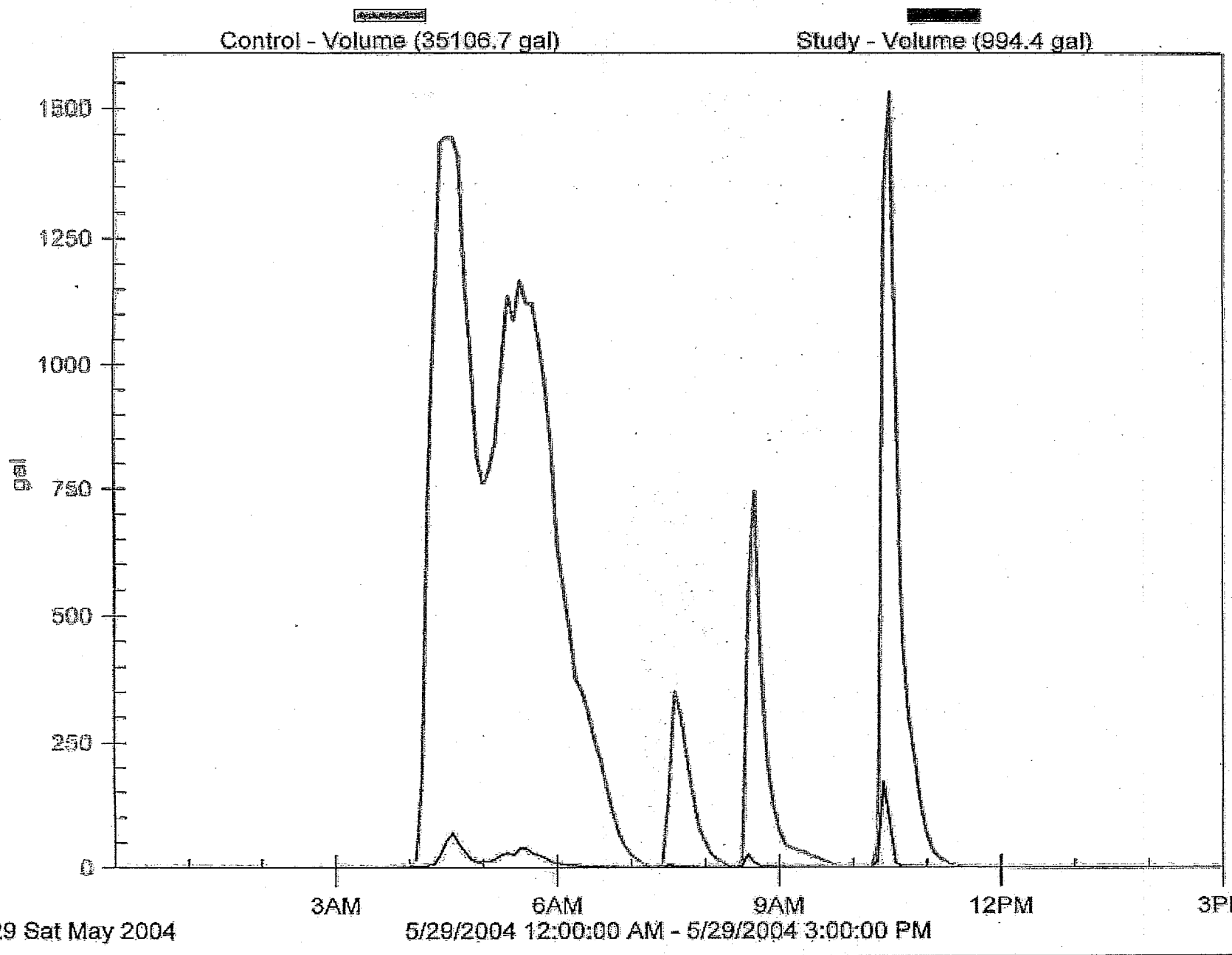
4007029

Courtesy Maplewood MN

107

Post-Construction Runoff Volumes

May 29, 2004 - 0.71" Rainfall



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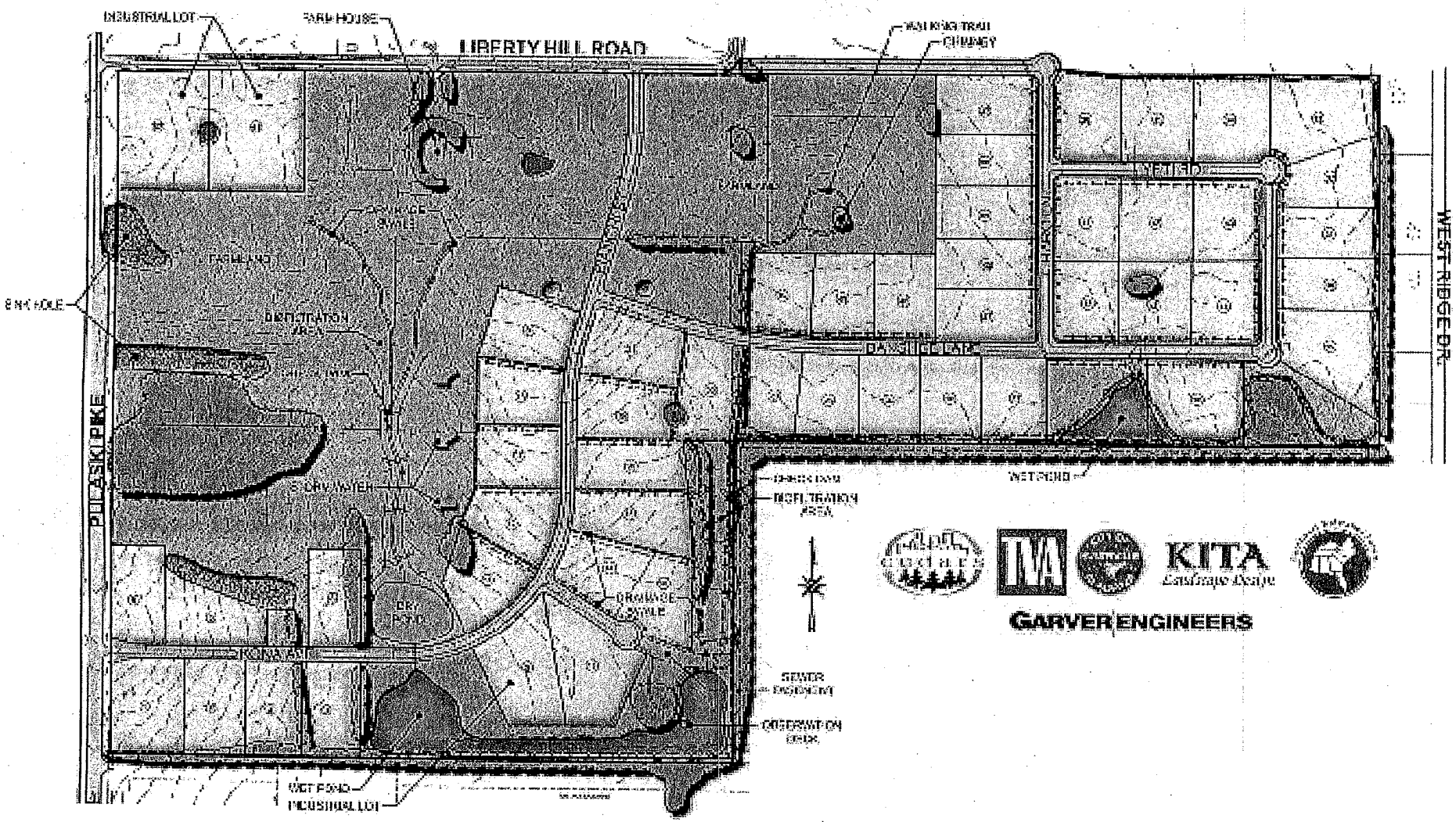


NORTH HUNTSVILLE CONSERVATION DESIGN INDUSTRIAL PARK

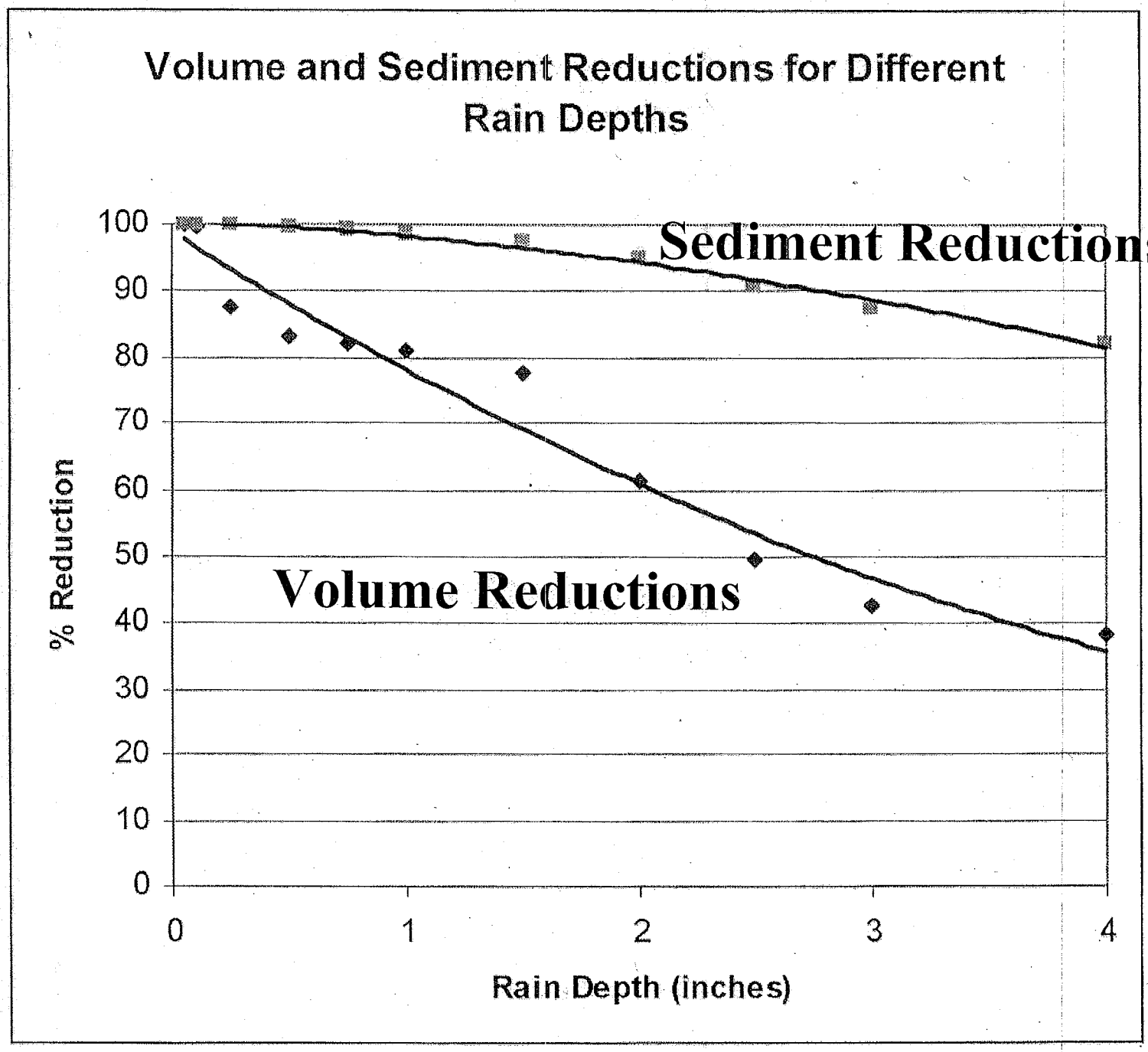
Courtesy Pitt 2005

ADD7022

Conservation Design Elements for North Huntsville, AL, Industrial Park

- Grass filtering and swale drainages
- Modified soils to protect groundwater
- Wet detention ponds
- Bioretention and site infiltration devices
- Critical source area controls at loading docks, etc.
- Pollution prevention through material selection (no exposed galvanized metal, for example) and no exposure of materials and products.

AR07021

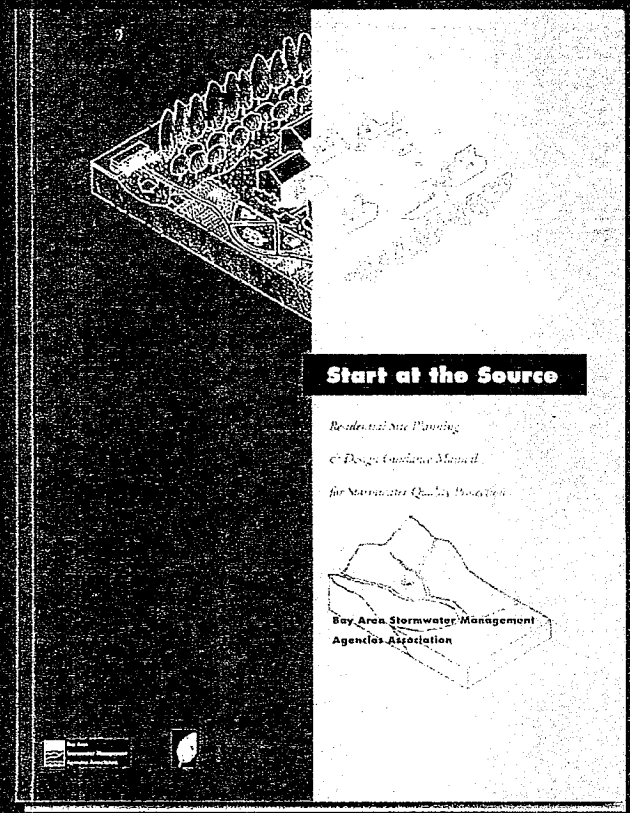

Volume and Sediment Reductions for Different Rain Depths
Sediment Reductions
Volume Reductions
% Reduction
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
Rain Depth (inches)

A007025

"Start at the Source" (BASMAA, 1999)

Site Planning and Design Guidance for the San Francisco Bay Area

- Provides guidance for residential, commercial, and industrial project design for water quality protection
- Communicates basic stormwater management concepts and illustrates simple, practical techniques to preserve the natural hydrologic cycle
- Includes detailed technical information on design concept applications and criteria, maintenance, and costs



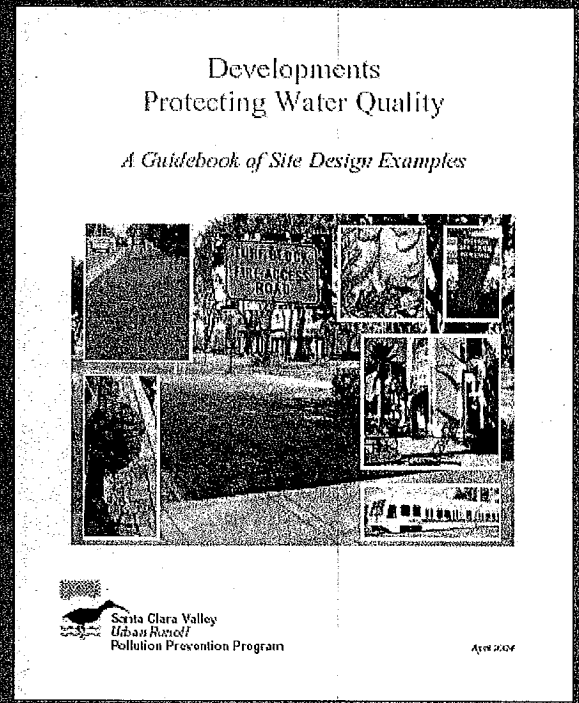
Obtain from:
www.basmaa.org

ABG7026

Santa Clara Valley Urban Runoff Program

Site Design Resources

- *Developments Protecting Water Quality - Site Design Examples Guidebook* (April 2004)
- BASMAA "Start at the Source" (1999)
- BASMAA "Using Site Design Techniques to Meet Development Standards" (2003)
- Site Design Dialogues Results



www.scvurppp.org

4007027



Low Impact Development (LID)

A sensible approach to land development and stormwater management

As educational program for land use decision makers that addresses the relationship between land use and natural resource protection.

What is Low Impact Development (LID)?

Low impact development is an ecological alternative to land development and stormwater management aimed at minimizing the impact of urbanization on natural habitats and hydrology. LID emphasizes designing with nature in mind, working with the natural landscape and hydrology to avoid unnecessary water pollution, environmental degradation, and flooding. LID accomplishes this through source control, collecting more water on the site where it falls, rather than conveying it directly into local water ways. The LID toolkit includes green roofs, porous pavements, grass swales, and bioretention cells. These techniques reduce the need for costly stormwater management practices, such as lengthy drainage systems, retention ponds, and flood control projects. In the past few years, LID has been applied to government, residential, and commercial development, and, in many cases, has proven to be a cost-efficient and effective method for managing runoff and protecting the environment.

Glossary

Green roofs: rooftops planted with vegetation that absorb rainwater and heat, reducing runoff and energy costs.

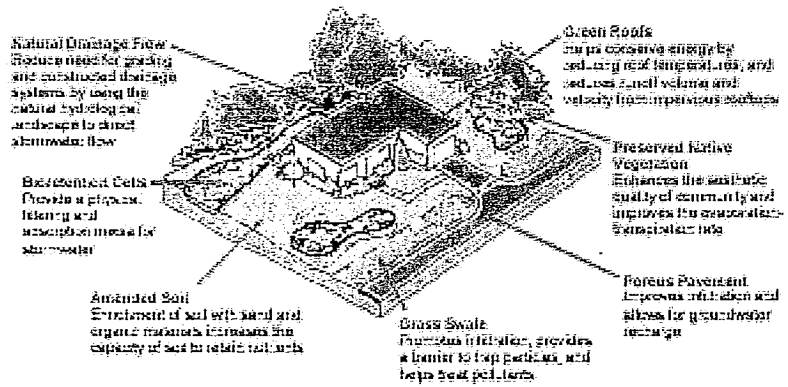
Porous pavement: type of asphalt or concrete that allows rain and snow to infiltrate, reducing runoff and processing storm pollutants (generally used for parking lots).

Grassy swale: vegetated channel that treats and slows storm runoff, reducing erosion and floods.

Bioretention cell (rain garden): depression that contains a variety of absorbent materials that retain and filter runoff.

GOAL of LID: Implement practical technology that mimics the pre-development balance of water runoff, infiltration, groundwater recharge, and evapotranspiration in order to manage stormwater, protect drinking water and the environment, and minimize flooding.

INCORPORATING LID INTO RESIDENTIAL DEVELOPMENT



Source: Adapted from Prince George's County Maryland Low-Impact Development Design Strategies

California State Water Control Board Partnerships

A557529

Moving Environmental Regulations (Restrictions) to an Economic and Asset and Adaptable Management Approach

- Regulations should even the playing field for economic/environmental development instead of being a minimum standard!
- Do those minimum standards really protect the watershed?
- Sustainability/ LEED may not be a good example, Economics are!
- What are the true costs/value to the community for stormwater?

A007029

Challenges and Unknowns

- Level of Performance
- Operations or Maintenance (who pays)
- Inspection
- Long Term Fate and Transport
- Policy and Code Development

4667969

Finally!!

The Watershed Approach

- End-or-Pipe (ended)
- Wetlands Restoration
- Stream Restoration (not stabilization)
- Uplands (LID)

A0077031

Thank You

After viewing the links to additional resources, please complete our online feedback form.



AG07632

Spring 2003

ANACOSTIA RIVER BUSINESS COALITION UPDATE

C/O ICPRB
6110 Executive Boulevard, Suite 300
Rockville, MD 20852

Rain Gardens: Beautifying your Business and Helping the Anacostia

Interested in simple, inexpensive ways to reduce your business' impact on the environment? Would you like to receive credit and publicity for your pollution prevention activities? Read on! If you like what you read, contact Steve Saari at (301) 984-1908x103 or ssaari@icprb.org for more information, or to set up a free and confidential evaluation of your business' property.

Rain . . . it's nature's way of nourishing our world and replenishing our water sources. However, many of our daily activities, from changing a car's oil to fertilizing lawns, can turn this precious resource into an environmental problem. The flow of water created by a rainstorm - storm water runoff - can be polluted by oil, chemicals, pesticides, and sediments built up on our lawns, driveways, streets, and parking lots. Rain washes these pollutants into storm drains and ultimately into local streams and rivers.

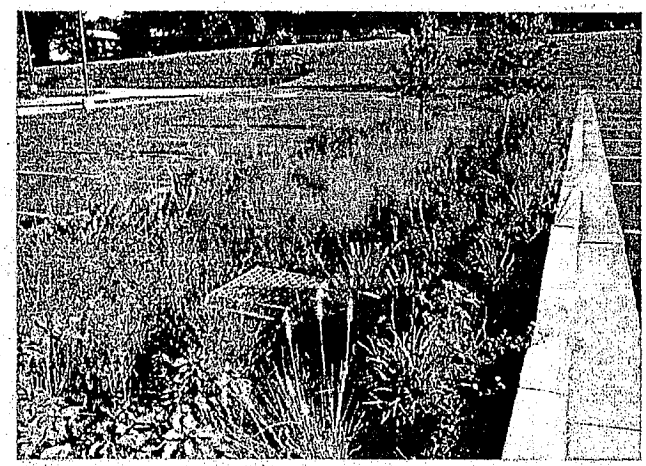
Why is Storm Water a Problem?

The Environmental Protection Agency (EPA) has determined that up to 70% of the pollution in our surface waters comes from storm water. We tend to think that most of this is caused by large industrial facilities, but this is not the case. Many studies have found that more than 50% of that pollution comes from small businesses, individuals and homeowners, due to lawn care, household chemicals and automobile usage.

What is a Rain Garden?

A rain garden is an attractive native plant garden with a special purpose: to reduce and filter the storm water entering our streams.
It is constructed as a place to direct storm water from roofs, driveways and parking lots, allowing water to be held in the plants, mulch and soil.

Rain Gardens aren't just for houses! In fact, the use of rain gardens for storm water management originated at commercial and industrial sites where space is limited, and the installation and maintenance of conventional environmental practices, such as oil and water separators and stormwater ponds, is expensive.



A Rain Garden Collecting Runoff from a Parking Lot in Prince George's County

Why a Rain Garden?

Rain Gardens use the concept of bioretention: a water quality practice in which plants and soils remove pollutants from storm water naturally.

Rain Gardens are created in a low-lying area, with specific layers of soil, sand, and organic mulch. These layers naturally filter the rain as it runs into the Rain Garden. During the next few days after a storm, the soil absorbs and stores the rainwater and nourishes the Garden's grasses, trees, and flowers.

The traditional system of curbs, gutters, and storm drains carries storm water runoff directly to local streams and rivers without any bioretention filtering process. Instead, Rain Gardens filter and reuse the water, reducing storm water pollution, while providing attractive landscaping.

In addition to their water quality benefits, Rain Gardens:

- ✓ Promote your business' environmental stewardship and community pride
- ✓ Provide habitat for wildlife and native plants
- ✓ Moderate air temperatures through evaporation
- ✓ Increase real estate values by creating an aesthetically pleasing landscape

Upcoming Events

Earth Day Tree Plantings at DC Schools - Volunteers are needed to help school children plant trees. Plantings will occur at various sites in the District between April 22nd and April 25th. For more information, contact Habieba Isreal at 202-535-2964.

Earth Day Anacostia River Cleanup - Volunteers are needed to help clean up sites in D.C. and P.G. County. The cleanup will take place the morning of April 26th. For more information, contact James Willie at 202-479-6710.

Frequently Asked Questions:

Q: - Don't rain gardens attract a lot of mosquitoes?

A: - No. For reproduction, mosquitoes require a number of days in standing water. Water rarely stands long enough for mosquito reproduction in a well-designed rain garden.

Q: - Can I create a rain garden that doesn't look too wild or messy?

A: - Yes! A wide variety of plants can be used in creating a rain garden so you can create one that suites your tastes.

Q: - What happens to water-tolerant plants when we have a dry spell?

A: - Native plants can withstand a range of weather conditions. Native plants that do well in poorly drained soil will be fine during dry weather.

Q: - How large must a rain garden be to be worthwhile?

A: - Any water that seeps into the ground instead of running into a storm sewer helps water quality. A rain garden of any size has a positive impact, however, to completely absorb rain water from a site the system should be sized between 5% and 10% of the impervious area draining to it.

Q: - How difficult are rain gardens to maintain?
A: - Rain gardens are like any other garden. They require more care initially to establish the plants, but then only monthly inspections are needed to repair eroding areas, prune and repair vegetation and remove trash and debris.

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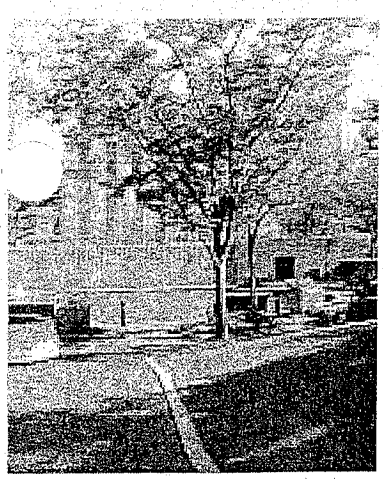
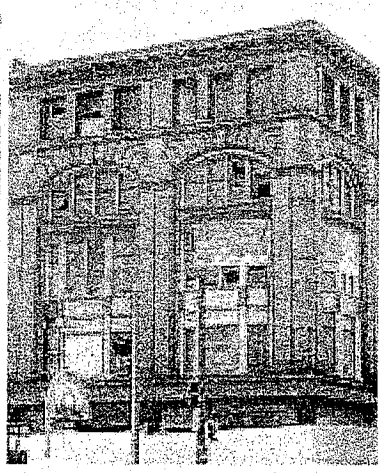
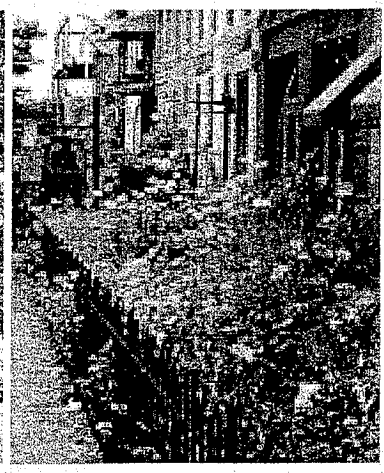
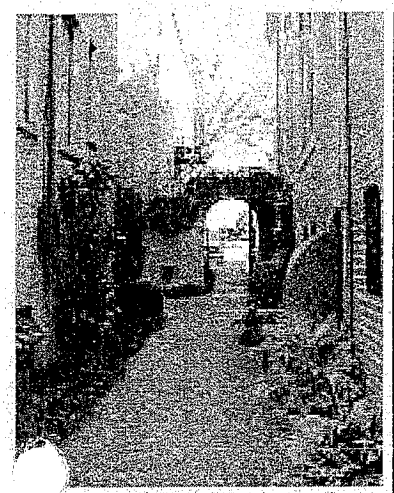



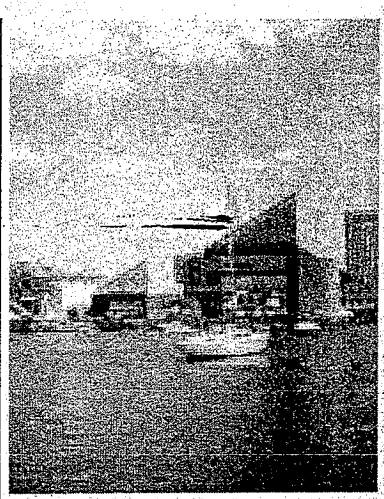
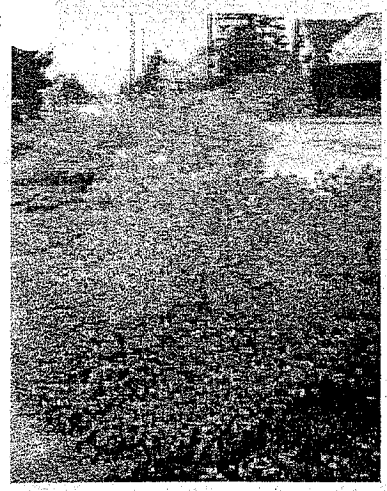
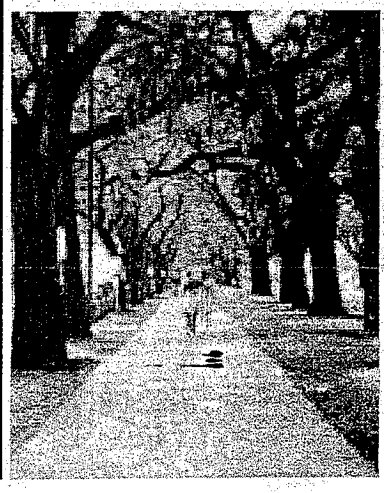
Redevelopment Roundtable

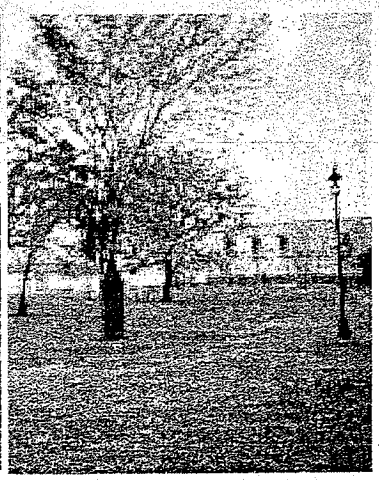
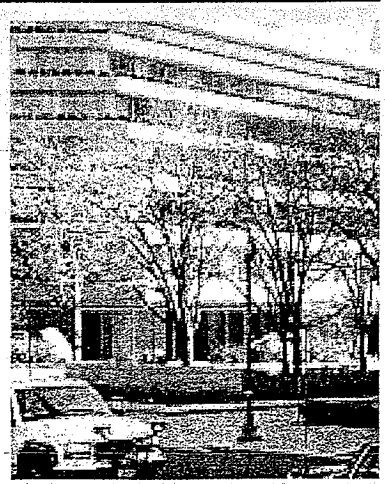
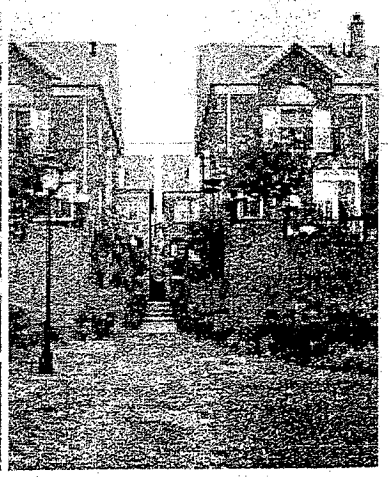
Consensus Agreement

Smart Site Practices for Redevelopment and Infill Projects

October 2001

Center for Watershed Protection

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About the Center for Watershed Protection

Founded in 1992, the Center for Watershed Protection (CWP) is a non-membership, nonprofit 501(c)3 corporation dedicated to providing objective and scientifically sound information on effective tools and techniques for watershed planning, protection and restoration. CWP implements this mission in several ways, including providing technical assistance to federal and local governments as well as non-profits and other organizations.

For more information on the CWP and our current projects, visit our websites at www.cwp.org and www.stormwatercenter.net.

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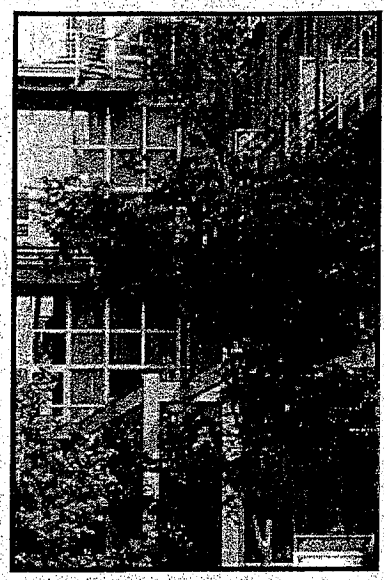
A007836

Introduction

While the U.S. is expected to grow by an additional ten million households over the next ten years, the proportion of people living in many of our city centers is actually declining. In fact, homeowner and rental vacancy rates are 20% higher in many city centers compared to their suburban counterparts (U.S. Census Bureau, 1999). This population shift leaves urban watershed managers with the challenge of protecting some areas from further development while at the same time restoring watersheds that are already severely impacted. Increasingly, urban redevelopment and infill projects are emerging as a means to help rejuvenate sagging city centers while simultaneously providing opportunities for more environmentally-friendly growth.



Canton Cove: *Baltimore, MD*
* Adaptive reuse project
* First water quality project on the Harbor
* Existing structure salvaged
* Original building footprint retained
* Garden courtyard used for stormwater management

Photo courtesy: Cho, Benn & Holback Architects

However, making redevelopment and infill projects a successful reality requires multiple stakeholders at various levels to evaluate the types of programs and practices necessary to help achieve various economic, environmental and social goals. From a development standpoint, the challenges of any particular project might require charting unknown territories, which can result in higher development costs. From an environmental perspective, the location of infill and redevelopment projects can further impact existing water resources. In addition, current building, zoning and other regulations need to be investigated, adapted, and integrated with issues of stormwater, water quality, air quality and habitat, along with the regulatory issues and politics of stormwater management and brownfields.



Municipal Parking Lot: *Prince George's County, MD*
* Previously untreated parking lot
* Redesigned to locate a bioretention facility

Recognizing that many interests need to be coordinated to promote Smart Growth, the Center for Watershed Protection convened the Redevelopment Roundtable, a group of national and local stakeholders who participated in a process to develop Smart Site Practices specifically for redevelopment and infill sites. This year-long process produced 11 practices to help reduce pollutants and improve the environmental quality of development sites in highly urban watersheds. Applied together, these practices have benefits for all local stakeholders, including developers, local government, community residents, and others who are interested in designing redevelopment and infill sites to better protect local streams, lakes, wetlands, and estuaries.

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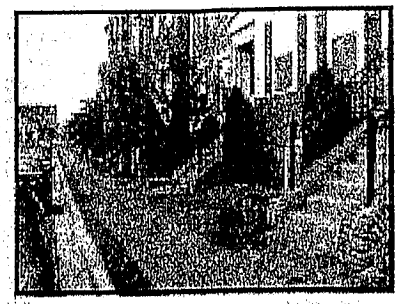
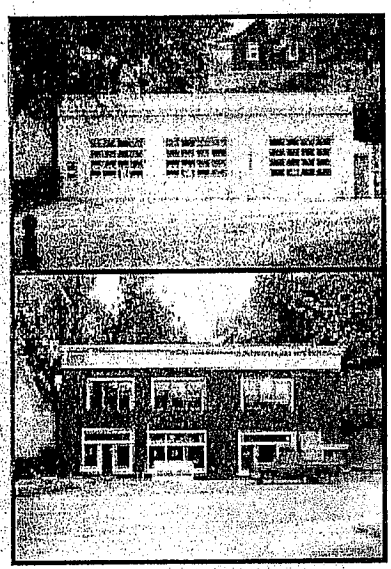


Potomac Yard: *Alexandria, VA*
* Redevelopment project
* Incorporates narrow sidewalks
* Incorporates small front setbacks
* Incorporates native vegetation
* Applies several stormwater management techniques

Photo courtesy: Larry Gavan



CWP Office Building: *Ellicott City, MD*
* Old filling station converted to a two-story office building
* Illustrates the efficient use of impervious cover

What Is the Redevelopment Roundtable?

The Redevelopment Roundtable represents a one-of-a-kind effort to engage a diverse spectrum of national and local stakeholders in a consensus process to address site level redevelopment and infill issues. The Roundtable was created to assure local communities that stakeholders in the redevelopment arena can agree on specific practices and programs that can help protect our existing natural resources and help build better communities. The Redevelopment Roundtable reached consensus on the 11 Smart Site Practices for Redevelopment and Infill.

What Are the 11 Smart Site Practices?

The term "Smart Site Practices" refers to site planning practices that can be used to mitigate watershed impacts in highly urban watersheds. Designed primarily with the developer in mind, the smart site practices represent the best techniques for protecting water quality and habitat in the highly constrained setting of urban infill and redevelopment. These practices are intended to complement municipal actions under the Smart Watersheds plan.

What Type of Redevelopment and Infill Projects Do Smart Site Practices Address?

The Redevelopment Roundtable recognizes that a vast array of redevelopment and infill projects exist. For the purposes of this project, redevelopment is defined as the process by which an existing developed area is adaptively reused, rehabilitated, restored, renovated and/or expanded. Infill, on the other hand, is development that occurs on smaller parcels that remain undeveloped but are within or very close to existing urban areas. In both cases, the development relies on existing infrastructure, and does not require an extension of water, sewer or other public utilities. In addition, the project must be located in a highly developed watershed, encouraged by the public sector, and water quality limited or biologically impaired. Example of redevelopment and infill projects are listed in the table below.

Various Types of Redevelopment and Infill Projects	
* Historic preservation	* Downtown business district
* Waterfront development	* Multifamily
* Brownfields	* Suburban commercial
* Residential infill	* Mixed use development
* Adaptive reuse	* Roadway expansion

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How Can the Smart Site Practices Be Applied?

While the Smart Site Practices were developed primarily as a tool for designers, they can be used by developers, local government officials, planners, and environmentalists alike. For example, developers who are concerned about larger community environmental issues can refer to the Smart Site Practices for guidance on how their projects might be better designed to address watershed impacts. Local governments can utilize the Smart Site Practices to develop better criteria on which to gauge the potential impact of a development site. Lastly, communities can utilize the Smart Site Practices to gain insights on redevelopment and infill from a watershed protection perspective.



Barrister Court: *Baltimore, MD*
* Historic preservation project
* Used alternative pavers
* Parking lot transformed into a garden

Photo courtesy: Cho, Benn & Holback Architects

The Smart Site Practices

Practice #1: Redevelopment and infill planning should include environmental site assessments that protect existing natural resources and identify opportunities for restoration where feasible.

Rationale: Requirements under existing brownfields and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) legislation, as well as bank purchase and loan requirements, help to mitigate the impact of some pollution sites by requiring basic site history investigation and surface soil and water testing and cleanup. A more thorough environmental site assessment, which includes the production of a base map that outlines existing buildings, transportation networks, utilities, floodplains, wetlands, streams, and other natural features, can help address existing environmental constraints and highlight opportunities for restoration and reclamation at a site.

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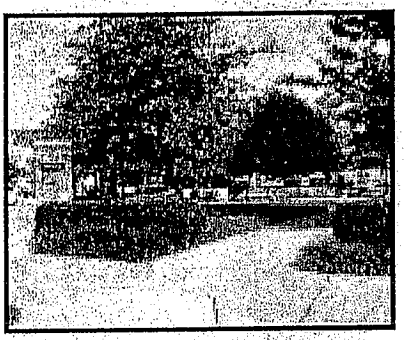
Practice #2: Sites should be designed to utilize impervious cover efficiently and to minimize stormwater runoff. Where possible, the amount of impervious cover should be reduced or kept the same. In situations where impervious cover does increase, sites should be designed to improve the quality of stormwater runoff at the site or in the local watershed.



Canton Square Development:
Baltimore, MD
* Previously undeveloped lot
* Townhouse development infill site
* Walking distance to transportation and amenities
* Centrally located park with natural area

Rationale: The amount of impervious cover is known to have a direct impact on annual runoff volume, and consequently affects annual pollutant loads, flooding frequency, stream channel degradation, and a host of other impacts. Some of these impacts can be mitigated by making efficient use of the existing impervious cover and reducing or keeping it the same when possible. Managing stormwater runoff can also help to reduce these impacts.

Practice #3: Plan and design sites to preserve naturally vegetated areas and to encourage revegetation, soil restoration and the utilization of native or non-invasive plants where feasible.

Rationale: Remaining natural areas have particular value in the urban environment, but are also strongly influenced by adjacent uses. Often found in small fragments, these areas can also suffer from poor quality soils, invasive plant species, dumping and extensive alteration by past development. Collecting and mapping natural features, working toward preserving these areas in a consolidated manner, and evaluating the site for potential stormwater management, revegetation, and passive recreational benefits can provide both environmental, economic and aesthetic benefits.

Practice #4: Establish mechanisms to guarantee long term management and maintenance of all vegetated areas.

Rationale: Guaranteed long-term management, financing and maintenance plans can assure continuous enjoyment and function of vegetated areas over the long run. Innovative partnerships, conservation easements, or donations to land trusts can help land owners ensure that intensively used vegetated areas on urban lands are actively kept up.

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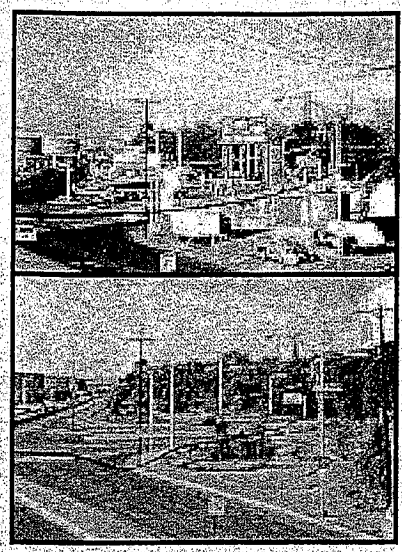
Practice #5: Manage rooftop runoff through storage, reuse, and/or redirection to pervious surfaces for stormwater management and other environmental benefits.

Rationale: Reducing the runoff generated from urban rooftops can reduce pollutant loads, flooding, channel erosion, and many other stream impacts. In addition, many rooftop runoff management practices can help conserve water and improve aesthetics. Examples of rooftop runoff management techniques include green rooftops, rooftop gardens, rain barrels and downspout disconnection. The design, slope and architecture of rooftops can reduce the volume of rooftop runoff as well.



26th Street Gateway: *Philadelphia, PA*
* Transformed post-industrial wasteland
* Preserved natural areas
* Planted native vegetation
Photo courtesy: Philadelphia Horticultural Society

Practice #6: Parking lots, especially surface lots, should be minimized and designed to reduce, store and treat stormwater runoff. Where site limitations or other constraints prevent full management of parking lot runoff, designers should target high use areas first.

Rationale: While adequate parking is often considered a critical ingredient to the success of most infill and redevelopment projects, parking lots are often one of the greatest sources of stormwater runoff. In addition, many older parking lots that are being redeveloped were designed with little regard to landscaping, actual parking demand, or effective stormwater treatment. Some of the techniques that can be utilized for managing parking lot runoff include making parking lots incrementally smaller, providing more functional landscaping, and where possible, treating the quality of stormwater runoff.

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Practice #7: Utilize a combination of Better Site Design techniques with infill projects to minimize stormwater runoff and maximize vegetated areas.



Buckman Heights Apts.: Portland, OR
* Converted vacant parking lots to affordable rental apartments
* Rooftop runoff captured by courtyard
* Incorporates on-site stormwater management and native plants
* Walking distance to many amenities and public transportation

Photo courtesy: Prendergast & Associates

Rationale: Many single lot or small multi-lot infill projects contribute to "impervious creep," which is defined as the increase in impervious cover seen over time in highly developed areas. On-site improvements, such as house additions, expanded driveways, new housing, and sidewalks all contribute to impervious creep. Typically, there are few or no requirements to manage stormwater runoff or preserve or restore natural features associated with these small and incremental projects. Better Site Design refers to a design approach that seeks to reduce the amount of impervious cover associated with development, increase the natural lands set aside for conservation, use pervious areas for more effective stormwater treatment, and achieve a marketable, cost-effective product. Better Site Design consists of a series of benchmarks that fall under three categories: parking lot and street design, lot development, and natural areas conservation. Many of these benchmarks are applicable to infill development that can be described as: 1) single lot or small multi-lot infill (up to 3 lots) and 2) larger infill subdivisions (10 to 30 lots). While infill development occurs on smaller lot sizes (10,000 square feet or less), it is often still possible to effectively cluster lots to provide more open space and reduce impervious cover.



Community Garden: Seattle, WA
* Features a garden irrigation system
* Fueled by rooftop runoff from a nearby daycare center

Practice #8: Utilize proper storage, handling and site design techniques to avoid the contact of pollutants with stormwater runoff.

Rationale: Opportunities exist to improve water quality by preventing contact of rainfall with pollutant sources stored or handled at the site of redevelopment and infill projects. Controlling pollutants at the site (source control) is usually the simplest and most cost-effective way to reduce stormwater pollution at many commercial sites. Source control measures include: 1) proper handling and storage of pollutants and 2) site design practices. Handling and storage practices focus on the storage of materials and vehicles in outdoor areas, while site design practices include designing better loading docks, covering materials stored outdoors, and containing dumpsters and fueling areas. Other source control opportunities exist at fleet parking areas, outdoor maintenance areas, landscaping areas and above ground storage tanks.

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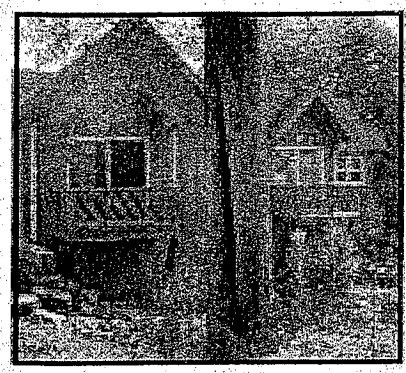
Practice #9: Design the streetscape to minimize, capture and reuse stormwater runoff. Where possible, provide planting spaces to promote the growth of healthy street trees while capturing and treating stormwater runoff. In arid climates, xeriscapes should be used to achieve similar benefits.

Rationale: With proper design and consideration, the interface between the street, sidewalk and other structures, known as the streetscape, can provide opportunities to manage stormwater runoff while providing many other environmental and aesthetic benefits. For example, streets can be made more narrow, and landscaped areas and/or trees can be incorporated into the street front and created so that they function to treat stormwater runoff. In addition, when tree pits are provided along with adequate soil and rooting space, street trees can provide additional stormwater capture and other numerous environmental benefits. Alternatively, xeriscaping (the practice of landscaping to conserve water) can be an important tool in more arid climates.

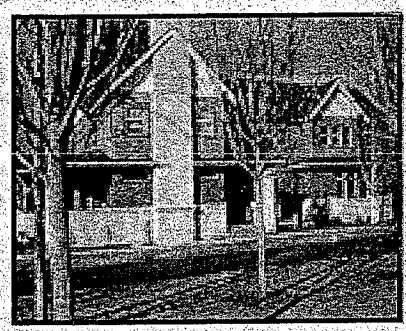


Cottage Creek: Albany, OR
* Restored area stream with species survey
* Replaced exotic plans with native plants to restore habitat
* Converted a semi-wild urban lot to affordable senior housing

Photo courtesy: Glenn Rea Company

Practice #10: Design courtyards, plazas, and amenity open space to store, filter or treat rainfall.

Rationale: Much of the open space found in redevelopment and infill projects consists of hard surfaces that are impervious to rainfall. Using creative site plans, these courtyards, plazas, and other hard open spaces can be designed to store, filter and treat rainfall. Examples include the use of alternative pavers, bioretention areas, and planting boxes.



Village Weistoria: Bend, OR
* Urban infill development, single-family residential
* Preserved large public green spaces
* Features narrow streets and short setbacks
* Most amenities within walking distance

Photo courtesy: Village Development Corps.

Practice #11: Design sites to maximize transportation choices in order to reduce pollution and improve air and water quality.

Rationale: Designing redevelopment and infill sites to increase connections to adjacent land uses, parks and public spaces through non-automotive related transportation choices (bike paths, pedestrian walkways, etc.) can improve environmental quality. Sites should also seek to provide links to mass transit when available, and provide commuter amenities such as bus shelters or bike racks. In addition, site designers may also wish to explore alternate pathway options for pedestrian movement, rather than the traditional sidewalk on both sides of the street.

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Consensus Statement

As members of the Redevelopment Roundtable, we acknowledge the Smart Site Practices as sound and practical redevelopment and infill techniques that can help maintain natural areas, reduce the effects of stormwater runoff, and protect local streams, lakes, wetlands and estuaries. We believe that the technical and case study information provided in these Smart Site Practices are based on sound research and encourage developers, environmental organizations, government agencies and the general public to utilize and promote the dissemination of the practices. The recommendations of the Redevelopment Roundtable reflect our professional and personal experience with redevelopment and infill and do not necessarily carry the endorsement of the organizations and agencies represented by their members.

Members of the Redevelopment and Infill Roundtable

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- Susan Van Buren, Maryland Department of Planning
- Bob McNamara, National Association of Home Builders
- Marolyn Parson, National Association of Home Builders
- Brad Rogers, 1000 Friends of Maryland
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- Javier Velez, Environmental Protection Agency Office of Policy, Economics and Innovation

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- Jennifer Zielinski, Watershed Engineer

Unless otherwise noted, photographs were contributed by Center staff.

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Resources

Title: *Smart Site Practices: Designing More Environmentally Sensitive Redevelopment and Infill Projects*
By: Center for Watershed Protection, 2001
URL: www.cwp.org
This resource provides some of the detailed technical background and information behind the 11 Smart Site Practices.

Title: *About Brownfields*
By: EPA Office of Solid Waste and Emergency Response, Brownfields Program
URL: www.epa.gov/brownfields

Title: *Brownfields Redevelopment: A Guide for Local Governments and Communities*
By: International City/County Managers Association and Northeast Midwest Institute, 1997
URL: www.icma.org

Title: *Exploring the Ecology of Greenroof Architecture*
By: Linda Velazquez, University of Georgia School of Environmental Design, 2000
URL: www.greenroofs.com

Title: *Financing Brownfields Redevelopment Projects– A Guide for Developers*
By: EPA Smart Growth Network, 2000
URL: www.smartgrowth.org/information/whatsnew.html

Title: *Parking Supply Management*
By: Federal Transit Administration
URL: www.fta.dot.gov/library/planning/tdmstatus/FTAPRKSP.HTM

Title: *Smart Growth: Building Better Places to Live, Work & Play*
By: National Association of Homebuilders, 2000
URL: www.nahb.org

Title: *Smart Growth Toolkit*
By: David O'Neill, Urban Land Institute, 2000
URL: www.uli.org

Title: *Urban Parks Online*
By: LWRD Urban Parks Institute and Project for Public Spaces, 1997
URL: pps.org/urbanparks/index.html

Title: *Smart Growth Network*
By: Network of stakeholders working to promote smart growth
URL: www.smartgrowth.org

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Municipalities LEEDing the way

PUBLIC WORKS Series 2004

A growing number of civic leaders are promoting the benefits of sustainable design principles.

BY LEO PIERRE ROY, AP

Government bureaucrats are not famous for innovation. But civic leaders in several municipalities around the country have joined the "green building" movement. They have enacted laws requiring the use of sustainable design principles to minimize adverse impacts to natural systems, to conserve water and energy, to use environmentally preferable materials, and to reduce waste and emissions.

For example, mayors seeking to revitalize their cities are demanding green roofs and improved stormwater management, among other key initiatives. Additionally, some insist that solar power is provided for citizens. These mayors are seeking greater health, improved worker productivity, and energy cost savings. Meanwhile, they are enhancing the livability and quality of life in urban areas.

Awareness of the impact of the built environment on the natural environment is emerging, as is a desire to increase the harmony between them. While private-sector participation in green building design and construction is completely voluntary (and is presently being undertaken by environmentally-motivated, non-profit organizations and forward-thinking private companies), municipal leaders are mandating the application of sustainable design principles in their communities because they recognize its extraordinary benefits.

Most municipalities that are promoting sustainable design have adopted the Leadership in Energy and Environmental Design™ (LEED) Green Building Rating System developed by the U.S. Green Building Council. The LEED criteria, created during a 10-year period through a voluntary, grassroots effort, have become a widely accepted standard for what is environmentally preferable in design and construction. These criteria are designed to reduce or eliminate the negative impacts of buildings on the environment and their occupants in five areas: sustainable site planning, water savings, energy efficiency and renewable power, materials and resource conservation, and indoor environmental quality.

To date, nearly 100 projects have been LEED certified, representing a staggering 149 million square feet. And more than 1,000 projects from throughout the nation are registered for future certification.

LEED certification is based on existing, proven technologies. It allows flexibility through a point system, as every project is not able to incorporate all sustainable design features. Ratings include Certification, Bronze, Silver, Gold, and Platinum, depending upon the level of criteria met by a project. LEED promotes a whole-building, integrated design process, encouraging early collaboration among all design, engineering, and construction disciplines.

The municipalities leading the green building movement use a variety of techniques to promote sustainable design principles. Most lead by example, requiring that any municip

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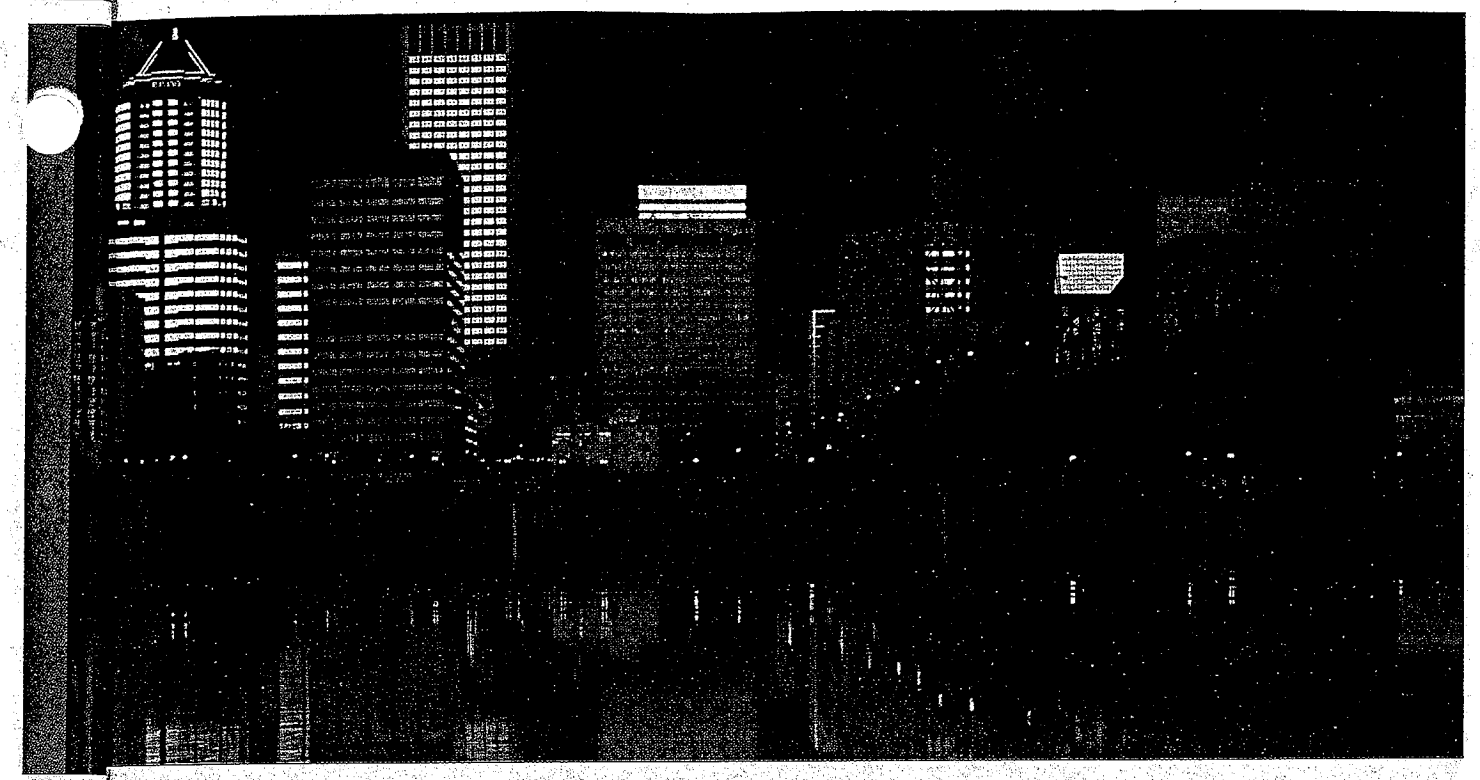


buildings over a certain size seek LEED certification. They make information on green building technologies available through resource centers where people can visit, through published materials, or through extensive websites that provide links to various sources. In some cities, such as Boston and Chicago, the mayors have made bold pronouncements, setting goals for their cities to be the greenest in America. Other cities support a more grassroots approach by offering developers incentives to achieve desired results.

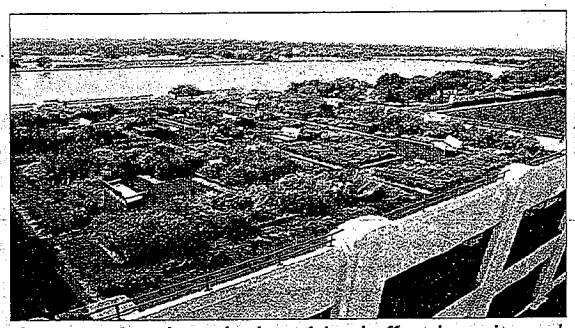
Progressive cities

In 2001, San Jose, Calif., became one of the first municipalities to require the use of the LEED standard on all municipal buildings larger than 10,000 square feet. More than a dozen cities, including Arlington, Va.; Austin, Texas; Dallas; Los Angeles; Portland, Ore.; Seattle; and, most recently, San Francisco, have passed similar ordinances. Federal agencies also have embraced the LEED standard, including the General Services Administration, which builds non-military federal buildings. It has a goal of LEED Silver rating on all structures costing $2 million or more. Other federal agencies that have adopted LEED include the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers, as well as the Navy and Air Force.

The city of Arlington, Va., adopted the requirement for LEED Silver for all municipal buildings. Additionally, it requires all commercial developers to submit a LEED scorecard in the early design phase to encourage the consideration of sustainable design features. Developers are not required to implement the green building features, but are required to at least consider them. Arlington also offers private developers of commercial office space the ability to apply for additional density in exchange for achieving LEED Silver rating on their projects. This city's own projects, including schools, community centers, and a fire station, lead by example. Its informative website (www.arlingtonva.us/Departments/EnvironmentalServices/EnvironmentalServicesMain.aspx) provides information about current city projects and its green building program.

The city of Austin, Texas, was another early adopter of sustainable design principles, starting in the early 1990s. It has a formal Green Building Program, which offers a credit of up to 100 percent of the development and infrastructure fees, as well as utility charges, for projects that comply with its Smart Growth Criteria. Austin also offers rebates for efficient irrigation and rainwater collection systems. Part of the city's motivation to encourage sustainable design is to protect its sole-source water supply aquifer from contaminates such as pesticides, herbicides, and fertilizers. Austin operates a walk-in green building resource center with reference materials and referrals to technical experts; it also publishes the widely used *Sustainable Building Sourcebook*. Austin has an excellent website (www.ci.austin.tx.us/greenbuilder), which includes the *Sourcebook*, as well as product information, relevant articles, and other publications.

Boston Mayor Thomas Menino appointed a Green Building Task Force to recommend ways to expand the city's green building activity. Additionally, the Boston Re-



Weston Solutions, Inc.

Green roofs reduce the heat island effect in a city and provide an amenity for building occupants. The modular Green Grid™ green roof system shown here can be retrofitted onto existing roofs.

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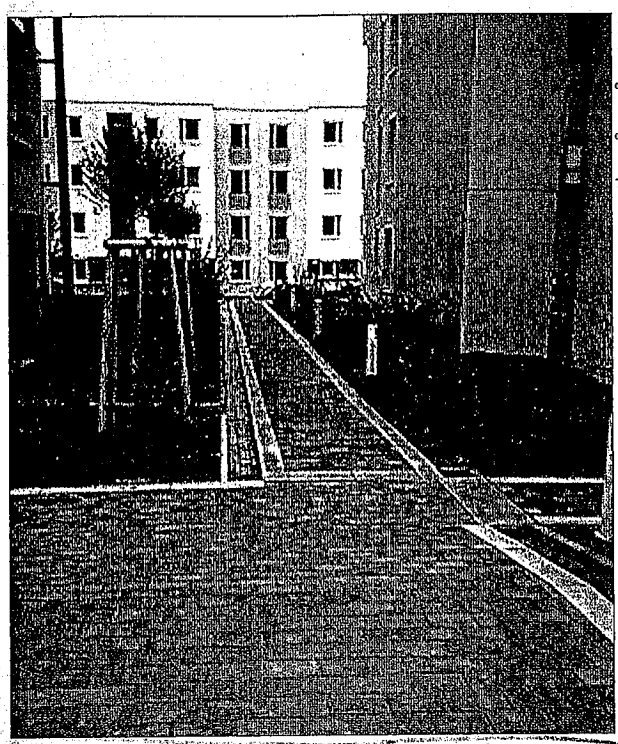
development Authority established a grant program to explore green building technologies during early-stage feasibility studies conducted by developers. This seed money will encourage consideration of sustainable design principles by developers who ordinarily would not consider features with long-term return on investment, but that offer significant environmental benefits.

The Boston area has several outstanding examples of green architecture, including the Genzyme world headquarters in East Cambridge, and Manulife Financial's headquarters in the new Seaport District. Both of these projects feature glass facades with double walls, which allow for air circulation within the façade to help with heating in the winter and cooling in the summer. Additionally, both buildings have full-height atriums to bring in natural light, as well as vegetated, or green roofs to reduce the heat island effect and to provide an amenity for building occupants.



The Bioengineering Group, Inc.

Hard surfaces in the built environment can be used to transport runoff into landscaped areas for infiltration.

Additionally, Harvard University and Massachusetts Institute of Technology (MIT) recently built high-profile green buildings. Harvard's 240-unit graduate student dormitory complex at One Western Avenue in Boston has an Energy Star roof; it used locally-sourced and environmentally friendly materials; and it has a heat recovery exhaust system. The startling MIT Stata Center, designed by the unconventional architect Frank Gehry, is noted for its highly efficient HVAC system and its rainwater collection system for toilet flushing.

Chicago Mayor Richard Daley vowed to make his city the greenest in the country. He put a green roof on the city hall and is strong-arming developers to follow suit on their buildings. Daley has a similar fondness for solar power, encouraging the installation of photovoltaic panels on downtown buildings. Chicago's Center for Green Technology features rubber floors made from old tires and uses vegetable oil instead of hydraulic oil in its elevator.

Pittsburgh, known in the past more for its pollution than green progress, boasts the largest number of green buildings in the United States. Its newly opened convention center, the world's largest green building, is LEED Gold certified. Impressive features include stunning natural light, a highly efficient HVAC system, and a system that purifies greywater from sinks to recycle it for toilet flushing and irrigation. Pittsburgh hosted the 2003 U.S. Green Building Council annual meeting, which drew almost 7,000 participants.

New York City is home to a dramatic example of the private market's response to green buildings. The 27-story Solaire project in Battery Park City, a residential complex of 293 units in lower Manhattan, was rented out in record time, even with most units going for 4 percent to 5 percent above market rates. The project incorporated and promoted a number of green building features that clearly distinguished the project in the marketplace. For instance, the building uses 67 percent less energy at peak times, which saves money and reduces demand on the grid. New York City also has a significant green roof initiative, called Greening Gotham, which is led by Earth Pledge, a nonprofit organization.

Portland, Ore., also is a leader in green building measures. The city's stormwater management bylaw requires a reduction in impervious surfaces on building sites and mandates the use of best management practices for stormwater. Those implementing sustainable stormwater management techniques are given a discount on applicable fees.

Interestingly, Portland initially started collecting information on stormwater management alternatives to save money. Eventually, the research effort grew to include other sustainable design practices. The city's Stormwater Management Manual can be found on its website at www.portlandonline.com.

Portland established an Office of Sustainable Development to keep requirements consistent across the community. It offers direct reimbursement of up to $20,000 of first costs for those commercial projects seeking LEED Silver certification and provides rebates for energy and water conservation efforts. Portland also offers a great green roof incentive — an extra 3 square feet of building for every 1 square foot of green roof with a total coverage of 60 percent or more of the whole roof area.

The city shines in how it makes information on green building technologies broadly available. Its comprehensive website (www.sustainableportland.org) offers valuable project data, including current research on green roofs, the costs of green building features, and links to other sites.

In 2002, Los Angeles began requiring that all municipally funded buildings larger than 7,500 square feet be LEED certified. Nearly 2 million square feet of projects are presently being developed under this requirement, including 18 fire stations, seven animal care facilities, five police stations, two bomb squad facilities, and police headquarters. While Los Angeles is demonstrating a significant commitment to green buildings, it is not to be outdone by its neighbor to the north, San Francisco, which also has adopted a Green Building Ordinance.

This decree, which became effective in September, requires that all city-owned facilities and leaseholds achieve at least a LEED Silver rating. The city council was motivated to enact the requirement to reduce future building operation costs, as well as to improve city worker health and productivity. The Bay Area already is home to a number of notable green buildings, including the headquarters for The Gap and a Pottery Barn retail outlet.

Even Dallas — better known for cowboys, oil wells, and J.R. — has demonstrated a commitment to sustainability. The city has

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replaced its incandescent traffic signals with light emitting diodes, saving 3.6 million kWh annually.

Additionally, Dallas runs a fleet of alternative fueled vehicles, mostly using clean burning, compressed natural gas (CNG), and has established a system of some 22 public-access CNG refueling stations.

Further, city officials revised Dallas' zoning and building development codes to offer expedited review of building permits and certificates of occupancy for green building projects. It established a new Office of Environmental Management and published a public resource guide on Green Dallas Initiatives. In addition to these outstanding examples of sustainability in action, Dallas requires all new municipal buildings larger than 10,000 square feet to meet LEED Silver certification.

Conclusion

Nationwide, grants and tax policies are providing incentives for green buildings. For example, during California Governor Arnold Schwarzenegger's State of the State address, he announced the creation of a Green Bank of loan guarantees to support the retrofit of existing buildings for energy efficiency. New York Governor George Pataki sponsored a green building tax credit to encourage design and construction of buildings with greater energy efficiency, better indoor air quality, and reduced environmental impact. It provides for a 7-percent credit for buildings larger than 20,000 square feet if both the base building and tenant space use green building technology. Portland, Ore.'s grant program helped to spawn 44 green buildings — totaling 4 million square feet — and encouraged a well-established, sustainable design ethic in the community.

Currently, nearly every municipal green building program in the United States offers incentives to encourage property developers to participate, such as grants to study the feasibility of incorporating green design features, increased project density, or expedited project permitting. Municipalities promote green projects in their communities, and use the media to educate and inform.

For instance, hosting the U.S. Green Building Council's annual conference is a great way to showcase progress in green buildings; it has been held in Austin and Pittsburgh. This month, it is being held in Portland, Ore. Most municipalities also offer educational resources, including access to information and technical advice, but the financial incentives appear to be the most persuasive.

The leadership demonstrated by a number of municipal officials in promoting sustainable design and green buildings is encouraging. It shows a commitment to citizens by reducing environmental impacts, improving the health and productivity of building occupants, and saving money through the efficient use of energy and other resources. Through these efforts, municipal leaders are making a difference as they work to improve the quality of life in their communities. ■

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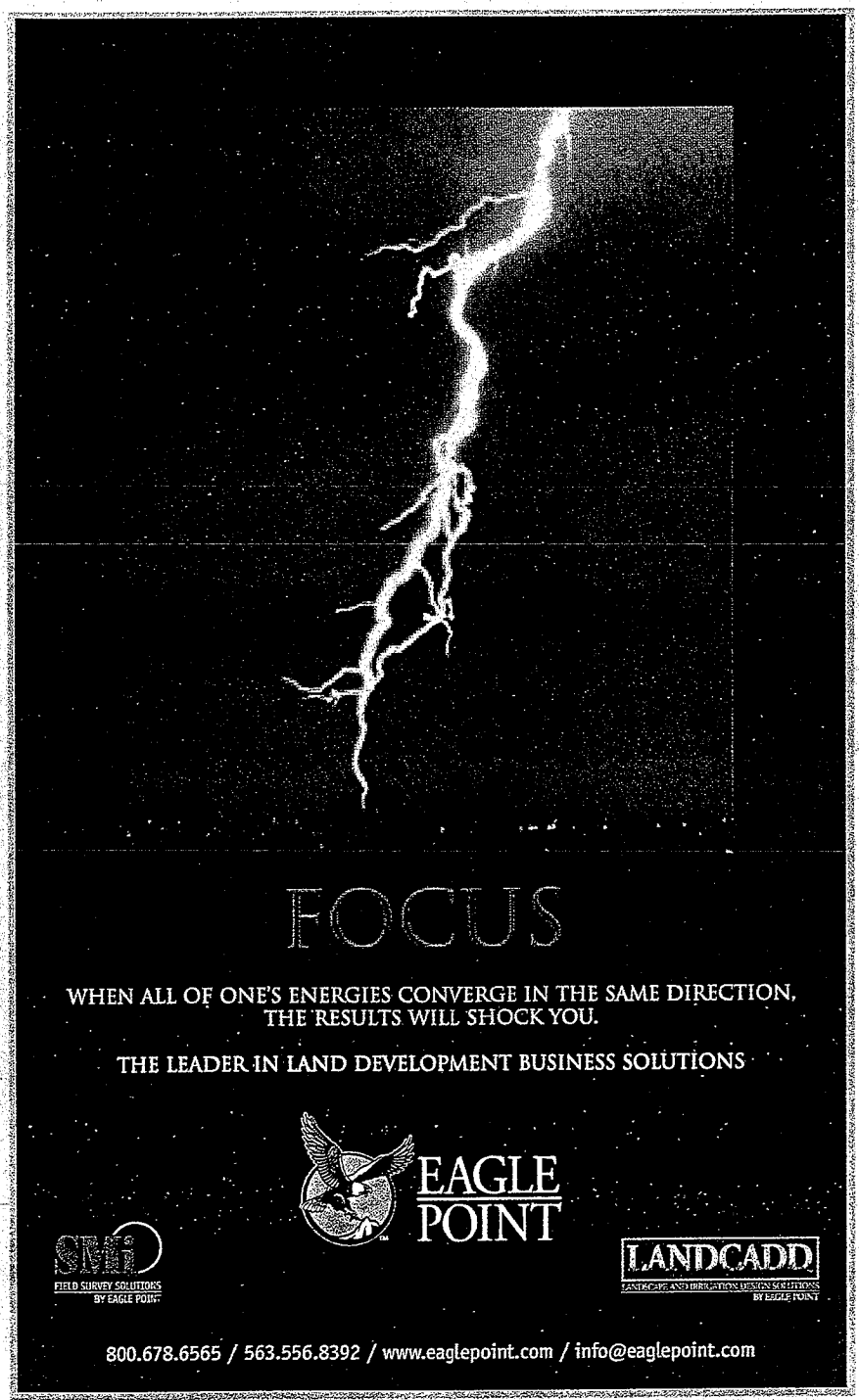

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ENHANCING STORM WATER INFILTRATION TO REDUCE WATER TEMPERATURE DOWNSTREAM

Joseph M. Dorava, Vierbicher Associates, Inc.
Aircardo Roa Espinosa, Dane County Land Conservation Department
Ken Johnson, Wisconsin Department of Natural Resources
Daryl Severson, City of Sun Prairie

A substantial storm water management project was recently completed in the city of Sun Prairie, about ten miles east of Madison, Wisconsin. The primary goal of this project was to protect the water quality of Token Creek, one of the last remaining cold-water trout streams in south central Wisconsin.

Reducing the downstream movement of sediment and preventing excessive heating of the runoff were two challenges faced in this project. A team of engineers and scientists from the city of Sun Prairie, the Wisconsin Department of Natural Resources, Dane County's Land Conservation Department, and Vierbicher Associates, Inc., joined forces to meet the goals of this project. This team designed and built a series of stone-filled gabion weirs to filter sediment, and they engineered a stone-lined channel to infiltrate runoff into the ground.

State funding earmarked for the reduction of non-point source pollution supported this project. The outcome being a system which treats storm water runoff from more than 492 acres of new residential development. Enhanced infiltration provided by the stone-lined channel is designed to reduce stream water temperatures by moving the surface runoff under ground. The gabion weirs are designed to remove sediment from the streamflow by trapping large particles and filtering smaller ones. The capability of this storm water treatment system to reduce stream temperature was designed with a site-specific thermal model. The substantial accumulation of sediment upstream from the gabions indicates the systems ability to treat storm water runoff. The system's design and functionality, along with its aesthetic appearance in a densely developed subdivision, demonstrate its success in suburban Sun Prairie. Because infiltration is becoming more important as a storm water management practice, this treatment strategy may have applications wherever development occurs.

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Introduction

The Token Creek Watershed is a 27 square-mile sub basin of the Yahara-Lake Mendota Priority Watershed in south central Wisconsin, on the northeast side of Madison, immediately adjacent to the city of Sun Prairie (Figure 1). This watershed supported a native brook trout fishery prior to European settlement (Sorge, 1996). Today, natural springs, which discharge more than 4000 gallons per minute of 50-degree Fahrenheit water to Token Creek, continue to support a cold-water fishery (University of Wisconsin, 1997, Wisconsin Department of Natural Resources Unpublished Data). Development around the city of Madison and especially the outlying areas near Sun Prairie is increasing. The result is increased pressure to build near wildlife habitat areas and watersheds that support such fisheries. The challenge then is to create development that is compatible with the surrounding environment and to develop in ways that minimize degradation of natural resources.

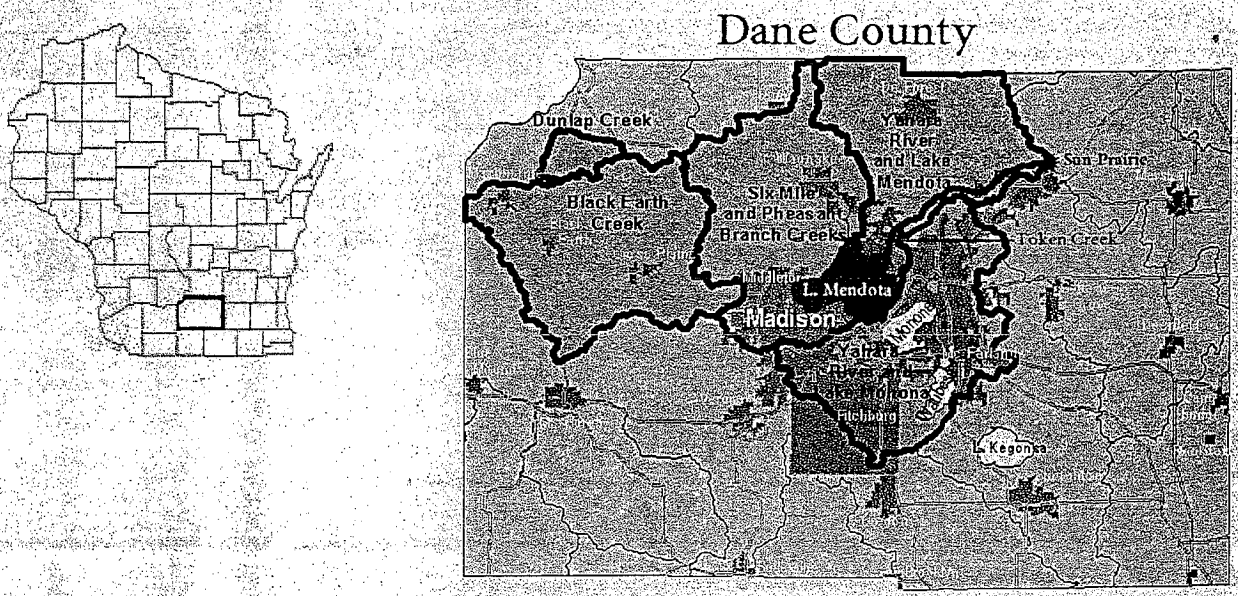

Figure 1. Location of Dane County, Wisconsin, and Token Creek in the Yahara River and Lake Mendota Priority Watershed. The proximity of Token Creek to the growing cities of Madison and Sun Prairie increases the demand for development in the watershed. The importance of the cold-water fishery in Token Creek and the priority designation of downstream lakes create a regulatory agency emphasis on protecting water quality. Map modified from Dane County, http://www.co.dane.wi.us/landcopnservation/pwshed.htm.

Background

Regulatory agencies realize the importance of the natural resources and they understand the value of limiting sediment inflow and water temperature increases to an urbanizing stream that also supports a cold-water fishery. As a result, proposed developments in the Token Creek Watershed are closely scrutinized for their contributions of non-point source pollution. In addition, there is a regulatory emphasis placed on managing water temperature increases and there are no concise compliance standards, documented best management practices (BMPs), or design manuals to rely upon or use as targets. Therefore, biologists and engineers commonly use professional judgement, personal experience, and modeling to predict the outcome of various management practices.

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In the case of Token Creek, where there were benefits to protecting the creek for, the participants were quite cooperative. For example, the developer for the residential subdivision generously donated land along Token Creek tributary drainageways to the city of Sun Prairie so it could be managed in the public interest. The developer realized benefits from protecting Token Creek if home site and property values are higher as a result of the attractive storm water management features in the dedicated public lands and a viable cold-water fishery downstream. Furthermore, the city of Sun Prairie will benefit from an increased tax base of the higher home values. Regulatory agencies also benefit because enhanced protection of the natural resources is one of their primary directives.

Purpose and Scope

Token Creek is part of the Yahara-Mendota designated Priority Watershed Project, which aims to reduce sediment and nutrient flows into Lake Mendota. This designation and the creek's high value as a cold-water fishery, prompted the State of Wisconsin's Department of Natural Resources, (WiDNR) to award a Non-Point Source Pollution Abatement Program cost-share grant to the city of Sun Prairie to design and install BMPs in the Token Creek Watershed. In support of the Priority Watershed Program, Dane County's Land Conservation Department is working with the agricultural industry to ensure that agricultural BMPs are installed throughout the watershed to reduce sediment inflows to the lake. The Land Conservation Department is also developing a model to predict the effects of land-use change on water temperature and to predict the change in water temperature derived from various land-management practices. The resources at Dane County and the WiDNR assisted the city of Sun Prairie and their engineering consultant, Vierbicher Associates Inc., with the design of BMPs to reduce the movement of sediment and heated runoff to Token Creek.

The cost-share grant from WiDNR supported design and construction of BMPs in a proposed 492-acre residential subdivision along a tributary to Token Creek. Dane County provided design recommendations based on their experience with agricultural practices in the area and results of detailed temperature modeling. Vierbicher Associates provided engineering design and construction plans. The city of Sun Prairie supervised design and construction of the project and the WiDNR and Dane County provided regulatory agency oversight. The two primary goals of the project:

- To protect the water quality of Token Creek (primarily by controlling sediment inflow and water-temperature increases)
- To provide BMPs that are attractive and improve property values

The purpose of this paper is to describe the Token Creek Water Quality Control Project and the design process used to select BMPs for this project. Primarily because the project provides an introduction to relatively new storm water management techniques (rock-filled gabion dams and rock-lined channel storm water infiltration), and a new engineering tool (water temperature modeling). These new techniques and tools provide protection against non-point source pollution, in addition to mitigating thermal impacts from storm water runoff. Both the project's design process, including the new engineering techniques and tools and the project's unique BMPs, should have broad applications in urban storm water management. The project also provides valuable examples of cooperation between adjacent city governments, regulatory and funding agencies, and design professionals.

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BMP Selection

The proposed 492-acre single-family development was planned to include about 15 acres of green space along the tributary drainageways to Token Creek and the remaining land converted to approximately 0.25-acre residential lots (Figure 2). Each lot was planned to contain a 3-bedroom home (2,500 square feet) and a 2-car garage (480 square feet). This lot configuration results in about 4,400 square feet of total impervious surface if an allowance of 900 square feet is made for roads and 520 square feet is allowed for driveways, and sidewalks. The result of this development is an alteration of land use from 100 percent open-pastureland and forest to about 34 percent impervious area.

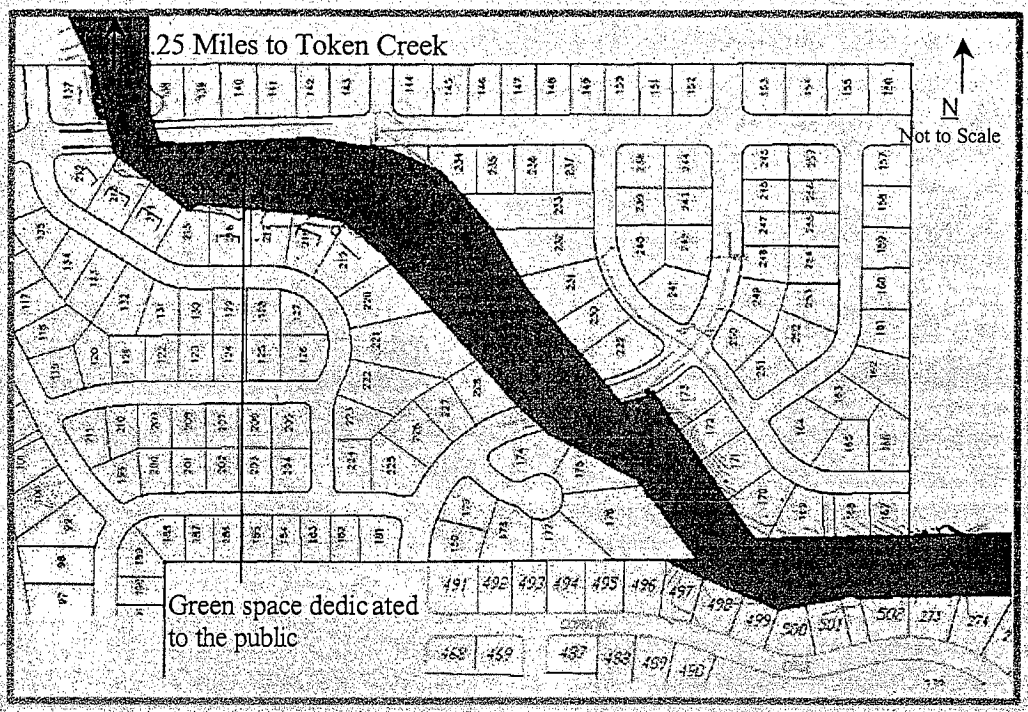

Figure 2. Proposed single-family residential development in the watershed of a tributary to Token Creek. Of the approximately 492-acres proposed for development, 15-acres will be dedicated to the public as green space and the remaining land will be subdivided into approximate 0.25-acre lots.

The result of this type of land-use conversion typically is an increase in runoff and a substantial increase in peak discharge, severe streambank erosion, and degradation of water quality including elevated water temperatures. Common BMPs available to address these concerns would include storm water detention ponds, streambank reinforcement, and created wetlands. Principal concerns with these common BMPs as a result of a cold-water fishery less than 0.25 miles downstream include storing and ponding water that would potentially increase the water temperature and unsightly wetland areas that might attract mosquitoes. The city of Sun Prairie as the supervisor of design and construction and the regulatory agencies within their review capacity both understood the need to closely coordinate this project. Early in the design process consultations with regulatory agency staff resulted in considerable efficiencies in the design. For example, in headwater areas where wetlands prevail along the drainageway, consideration of the need to infiltrate runoff and preserve wetlands resulted in agreement on selection of an erosion control mat for stream bank stabilization instead of rock lining. In addition, the agreement between engineers and regulators to place rock dams near planned or existing roadway and bike path embankments minimized the disturbance to the

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site by concentrating fill materials and provided for easy maintenance of the storm water management system. The common acceptance of the need to mitigate water temperature increases in Token Creek among designers and reviewers brought together a team of engineers and scientists that otherwise would be working independently. The design process, techniques, and tools this team used to complete this one project are now complementary items in new countywide storm water management and erosion control ordinances, Statewide model ordinances, and the daily practice of the individual engineers and scientists involved in the project. One of the most important new engineering tools is the application of a temperature model developed during the project.

Temperature Modeling

A Temperature Urban Runoff Model (TURM) was developed and tested in Dane County, Wisconsin, to predict the thermal impact of proposed development projects (Arrington et al., 2002, Roa-Espinosa, 2003). A number of sample model runs are presented here to help understand how several variables interact to result in the stream temperatures predicted by the model. Three of the important variables that determine stream temperature as a result of a storm are:

- the percentage of impervious area of the parcel,
- the parcel area and
- the baseflow of the stream that the parcel drains into.

Percentage of Impervious Area and Water Temperature

Impervious surfaces, such as pavement or asphalt, increase stream temperature for two reasons. First, impervious surfaces absorb solar radiation, which raises their surface temperature. When it storms, some of this heat is transferred to the water that falls on these surfaces as precipitation. Second, impervious surfaces reduce infiltration, which increases the runoff volume from these surfaces. (Pervious surfaces, like grass or other vegetation, allow some of the precipitation that falls on them to infiltrate into the soil.) As the percentage of impervious area of a parcel increases, more of the total runoff from the parcel comes from the heated runoff contributed by the impervious surfaces. Therefore, as percentage impervious area increases, the temperature of the water runoff from the parcel increases and the temperature of the stream that the runoff enters increases as well.

Because there are some significant seasonal variations in storms and their effect on water temperature the model uses a typical summer rainstorm event in Dane County to predict water temperature changes. The assumed storm and local environmental conditions accompanying the storm event are described in Table 1.

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Table 1. Typical storm and environmental conditions assumed for mid-summer storms in Dane County, Wisconsin from TURM predictions.

rainfall depth	0.5	inches
rainfall duration	4	hours
hour of day rain start (between 1 and 24 hours)	14	
Time of concentration (Tc)	0.100	hours
wind speed	10.2	ft/s
rain temperature (during storm)	73.7	°F
Initial temp. of impervious surface	93.6	°F
Air temperature	80.0	°F
Relative humidity	80.0%	

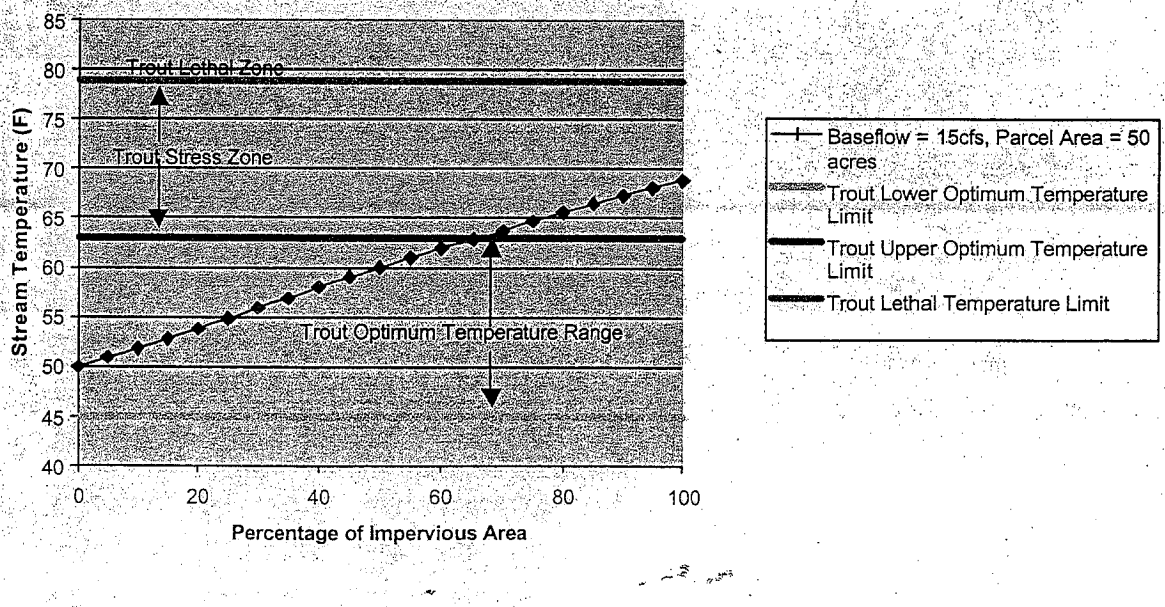

Figure 3. There is an increasing trend in stream temperature with increasing percentage impervious area for a given parcel area and baseflow. Baseflow is given in cubic feet per second (cfs).

Parcel Area and Water Temperature

In general, at a given percentage of imperviousness, the larger the parcel area, the more runoff it contributes to the stream. More heated runoff means greater stream temperature increases resulting from a storm.

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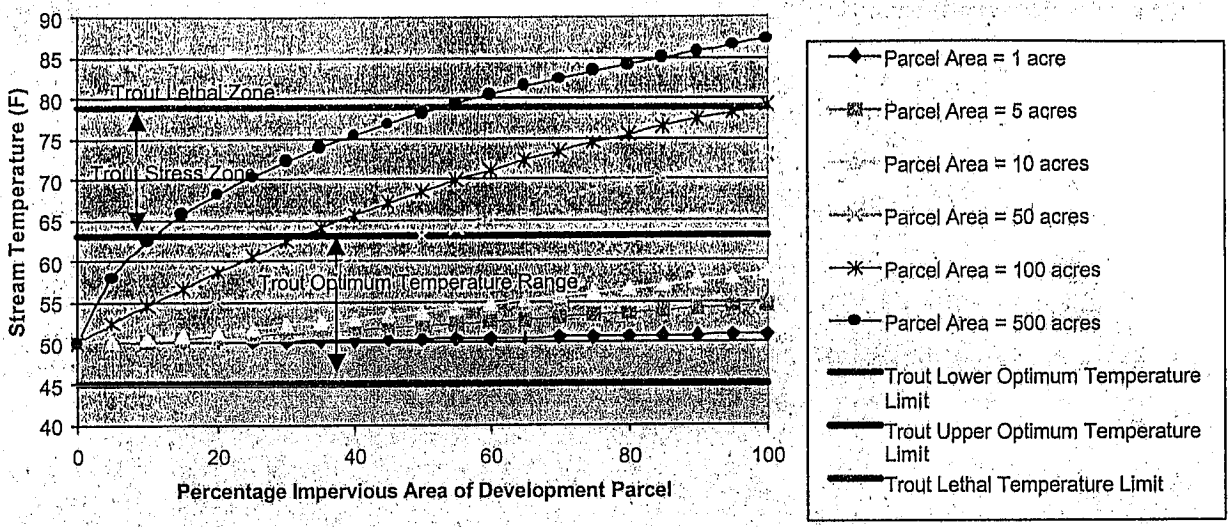

Figure 4. For a given percentage of impervious area and a given baseflow, the greater the parcel area, the greater the stream temperature.

Baseflow and Water Temperature

Baseflow is the flow rate (volume of water per unit time) of a stream before a storm. Typically small baseflow is found on small streams and tributaries, whereas large baseflow is found on larger streams. Stream temperature resulting from a storm is a mixture of the initial stream temperature and the runoff temperature. At a given volume of heated runoff (determined from the parcel area and the percentage imperviousness) there is a greater stream temperature increase in a stream with a small baseflow than a stream with a large baseflow. This is because the runoff volume is a greater proportion of the stream volume in a small baseflow stream than a large baseflow stream.

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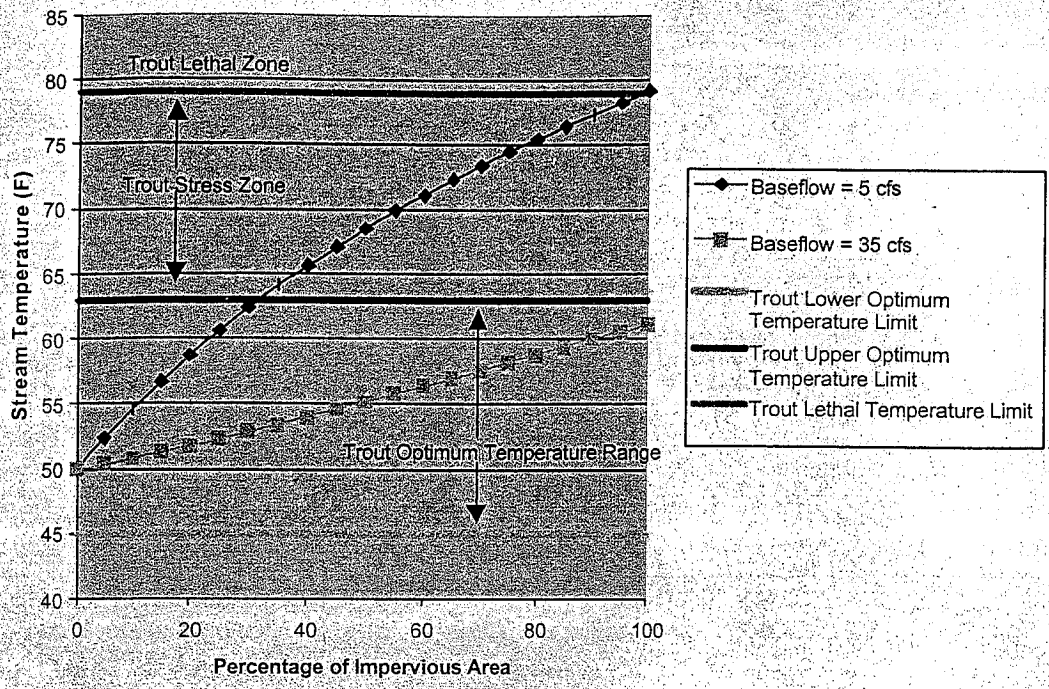

Figure 5. For a given parcel area and a given percentage of imperviousness, higher stream temperatures are found in streams with smaller baseflow and lower stream temperatures are found in streams with larger baseflow. Baseflow is given in cubic feet per second (cfs).

Watershed Characteristics and Water Temperature

Understanding the inter-relation between watershed characteristics and water temperature elucidates opportunities to manage development or mitigate the effects of development in a watershed (Figure 6). For this developing tributary watershed to Token Creek, which generally has a larger parcel area (492-acres) and a lower base flow about (9 cubic feet per second), mitigating increases in stream temperature and reducing the movement of sediment to the creek were common goals of the developer, the city, and the regulatory and funding agencies. Because additional single-family housing is in high demand in this area mitigating the potential harmful effects of development was more desirable than reducing the size or number of housing units developed.

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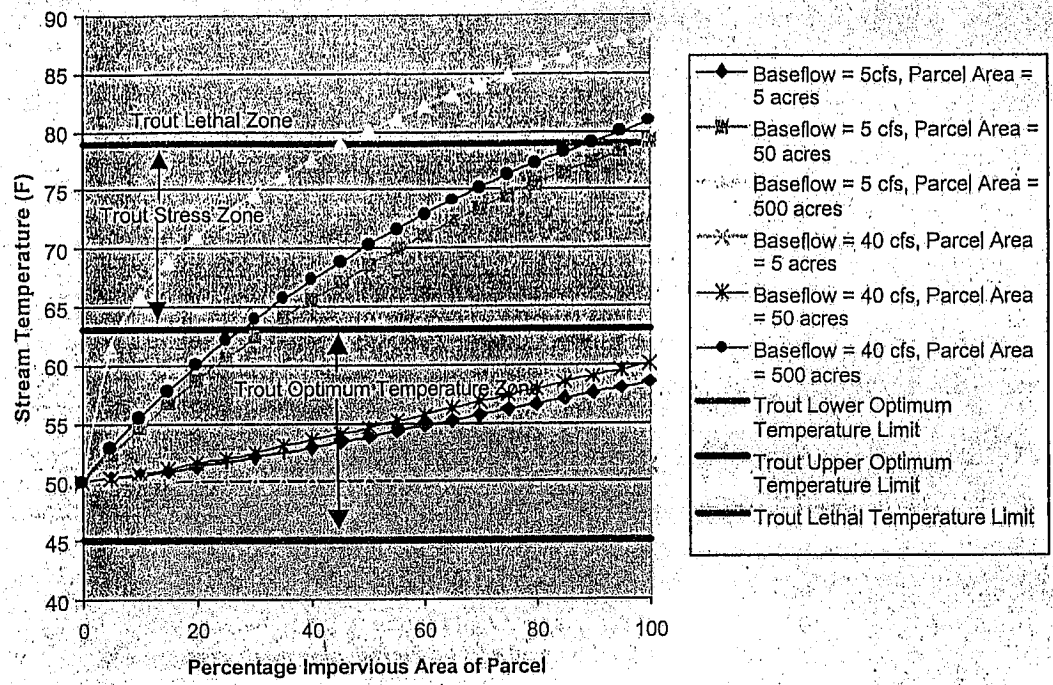

Figure 6. The relative trends of how stream temperature varies with percentage impervious area for different combinations of parcel areas and baseflow. For small parcels and large baseflow, there is little thermal impact to the stream, regardless of the percentage of impervious area. On the other hand, large parcels that drain into a stream with a small baseflow cause a substantial stream temperature increase, even at relatively low percentages of imperviousness. Baseflow is given in cubic feet per second (cfs).

A 21.6-degree F increase in stream temperature is predicted to result from the proposed development in this Token Creek Tributary watershed by the TURM (Table 2). The resulting water temperature of 71.6 degrees F is above the stress zone for trout and, thus, is undesirable. Therefore some temperature mitigating management practices are necessary.

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Table 2. For a given rainfall event a temperature increase of 21.6 degree F is predicted to result from the proposed development in this tributary to Token Creek.

Temperature Urban Runoff Model

POST-DEVELOPMENT

Units: english

Required Inputs:

% Connected imperviousness in watershed	34%	
Watershed area	492.00	acres
Base flow in stream	9.0	cfs
Existing stream temp.	50.0	°F

Outputs:

Temp. of runoff from development	93.8	°F
Difference between runoff and stream temp	43.8	°F
Temp. of stream after development	71.6	°F
Increase in stream temp.	21.6	°F

The model runs described here represent the relative thermal impact of various development scenarios if heated runoff has little opportunity to cool before entering a stream. The combinations of percentage of impervious area, parcel area, and baseflow do not necessarily have the impact shown above if temperature reduction practices are used to mitigate the thermal impacts of development. The two basic principles behind thermal reduction practices are to slow down heated runoff on its way to the stream (to give it time to cool) and to increase infiltration of heated runoff (to reduce the volume of heated water that reaches the stream). Some useful temperature reduction practices include rock cribs, thermal swales, and retention/infiltration area.

In this development a treatment train was proposed where storm water runoff was collected in the streets and developed lots and directed to the existing drainageway. In the most headwater areas where the drainageway was poorly defined, an erosion mat was used to stabilize the channel and rock-check dams slowed the water and enhanced infiltration (Figure 7).

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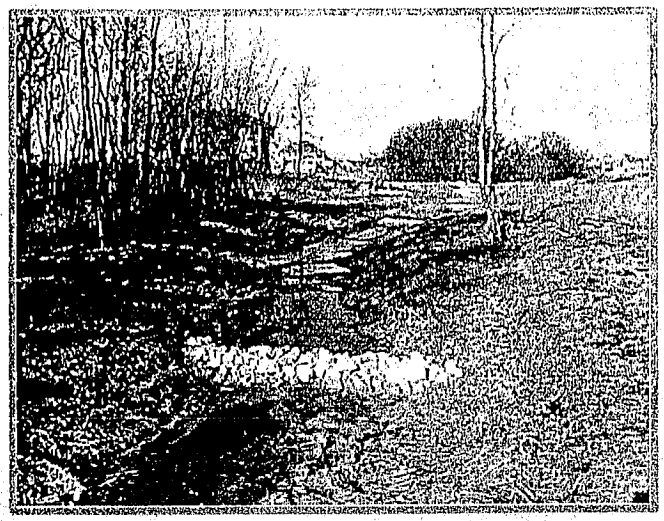

Figure 7. Erosion control matting and a rock check dam combine to reduce stream channel erosion and enhance storm water infiltration in developed headwater areas.

In areas where runoff is concentrated into a defined channel, a rock lining was used in the channel to protect the streambank from erosion, to dissipate heat by contact, and to more rapidly infiltrate the runoff below the surface (Figure 8). Rock-filled gabion dams were installed along the drainageway where flow was restricted by a roadway or bike path embankment. These rock dam sites were also used for maintenance access as considerable debris and sediment accumulated upstream from these structures (Figure 8).



Figure 8. A rock lined channel provided rapid infiltration of runoff, substantial heat dissipation, and near complete control of channel erosion. Rock-filled gabion dams located near channel restrictions provided easily accessible maintenance sites. Sediment and debris that accumulated upstream from the dams could be readily removed in these areas. The rock dams filtered large sediment and debris, slowed the flow of water, and dissipated heat.

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The treatment train strategy implemented in the Token Creek Water Quality Project included a total of 3,055 feet of channel reinforcement and five gabion-dam structures (Figure 9). TURM predicted an increase in water temperature of only 10.7 degrees F as a result of the planned development following installation of the storm water BMPs (Table 3).

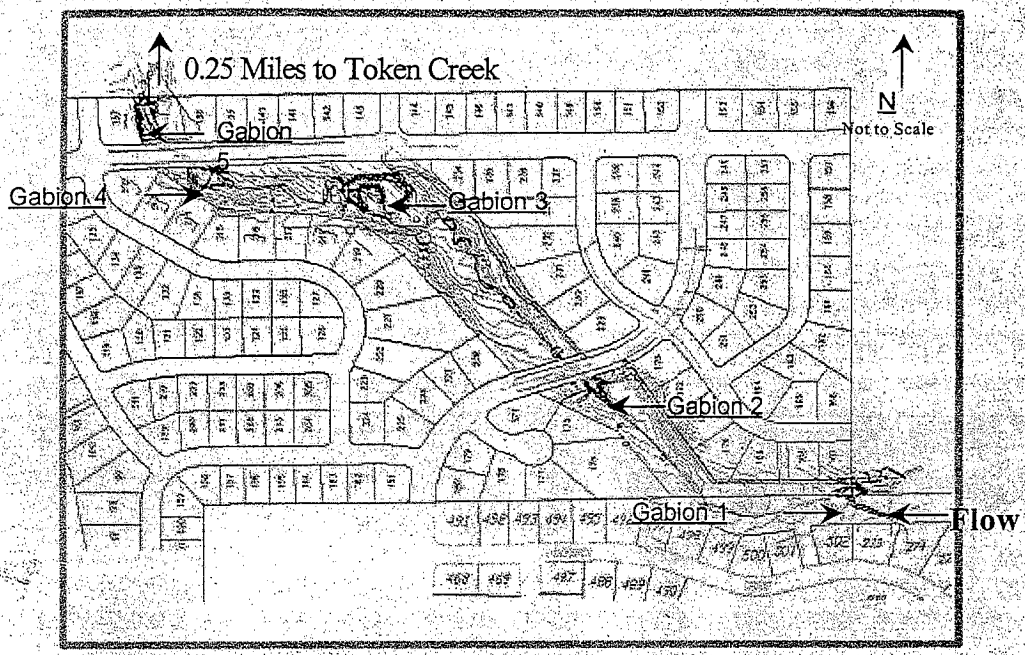

Figure 9. A storm water treatment train that included five gabion dams and 3,055 feet of channel reinforcement was installed along this tributary to Token Creek to mitigate water temperature increases and reduce stream bank erosion.

Table 3. TURM predicted the water temperature in Token Creek would be 60.7 degrees F following the development of a 492-acre single-family residential area once BMP's designed to mitigate for water temperature increases were in place. The increase in water temperature of 10.7 degrees F relates back to the 9-cfs baseflow from the springs that had a temperature of 50 degrees F.

Temperature Urban Runoff Model

POST-DEVELOPMENT

Temperature Reduction Practices:

☑ stone bed/basin	40000 cubic feet, 6 inch stone	
Temperature outletting practices:	66.5	°F
Temperature of stream after practices	60.7	°F
Increase in stream temp. after practices	10.7	°F

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Conclusions

The Token Creek Water Quality Control Project positively affected the water quality of the creek. The project also demonstrated the success of close working relationships among designers, regulatory and funding agencies, and contractors. Everyone, including the developer, supported the project's emphasis on mitigating thermal impacts and controlling the downstream movement of sediment. The rapid and profitable sales of homes in the subdivision demonstrate the project's acceptance by the public. The lack of streambank erosion and the accumulation of debris and sediment upstream from the rock-filled gabion dams indicate adequate performance of the project's erosion control features. Although not supported by a post-construction monitoring program at this site, a healthy cold-water fishery downstream in Token Creek indicates the relatively new TURM may be providing useful guidance to designers. Although specifically developed for Dane County Wisconsin, this temperature model, the temperature mitigating BMP's, and the design process used on this project may have applications much wider than the local area. More details of the TURM are also presented in these proceedings (Roa-Espinosa, 2003). Additional documentation of the TURM and guidance for its use can be found on the Dane County WWW page at "http://www.co.dane.wi.us/landconservation/thmodelpg.htm". Additional examples of similar BMP's and projects are also available by contacting any of the authors.

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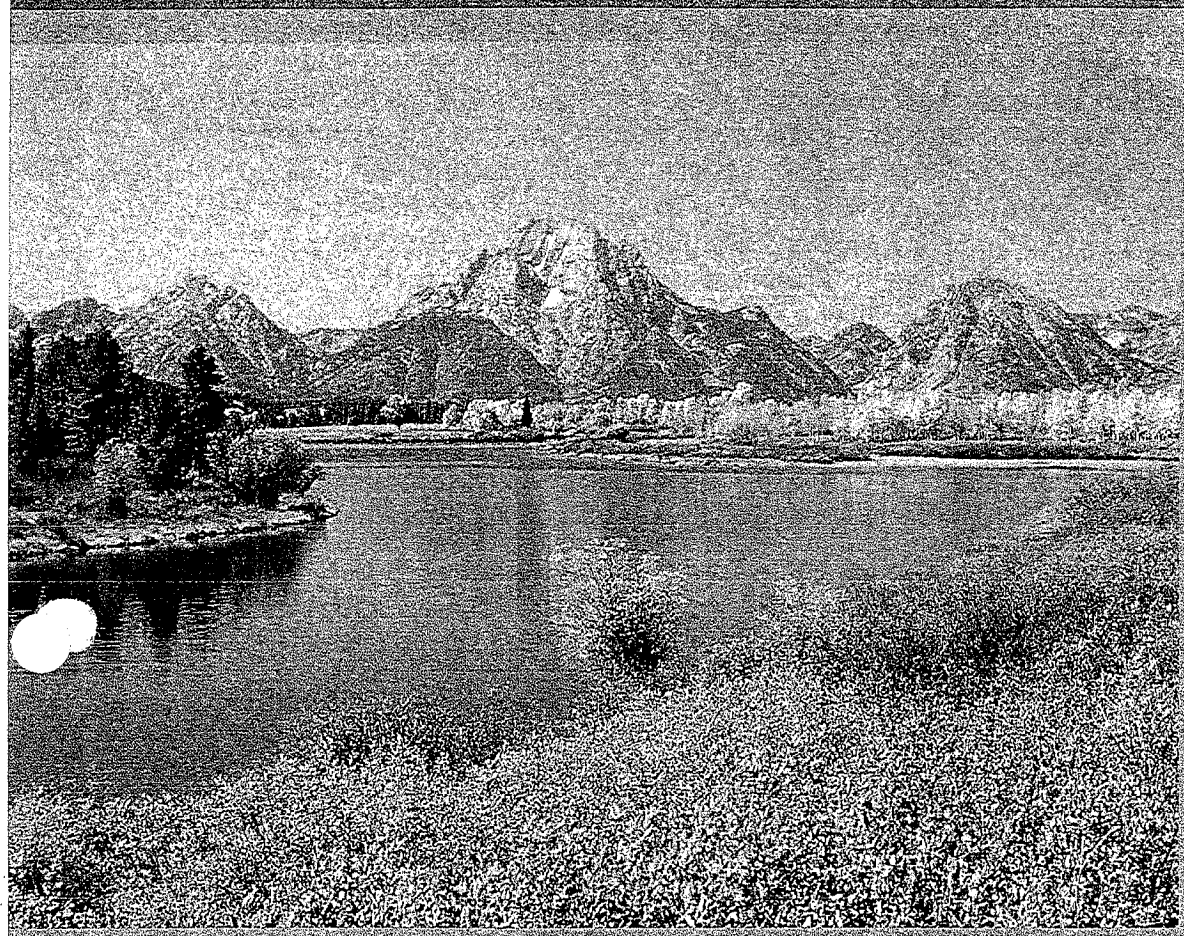

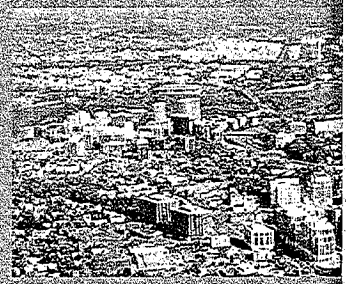





Protecting Water Resources with Higher-Density Development

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Front cover photos:

Left: The Snake River flows outside Jackson, Wyoming. Photo courtesy of USDA NRCS.
Top right: Rosslyn-Ballston Corridor, Arlington County, Virginia. Arlington County Department of Community Planning, Housing, and Development received a 2002 National Award for Smart Growth Achievement in the Overall Excellence category for its planning efforts in the Rosslyn-Ballston Corridor. Photo courtesy of Arlington County.
Middle right: People gather at Pioneer Square in Portland, Oregon. Photo courtesy of US EPA.

Back cover photos:

Top left: This hillside in Northern California is covered by wildflowers. This open space provides habitat to wildlife as well as serving important watershed services. Photo courtesy of USDA NRCS.
Middle left: A family enjoys open space in central Iowa. Photo courtesy of USDA NRCS.
Bottom left: A stream flows through western Maryland. Photo courtesy of USDA NRCS.
Right: This redevelopment site in Arlington, Virginia, which includes stores, apartments townhomes, single family homes, parking garages, and a one-acre public park, was formerly a large department store surrounded by surface parking. Photo courtesy of US EPA.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

Dear Colleague:

We are excited to share with you the enclosed report, *Protecting Water Resources with Higher-Density Development*. For most of EPA's 35-year history, policymakers have focused on regulatory and technological approaches to reducing pollution. These efforts have met with significant success. But, the environmental challenges of the 21st century require new solutions, and our approach to environmental protection must become more sophisticated. One approach is to partner with communities to provide them with the tools and information necessary to address current environmental challenges. It is our belief that good environmental information is necessary to make sound decisions. This report strives to meet that goal by providing fresh information and perspectives.

Our regions, cities, towns, and neighborhoods are growing. Every day, new buildings or houses are proposed, planned, and built. Local governments, working with planners, citizen groups, and developers, are thinking about where and how this new development can enhance existing neighborhoods and also protect the community's natural environment. They are identifying the characteristics of development that can build vibrant neighborhoods, rich in natural and historic assets, with jobs, housing, and amenities for all types of people. They are directing growth to maintain and improve the buildings and infrastructure in which they have already invested.

In addition to enjoying the many benefits of growth, communities are also grappling with growth's challenges, including development's impact on water resources. In the face of increasing challenges from non-point source pollution, local governments are looking for, and using, policies, tools, and information that enhance existing neighborhoods and protect water resources. This report gives communities a different perspective and set of information to address the complex interactions between development and water quality.

Protecting Water Resources with Higher-Density Development is intended for water quality professionals, communities, local governments, and state and regional planners who are grappling with protecting or enhancing their water resources while accommodating growing populations. We hope that you find this report informative as your community strives to enjoy the many benefits of growth and development and cleaner water.

For additional free copies, please send an e-mail to ncepimal@one.net or call (800) 490-9198 and request EPA publication 231-R-06-001. If you have any questions concerning this study, please do not hesitate to contact Lynn Richards at (202) 566-2858.

Sincerely,

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Executive Summary

Growth and development expand communities' opportunities by bringing in new residents, businesses, and investments. Growth can give a community the resources to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, shop, and play. However, with the benefits come challenges. The environmental impacts of development can make it more difficult for communities to protect their natural resources. Where and how communities accommodate growth has a profound impact on the quality of their streams, rivers, lakes, and beaches. Development that uses land efficiently and protects undisturbed natural lands allows a community to grow and still protect its water resources.

The U.S. Census Bureau projects that the U.S. population will grow by 50 million people, or approximately 18 percent, between 2000 and 2020. Many communities are asking where and how they can accommodate this growth while maintaining and improving their water resources. Some communities have interpreted water-quality research to mean that low-density development will best protect water resources. However, some water-quality experts argue that this strategy can backfire and actually harm water resources. Higher-density development, they believe, may be a better way to protect water resources. This study intends to help guide communities through this debate to better understand the impacts of high- and low-density development on water resources.

To more fully explore this issue, EPA modeled three scenarios of different densities at three scales—one-acre level, lot level, and watershed level—and at three different time series build-out examples to examine the premise that lower-density development is always better for water quality. EPA examined stormwater runoff from different development densities to determine the comparative difference between scenarios. This analysis demonstrated:

- The higher-density scenarios generate less stormwater runoff per house at all scales—one acre, lot, and watershed—and time series build-out examples;
- For the same amount of development, higher-density development produces less runoff and less impervious cover than low-density development; and
- For a given amount of growth, lower-density development impacts more of the watershed.

Taken together, these findings indicate that low-density development may not always be the preferred strategy for protecting water resources. Higher densities may better protect water quality—especially at the lot and watershed levels. To accommodate the same number of houses, denser developments consume less land than lower density developments. Consuming less land means creating less impervious cover in the watershed. EPA believes that increasing development densities is one strategy communities can use to minimize regional water quality impacts. To fully protect water resources, communities need to employ a wide range of land use strategies, based on local factors, including building a range of development densities, incorporating adequate open space, preserving critical ecological and buffer areas, and minimizing land disturbance.

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Introduction

Growth and development expand communities' opportunities by bringing in new residents, businesses, and investments. Growth can give a community the resources to revitalize a downtown, refurbish a main street, build new schools, and develop vibrant places to live, work, shop, and play. However, with the benefits come challenges. The environmental impacts of development can make it more difficult for communities to protect their natural resources. Where and how communities accommodate growth has a profound impact on the quality of their streams, rivers, lakes, and beaches. Development that uses land efficiently and protects undisturbed natural lands allows a community to grow and still protect its water resources.

The U.S. Census Bureau projects that the U.S. population will grow by 50 million people, or approximately 18 percent, between 2000 and 2020. Many communities are asking where and how they can accommodate this growth while maintaining and improving their water resources. Some communities have interpreted water-quality research to mean that low-density development will best protect water resources. However, some water-quality experts argue that this strategy can backfire and actually harm water resources. Higher-density development, they believe, may be a better way to protect water resources. This study intends to help guide communities through this debate to better understand the impacts of high- and low-density development on water resources.

Which is a better strategy to protect water quality: low- or high-density development?

Virtually every metropolitan area in the United States has expanded substantially in land area in recent decades. According to the U.S. Department of Agriculture's National Resources Inventory (NRI), between 1954 and 1997, urban land area almost quadrupled, from 18.6 million acres to about 74 million acres in the contiguous 48 states (USDA, 1997b). From 1982 to 1997, when population in the contiguous United States grew by about 15 percent, developed land increased by 25 million acres, or 34 percent. Most of this growth is taking place at the edge of developed areas, on greenfield sites, which can include forestland, meadows, pasture, and rangeland (USDA, 1997a). Indeed, in one analysis of building permits in 22 metropolitan areas between 1989 and 1998, approximately 95 percent of building permits were on greenfield sites (Farris, 2001).

Between 1954 and 1997, urban land area almost quadrupled, from 18.6 million acres to about 74 million acres in the contiguous 48 states.

According to the American Housing Survey, 35 percent of new housing is built on lots between two and five acres, and the median lot size is just under one-half acre (Census, 2001). Local zoning may encourage building on relatively large lots, in part because local governments often believe that it helps protect their water quality. Indeed, research has revealed that more impervious cover can degrade water quality. Studies have demonstrated that at 10 percent imperviousness, a watershed is likely to become impaired and grows more so as imperviousness increases (Arnold, 1996; Schueler, 1994). This research has prompted many communities to adopt low-density zoning and site-level imperviousness limits, e.g., establishing a percentage of the site, such as 10 or 20 percent, that can be covered by

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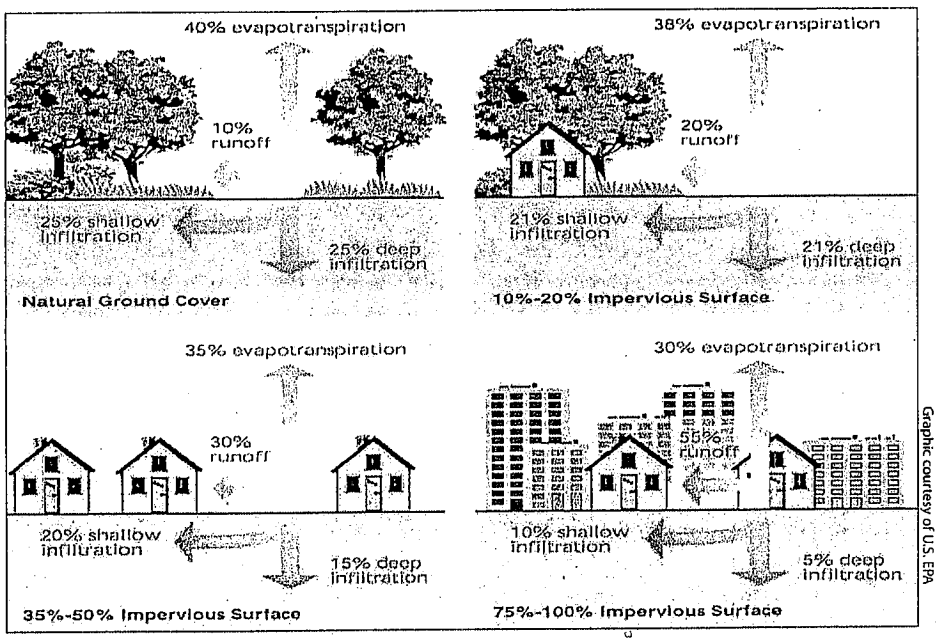
impervious surfaces such as houses, garages, and driveways. These types of zoning and development ordinances are biased against higher-density development because it has more impervious cover. But do low-density approaches protect our water resources?

This study examines the assumption that low-density development is always better for water quality.[1] EPA modeled stormwater runoff from different development densities at the site level and then extrapolated and analyzed these findings at the watershed level. Modeling results were used to compare stormwater runoff associated with several variations of residential density.

Impacts from Development on Watershed Functions

A watershed is a land area that drains to a given body of water. Precipitation that falls in the watershed will either infiltrate into the ground, evapotranspirate back into the air, or run off into streams, lakes, or coastal waters. This dynamic is described in Exhibit 1.

EXHIBIT 1: Watershed Services



Graphic courtesy of U.S. EPA

As land cover changes, so does the amount of precipitation that absorbs into the ground, evaporates into the air, or runs off.

A watershed may be large or small. The Mississippi River, for example, drains a one-million-square-mile watershed made up of thousands of smaller watersheds, such as the drainage basins of the creeks that flow into tributaries of the Mississippi. In smaller watersheds, a few acres of land may drain into small streams, which flow into larger streams or rivers; the lands drained by these streams or rivers make up a larger watershed. These streams support

[1] Stormwater runoff was used as a proxy for overall water quality. In general, the more stormwater runoff a region experiences, the more associated pollutants, such as total nitrogen, phosphorus, and suspended solids, will enter receiving waterbodies.

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diverse aquatic communities and perform the vital ecological roles of processing the carbon, sediments, and nutrients upon which downstream ecosystems depend. Healthy, functioning watersheds naturally filter pollutants and moderate water quality by slowing surface runoff and increasing the infiltration of water into soil. The result is less flooding and soil erosion, cleaner water downstream, and greater ground water reserves.

Land development directly affects watershed functions. When development occurs in previously undeveloped areas, the resulting alterations to the land can dramatically change how water is transported and stored. Residential and commercial development create impervious surfaces and compacted soils that filter less water, which increases surface runoff and decreases ground water infiltration. These changes can increase the volume and velocity of runoff, the frequency and severity of flooding, and peak storm flows.

Moreover, during construction, exposed sediments and construction materials can be washed into storm drains or directly into nearby bodies of water. After construction, development usually replaces native meadows, forested areas, and other natural landscape features with compacted lawns, pavement, and rooftops. These largely impervious surfaces generate substantial runoff. For these reasons, limiting or minimizing the amount of land disturbed and impervious cover created during development can help protect water quality.

Critical Land Use Components for Protecting Water Quality for Both Low- and High-Density Development

What strategies can communities use to continue to grow while protecting their water quality? Watershed hydrology suggests that three primary land use strategies can help to ensure adequate water resource protection:

- Preserve large, continuous areas of absorbent open space;
- Preserve critical ecological areas, such as wetlands, floodplains, and riparian corridors; and
- Minimize overall land disturbance and impervious surface associated with development.

These approaches work because, from a watershed perspective, different land areas have different levels of ecological value. For example, a nutrient-rich floodplain has a higher ecological value than a grass meadow. Communities should view these strategies as basic steps to preserve watershed function and as the framework within which all development occurs.

Preserving Open Space

Preserving open space is critical to maintaining water quality at the regional level. Large, continuous areas of open space reduce and slow runoff, absorb sediments, serve as flood control, and help maintain aquatic communities. To ensure well-functioning watersheds, regions should set aside sufficient amounts of undisturbed, open space to absorb, filter, and store rainwater. In most regions, this undeveloped land comprises large portions of a watershed, filtering

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out trash, debris, and chemical pollutants before they enter a community's water system. Open space provides other benefits, including habitat for plants and animals, recreational opportunities, forest and ranch land, places of natural beauty, and community recreation areas.

To protect these benefits, some communities are preserving undeveloped parcels or regional swaths of open space. One of the most dramatic examples is the New York City Watershed Agreement. New York City, New York State, over 70 towns, eight counties, and EPA signed the agreement to support an enhanced watershed protection program for the New York City drinking water supply. The city-funded, multi-year, $1.4-billion agreement developed a multi-faceted land conservation approach, which includes the purchase of 80,000 acres within the watershed as a buffer around the city's drinking water supply. This plan allows the city to avoid the construction of filtration facilities estimated to cost six to eight billion dollars (New York City, 2002).

Preserving Ecologically Sensitive Areas

Some types of land perform watershed functions better than others do. Preserving ecologically important land, such as wetlands, buffer zones, riparian corridors, and floodplains, is critical for regional water quality. Wetlands are natural filtration plants, slowing water flow and allowing sediments to settle and the water to clarify. Trace metals bound to clay carried in runoff also drop out and become sequestered in the soils and peat at the bed of the marsh instead of entering waterbodies, such as streams, lakes, or rivers. Preserving and maintaining wetlands are critical to maintain water quality.



Photo courtesy of USDA NRCS

Wetlands, such as this one in Butte County, California, provide critical watershed services for the region.

In addition, strips of vegetation along streams and around reservoirs are important buffers, with wooded buffers offering the greatest protection. For example, if soil conditions are right, a 20- to 30-foot-wide strip of woodland removes 90 percent of the nitrates in stormwater runoff (Trust for Public Land, 1997). These buffer zones decrease the amount of pollution entering the water system. Tree and shrub roots hold the bank in place, preventing erosion and its resulting sedimentation and turbidity. Organic matter and grasses slow the flow of runoff, giving the sediment time to settle and water time to percolate, filter through the soil, and recharge underlying ground water. Research has shown that wetlands and buffer zones, by slowing and holding water, increase ground water recharge, which directly reduces the potential for flooding (Schueler, 1994). By identifying and preserving these critical ecological areas, communities are actively protecting and enhancing their water quality.

Minimizing Land Disturbance and Impervious Cover

Minimizing land disturbance and impervious cover is critical to maintaining watershed health. The amount of land that is converted, or "disturbed," from undeveloped uses, such as forests and meadows, to developed uses, such as lawns and playing fields, significantly affects watershed health. Research now shows that the volume of runoff from highly compacted lawns is almost as high as from paved surfaces (Schueler, 1995, 2000; USDA, 2001). This research indicates that lawns and other residential landscape features do not function, with regard to water, in the same way as nondegraded natural areas. In part, the difference arises because developing land in greenfield areas involves wholesale grading of the site and removal of topsoil, which can lead to severe erosion during construction, and soil compaction by heavy equipment. However, most communities focus not on total land disturbed, but on the amount of impervious cover created.

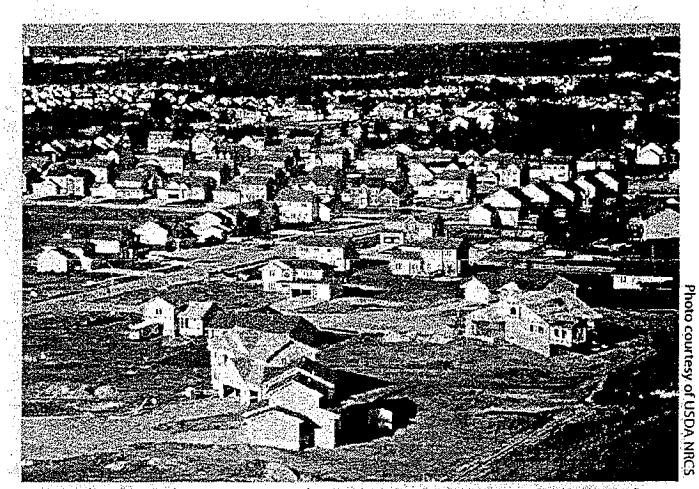

Photo courtesy of USDA NRCS

Current construction practices generally disturb the entire development site, as shown by this site in Des Moines, Iowa.

Research has revealed a strong relationship between impervious cover and water quality (Arnold, 1996; Schueler, 1994; EPA, 1997). Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles, or derived from other sources. During storms, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems. Studies have demonstrated that at 10 percent imperviousness,[2] a watershed is likely to become impaired (Schueler, 1996; Caraco, 1998; Montgomery County, 2000), the stream channel becomes unstable due to increased water volumes and stream bank erosion, and water quality and stream biodiversity decrease. At 25 percent imperviousness, a watershed becomes severely impaired, the stream channel can become highly unstable, and water quality and stream biodiversity are poor[3] (Schueler, 2000). The amount of impervious cover is an important indicator of watershed health, and managing the degree to which a watershed is developed is critical to maintaining watershed function.

Although the 10 percent threshold refers to overall imperviousness within the watershed, municipalities have applied it to individual sites within the watershed, believing that lower densities better protect watershed functions. Indeed, as mentioned earlier, some localities have gone so far as to create strong incentives for, or even require, low densities—with water resource protection as an explicit goal. These communities are attempting to minimize hard

[2] The 10 percent figure is not an absolute threshold. Recent studies have indicated that in some watersheds, serious degradation may begin well below 10 percent. However, the level at which watershed degradation begins is not the focus of this study. For purposes of our analysis, EPA uses the 10 percent threshold as an indicator that water resources might be impacted.

[3] There are different levels of impairment. In general, when the term is used in EPA publications, it usually means that a waterbody is not meeting its designated water quality standard. However, the term can also imply a decline or absence of biological integrity; for example, the waterbody can no longer sustain critical indicator species, such as trout or salmon. Further, there is a wide breadth of levels of impairment, from waterbodies that are unable to support endangered species to waterbodies that cannot support any of the beneficial-use designations.

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surfaces at the site level. They believe that limiting densities within particular development sites limits regional imperviousness and thus protects regional water quality. The next section examines this proposition and finds that low-density development can, in fact, harm water quality.

Low-Density Development—Critiquing Conventional Wisdom

As discussed, studies have demonstrated that watersheds can suffer impairment at 10 percent impervious cover and that at 25 percent imperviousness, the watershed is typically considered severely impaired. Communities have often translated these findings into the notion that low-density development at the site level results in better water quality. Such conclusions often come from analysis such as: a one-acre site has one or two homes with a driveway and a road passing by the property. The remainder of the site is lawn. Assuming an average housing footprint of 2,265 square feet[4] (National Association of Home Builders, 2001), the impervious cover for this one-acre site is approximately 35 percent (Soil Conservation Service, 1986). By contrast, a higher-density scenario might have eight to 10 homes per acre and upwards of 85 percent impervious cover (Soil Conservation Service, 1986). The houses' footprints account for most of the impervious cover. Thus, low-density zoning appears to create less impervious cover, which ought to protect water quality at the site and regional levels. However, this logic overlooks several key caveats.

1. *The "pervious" surface left in low-density development often acts like impervious surface.* In general, impervious surfaces, such as a structure's footprint, driveways, and roads, have higher amounts of runoff and associated pollutants than pervious surfaces. However, most lawns, though pervious, still contribute to runoff because they are compacted. Lawns are thought to provide "open space" for infiltration of water. However, because of construction practices, the soil becomes compacted by heavy equipment and filling of depressions (Schueler, 1995, 2000). The effects of this compaction can remain for years and even increase due to mowing and the presence of a dense mat of roots. Therefore, a one- or two-acre lawn does not offer the same infiltration or other water quality functions as a one- or two-acre undisturbed forest. Minimizing impervious surfaces by limiting the number of houses but allowing larger lawns does not compensate for the loss of watershed services that the area provided before development (USDA, 2001).

   Lawns still contribute to runoff because they are compacted and disturbed.

2. *Density and imperviousness are not equivalent.* Depending on the design, two houses may actually create as much imperviousness as four houses. The impervious area per home can vary widely due to road infrastructure, housing design (single story or multistory), or length and width of driveways. To illustrate, a three-story condominium building of 10 units on one acre can have less impervious surface than four single-family homes on the same acre. Furthermore, treatment of the remaining undeveloped land on that acre can

[4] The average house built in 2001 included three or more bedrooms, two and a half baths, and a two-car garage.

vary dramatically between housing types. For example, in some dispersed, low-density communities, such as Fairfax County, Virginia, some homeowners are paving their front lawns to create more parking for their cars (Rein, 2002).

3. *Low-density developments often mean more off-site impervious infrastructure.* Development in the watershed is not simply the sum of the sites within it. Rather, total impervious area in a watershed is the sum of site developments plus the impervious surface associated with infrastructure supporting those sites, such as roads and parking lots. Lower-density development can require substantially higher amounts of this infrastructure per house and per acre than denser developments. Recent research has demonstrated that on sites with two homes per acre, impervious surfaces attributed to streets, driveways, and parking lots can represent upwards of 75 percent of the total site imperviousness (Cappiella, 2001). That number decreases to 56 percent on sites with eight homes per acre. This research indicates that low densities often require more off-site transportation-related impervious infrastructure, which is generally not included when calculating impervious cover.

Water quality suffers not only from the increase in impervious surface, but also from the associated activities: construction, increased travel to and from the development, and extension of infrastructure.

Furthermore, water quality suffers not only from the increase in impervious surface, but also from the associated activities: construction, increased travel to and from the development, extension of infrastructure, and chemical maintenance of the areas in and surrounding the development. Oil and other waste products, such as heavy metals, from motor vehicles, lawn fertilizers, and other common solvents, combined with the increased flow of runoff, contribute substantially to water pollution. As imperviousness increases, so do associated activities, thereby increasing the impact on water quality.

4. *If growth is coming to the region, limiting density on a given site does not eliminate that growth.* Density limits constrain the amount of development on a site but have little effect on the region's total growth (Pendall, 1999, 2000). The rest of the growth that was going to come to the region still comes, regardless of density limits in a particular place. Forecasting future population growth is a standard task for metropolitan planning organizations as they plan where and how to accommodate growth in their region. They project future population growth based on standard regional population modeling practices, where wage or amenity differentials, such as climate or culture (Mills, 1994)—and not zoning practices such as density limits—account for most of a metropolitan area's population gain or loss.[5] While estimates of future growth within a particular time frame are rarely precise, a region must use a fixed amount of growth to test the effects of adopting

Growth is still coming to a region, regardless of density limits in a particular place.

[5] The most widely-used such model—the REMI® Policy Insight™ model—uses an amenity variable. However, even this is implemented as an additional change in the wage rate. See Remi Model Structure. <www.remi.com/Overview/Evaluation/Structure/structure.html>. The in-house model used by the San Diego Association of Governments is an advanced example of the type used by councils of governments around the country.<www.sandag.cog.ca.us/resources/demographics_and_other_data/demographics/forecasts/index.asp>.

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different growth planning strategies because it still must understand the economic, social, and environmental impacts of accommodating a growing population. Absent regional coordination and planning, covering a large part of a region with density limits will likely drive growth to other parts of the region. Depending on local conditions, water quality may be more severely impaired than if the growth had been accommodated at higher densities on fewer sites.

Testing the Alternative: Can Compact Development Minimize Regional Water Quality Impacts?

To more fully understand the potential water quality impacts of different density levels, this section compares three hypothetical communities, each accommodating development at different densities—one house per acre, four houses per acre, and eight houses per acre.[6] To assess regional water quality impacts, EPA modeled the stormwater impacts from different development densities. In general, the more stormwater runoff generated within a region, the more associated pollutants, such as total nitrogen, phosphorus, and suspended solids, will enter receiving waterbodies. The three density levels capture some of the wide range of zoning practices in use throughout the country. All of these densities are consistent with single-family, detached housing. EPA examined the stormwater impacts from each density scenario at various scales of residential development[7]—one-acre, lot, and watershed levels—and through a 40-year time series build-out analysis.

The Model and Data Inputs

The model used to compare the stormwater impact from the scenarios is the Smart Growth Water Assessment Tool for Estimating Runoff (SG WATER), which is a peer-reviewed sketch model that was developed specifically to compare water quantity and quality differences among different development patterns (EPA, 2002). SG WATER's methodology is based on the Natural Resources Conservation Service (NRCS) curve numbers (Soil Conservation Service, 1986), event mean concentrations, and daily rainfall data.[8] The model requires the total number of acres developed at a certain development density. If density is unknown, total percent imperviousness can be used. The model was run using overall percent imperviousness.

EPA believes that the results presented here are conservative. SG WATER uses a general and simple methodology based on curve numbers. One limitation of curve numbers is that they tend to underestimate stormwater runoff for smaller storms (less than one inch). This underestimate

[6] Densities at one, four, and eight residential units per acre are used here for illustrative purposes only. Many communities now are zoning for one unit per two acres at the low-density end of the spectrum. Low-density residential zoning exists in places as diverse as Franklin County, Ohio, which requires no less than two acres per unit <www.co.franklin.oh.us/development/franklin_co/LDR.html#304.041>) to Cobb County, Georgia, outside of Atlanta, which requires between one and two units per acre in its low-density residential districts (<www.cobbcounty.org/community/plan_bza_commission.htm>). By comparison, some communities are beginning to allow higher densities, upwards of 20 units per acre. For example, the high-density residential district in Sonoma County, California permits between 12 and 20 units per acre (<www.sonoma-county.org/prmd/Zoning/article_24.htm>), and the city of Raleigh, North Carolina, allows up to 40 units per acre in planned development districts.

[7] This example and others throughout this study compare residential units, but a similar comparison including commercial development could also be done.

[8] Daily time-step rainfall data for a 10-year period (1992-2001, inclusive) were used.

can be significant since the majority of storms are small storms. In addition, the curve numbers tend to overestimate runoff for large storms. However, curve numbers more accurately predict runoff in areas with more impervious cover.[9] For the analysis here, the runoff from the low-density site is underestimated to a larger degree than the runoff from the higher-density site because the higher-density site has more impervious cover. Simply put, because of methodology, the difference in the numbers presented here is conservative—it is likely that the comparative difference in runoff between the sites would be greater if more extensive modeling were used.

To isolate the impacts that developing at different densities makes on stormwater runoff, EPA made several simplifying assumptions in the modeling:

- EPA modeled only residential growth and not any of the corresponding commercial, retail, or industrial growth that would occur in addition to home building. Moreover, EPA assumed that all the new growth would occur in greenfields (previously undeveloped land). Infill development, brownfield redevelopment, and other types of urban development were not taken into consideration, nor were multifamily housing, apartments, or accessory dwelling units.[10]
- The modeling did not take into account any secondary or tertiary impacts, such as additional stormwater benefits, that may be realized by appropriately locating the development within the watershed. For example, siting development away from headwaters, recharge areas, or riparian corridors could better protect these sensitive areas. Denser development makes this type of protective siting easier since less land is developed. However, these impacts are not captured or calculated within the modeling.
- Whether developed at one, four, or eight houses per acre, when one acre is developed, EPA assumed the entire acre is disturbed land (e.g., no forest or meadow cover would be preserved), which is consistent with current construction practices.
- All the new growth is assumed to be single-family, detached houses.[11] Whether developed at one, four, or eight houses per acre, each home has a footprint of 2,265 square feet, roughly the current average size for new houses (National Association of Home Builders, 2001).

[9] Most existing stormwater models incorrectly predict flows associated with small rains in urban areas. Most existing urban runoff models originated from drainage and flooding evaluation procedures that emphasized very large rains (several inches in depth). These large storms contribute only very small portions of the annual average discharges. Moderate storms, occurring several times a year, are responsible for the majority of the pollutant discharges. These frequent discharges cause mostly chronic effects, such as contaminated sediment and frequent high flow rates, and the inter-event periods are not long enough to allow the receiving water conditions to recover.

[10] Single-family, detached housing dominates many low-density residential developments. However, higher-density developments support a range of housing types, including townhouses, apartments, and other forms of multifamily housing. These housing types generally have a smaller footprint per house than 2,265 square feet. Therefore, a more realistic situation for the higher-density scenarios would either be a smaller housing footprint or an increase in the number of homes accommodated on one acre. In either case, including these different housing types in the analysis would produce less overall stormwater runoff and less per house runoff for the higher-density scenarios.

[11] It is possible that when additional land uses, such as commercial, transportation, or recreation, are included in the analysis, the low-density scenarios become relatively less dense while the higher-density scenarios become relatively more dense. In general, low-density residential development tends to be associated with low-density commercial development, characterized by large retail spaces, wide roads, large parking lots, and minimal public transportation. Higher-density residential areas are more likely to have high-density commercial options, with smaller retail spaces, mixed land uses, narrower streets, parking garages, on-street parking, and sometimes a well-developed public transportation system, which can reduce parking needs.

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- The same percentage of transportation-associated infrastructure, such as roads, parking lots, driveways, and sidewalks, is allocated to each community acre, based on the curve number methodology from the NRCS. For example, each scenario has the same width of road, but because the higher-density scenario is more compact, it requires fewer miles of roads than the lower-density scenarios. So while the same percentage is applied, the amounts differ by scenario. Collector roads or arterials that serve the development are not included.
- The modeled stormwater runoff quantity for each scenario is assumed to come from one hypothetical outfall.
- The model does not take into account wastewater or drinking water infrastructure, slope, or other hydrological interactions that the more complex water modeling tools use.

Summary of Scenarios

Example 1 examines the stormwater runoff impacts on a one-acre lot that accommodates one house (Scenario A), four houses (Scenario B), or eight houses (Scenario C). Example 2 expands the analysis to examine stormwater runoff impacts within a lot-level development that accommodates the same number of houses. Because of different development densities, this growth requires different amounts of land. Scenario A requires eight acres for eight houses, Scenario B requires two acres for eight houses, and Scenario C requires one acre for eight houses.

Examples 3, 4, and 5 explore the relationship between density and land consumption by building in a watershed at different densities. Again, different amounts of land are required to support the same amount of housing. Examples 6, 7, and 8 examine how the hypothetical community grows over a 40-year timeframe with different development densities.

The scenarios and scales of development are summarized in Exhibit 2. EPA expects to capture the differences in stormwater runoff associated with different development densities by using these three scenarios (Scenarios A, B, and C) at four different scales (one acre, lot, watershed, and build-out).

EXHIBIT 2: Summary of Scenarios

Scale of Analysis	Scenario A: One house per acre	Scenario B: Four houses per acre	Scenario C: Eight houses per acre
Example 1: One acre	1 house per acre	4 houses per acre	8 houses per acre
Example 2: Lot—Each development lot accommodates the same number of houses	8 houses built on 8 acres	8 houses built on 2 acres	8 houses built on 1 acre

Example 3: Watershed—Each 10,000-acre watershed accommodates the same number of houses	10,000 houses built on 10,000 acres	10,000 houses built on 2,500 acres or ¼ of the watershed	10,000 houses built on 1,250 acres or ⅛ of the watershed
Example 4: Watershed—Each 10,000-acre watershed is fully built out at different densities	10,000 houses built on 10,000 acres	40,000 houses built on 10,000 acres	80,000 houses built on 10,000 acres
Example 5: Watershed—Each scenario accommodates the same number of houses	80,000 houses consume 8 watersheds	80,000 houses consume 2 watersheds	80,000 houses consume 1 watershed
Example 6: Hypothetical build-out in the year 2000	10,000 houses built on 10,000 acres	10,000 houses built on 2,500 acres	10,000 houses built on 1,250 acres
Example 7: Hypothetical build-out in the year 2020	20,000 houses built on 20,000 acres, or 2 watersheds	20,000 houses built on 5,000 acres, or ½ of 1 watershed	20,000 houses built on 2,500 acres, or ¼ of 1 watershed
Example 8: Hypothetical build-out in the year 2040	40,000 houses built on 40,000 acres, or 4 watersheds	40,000 houses built on 10,000 acres, or 1 watershed	40,000 houses built on 5,000 acres, or ½ of 1 watershed

Before analyzing the impacts of these different scenarios, it is useful to clarify some underlying premises. This analysis assumes that:

1. Metropolitan regions will continue to grow. This assumption is consistent with U.S. Census Bureau projections that the U.S. population will grow by roughly 50 million people by 2020 (Census, 2000). Given this projected population growth, most communities across the country are or will be determining where and how to accommodate expected population increases in their regions.

2. Housing density affects the distribution of new growth within a given region, not the amount of growth. Individual states and regions grow at different rates depending on a variety of factors, including macroeconomic trends (e.g., the technology boom in the 1980s spurring development in the Silicon Valley region in California) and demographic shifts. Distribution and density of new development do not significantly affect these factors.

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3. The model focuses on the comparative differences in stormwater runoff between scenarios, not absolute values. As discussed, using the curve number and event mean concentration approach can underestimate the total quantity of stormwater runoff for smaller storm events and in areas of lower densities. Because of this and other model simplifications discussed above, the analysis does not focus on the absolute value of stormwater runoff generated for each scenario but instead focuses on the comparative difference, or the delta, in runoff between scenarios.

Results

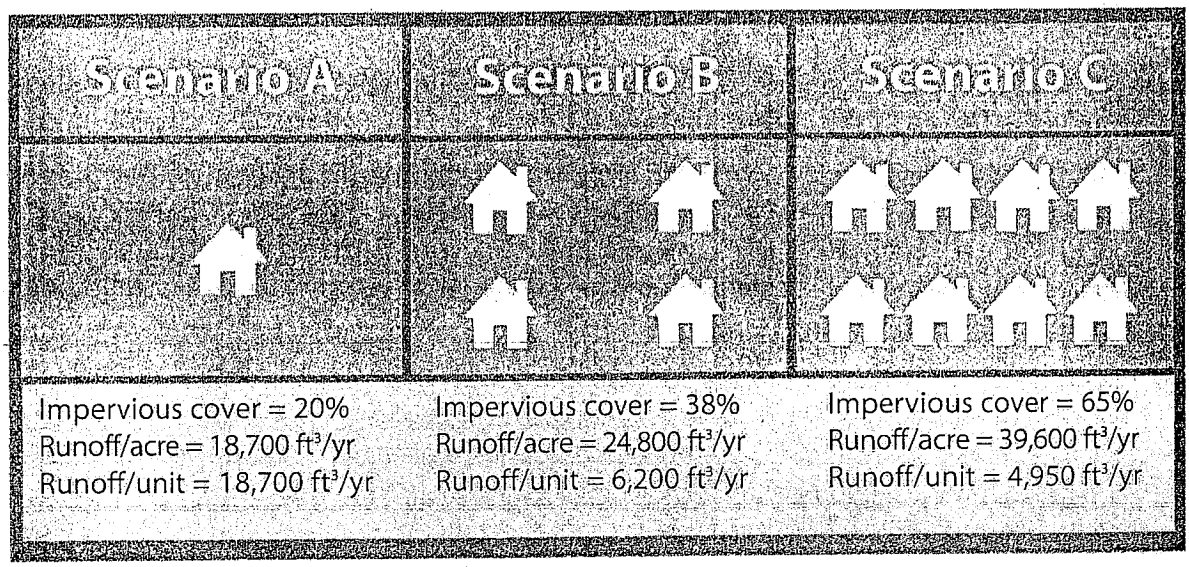
The results from the eight examples for all three scenarios are presented below.

EXAMPLE 1: ONE-ACRE LEVEL

Scale of Analysis	Scenario A	Scenario B	Scenario C
One Acre	1 house	4 houses	8 houses

EPA examined one acre developed at three different densities: one house, four houses, and eight houses. The results are presented in Exhibit 3. As Exhibit 3 demonstrates, the overall percent imperviousness for Scenario A is approximately 20 percent with one house per acre, 38 percent for Scenario B with four houses per acre, and 65 percent for Scenario C with eight houses per acre (Soil Conservation Service, 1986).

EXHIBIT 3: Total Average Annual Stormwater Runoff for All Scenarios



Examining the estimated average annual runoff at the acre level, as illustrated in Exhibit 4, the low-density Scenario A, with just one house, produces an average runoff volume of 18,700 cubic feet per year (ft^3/yr). Scenario C, with eight houses, produces 39,600 ft^3/yr, and Scenario B falls between Scenarios A and C at 24,800 ft^3/yr. In short, looking at the comparative differences between scenarios, runoff roughly doubles as the number of houses increases from one house per acre to eight houses per acre. Scenario C, with more houses on the acre, has the greatest amount of impervious surface cover and thus generates the most runoff at the acre level.

Looking at the comparative difference of how much runoff each individual house produces, in Scenario A, one house yields 18,700 ft^3/yr, the same as the per acre level. In the denser Scenario C, however, each house produces 4,950 ft^3/yr average runoff. The middle scenario, Scenario B, produces considerably less runoff—6,200 ft^3/yr—per house than Scenario A, but more than Scenario C. Each house in Scenario B produces approximately 67 percent less runoff than a house in Scenario A, and each house in Scenario C produces 74 percent less runoff than a house in Scenario A. This is because the houses in Scenarios B and C create less impervious surface per house than the house in Scenario A. Therefore, per house, each home in the higher-density communities results in less stormwater runoff.

Each house in Scenario B produces approximately 67 percent less runoff than a house in Scenario A, and each house in Scenario C produces 74 percent less runoff than a house in Scenario A.

Modeling at the acre level demonstrates that, in this example, when density is quadrupled (from one house to four houses), stormwater runoff increases by one-third per acre, but decreases by two-thirds per house. Moreover, when density increases by a factor of eight—from one house to eight houses—stormwater runoff doubles per acre, but decreases by almost three-quarters per house.

These results indicate when runoff is measured by the acre, limiting density does minimize water quality impacts compared to the higher-density scenarios. However, when measured by the house, higher densities produce less stormwater runoff.

EXAMPLE 2: LOT LEVEL

Scale of Analysis	Scenario A	Scenario B	Scenario C
Lot	8 houses built on 8 acres	8 houses built on 2 acres	8 houses built on 1 acre

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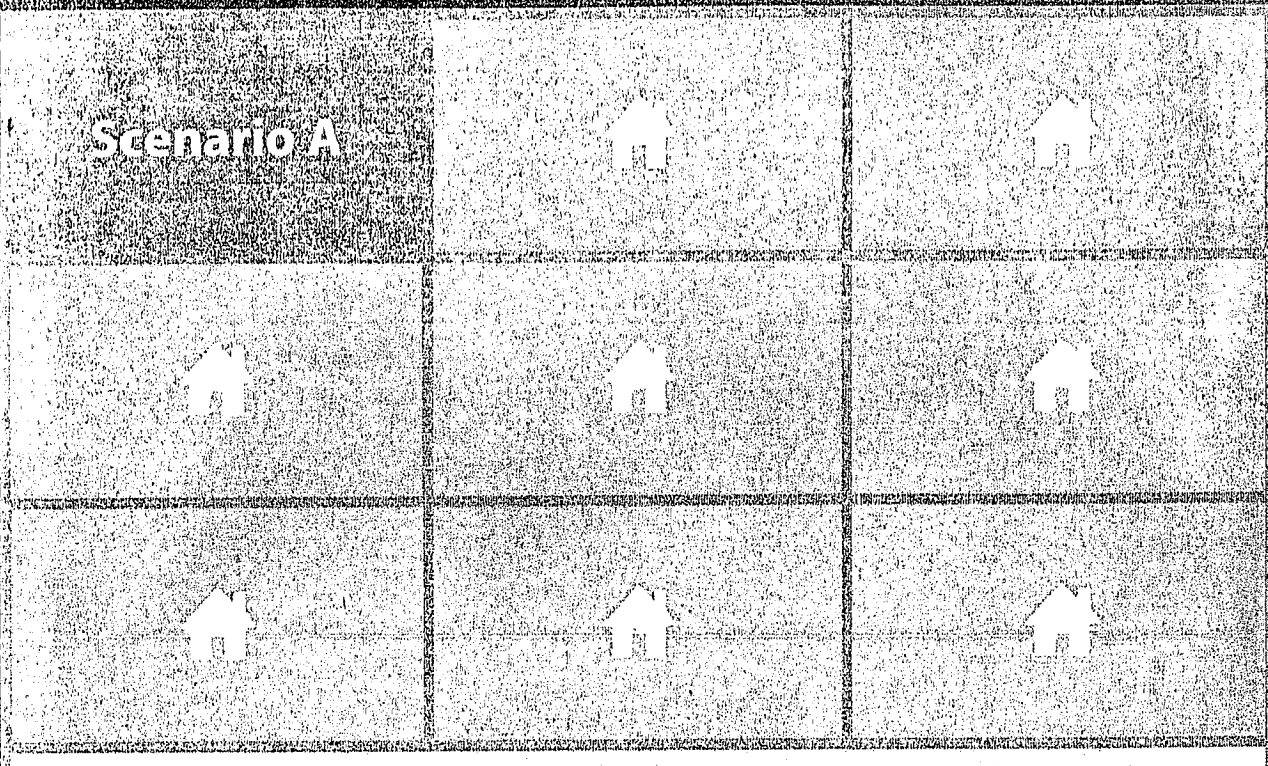
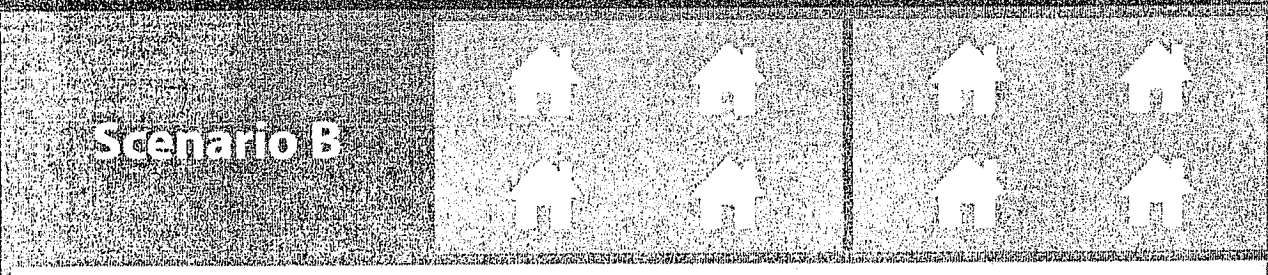
EXHIBIT 4: Each Scenario Accommodates Eight Houses

Scenario A



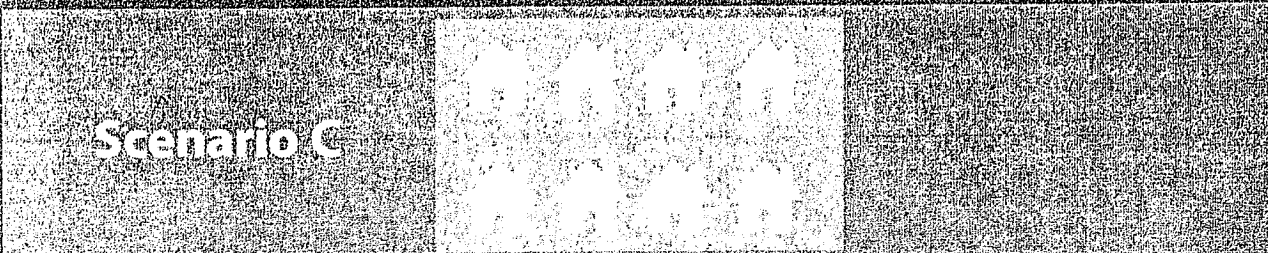
Impervious cover = 20%	Total runoff (18,700 ft³/yr x 8 acres) = 149,600 ft³/yr	Runoff/house = 18,700 ft³/yr

Scenario B



Impervious cover = 38%	Total runoff (24,800 ft³/yr x 2 acres) = 49,600 ft³/yr	Runoff/house = 6,200 ft³/yr

Scenario C



Impervious cover = 65%	Total runoff = 39,600 ft³/yr	Runoff/house = 4,950 ft³/yr

For each development to accommodate the same number of houses, the lower-density scenarios require more land to accommodate the same number of houses that Scenario C has accommodated on one acre. Specifically, Scenario A must develop seven additional acres, or eight acres total, to accommodate the same number of houses as Scenario C. Scenario B must develop two acres to accommodate the same number of houses. Exhibit 4 illustrates.

The increase in runoff for Scenario A is due to the additional land consumption.

With each scenario accommodating the same number of houses, this analysis shows that total average runoff in Scenario A is 149,600 ft^3/yr (18,700 ft^3/yr x 8 acres), which is a 278 percent increase from the 39,600 ft^3/yr total runoff in Scenario C. Total average runoff from eight houses in Scenario B is 49,600 ft^3/yr (24,800 ft^3/yr x 2 acres), which is a 25 percent increase in runoff from Scenario C. The increase in runoff for Scenario A is due to the additional land consumption and associated runoff. The impervious cover for Scenario A remains the same at 20 percent, but now, seven additional acres have 20 percent impervious cover.

Examining the comparative difference in runoff between scenarios shows that lower densities can create less total impervious cover, but produce more runoff when the number of houses is kept consistent between scenarios. Furthermore, the higher-density scenario produces less runoff per house and per lot.

EXAMPLE 3: WATERSHED LEVEL

Scale of Analysis	Scenario A	Scenario B	Scenario C
Watershed—Each 10,000-acre watershed accommodates the same number of houses	10,000 houses built on 10,000 acres	10,000 houses built on 2,500 acres	10,000 houses built on 1,250 acres

Taking the analysis to the watershed level, EPA examined the comparative watershed stormwater runoff impacts from accommodating growth at different densities. The watershed used in this analysis is a hypothetical 10,000-acre watershed accommodating only houses. As discussed, the modeling does not include retail, business centers, farms, or any other land uses typically seen in communities, nor does it take into consideration where the development occurs within the watershed. Research has shown that upper sub-watersheds, which contain smaller streams, are generally more sensitive to development than lower sub-watersheds (Center for Watershed Protection, 2001).

Accommodating 10,000 houses at one house per acre in the 10,000-acre watershed would fully build out the watershed. At the higher density of four houses per acre, one-quarter of the watershed would be developed, and at eight houses per acre, one-eighth of the watershed would be developed. Exhibit 5 shows the runoff associated with each of these scenarios.

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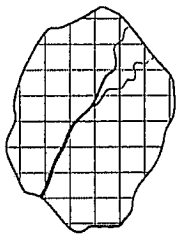
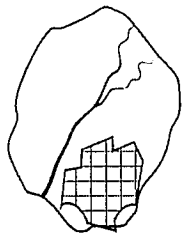
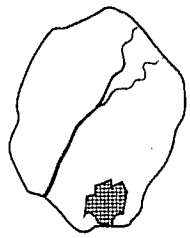
EXHIBIT 5: 10,000-Acre Watershed Accommodating 10,000 Houses

Scenario A	Scenario B	Scenario C
		
10,000 houses built on 10,000 acres produce: 10,000 acres x 1 house x 18,700 ft^3/yr of runoff = **187 million ft^3/yr of stormwater runoff** **Site: 20% impervious cover** **Watershed: 20% impervious cover**	**10,000 houses built on 2,500 acres produce:** **2,500 acres x 4 houses x 6,200 ft^3/yr of runoff = 62 million ft^3/yr of stormwater runoff** **Site: 38% impervious cover** **Watershed: 9.5% impervious cover**	10,000 houses built on 1,250 acres produce: 1,250 acres x 8 houses x 4,950 ft^3/yr of runoff = **49.5 million ft^3/yr of stormwater runoff** **Site: 65% impervious cover** **Watershed: 8.1% impervious cover**

As Exhibit 5 illustrates, if development occurs at a lower density, e.g., one house per acre, the entire watershed will be built out, generating 187 million ft^3/yr of stormwater runoff. Scenario B, at four houses per acre, consumes less land and produces approximately 62 million ft^3/yr of stormwater runoff, while Scenario C, at the highest density, consumes the least amount of land and produces just 49.5 million ft^3/yr of stormwater runoff. Looking at the comparative differences, Scenario A generates approximately three times as much runoff from development as Scenario B, and approximately four times as much stormwater runoff as Scenario C.

Exhibit 5 also illustrates that, in this example, overall impervious cover for the watershed decreases as site density increases. Scenario C, which has a lot-level imperviousness of 65 percent, has a watershed-level imperviousness of only 8.1 percent, which is lower than the 10

Overall impervious cover for the watershed decreases as site density increases.

percent threshold discussed earlier. Scenario B, with a density of four houses per acre, has a site-level impervious cover of 38 percent, but a watershed imperviousness of 9.5 percent, which is still lower than the 10 percent threshold. Finally, Scenario A, at a lot-level imperviousness of 20 percent, has the same overall imperviousness at the watershed level. **Both of the higher-density scenarios consume less land and maintain below-the-threshold imperviousness.**

This simplistic illustration demonstrates a basic point of this analysis—higher-density developments can minimize stormwater impacts because they consume less land than their lower-density counterparts. For example, imagine if Manhattan, which accommodates 1.54 million people on 14,720 acres (23 square miles) (Census, 2000), were developed not at its current density of 52 houses per acre, but at one or four houses per acre. At one house per acre, Manhattan would need approximately 750,000 more acres, or an additional 1,170 square miles, to accommodate its current population at two people per household. That's approximately the size of Rhode Island. At four houses per acre, Manhattan would need approximately 175,000 more acres, or an additional 273 square miles.

At one house per acre, Manhattan would need approximately 750,000 more acres, or an additional 1,170 square miles, to accommodate its current population at two people per household.

Reducing land consumption is crucial to preserving water quality because, as discussed previously, preserving large, continuous areas of open space and sensitive ecological areas is critical for maintaining watershed services. In addition, because of their dense development pattern, Scenarios B and C may realize additional stormwater benefits if the developed land is appropriately sited in the watershed to protect sensitive ecological areas, such as headwaters, wetlands, riparian corridors, and floodplains.

Example 4: Remaining Land in the Watershed Developed

What happens if the remaining undeveloped parts of the watershed in Scenarios B and C are developed? Exhibit 6 considers this situation.

Scale of Analysis	Scenario A	Scenario B	Scenario C
Watershed—Each 10,000-acre watershed is fully built out at different densities	10,000 houses built on 10,000 acres	40,000 houses built on 10,000 acres	80,000 houses built on 10,000 acres

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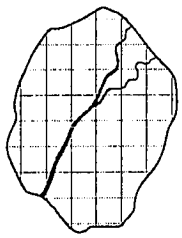
EXHIBIT 6: 10,000-Acre Watershed Accommodating Different Numbers of Houses

Scenario A



The watershed is fully built out at *1 house per acre*. 10,000 acres accommodates **10,000 houses**, translating to:

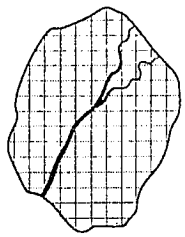
10,000 acres x 1 house x 18,700 ft^3/yr of runoff =

187 million ft^3/yr stormwater runoff

Site: 20% impervious cover

Watershed: 20% impervious cover

Scenario B



The watershed is fully built out at *4 houses per acre*. 10,000 acres accommodates **40,000 houses**, translating to:

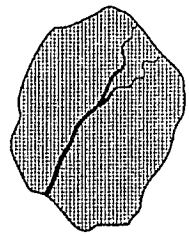
10,000 acres x 4 houses x 6,200 ft^3/yr of runoff =

248 million ft^3/yr stormwater runoff

Site: 38% impervious cover

Watershed: 38% impervious cover

Scenario C



The watershed is fully built out at 8 *houses per acre*. 10,000 acres accommodates **80,000 houses**, translating to:

10,000 acres x 8 houses x 4,950 ft^3/yr of runoff =

396 million ft^3/yr stormwater runoff

Site: 65% impervious cover

Watershed: 65% impervious cover

Each watershed is fully built out, and the watershed developed at the highest density (Scenario C) is generating approximately double the total stormwater runoff of Scenario A. Scenario B is generating approximately one-third more runoff than Scenario A. Similar to the acre-level and lot-level results, Scenario C has the highest degree of impervious cover at 65 percent, while Scenario A maintains the lowest level at 20 percent.

Scenarios A and B accommodate only a small portion of the expected growth. The rest will have to be built in other watersheds.

The higher densities found in Scenario B and C are degrading their watershed services to a greater extent than Scenario A. However, the number of houses accommodated in each community is not the same. Scenario B is accommodating **30,000 more houses** (four times the number of Scenario A), and Scenario C is accommodating **70,000 more houses** (eight times the number of Scenario A). Recall that density limits shift growth and do not generally affect the total amount of growth in a given time period. Therefore, this is not a fair comparison. Scenarios A and B accommodate only one-eighth and one-half, respectively, of the 80,000 houses accommodated in Scenario C. Where do the other houses, households, and families go? To get a true appreciation for the effects of density, Scenarios A and B must also show where those homes will be accommodated. It is likely that they would be built in nearby or adjacent watersheds. Our hypothetical community that develops at one house per acre (Scenario A) is able to accommodate only 10,000 houses. For the community that develops at that density to accommodate the same number of houses that Scenario C contains, it must disturb and develop land from nearby or adjacent watersheds.

Example 5: Accommodating the Same Number of Houses

Scale of Analysis	Scenario A	Scenario B	Scenario C
Watershed—Each scenario accommodates the same number of houses	1 house per acre—80,000 houses consume 8 watersheds	4 houses per acre—80,000 houses consume 2 watersheds	8 houses per acre—80,000 houses consume 1 watershed

As discussed, the U.S. population will increase by an estimated 50 million people by 2020. Different areas of the country will grow at different rates in the future. Whether a region anticipates 1,000 or 80,000 new households to come to the region over the next 10 years, comparisons between build-out scenarios must keep the number of homes consistent. In this case, if Scenario C is developed so that its entire watershed is built out to 80,000 houses, then for a fair comparison, Scenarios A and B must also include 80,000 houses. Exhibit 7 illustrates this situation.

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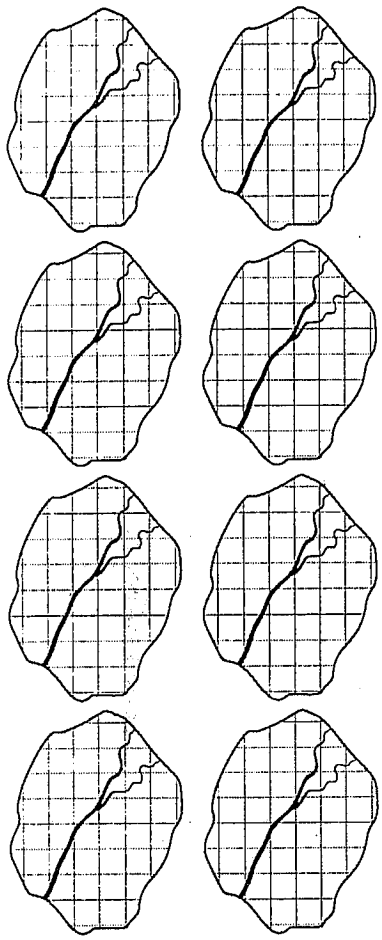
EXHIBIT 7: 80,000 Houses Accommodated

Scenario A



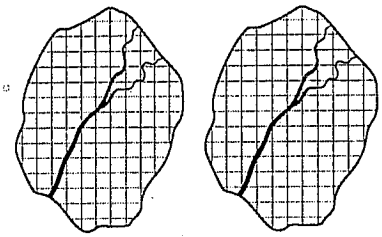
At 1 house per acre, 80,000 houses require 80,000 acres, or *8 watersheds*, translating to:

80,000 acres x 1 house x 18,700 ft^3/yr of runoff =

1.496 billion ft^3/yr of stormwater runoff

8 watersheds at 20% impervious cover

Scenario B



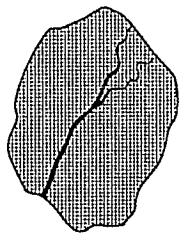
At 4 houses per acre, 80,000 houses require 20,000 acres, or *2 watersheds*, translating to:

20,000 acres x 4 houses x 6,200 ft^3/yr of runoff =

496 million ft^3/yr of stormwater runoff

2 watersheds at 38% impervious cover

Scenario C



At 8 houses per acre, 80,000 houses require 10,000 acres, or *1 watershed*, translating to:

10,000 acres x 8 houses x 4,950 ft^3/yr of runoff =

396 million ft^3/yr of stormwater runoff

1 watershed at 65% impervious cover

When the number of houses is kept consistent, Scenario A would need to develop an *additional seven watersheds* (assuming the same size watersheds) and Scenario B would need to develop *one additional watershed* to accommodate the same growth found in Scenario C.

As Exhibit 7 demonstrates, for Scenario A to accommodate the additional 70,000 homes already accommodated in Scenario C, it must develop another seven watersheds. This generates 1.496 billion ft^3/yr of stormwater runoff. Scenario C, with a development density of eight houses per acre, has still developed just one watershed and is generating approximately 74 percent less stormwater runoff than Scenario A—or 396 million ft^3/yr. Scenario B, at four houses per acre, is generating 496 million ft^3/yr runoff, or two-thirds less runoff than Scenario A, but 100 million ft^3/yr more than Scenario C.

Scenario A would need to develop an *additional seven watersheds* and Scenario B would need to develop *one additional watershed* in order to accommodate the same growth found in Scenario C.

EXAMPLE 6: TIME SERIES BUILD-OUT ANALYSIS: BUILD-OUT IN 2000

Scale of Analysis	Scenario A	Scenario B	Scenario C
Hypothetical build-out in the year 2000	10,000 houses built on 10,000 acres	10,000 houses built on 2,500 acres	10,000 houses built on 1,250 acres

Another way to examine this issue is to look at what happens to build-out of the three scenarios over time. A basic assumption for EPA's modeling is that growth is coming to the hypothetical community, and that growth will be accommodated within a fixed time horizon. But what happens to growth in the hypothetical community over several, sequential time horizons?

Given the dynamic nature of population growth, what will build-out look like in the hypothetical community in 2000, 2020, and 2040 at different development densities? The next several examples examine the amount of land required to accommodate increasing populations within a watershed that develops at different densities. The purpose of this time series build-out is to examine how much land is consumed as the population grows in 20-year increments.

Starting in the year 2000, the three watersheds each begin with 10,000 homes. The only difference between the watersheds is the densities at which the building occurs. In 2000, they might look something like Exhibit 8.

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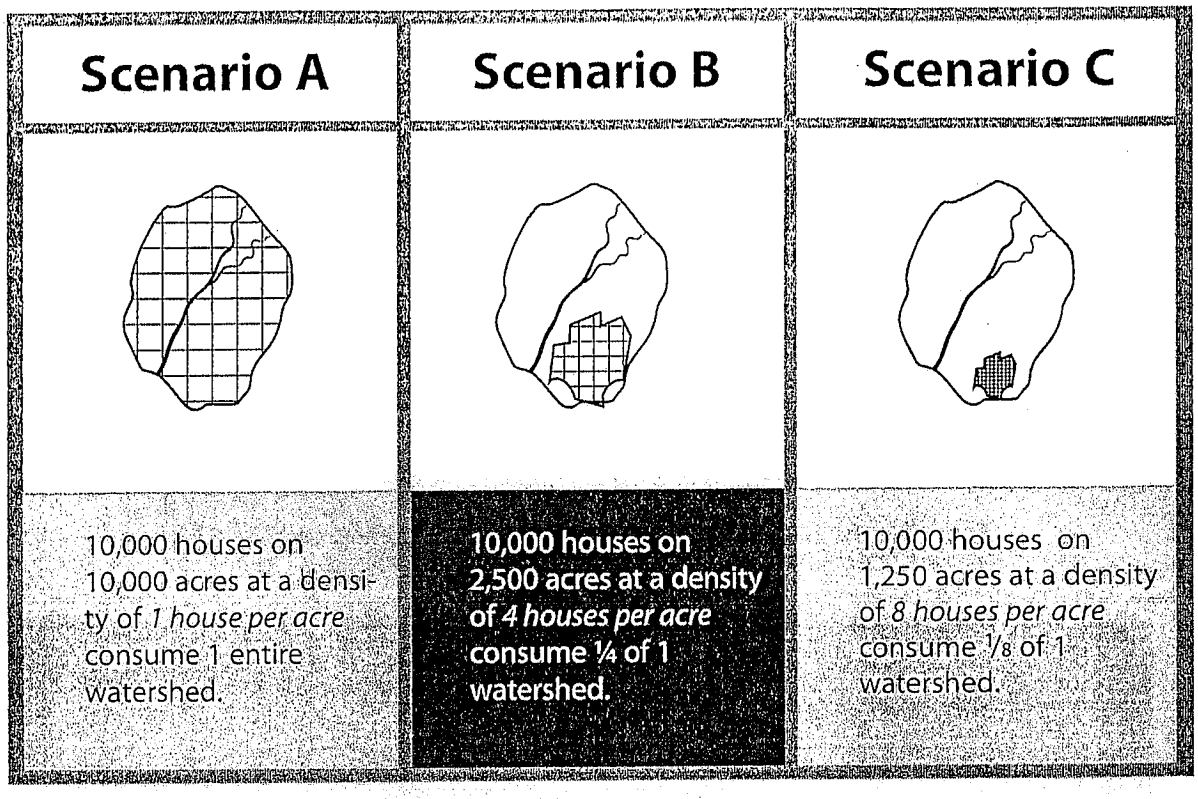
EXHIBIT 8: Time Series Build-out Analysis: Build-out in 2000



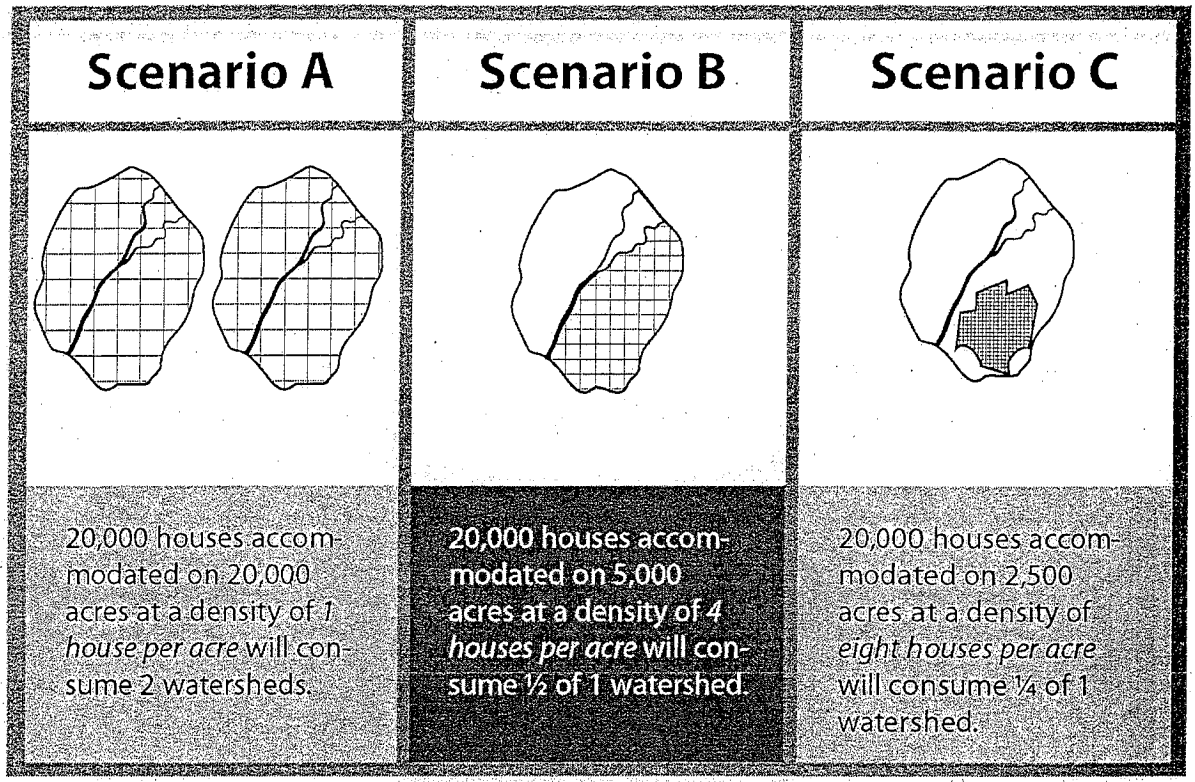
As previously demonstrated in Example 3, building at higher densities consumes, or converts, less land within the watershed. Scenario A, developing at one unit per acre, requires the entire 10,000-acre watershed to accommodate 10,000 houses. Scenario C, on the other hand, developing at eight units an acre, requires significantly less land to accommodate the same amount of development.

EXAMPLE 7: TIME SERIES BUILD-OUT ANALYSIS: BUILD-OUT IN 2020

Scale of Analysis	Scenario A	Scenario B	Scenario C
Hypothetical build-out in the year 2020	20,000 houses built on 20,000 acres, or 2 watersheds	20,000 houses built on 5,000 acres, or ½ of 1 watershed	20,000 houses built on 2,500 acres, or ¼ of 1 watershed

Fast-forwarding 20 years, the population in the hypothetical community has doubled from 10,000 houses to 20,000 houses. Each scenario must accommodate this additional growth at different development densities. Exhibit 9 demonstrates how this development might look.

EXHIBIT 9: Time Series Build-out Analysis: Build-out in 2020



As Exhibit 9 demonstrates, Scenario A, developing at one house per acre, requires another whole watershed to accommodate the additional growth. Scenarios B and C, developing at higher densities, can accommodate the additional growth within the same watershed. Moreover, by developing at higher densities within the watershed, ample open space or otherwise undeveloped land remains to perform critical watershed functions. No such land exists in Scenario A, and, as previously discussed, lawns typically associated with one house per acre are not able to provide the same type of watershed services as forests, meadows, or other types of unconverted land.

EXAMPLE 8: TIME SERIES BUILD-OUT ANALYSIS: BUILD-OUT IN 2040

Scale of Analysis	Scenario A	Scenario B	Scenario C
Hypothetical build-out in the year 2040	40,000 houses built on 40,000 acres, or 4 watersheds	40,000 houses built on 10,000 acres, or 1 watershed	40,000 houses built on 5,000 acres, or ½ of 1 watershed

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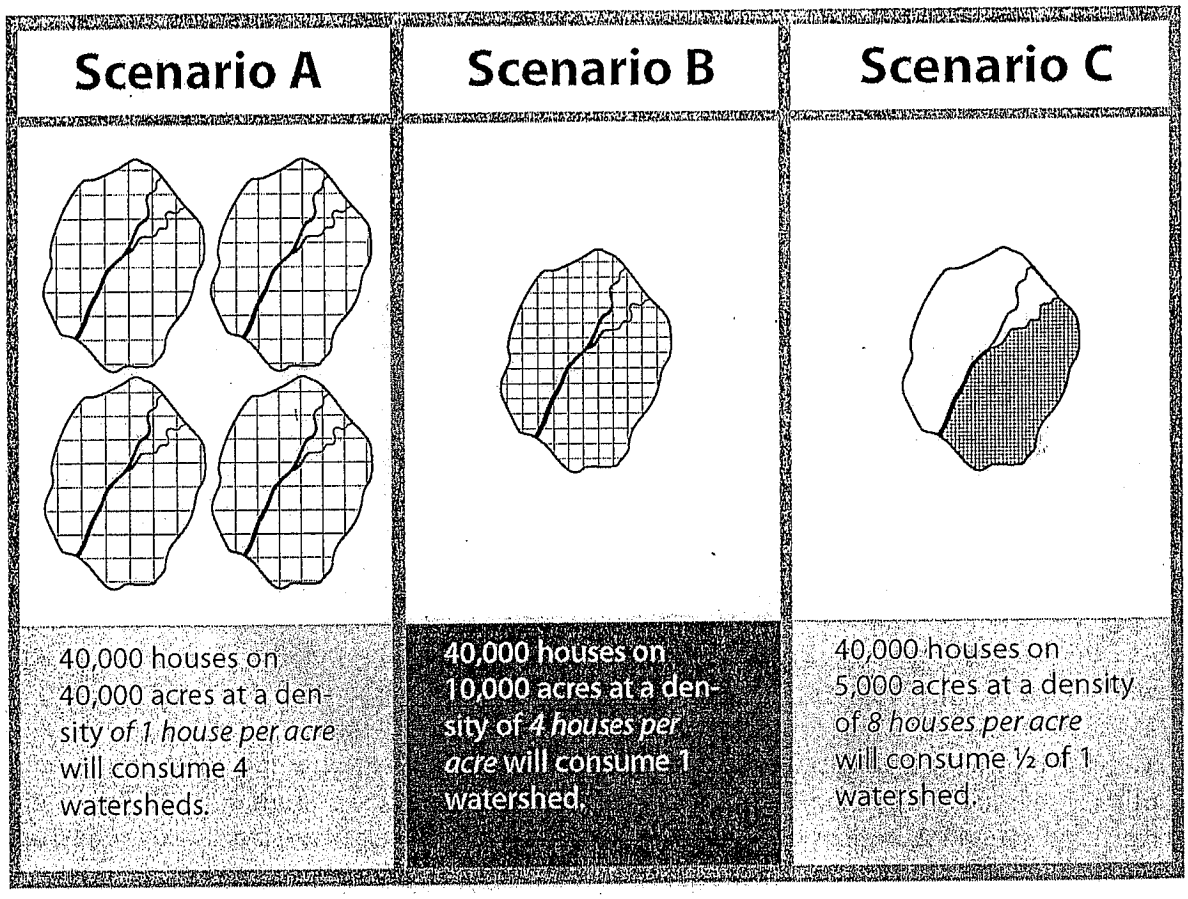
The hypothetical community continues to grow and, in another 20 years, population has doubled again, requiring each scenario to accommodate 20,000 more homes at different development densities. Exhibit 10 demonstrates how this development might look.

EXHIBIT 10: Time Series Build-out Analysis: Build-out in 2040



As Exhibit 10 demonstrates, Scenario A, developing at one house per acre, must develop land in four watersheds, or 40,000 acres, to accommodate all its houses. Scenario B, developing at a slightly higher density, uses its remaining land to accommodate the additional growth. Scenario C is still developing within the same watershed and still has additional land available to provide watershed services. Scenario A and B do not. Any land for watershed services would need to come from additional watersheds.

Lower-density development always requires more land than higher densities to accommodate the same amount of growth.

This build-out analysis can continue indefinitely with the same result: lower-density development always requires more land than higher densities to accommodate the same amount of growth. Because more land is required, more undeveloped land is converted.

Findings/Discussion

The results indicate when runoff is measured *by the acre*, limiting density does produce less stormwater runoff when compared to the higher-density scenarios. However, when measured *by the house*, higher densities produce less stormwater runoff. So, which is the appropriate measure?

Typically, a planning department analyzes the projected stormwater runoff impacts of a developer's proposal based on the acreage, not the number of houses being built. Based on the results from the one-acre level example, communities might conclude that lower-density development would minimize runoff. Runoff from one house on one acre is roughly half the runoff from eight houses. However, where did the other houses, and the people who live in those houses, go? The answer is almost always that they went somewhere else in that region—very often somewhere within the same watershed. Thus, those households still have a stormwater impact. To better understand the stormwater runoff impacts from developing at low densities, the impacts associated with those houses locating elsewhere need to be taken into account. This approach has two advantages:

- It acknowledges that the choice is not whether to grow by one house or eight but is instead where and how to accommodate the eight houses (or whatever number by which the region is expected to grow).
- It emphasizes minimization of total imperviousness and runoff within a region or watershed rather than from particular sites—which is more consistent with the science indicating that imperviousness within the watershed is critical.

To more fully explore this dynamic, EPA modeled scenarios at three scales—one acre, lot, and watershed—and at three different time series build-out examples to examine the premise that lower-density development better protects water quality. EPA examined stormwater runoff from different development densities to determine the comparative difference between scenarios. The higher-density scenarios generated less stormwater runoff per house at all scales and time series build-out examples. Exhibit 11 summarizes these findings.

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EXHIBIT 11: Summary of Findings

Scenario					
One-Acre Level: Different densities developed on one acre					
A: One house/acre	1	20.0	18,700	18,700	0
B: Four houses/acre	1	38.0	24,800	6,200	67
C: Eight houses/acre	1	65.0	39,600	4,950	74
Lot Level: Eight houses accommodated at different density levels					
Scenario A	8	20.0	149,600	18,700	0
Scenario B	2	38.0	49,600	6,200	67
Scenario C	1	65.0	39,600	4,950	74
Watershed Level: 10,000 houses accommodated in one 10,000-acre watershed					
Scenario A	10,000	20.0	187 M	18,700	0
Scenario B	2,500	9.5	62 M	6,200	67
Scenario C	1,250	8.1	49.5 M	4,950	74

Scenario	Summary of Build-out Examples
Watershed Level: Time Series Build-out Analysis: Build-out in 2000	
Scenario A	10,000 houses built on 10,000 acres: 1 watershed is consumed
Scenario B	10,000 houses built on 2,500 acres: ¼ of 1 watershed is consumed
Scenario C	10,000 houses built on 1,250 acres: ⅛ of 1 watershed is consumed
Watershed Level: Time Series Build-out Analysis: Build-out in 2020	
Scenario A	20,000 houses built on 20,000 acres: 2 watersheds are consumed
Scenario B	20,000 houses built on 5,000 acres: ½ of 1 watershed is consumed
Scenario C	20,000 houses built on 2,500 acres: ¼ of 1 watershed is consumed
Watershed Level: Time Series Build-out Analysis: Build-out in 2040	
Scenario A	40,000 houses built on 40,000 acres: 4 watersheds are consumed
Scenario B	40,000 houses built on 10,000 acres: 1 watershed is consumed
Scenario C	40,000 houses built on 5,000 acres: ½ of 1 watershed is consumed

Specifically, this analysis demonstrates:

- With more dense development (Scenario C), runoff rates per house decrease by approximately 74 percent from the least dense scenario (Scenario A);
- For the same amount of development, denser development produces less runoff and less impervious cover than low-density development; and
- For a given amount of growth, lower-density development uses more of the watershed.

EPA found that the higher-density scenarios generate less stormwater runoff per house at all scales—one acre, lot, watershed—and time series build-out examples.

Taken together, these findings indicate that low-density development may not always be the preferred strategy for reducing stormwater runoff. In addition, the findings indicate that higher densities may better protect water quality—especially at the lot and watershed levels. Higher-density developments consume less land to accommodate the same number of houses as lower density. Consuming less land means less impervious cover is created within the watershed. To better protect watershed function, communities must preserve large, continuous areas of open space and protect sensitive ecological areas, regardless of how densely they develop.

However, while increasing densities on a regional scale can, on the whole, better protect water resources at a regional level, higher-density development can have more site-level impervious cover, which can exacerbate water quality problems in nearby or adjacent waterbodies. To address this increased impervious cover, numerous site-level techniques are available to mitigate development impacts. When used in combination with regional techniques, these site-level techniques can prevent, treat, and store runoff and associated pollutants. Many of these practices incorporate some elements of low-impact development techniques (e.g., rain gardens, bioretention areas, and grass swales), although others go further to include changing site-design practices, such as reducing parking spaces, narrowing streets, and eliminating cul-de-sacs.

Incorporating these techniques can help communities meet their water quality goals and create more interesting and enjoyable neighborhoods.

A University of Oregon study, *Measuring Stormwater Impacts of Different Neighborhood Development Patterns* (University of Oregon, 2001), supports this conclusion. The study, which included a study site near Corvallis, Oregon, compared stormwater management strategies in three common neighborhood development patterns. For example, best management practices, such as disconnecting

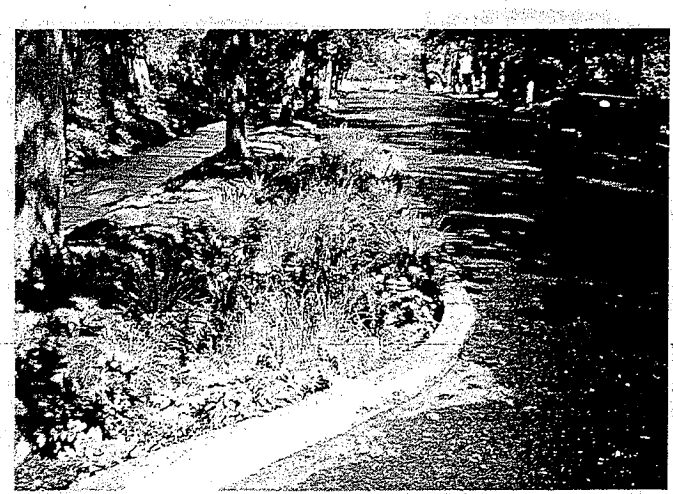

Photo courtesy of the City of Portland, Oregon

The city of Portland, Oregon, is developing urban stormwater strategies, such as these curb extensions that can absorb the street's runoff from large storm events.

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residential roofs and paved areas from the stormwater system, introducing swales and water detention ponds into the storm sewer system, and strategically locating open space, considerably reduced peak water runoff and improved infiltration. The study concluded that "some of the most effective opportunities for reducing stormwater runoff and decreasing peak flow are at the site scale and depend on strategic integration with other site planning and design decisions." The study also found that planting strips and narrower streets significantly reduced the amount of pavement and, as a result, runoff in developed areas.

A development in Tacoma, Washington, demonstrates that increasing densities and addressing stormwater at the site level can work effectively. The Salishan Housing District was built on Tacoma's eastern edge in the 1940s as temporary housing for ship workers. It is currently a public housing community with 855 units.

Redevelopment of Salishan will increase densities to include 1,200 homes (public housing, affordable and market rate rentals, and for-sale units), local retail, a farmers market, a senior housing facility, a daycare center, a health clinic, commercial office space, and an expanded community center. Among the most important priorities for the redevelopment is restoring the water quality of Swan Creek, which forms the eastern edge of Salishan. The creek is a spawning ground for indigenous salmon populations that feed into the Puyallup River and Puget Sound. The site plan seeks to restore 65 percent of the land to forest and pervious landscape. In addition, the streets will be narrowed to reduce impervious surfaces and also make the neighborhood more inviting for walking. Some streets may be eliminated and replaced with pedestrian paths. The remaining streets will be bordered by rain gardens that would accept, filter, and evapotranspire runoff. Most existing street surfaces would be reused, although some may be replaced with pervious pavers.

Salishan Housing District is replacing 855 public housing units with 1,200 units. Numerous site-level strategies, such as integrating uses, narrowing the streets, installing rain gardens, and daylighting a stream, are used to restore the water quality of Swan Creek and revitalize an existing neighborhood.

Communities can enjoy a further reduction in runoff if they take advantage of underused properties, such as infill, brownfield, or greyfield[12] sites. For example, an abandoned shopping center (a greyfield property) is often almost completely impervious cover and is already producing high volumes of runoff (Sobel, 2002). If this property were redeveloped, the net runoff increase would likely be zero since the property was already predominately impervious cover. In many cases, redevelopment of these properties breaks up or removes some portion of the impervious cover, converting it to pervious cover and allowing for some stormwater infiltration. In this case, redevelopment of these properties can produce a net improvement in regional water quality by decreasing total runoff. Exhibit 12 illustrates this opportunity.

[12] Greyfield sites generally refer to abandoned or underutilized shopping malls, strip malls, or other areas that have significant paved surface and little or no contamination.

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EXHIBIT 12: Redevelopment of a Greyfield Property



Photos courtesy of Juan Ayala, Invisioneering, for the New Jersey Office of State Planning

Redevelopment of a former shopping mall in Boca Raton, Florida, provides an example of this type of opportunity. The Mizner Park shopping mall was redesigned from its original pattern of a large retail structure surrounded by surface parking lots; the 29-acre site now includes 272 apartments and townhouses, 103,000 square feet of office space, and 156,000 square feet of retail space. Most parking is accommodated in four multistory parking garages. Designed as a village within a city, the project has a density five times higher than the rest of the city and a mix of large and small retailers, restaurants, and entertainment venues (Cooper, 2003). Most significantly, the final build-out of Mizner Park decreased overall impervious surface on the site by 15 percent through the addition of a central park plaza, flower and tree planters, and a large public amphitheater.

Redeveloping brownfield and greyfield sites can reduce regional land consumption. A recent George Washington University study found that for every brownfield acre that is redeveloped, 4.5 acres of open space are preserved (Deason, 2001). In addition to redeveloping brownfield sites, regions can identify underused properties or land, such as infill or greyfield sites, and target those areas for redevelopment. For example, a recent analysis by King County, Washington, demonstrated that property that is vacant and eligible for redevelopment in the county's growth areas can accommodate 263,000 new houses—enough for

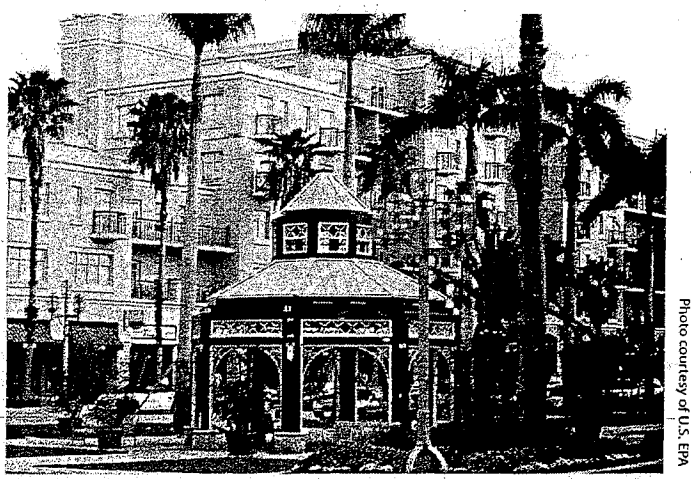

Photo courtesy of U.S. EPA

The redevelopment of Mizner Park, a former shopping mall, decreased impervious cover by 15 percent through the addition of this central plaza.

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500,000 people (Pryne, 2002). Redeveloping this property is an opportunity to accommodate new growth without expanding into other watersheds. As Kurt Zwikl, executive director of the Pottstown, Pennsylvania-based Schuylkill River Greenway Association, said, "Certainly, if we can get redevelopment going in brownfields and old industrial sites in older riverfront boroughs like Pottstown and Norristown, that's a greenfield further out in the watershed that has been preserved to absorb more stormwater" (Brandt, 2004).

Redeveloping brownfield and greyfield sites can reduce regional land consumption.

Other Research

Current research supports the findings of this study. Several site-specific studies have been conducted across the United States and in Australia that examine stormwater runoff and associated pollutants in relation to different development patterns and densities. Several case studies approach the research question with varying levels of complexity. Studies of Highland Park, Australia; Belle Hall, South Carolina; New Jersey; Chicago, Illinois; and the Chesapeake Bay each analyze the differences in runoff and associated water pollution from different types of development patterns.

Queensland University of Technology, Gold Coast City Council, and the Department of Public Works in Brisbane, Australia, examined the relationship between water quality and six different land uses to offer practical guidance in planning future developments. When comparing monitored runoff and associated pollutants from six areas, they found the most protective strategy for water quality was high-density residential development (Goonetilleke, 2005).

The Belle Hall study, by the South Carolina Coastal Conservation League, examined the water quality impacts of two development alternatives for a 583-acre site in Mount Pleasant, South Carolina. The town planners used modeling to examine the potential water quality impacts of each site design. In the "Sprawl Scenario," the property was analyzed as if it developed along a conventional suburban pattern. The "Town Scenario" incorporated traditional neighborhood patterns. In each scenario, the overall density and intensity (the number of homes and the square feet of commercial and retail space) were held constant. The results found that the "Sprawl Scenario" consumed eight times more open space and generated 43 percent more runoff, four times more sediment, almost four times more nitrogen, and three times more phosphorous than the "Town Scenario" development (South Carolina Coastal Conservation League, 1995).

These findings hold at a larger, state scale. New Jersey's State Plan calls for increasing densities in the state by directing development to existing communities and existing infrastructure. Researchers at Rutgers University analyzed the water quality impacts from current development trends and compared them to water quality impacts from the proposed compact development. The study found that compact development would generate significantly less water pollution than current development patterns, which are mostly characterized by low-density development, for all categories of pollutants (Rutgers University, 2000). The reductions ranged from over 40 percent for phosphorus and nitrogen to 30 percent for runoff. These conclusions supported a similar statewide study completed in 1992 that

concluded that compact development would result in 30 percent less runoff and 40 percent less water pollution than would a lower-density scenario (Burchell, 1995).

Researchers at Purdue University examined two possible project sites in the Chicago area (Harbor, 2000). The first site was in the city; the second was on the urban fringe. The study found that placing a hypothetical low-density development on the urban fringe would produce 10 times more runoff than a higher-density development in the urban core.

Finally, a study published by the Chesapeake Bay Foundation in 1996 comparing conventional and clustered suburban development on a rural Virginia tract found that clustering would convert 75 percent less land, create 42 percent less impervious surface, and produce 41 percent less stormwater runoff (Pollard, 2001). These studies suggest that a low-density approach to development is not always the preferred strategy for protecting water resources.

Conclusions

Our regions, cities, towns, and neighborhoods are growing. Every day, new buildings or houses are proposed, planned, and built. Local governments, working with planners, citizen groups, and developers, are thinking about where and how this new development can enhance existing neighborhoods and also protect the community's natural environment. They are identifying the characteristics of development that can build vibrant neighborhoods, rich in natural and historic assets, with jobs, housing, and amenities for all types of people. They are directing growth to areas that will maintain and improve the buildings and infrastructure in which they have already invested. In addition to enjoying the many benefits of growth, communities are also grappling with growth's challenges, including development's impact on water resources.

Many communities assume that low-density development automatically protects water resources. This study has shown that this assumption is flawed and that pursuit of low-density development can in fact be counterproductive, contributing to high rates of land conversion and stormwater runoff and missing opportunities to preserve valuable land within watersheds.

The purpose of this study is to explore the effects of development density on stormwater runoff and to illustrate the problems with the assumption that low-density development is automatically a better strategy to protect water quality. To that end, three different development densities were modeled at the one-acre, lot, and watershed levels, as well as in the time series build-out examples. The modeling results suggest that low-density development is not always the preferred strategy for protecting water resources. Furthermore, the results seem to suggest that higher-density development could better protect regional water quality because it consumes less land to accommodate the same number of homes.

However, while this study shows that low-density development does not automatically better protect water resources, it does not conclude that high-density development is therefore necessarily more protective. This study has not considered all factors, such as location of development within the watershed, varying soil types, slope, advanced post-construction controls (and their performance over time), and many other factors. In that sense, this study concludes that there

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are good reasons to consider higher-density development as a strategy that can better protect water resources than lower-density development. However, any bias toward either is inappropriate from a water perspective. A superior approach to protect water resources locally is likely to be some combination of development densities, based on local factors, incorporating adequate open space, preserving critical ecological and buffer areas, and minimizing land disturbance.

These conclusions have implications for how communities can enjoy the benefits of growth and development while also protecting their water quality. Additional relevant information can be found in other resources, such as *Protecting Water Resources with Smart Growth* and *Using Smart Growth Techniques as Stormwater Best Management Practices.*[13] Both publications draw on the experience of local governments, which has shown that regional and site-specific strategies are most effective when implemented together. In addition, *Creating Great Neighborhoods: Density in Your Community*, by the Local Government Commission and the National Association of Realtors, can provide information on some of the other benefits from density that communities can enjoy.

Additional relevant information can be found in these resources:

- *Protecting Water Resources with Smart Growth,* available at: www.epa.gov/smartgrowth/pdf/waterresources_with_sg.pdf.
- *Creating Great Neighborhoods: Density in Your Community,* available at: www.epa.gov/smart growth/pdf/density.pdf.

Nationwide, state and local governments are considering the environmental implications of development patterns. As low-density development and its attendant infrastructure consume previously undeveloped land and create stretches of impervious cover throughout a region, the environment is increasingly affected. In turn, these land alterations are not only likely to degrade the quality of the individual watershed, but are also likely to degrade a larger number of watersheds. EPA believes that increasing development densities is one strategy communities can use to minimize regional water quality impacts.

[13] Forthcoming EPA publication.

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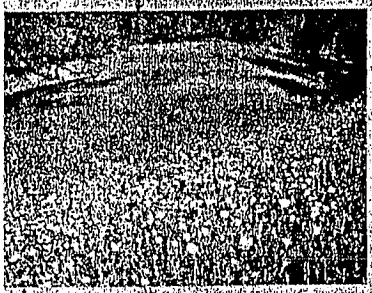







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FOREWORD

There is a continuing need to address the ongoing impacts of stormwater runoff in urban watersheds to improve water quality and designated uses in urban rivers and streams. Increasingly, state and federal regulatory programs are focusing on how to restore the quality of the nation's degraded urban waters. For example, more than 1,000 communities are currently permitted under Phase I MS4 NPDES stormwater permits and an additional 5,000 communities will be captured by Phase II MS4 stormwater permits (U.S. EPA, 1999 and 2000).

This document distills the lessons learned from around the country into a self-assessment tool to help local communities integrate and align their urban watershed programs to meet their water resource goals. What exactly is meant by integrate and align? Program integration is the extent to which municipalities coordinate individual planning, restoration and education programs to focus them on clear watershed restoration goals. Program alignment refers to the geographic targeting of restoration programs to priority subwatersheds. The tool is designed to help local program managers and watershed groups make better decisions on watershed restoration priorities to maximize the performance of staff and financial resources.

Many individuals contributed significantly to the development of the Smart Watershed benchmarking tool. We are grateful to the many communities that assisted us with this project.

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LIST OF ACRONYMS

CERCLA Comprehensive Environmental Response, Compensation, and Liability Act (Superfund Program)
CSO Combined Sewer Overflow
EPA Environmental Protection Agency
FEMA Federal Emergency Management Agency
GIS Geographic Information System
MS4 Municipal Separate Storm Sewer System
NGOs Non-Governmental Organizations
NPDES National Pollutant Discharge Elimination System
P2 pollution prevention
RTE rare, threatened and endangered species
TMDL Total Maximum Daily Load

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INTRODUCTION

This report presents a tool to help stormwater and watershed managers align their municipal restoration programs to meet local watershed goals and regulatory drivers. The term Smart Watershed refers to 14 different program areas that can be integrated together to restore urban watersheds.

According to the 2000 Census, 69% of the U.S. population lives in urbanized areas that occupy only 2% of the nation's land area. It is also projected that future population growth will produce additional infill and redevelopment pressure into these urbanized areas. One of the key tenets of Smart Growth is that redevelopment and infill should be directed to existing urbanized areas that already possess infrastructure. Development that occurs within an already developed watershed is preferred to development that happens in a rural watershed. Redevelopment can help absorb some of the demand for new housing and reduce pressure on rural watersheds. Redevelopment tends to concentrate density and impervious cover in existing urban watersheds, and can help to prevent sprawl from encroaching on more distant and less developed, higher quality watersheds.

While redevelopment and infill are desirable on a regional basis, they can contribute to already serious water quality problems in highly urban watersheds. Quite simply, highly urban watersheds are often degraded, do not meet water quality standards, and as a consequence are subject to many regulatory "drivers" that are complex, costly and confusing to implement.

This tool lays out a framework for pursuing a watershed-based approach to align municipal restoration programs. The framework can help communities make better decisions on watershed restoration priorities and make the most out of limited funding and staffing resources.

Organization of the Report

The report is organized in three chapters. The first chapter presents an overview of Smart Watershed programs, outlines why they were developed, and reviews some of the benefits and applications of the benchmarking tool for local communities. Chapter 2 presents a series of detailed profile sheets that describe each of the 14 Smart Watershed programs. Each profile sheet contains the following elements:

- Program Description and Goal
- Benchmarks for the Program
- National Average of Program Activity
- A Case Study Illustrating an Outstanding Municipal Program
- Tips on Program Implementation
- Resources on the Program Area, including links to additional examples and technical resources

Chapter 3 presents the Smart Watershed benchmarking tool and contains step-by-step guidance on how to complete the tool and interpret community scores. The report also contains four appendices that provide further details on restoration budgeting and adapting the benchmarking tool for special community conditions.

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CHAPTER 1
INTRODUCTION TO SMART WATERSHEDS

The term Smart Watershed refers to the integration and alignment of 14 municipal programs to treat stormwater runoff, restore stream corridors and reduce pollution discharges in urban watersheds (see Table 1). Taken together, the programs create a unified framework to integrate diverse programs and regulatory drivers into a coherent strategy to restore urban watersheds that measurably improves water quality.

TABLE 1: SUMMARY OF SMART WATERSHED PROGRAMS

1	Subwatershed Restoration Planning
2	Stream and Subwatershed Field Assessment
3	Subwatershed Monitoring and Reporting
4	Watershed Restoration Financing
5	Management of Natural Area Remnants
6	Stormwater Retrofitting
7	Urban Stream Repair/Restoration
8	Illicit Discharge Detection and Elimination
9	Maintenance, Inspection and Enforcement
10	Smart Site Practices During Redevelopment
11	Watershed Education and Personal Stewardship
12	Public Involvement and Neighborhood Consultation
13	Pollution Prevention at Stormwater Hotspots
14	Pollution Prevention at Municipal Operations

Each community differs in area, population, regulatory status and watershed goals. In the context of this document, three kinds of communities are defined, as follows:

- Small communities, with a population less than 50,000
- Medium communities have populations between 50,000 to 250,000 and are normally regulated under NPDES MS4 Phase I or II stormwater permits
- Large communities have populations greater than 250,000, and with a few exceptions, are regulated under NPDES MS4 Phase I stormwater permits

1.1 The History of the Smart Watershed Program

A basic tenet of the Center watershed management approach is that new growth should be directed to subwatersheds that are already impacted from existing development and away from more sensitive subwatersheds. Although redevelopment and infill are desirable on a regional basis, they have the potential to contribute to already serious water quality problems in highly urban watershed. These pervasive urban water quality problems, in turn, trigger increased regulation and compliance costs for many communities. At the same time, redevelopment can present opportunities to address existing water quality impairments – if a community has integrated watershed restoration programs in place.

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Over the last five years, the Center has undertaken a series of national initiatives to develop tools to restore highly urban watersheds. The effort began when the Center convened a redevelopment roundtable in 2000. The roundtable consisted of a group of national and local experts who agreed on 11 design practices to apply to urban redevelopment and infill sites to reduce pollutant loads and improve runoff quality. These Smart Site practices, when applied together, reduce impervious cover, conserve natural area remnants and improve treatment of stormwater runoff at individual redevelopment and infill sites. Appendix B presents text from the consensus agreement on Smart Site practices.

While Smart Site practices help mitigate the impact of individual redevelopment projects, a broader approach was needed to organize municipal programs to restore conditions at the watershed scale. The genesis of Smart Watersheds was a series of meetings in 2001 with regional and national experts that focused on the challenges of managing growth in highly urban watersheds. The group agreed that a unified framework was urgently needed to organize municipal programs into a coherent strategy to restore urban watersheds.

The Center responded to this need by developing a national report card on municipal watershed restoration activity, based on a survey of more than 50 communities across the country. The report card had three major headlines. The first was that many communities have made dramatic progress in improving their overall watershed restoration capability in recent years. Predictably, more restoration activity was reported for large communities, compared to medium and small communities.

The second key headline was that the integration of restoration programs has been poor in most communities, which has prevented them from achieving measurable improvements in water quality. This finding suggests many communities possess the tools, staff and financial resources to effectively restore urban watersheds, but need better coordination and integration to achieve better watershed results.

The third key headline was that the EPA and other regulatory agencies are increasingly requiring urban communities to quantify pollutant reductions to meet regulatory mandates — at the same time communities are having extreme difficulties in documenting improvements from long-term restoration programs.

Based on these findings, the Center produced a report in 2003 entitled *Integrating Local Programs to Achieve Measurable Progress in Urban Watershed Restoration*. The report outlined a unified framework to integrate 14 municipal programs to restore urban watersheds. The next step involved developing a benchmarking tool to help communities quantitatively assess their own restoration program performance. A draft benchmarking tool was developed in late 2004, which was subject to extensive review by local, state and federal agencies.

The benchmarking tool was then tested in five communities in 2005. As shown in Table 2, the

TABLE 2: CHARACTERISTICS OF TEST COMMUNITIES

Community	Population	MS4 NPDES Status
Santa Monica, CA	84,000	Phase I co-permittee*
Cary, NC	112,000	Phase II
Austin, TX	672,000	Phase I
Baltimore County, MD	755,000	Phase I
Philadelphia, PA	1,500,000	Phase I

** with the City of Los Angeles and other municipalities*

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test communities were diverse with respect to population, geographic area, and stormwater permit status. The test communities were also chosen since they had progressive watershed restoration and/or stormwater management programs. Center staff conducted on-site testing in cooperation with municipal staff over several weeks in each community. The purpose of the testing was to assess the applicability of benchmark questions, evaluate ways to make it easier to complete the tool, and calibrate the overall scoring for the tool.

Several major refinements were made to the benchmarking tool based on the testing phase.

For example, the tool was changed to provide:

- Alternative scoring system for small communities
- Alternative scoring system for communities that lack perennial streams (e.g., ultra-urban watersheds and arid regions)
- More guidance on deriving Smart Watershed budget data
- More guidance on a step-by-step process to complete the benchmarking tool
- Reduced scoring for extra credit points

Staff from the test communities indicated that it generally took about 40 hours to complete the tool and provide supporting documentation. In general, test communities found the results to be useful in assessing the strengths and weaknesses of their management programs. The test communities generally indicated that further improvement in their programs was possible, but they needed to overcome staffing, financing, coordination and technical challenges. The test communities consistently scored between the mid 70s and low 90s when extra credit points are accounted for. Several consistent areas of program weakness were reported, most notably in subwatershed-based prioritization, assessment of upland restoration potential, and management of natural area remnants.

This report releases the final benchmarking tool for general use for communities across the nation. It will be periodically updated in response to user comments and feedback.

1.2 The Benefits of Implementing Smart Watershed Programs

Communities may realize several benefits if they pursue a Smart Watershed approach. The primary benefit is that it creates a unified framework to address many different programs, regulatory mandates and permit requirements that confront municipalities. These regulatory drivers are often complex, costly and confusing to implement. Some of the major regulatory and funding drivers are profiled in Table 3. Most urban communities are subject to many different regulatory drivers, and as can be seen, multiple smart watershed programs are needed to comply with them. In addition, many communities are also driven by regional watershed planning initiatives that promote implementation of urban watershed restoration practices. The value of the Smart Watershed approach is that it presents a single unified approach to watershed restoration that can simultaneously address many different regulatory and funding drivers.

Some additional community benefits of the Smart Watershed approach are that it:

- Directly links Smart Growth initiatives to urban watershed restoration practices
- Provides a legitimate basis to grant flexibility and incentives for individual redevelopment and infill sites, in the form of relaxed or modified stormwater requirements if overall subwatershed goals can be achieved
- Maintains or enhances water quality and habitat conditions within urban watersheds, and provides a yardstick to measure future improvements

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TABLE 3: REGULATORY AND FUNDING DRIVERS FOR SMART WATERSHED PROGRAMS

Regulatory Driver	Key Objective	Smart Watershed Programs
CERCLA (EPA, States) Brownfields)	Clean up polluted brownfield sites and promote redevelopment	Programs 4, 5, 10, 13, 14
CSO/SSO Policy (EPA)	Eliminate wastewater discharges to streams	Programs 1, 2, 3, 6, 8, 9, 12
National Flood Insurance Program (FEMA)	Protect floodways and riparian areas	Programs 1, 2, 6, 7, 9, 11
MS4 NPDES Phase I & II (EPA, States)	Reduce pollution from stormwater runoff	Programs 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14
Safe Drinking Water Act (EPA, States)	Source water assessments and protection efforts	Programs 1, 3, 4 6, 8, 13, 14
TMDL (EPA, States)	Establish specific limits on pollutant loads to protect designated uses	Programs 1, 3, 4, 6, 8, 9, 13
Wetlands Regulations (U.S. Army Corps of Engineers)	Protect existing wetlands from disturbance and mitigate impacts	Programs 1, 2, 5, 7, 9, 11
Watershed Planning Guidance (EPA)	Eligibility for funding for restoration implementation	Programs 1, 2, 3, 4, 11, 12

- Enables communities to target, experiment and demonstrate restoration practices at the subwatershed level rather than across an entire jurisdiction
- Presents an opportunity to streamline many individual government functions into a single restoration strategy and reduces duplicative efforts
- Creates a "safe harbor" to document solid program implementation performance that may assist in complying with many state and federal regulatory drivers

1.3 Suggested Uses of the Benchmarking Tool

Communities can use the benchmarking tool to build or strengthen their programs in several ways:

- *Assessment of Specific Watershed Restoration Plans* - A community or watershed group may use the tool to evaluate an existing watershed restoration plan to determine how well local programs and resources are focused in the watershed. The scoring can identify gaps in implementation, suggest new local partners to involve in the plan and identify opportunities to coordinate existing local programs to improve restoration efforts.
- *Self-Assessment of Community Restoration Programs* – A local stormwater or watershed program manager may choose to use the tool to evaluate the integration and alignment of current local programs. Scores from the self assessment can identify program strengths and weaknesses, thereby providing a basis to streamline watershed services, justify budget requests, validate ongoing efforts, and promote greater interagency coordination. The tool is a useful checkup for managers of exist-

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ing programs, and also provides a yardstick to help managers build new programs where they do not exist.

- *Overall Assessment of MS4 NPDES Stormwater Permit Compliance* - In this application, the tool is used as a streamlined way to review overall compliance with existing MS4 NPDES stormwater permits. State or federal permitting agencies could use individual quantitative benchmarks or the overall community score to assess program implementation. The tool is currently calibrated for Phase I MS4 NPDES communities, but could easily be adapted for Phase II communities. The current NPDES stormwater permitting program lacks quantitative indicators of program performance, and the Smart Watershed benchmarking tool presents a comprehensive way to evaluate compliance. The tool could also provide a safe harbor, whereby communities that exceed a defined minimum score would be deemed to be in full compliance with permitting requirements.
- *Certification of Excellence in Local Watershed Restoration* - Until now, there has been no mechanism to recognize and reward local programs that go beyond the minimum to achieve better watershed restoration. The benchmarking tool has been designed to certify excellent programs according to objective and consistent benchmarks that have been tested nationally. Ideally, an independent third party could use the tool to define:

  - Minimum acceptable program elements
  - Compliance with national norms for individual program achievement; and
  - Overall excellence in local watershed programs.

The application is patterned after other certification tools, such as the Leadership in Environmental and Energy Efficient Design (LEED) certification program administered by the Green Building Council to set verifiable standards for green building. The level of detail and supporting documentation in the benchmarking tool enables it to meet certification objectives, if an independent third party can review and verify the scoring. If funding support materializes, the Center may take on the certification role to promote more widespread and consistent implementation of Smart Watershed programs.

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CHAPTER 2

THE 14 SMART WATERSHED PROGRAMS

The chapter presents individual profile sheets that describe each of the 14 Smart Watershed programs that are organized as follows:

- Description of the Program
- Smart Watershed Objectives Fulfilled
- List of Specific Program Benchmarks
- National Average of Communities Reporting in the Program Area (based on the 2003 survey)
- Local Case Study of Effective Programs
- Tips on Effective Program Implementation
- Resources to Build or Strengthen Local Programs

Each profile sheet describes how to evaluate and strengthen the effectiveness of current programs. It is advisable to review the profile sheets to gain a better understanding of Smart Watershed before attempting to complete the benchmarking tool.

Program 1 Subwatershed Restoration Planning 11
Program 2 Stream and Subwatershed Field Assessment 13
Program 3 Subwatershed Monitoring and Reporting 15
Program 4 Financing Watershed Restoration 17
Program 5 Management of Natural Area Remnants 19
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PROGRAM 1 SUBWATERSHED RESTORATION PLANNING

The best method for integrating Smart Watershed programs is the small watershed plan, which analyzes the unique characteristics of each subwatershed, evaluates restoration potential, and ranks priority restoration practices for long-term implementation. Urban subwatersheds are typically defined as less than ten square miles in size and are considered the primary management unit for watershed restoration within a municipality. While technical studies are often undertaken at a larger watershed scale, subwatersheds should be the focus for the comprehensive application of restoration planning and implementation.

Smart Watershed Objectives

- Develop urban restoration plans for small watershed units that integrate stream and subwatershed assessments, and lead to implementation of stormwater retrofits, stream repairs, reforestation, discharge prevention, natural area restoration, education, and pollution prevention practices.
- Use a planning approach that screens and prioritizes the most restorable subwatersheds in the watershed.
- Ensure that any localized degradation caused by individual redevelopment and infill projects is counterbalanced by improvements in overall watershed health.

Benchmarks

1. Subwatershed-based restoration planning
2. Subwatershed planning activity
3. Clear goals driving restoration efforts
4. Comparative subwatershed analysis
5. Dedicated staffing for watershed coordination
6. Watershed management structure
7. Watershed-based GIS mapping system
8. Tracking of restoration information
9. Mechanism for plan adoption

National Average of Program Activity

Overall Score 55%

Large Communities 92%

Medium Communities 46%

Small Communities 36%

Case Study in Subwatershed Restoration Planning

Baltimore County MD Small Watershed Action Plans • Population: 758,930

Baltimore County, Maryland is developing a series of small watershed action plans (SWAPs) for 24 small urban and suburban watersheds. A SWAP is prepared using community collaboration to set protection and restoration goals for small watersheds. It outlines specific actions to be taken within each subwatershed to achieve restoration goals. The plans build on larger watershed assessments done over the past decade to characterize watershed conditions and identify restoration approaches. The planning process actively solicits public feedback to help prioritize restoration projects and programs for each subwatershed. The planning process also has links to many larger regional watershed drivers such as the 2000 Chesapeake Bay Agreement. The County is also a partner in the state's tributary strategy program that sets numerical nutrient reduction targets in order to achieve a healthier Bay. The County also intends to link the SWAPs with Total Maximum Daily Loads for impaired streams and receiving waters, and incorporate key recommendations into their MS4 NPDES stormwater permit. The SWAP process started in the winter of 2005, and several action plans are scheduled for completion in 2006.

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PROGRAM 1 SUBWATERSHED RESTORATION PLANNING

Building a Better Subwatershed Restoration Planning Program

Tips for Getting Started

Start out by conducting a Needs and Capabilities Assessment (NCA, Schueler and Kitchell, 2005). This simple checklist helps planners define key community concerns and regulatory drivers that shape watershed restoration goals. The NCA also evaluates local restoration capacity and can help the core team find out what restoration activities are being done and by whom.

- Communities may want to consult the chapters on Getting Started and Scoping and Budgeting in *Urban Subwatershed Restoration Manual No. 2* (Schueler and Kitchell, 2005).
- The core team should provide early opportunities to allow stakeholders to give input on restoration goals and determine how they want to be involved in the planning process.
- Think strategically on how local restoration programs can be linked to regional water quality management efforts and regulatory compliance.
- Define the approach for managing stakeholder involvement early in the planning process that is consistent with community preferences and resources.
- Be cautious about expending a lot of money on watershed modeling and monitoring unless more information is needed to characterize watershed conditions.
- Promote watershed planning as a way to connect residents to their neighborhood streams and protect key aquatic resources people care about.

Tips for Fine-Tuning Existing Programs

- Study program scores from the benchmarking tool to identify weak restoration program areas that could be strengthened.
- Periodically revisit restoration goals to check if progress is being made in achieving them.
- Recognize restoration partners through annual recognition programs and watershed forums.
- Avoid watershed studies that are not focused on project implementation and evaluation.
- Track implementation efforts annually and evaluate the effectiveness of restoration projects.
- Commit to adopting an annual restoration workplan that translates planning outcomes into actual project implementation.

Resources for Subwatershed Restoration Planning

Bowie, MD Watershed Restoration Action Strategies **http://www.cityofbowie.org/green/partners/wras.htm**

EPA Section 319 Success Stories – state by state project highlights from the Section 319 Program **http://www.epa.gov/owow/nps/Section319/index.htm**

Fairfax County, VA, Watershed Planning Project **http://www.fairfaxcounty-watersheds.net/**

Miami River Commission **http://miamirivercommission.org/river.htm**

Urban Subwatershed Restoration Manual 1: An Integrated Framework to Restore Small Urban Watersheds (Schueler, 2004)

Urban Subwatershed Restoration Manual 2: Methods to Develop Restoration Plans for Small Watersheds (Schueler and Kitchell, 2005)

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PROGRAM 2 STREAM AND SUBWATERSHED FIELD ASSESSMENT

Rapid assessments of the stream corridor and upland areas are an important ingredient for successful watershed restoration. Rapid assessments provide the restoration team with critical information on current impacts and potential restoration opportunities within the entire subwatershed. Stream corridor assessments also provide opportunities to engage watershed organizations and volunteers in the subwatershed restoration process.

Smart Watershed Objectives

- Conduct rapid stream corridor assessments on a subwatershed basis with the goal of covering all stream channel miles within a fixed time-period.
- Utilize assessment data to identify and prioritize degraded stream reaches that merit immediate attention.
- Identify any remaining high-quality streams in need of special protection.
- Incorporate assessment data as a primary source of information to develop a comprehensive subwatershed restoration plan.

Benchmarks

10. Rapid stream corridor assessments
11. Field evaluation of restoration potential in the stream corridor
12. Field evaluations of upland restoration potential

National Average of Program Activity

Overall Score 49%

Large Communities 69%

Medium Communities 38%

Small Communities 50%

Case Study in Stream and Subwatershed Field Assessment



Paxton Creek Stream and Subwatershed Assessments

Paxton Creek is a tributary to the Susquehanna River in the vicinity of Harrisburg, Pennsylvania. Over 63 miles of stream flow through forest, residential, commercial and industrial land uses. According to the State 303(d) list, the watershed contains 16.5 miles of streams impaired by urban runoff, construction and storm sewers. Stream and subwatershed assessments were conducted in a 7.4 square mile subwatershed of Paxton Creek using the Unified Stream Assessment (USA) and the Unified Subwatershed and Site Reconnaissance (USSR). The USA is a comprehensive stream walk protocol that evaluates stream, riparian and floodplain conditions in the urban stream corridor (Kitchell and Schueler, 2004). The USSR is a field survey to evaluate potential subwatershed pollution sources and restoration opportunities outside of the stream corridor (Wright, et al, 2004). The core team included the Paxton Creek Watershed and Education Association, the Canaan Valley Institute, and the Center. The rapid surveys helped the team identify and prioritize hundreds of potential source control, retrofit, reforestation, stream repair and discharge prevention practices. The intensive surveys, which were performed in a week, also found other problems such as sewer overflows, trash dumping and damaged outfalls throughout the subwatershed. The field survey results created a strong technical foundation to develop a detailed and action-oriented restoration plan for the Paxton Creek subwatershed.

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PROGRAM 2 STREAM AND SUBWATERSHED FIELD ASSESSMENT

Building a Better Stream and Subwatershed Field Assessment Program

Tips for Getting Started

- Use rapid assessment methods such as the Unified Stream Assessment (USA) and the Unified Subwatershed and Site Reconnaissance (USSR) to acquire information on watershed restoration opportunities in a test subwatershed.
- Remember to train municipal staff and volunteers on the assessment methods before going out in the field.
- Mapping and other simple desktop analysis conducted in the office can save a lot of time in the field.
- Make sure to incorporate digital photos of key impacts and problems in your watershed education materials.
- Combine stream corridor and upland assessments together within the same subwatershed.
- Check with local colleges and state agencies to see if they have any historic maps or monitoring data to compare with current field data.

Tips for Fine-Tuning Existing Programs

- Involve local enforcement staff in stream and subwatershed field work to take advantage of their knowledge of field conditions and rapid enforcement capability. Local inspectors may also know of chronic problem areas.
- Carefully consider how data from field assessments will be managed and checked for quality control, and who will perform this important function.
- Field assessments can generate hundreds of field forms so make sure to compile them into a well-organized database linked to the watershed-based GIS.
- Consider involving trained volunteers or watershed groups in field assessments to expand manpower and create a unique education experience.

Resources for Stream and Subwatershed Field Assessment

Urban Subwatershed Restoration Manual 10: The Unified Stream Assessment (USA): A Users Manual (Kitchell and Schueler, 2004)

Urban Subwatershed Restoration Manual 11: The Unified Subwatershed and Site Reconnaissance (USSR): A Users Manual. (Wright, *et al.*, 2004).

Urban Subwatershed Restoration Manual 2: Methods to Develop Restoration Plans for Small Watersheds (Schueler and Kitchell, 2005)

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PROGRAM 3 SUBWATERSHED MONITORING AND REPORTING

Subwatershed monitoring is important to determine major water quality, habitat and biological impacts, and to track progress made over time in improving stream conditions. Monitoring data is used to support many key decisions throughout the restoration planning process, and must be organized and clearly communicated to the appropriate audience.

Smart Watershed Objectives

Develop a comprehensive approach to monitoring that can help the team understand subwatershed baseline conditions, track restoration progress and prioritize water quality problems.

Benchmarks

13. Subwatershed monitoring program
14. Aquatic indicators linked to watershed goals
15. Public notification of water quality problems
16. Data management and reporting

National Average of Program Activity

Overall Score 57%

Large Communities 92%

Medium Communities 46%

Small Communities 43%

Case Study in Subwatershed Monitoring and Reporting

Austin, Texas Environmental Integrity Index

The City of Austin monitors their local creeks to track trends in ecological integrity and water quality impairment. The Watershed Protection Department developed an Environmental Integrity Index (EII) to track long-term trends in aquatic indicators. The index consists of six groups of water quality indicators that relate to the designated water uses of Austin creeks. The six designated uses include: contact recreation (swimming and wading), non-contact recreation, water quality, sediment quality, stability of stream channels, and aquatic life support. A subwatershed integrity index score is then calculated after a range of chemical, physical, and biological aquatic indicators are measured. The city felt that the index was needed because prior studies had shown that water quality data alone did not adequately describe the health of water resources. The index is used to rank the severity of problems based on the difference between a stream's water quality goal and its current measured condition. In order to track long-term trends, the city also maintains sentinel monitoring stations in Barton and Edwards Springs, and conducts runoff sampling for 18 stormwater pollutants in East Austin's Town Creek. Findings from the monitoring program are quickly posted on the city website: (**http://www.ci.austin.tx.us/watershed/learn_ws.htm**). The website also provides maps of watersheds and monitoring sites, land use information, index scores, photographs, and other watershed facts. Press releases regarding spills are posted on another website (**http://www.ci.austin.tx.us/water/**). The city devotes more than a million dollars annually to support the subwatershed monitoring program. For example, 20 creek and lake monitoring stations were sampled in 2004, along with 12 intensive water quality studies.

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PROGRAM 3 SUBWATERSHED MONITORING AND REPORTING

Building a Better Stream and Subwatershed Monitoring and Reporting Program

Tips for Building a Program

- Build your monitoring program around existing or historic monitoring stations to maximize coverage.
- Select a few good water quality indicators that are easy to measure. Guidance on choosing reliable but inexpensive indicators can be found in *Urban Subwatershed Restoration Manual No. 2* (Schueler and Kitchell, 2005).
- Look for opportunities to involve citizens and watershed groups in subwatershed monitoring efforts to enhance public involvement and education.
- Link your subwatershed monitoring efforts to the local NPDES MS4 stormwater permit to help comply with minimum management measures for citizen involvement and stormwater education.
- Invite sediment control inspectors and other local staff on a stream monitoring trip to expose them to the aquatic resources they work to protect daily.

Tips for Fine-Tuning Existing Programs

- Check the existing aquatic indicators that are monitored to make sure they are directly linked to watershed goals and can be used to measure progress toward them.
- Investigate ways to disseminate condensed summaries of monitoring data to stakeholders and the general public.
- Consider expanding the monitoring program to measure the long-term effectiveness of installed restoration projects to identify factors that lead to future project success or failure.
- Train local watershed groups and volunteers on monitoring protocols to expand municipal data gathering capabilities.
- Consider out-sourcing monitoring work to watershed groups to help them become more sustainable.

Resources for Subwatershed Monitoring and Reporting

Montgomery County, MD County-wide Stream Protection Strategy **http://www.montgomerycountymd.gov/deptmpl.asp?url=/content/dep/csps/index.asp**

Burlington Vermont Beach monitoring **http://www.uvm.edu/%7Eempact/water/data.php3**

Urban Subwatershed Restoration Manual 2: Methods to Develop Restoration Plans for Small Watersheds (Schueler and Kitchell, 2005)

Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists and Engineers (Burton and Pitt, 2001)

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PROGRAM 4 FINANCING WATERSHED RESTORATION

Smart Watershed programs require significant financial resources from a diverse array of local, state, federal and private sources. Communities need to evaluate how they currently finance overall watershed restoration efforts, and look for alternative revenue streams to ensure that future programs are adequately funded.

Smart Watershed Objectives

- Utilize a diverse blend of funding to support watershed restoration, including capital and operating budgets, stormwater utilities, stormwater fee-in-lieu projects, state and federal grants and revolving loans, and watershed partnership projects.
- Ensure that staff and resources are adequate to meet overall Smart Watershed program implementation goals.

Benchmarks

17. Total watershed program expenditures
18. Long-term funding for plan implementation
19. Local funding for Smart Watershed programs

National Average of Program Activity

Overall Score 63%

Large Communities 85%

Medium Communities 58%

Small Communities 50%

Case Study in Financing Watershed Restoration

Montgomery County, MD Watershed Management Program Budget

Montgomery County's watershed management budget provides an example of how to leverage multiple funding sources and educate local elected officials to garner greater program support. The mission outlined in the budget is to protect citizens and improve the quality of the environment by monitoring and restoring county streams and waterways. Specific line-items in the budget include watershed restoration planning, restoration project design and construction, and ongoing stream monitoring. Funds also support urban forestry, illicit discharge control, public outreach, citizen stewardship, and maintenance of stormwater practices. The capital budget for stormwater retrofit and stream restoration projects is leveraged to match state and federal grant funds. The main revenue that supports the local budget is a stormwater utility fee attached to residential property taxes. The annual budget is unique in that it contains specific performance measures related to many Smart Watershed program areas that are reported to the elected officials in a condensed graphic format. Examples of performance measures include the following:

- Percent of subwatersheds monitored in fiscal year with an improved (or declining) rating
- Miles of priority streams needing restoration
- Miles of restored stream showing improved stream condition
- Acres of stormwater practices added to developed areas
- Developed acres subject to uncontrolled runoff
- Percent of watersheds meeting urban/suburban tree canopy cover goals
- Number of environmental complaints received
- Percent of watersheds with monitoring data accessible via the internet

The County estimates that full stream restoration within priority subwatersheds will require about 19 years at current funding and implementation rates. The most recent budget document can be viewed at **http://www.montgomerycountymd.gov/content/omb/fy05/psprec/65-1.pdf**

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PROGRAM 4 FINANCING WATERSHED RESTORATION

Building a Better Watershed Restoration Financing Program

Tips for Building a Program

- Take time to project total financial resources needed to support effective restoration programs.
- Make sure to link restoration expenditures to measurable environmental outputs and benefits. Federal and state agencies, elected officials and the general public increasingly want to know the tangible benefits they will get from the restoration dollars they invest.
- Develop local partnerships to leverage funding in the form of cash or in-kind services.
- Become familiar with the different types of match that can be leveraged to attract state and federal funding grants and/or revolving funds.
- Understand the timing of the local budget cycle and learn exactly where and when each Smart Watershed program fits into the process.
- Create line items for both operating and capital budgets.
- Assign a project code for capital projects in each individual watershed to track progress toward implementation.
- Identify several early action projects that can demonstrate project or program success.

Tips for Fine-Tuning Existing Programs

- Focus on developing local revenue streams such as a stormwater utility that can be a stable and reliable funding source.
- Train municipal staff in grant-writing and management skills - many funders, colleges and professional organizations offer free or low-cost training.
- Seed the development of a local nonprofit watershed organization that can function as a strong partner and obtain funding on their own to augment municipal efforts.
- Develop specific performance measures to track the impact of local restoration spending that can help educate elected officials about restoration during the annual budget process.
- Remember the golden rule – each dollar of local revenue can be leveraged into ten dollars of bonds to finance capital projects.

Resources for Financing Watershed Restoration

http://www.stormwatercenter.net/ (Under Program Resources)

Environmental Finance Center web sites:

Great Lakes **http://urban.csuohio.edu/glefc/index.htm**

New England **http://efc.muskie.usm.maine.edu/**

New Mexico **http://efc.unm.edu/**

New York Region 2 **http://www.maxwell.syr.edu/efc/**

Southeast Regional **http://cepm.louisville.edu/organization/SEEFC/seefc.htm**

Maryland **http://www.efc.umd.edu/**

U.S. EPA Environmental Finance Center **http://www.epa.gov/efinpage/**

U.S. EPA Office of Water Funding/Grants **http://www.epa.gov/water/funding.html**

Plan2Fund: Watershed Planning and Budgeting Tool **http://sspa.boisestate.edu/efc/Tools_Services/Plan2Fund/plan2fund.htm**

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PROGRAM 5 MANAGEMENT OF NATURAL AREA REMNANTS

Remaining natural areas in an urban subwatershed are important pockets that provide habitat, green space and some stormwater treatment. At the same time, they are often fragmented, compacted, and stressed by stormwater runoff, poor soils, invasive plant species, and human disturbance. Municipalities often own or manage natural areas and many of these parcels are prime candidates for reforestation, wetland restoration and land reclamation. This program seeks to expand watershed benefits by systematically restoring and increasing natural areas at the subwatershed level. This program may also involve working with the community to convert vacant land to beneficial uses, such as community gardens.

Smart Watershed Objectives

- Comprehensively manage the remaining natural areas in a subwatershed, including urban forests, wetlands, stream corridors, open space and vacant lands.
- Directly link urban forestry to subwatershed restoration plans, with the goal of increasing healthy forest cover or canopy.
- Focus on creating urban forests on municipal lands such as public rights of way, vacant lands, parks, schools, riparian areas, transportation corridors and other areas of the urban landscape.
- Actively manage and restore priority natural area remnant areas.

Benchmarks

20. Inventory of natural area remnants
21. Natural area planning and management
22. Dedicated funding for natural area restoration/reforestation
23. Subwatershed restoration/reforestation activity

National Average of Program Activity

Overall Score 56%

Large Communities 77%

Medium Communities 49%

Small Communities 43%

Case Study in Management of Natural Area Remnants

Portland, Oregon Watershed Revegetation Program • Population: 538,180 • Budget $1,100,000

The City of Portland, Oregon is working to restore native vegetation through their Watershed Revegetation Program. The program is a voluntary partnership between the city and private landowners to restore degraded habitats through upland and riparian plantings, streambank repair, and wetland construction. Landowners pay 50 to 100% of project costs while the city provides native plants, contract labor, materials, and technical assistance. The restoration projects are designed to improve water quality, control erosion and reduce stormwater pollution –with the ultimate goal of recovering salmon populations. The program is funded by grants, the state revolving loan fund, sewer system charges and landowner cost share. Since 1996, 1,867 acres of native vegetation have been planted and an additional 2,217 acres are actively managed to control invasive plants. The program seeks to begin re-vegetation on 100 new acres each year which adds to the total management portfolio. Projects typically take 5 to 10 years to complete — from initial design, installation, invasive weed control, maintenance and site monitoring. Program details can be viewed at **http://www.portlandonline.com/bes/index.cfm?c=dffci**

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PROGRAM 5 MANAGEMENT OF NATURAL AREA REMNANTS

Building Better Management of Natural Area Remnants

Tips for Getting Started

- Consolidate management efforts by multiple agencies and landowners into a single watershed plan to protect or restore all remaining natural area remnants.
- Utilize property maps or a watershed GIS to find out who owns or manages natural area remnants, including large institutional and commercial sites.
- Look at maps and aerial photos to explore opportunities to link fragmented natural areas in a subwatershed by creating hubs and corridors.
- Target municipal lands for innovative demonstration projects involving native landscaping and reforestation.
- Provide public access and interpretative signs to natural area remnants, when feasible.
- Work up-front with public safety officials to develop design approaches that address concerns about vandalism, vagrancy, and community policing issues.
- Think about cost sharing long-term management of natural areas to encourage greater participation by private landowners.

Tips for Fine-Tuning Existing Programs

- Keep existing inventories of forest, wetland and natural cover up to date, as they tend to change rapidly in urban watersheds.
- Establish numerical targets to guide the management of natural area remnants, such as:
    - Acres of public open space by type
    - Acres and ownership of vacant lands
    - Percent of open space that is permeable
    - Percent forest canopy coverage by subwatershed
    - Tree planting targets by subwatershed
    - Percent of turf or open space that can be reforested or re-vegetated with regionally appropriate plants
- Establish partnerships with businesses and large institutional land owners to manage their natural area remnants. A good example is the Wildlife Habitat Certification program. This program, managed by the Wildlife Habitat Council, recognizes commendable habitat management and environmental education programs at individual sites. Certification by an independent third-party ensures an objective evaluation of habitat restoration projects.

Resources for Management of Natural Area Remnants

Denver Urban Gardens **http://dug.org/gardens.html**

Wildlife Habitat Council **http://www.wildlifehc.org/registry_certifiedsites/index.cfm**

Revitalizing Baltimore – Parks and People Foundation **http://www.parksandpeople.org/programs.html**

Philadelphia Green Program **http://www.pennsylvaniahorticulturalsociety.org/phlgreen/**

Forever Wild: Nature in New York City **http://nycgovparks.org/sub_about/parks_divisions/nrg/forever_wild/foreverwild_home.html**

Center for Urban Restoration Ecology **http://www.i-cure.org/**

Seattle P-Patch Community Gardens **http://www.seattle.gov/neighborhoods/ppatch/**

Urban Watershed Forestry Manual Part 1: Methods for Increasing Forest Cover in a Watershed (Cappiella *et al.*, 2005a). **http://www.cwp.org**

Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites. (Cappiella *et al* 2005b) **http://www.cwp.org**

Urban Watershed Forestry Manual Part 3: Urban Tree Planting Guide. (Cappiella *et al* 2006) **http://www.cwp.org**

A007136

PROGRAM 6 STORMWATER RETROFITTING

Retrofits are installed in urban watersheds to treat and manage runoff from areas that were developed prior to any stormwater management requirements, or with older technologies that can be improved upon to achieve better treatment. Ponds, wetlands and bioretention are re-engineered back into the urban landscape to help remove pollutants and protect stream channels, and are often located on public lands.

Smart Watershed Objectives

- Systematically evaluate the potential for stormwater retrofit opportunities within all subwatersheds.
- Utilize the inventory data to screen, design and construct priority stormwater retrofit projects to meet subwatershed goals.

Benchmarks

24. Subwatershed retrofit inventory
25. Level of stormwater retrofit implementation
26. Demonstration of innovative technology

National Average of Program Activity

Overall Score 53%

Large Communities 69%

Medium Communities 42%

Small Communities 57%

Case Study in Stormwater Retrofitting



Seattle Natural Drainage System Program • Population 572,600 • Budget: $4,000,000

The City of Seattle has implemented a retrofit program that utilizes alternatives to traditional street drainage design to help address impacts from urban runoff. The program works to redesign residential street right-of-ways to incorporate vegetated swales, stormwater cascades, and small wetland ponds to mimic predevelopment hydrology. The objective of street retrofits is to infiltrate stormwater, decrease impervious cover, filter pollutants, promote porous paving, increase vegetation, and improve pedestrian amenities. The watershed goals are to maintain natural stream hydrology, reduce habitat degradation, provide channel protection, and reduce pollutant loads to local creeks. The program is funded by a drainage fee paid by Seattle property owners based on impervious surface coverage. In order to fund a project, the city must show that street retrofits are more cost-effective than traditional street design with curb and gutter. Project sites are selected based on a set of criteria including proximity to creeks needing restoration, the slope, length, and existing infrastructure of the street and community interest. A staff of seven in the stormwater planning group initially assesses the feasibility of potential street retrofit projects, with actual implementation handled by many different agencies. The city has many street retrofit projects in the pipeline, with a typical project timeline of about three years from design to completion. The city estimates that capital costs and life-cycle maintenance costs for street retrofits are less expensive than traditional drainage systems. Street retrofits are engineered to treat runoff for storms up to the two-year design storm that make up the majority of rainfall events in Seattle. Monitoring has confirmed that street retrofits improve both the quality and quantity of stormwater runoff, which has prompted the city to utilize street retrofits as its primary stormwater management approach in all areas that drain directly to creeks. Designers are currently working on expanding street retrofits in four parts of the city, including an ultra-urban redevelopment area. **http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Natural_Drainage_Overview/index.asp**

A007137

PROGRAM 6 STORMWATER RETROFITTING

Building a Better Stormwater Retrofitting Program

Tips for Getting Started

- Systematically focus retrofitting efforts in a few priority subwatersheds to maximize the degree of stormwater treatment.
- Precisely define the stormwater treatment objectives that retrofits will accomplish in restoring a particular subwatershed (e.g., pollutant removal, channel protection, recharge, etc.).
- Combine retrofits with stream repairs and other restoration practices to maximize stream benefits.
- Start with an accurate base-map of existing stormwater management practices to identify older structures with good retrofit potential (e.g., older dry ponds that may have chronic maintenance problems).
- Train staff in rapid field methods such as the Retrofit Reconnaissance Inventory to quickly identify potential retrofit locations in a single subwatershed.
- Demonstrate diversity of innovative retrofit projects on municipal parks and schools, particularly if retrofits are new to the community.
- Public works maintenance yards are excellent retrofit locations that can address multiple NPDES MS4 stormwater permit requirements.
- Consult with local planning staff to verify that vacant parcels don't have development plans in the pipeline that will render them infeasible.

Tips for Fine-Tuning Existing Programs

- Devote more effort to landscaping and community amenities during the design phase to improve public acceptance of stormwater retrofits.
- Re-examine old retrofit inventories in light of new approaches and technologies. Retrofit sites that were discarded in the past may be suitable for new or emerging stormwater practices.
- Consider combining stormwater maintenance and retrofit programs into a single program to maximize efficiency.
- Local willingness to assume maintenance for older practices makes retrofitting much more attractive to private landowners.
- Be creative in working around existing utilities; in some cases, existing sewer lines and other utilities can be worked around or relocated.

Resources for Stormwater Retrofitting

Anacostia Watershed Network (Restoration and Retrofitting) **http://www.anacostia.net/progress.htm**

"The Art of Opportunity" Slideshow at Stormwater Manager's Resource Center web site **http://www.stormwatercenter.net/Slideshows/retrofits.htm**

"Article 143: Stormwater Retrofits: Tools for Watershed Enhancement," *Practice of Watershed Protection* (Schueler and Holland, 2000)

Proceedings from National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments by the U.S. EPA Office of Research and Development **http://www.epa.gov/ORD/NRMRL/pubs/625r99002/625r99002.htm**

"Stormwater Retrofitting primer" at the Wisconsin Department of Natural Resources web site **http://www.dnr.state.wi.us/permitprimer/stormwater/retro.html**

A007138

PROGRAM 7 URBAN STREAM REPAIR AND RESTORATION

Stream repair practices enhance the appearance, structure and function of the urban stream network to address a series of subwatershed restoration objectives. Stream repair includes activities undertaken to address damage to stream channels stemming from uncontrolled runoff and other stream channel alterations caused by past development. Communities may choose more than one stream repair objective to guide their subwatershed restoration efforts as long as they are realistic and achievable. In most cases, the ability to achieve stream repair objectives is fundamentally constrained by subwatershed impervious cover and limited stormwater retrofit potential.

Smart Watershed Objectives

- Comprehensively analyze stream conditions to identify the best stream repair practices to address restoration objectives within a given subwatershed.
- Utilize the data to screen, design and construct innovative stream repair projects to meet subwatershed goals.

Benchmarks

27. Systematic subwatershed approach
28. Level of stream repair implementation
29. Sophistication of stream repair practices
30. Post-construction project evaluation/monitoring

National Average of Program Activity

Overall Score 51%

Large Communities 77%

Medium Communities 42%

Small Communities 43%

Case Study in Urban Stream Repair and Restoration

King County Small Habitat Restoration Program • Population: 1,761,411 • Budget: $426,000

King County (Washington State) developed a Small Habitat Restoration Program to build low-cost projects to restore streams and wetlands in urban and rural watersheds. Projects are selected based on the restoration benefits provided and the cost-effectiveness of installation. Typical projects include streamside and wetland planting, livestock fencing, in-stream habitat improvements, removal of fish barriers and control of invasive plants. The program also provides technical assistance to property owners and other agencies interested in pursuing their own habitat restoration projects. The annual budget for the habitat program is less than a half million dollars and covers 2,134 square miles of unincorporated King County. The program is funded by a county surface water management fee, which is a property tax formula based on the areas of impervious cover. Administration accounts for about 10% of the program budget, and the project cost ratio is 60:40 for labor and construction. As of 2005, 71 habitat restoration projects were in some phase of scoping, design, permitting, construction or management. Individual projects take three to five years to complete, depending on the complexity of permitting and post-installation monitoring. Funds are also allocated for technical assistance which covers up to two days of assistance from program staff for private property owners. The staff generally advises on ways to address property management issues such as streambank erosion, invasive plant control, and wetland restoration. **http://dnr.metrokc.gov/wlr/cposa/shrp/index.htm**

A007139

PROGRAM 7 URBAN STREAM REPAIR AND RESTORATION

Building a Better Urban Stream Repair and Restoration Program

Tips for Getting Started

- Streamwalks are an excellent means to gain momentum for stream restoration and educate residents on the relationship between stream conditions and aquatic life.
- Choose realistic and achievable restoration objectives for each urban stream segment, given that each segment is influenced differently by upstream and downstream factors. For a good systematic approach for assessing subwatershed stream repair potential, consult *Urban Subwatershed Restoration Manual No. 4.*
- Although most communities have traditionally engaged in stream repair to protect threatened infrastructure and property, consider expanding objectives to include fishery habitat and channel stability.
- Develop a process for evaluating and ranking local stream repair projects based on watershed benefits – otherwise projects will be prioritized to respond to the loudest complaints – not necessarily the most important problems.

Tips for Fine-Tuning Existing Programs

- Invite local volunteer groups to assist in post-construction monitoring of restoration projects, and to keep sites free of invasive plants.
- Stream repair projects should be treated like any other infrastructure investment – they require inspection and maintenance over time to remain viable.
- Package stream repair projects in the context of subwatershed plans to be eligible for additional state and federal assistance.

Resources for Urban Stream Repair and Restoration

Montgomery County, MD - Sligo Creek Watershed Restoration **http://www.montgomerycountymd.gov/deptmpl.asp?url=/content/dep/csps/watersheds/csps/html/sligo.asp**

Montgomery County Anacostia Restoration Program **http://www.montgomerycountymd.gov/content/dep/Publications/pdf/anacostia_restoration.pdf**

Griffin,. GA - Streambank Restoration Program **http://www.forester.net/sw_0107_griffin.html** (as covered in *Stormwater Magazine*)

Berkeley, CA - Cordornices Creek Stream Daylighting **http://www.coastalconservancy.ca.gov/sccbb/0503bb/0503Board08_Cordornices_Creek.pdf**

Seattle Urban Creeks Legacy Project **http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Projects/Creek_Restoration/index.asp**

Urban Subwatershed Restoration Manual 4: Urban Stream Repair Practices (Schueler and Brown, 2004)

Urban Subwatershed Restoration Manual 10: The Unified Stream Assessment (USA): A Users Manual. (Kitchell and Schueler, 2004)

Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group at **http://www.nrcs.usda.gov/technical/stream_restoration/**

A007140

PROGRAM 8 ILLICIT DISCHARGE DETECTION AND ELIMINATION

The storm and sanitary sewer networks in many older watersheds can be a major source of pollutants through combined sewer overflows, sanitary sewer overflows, and illicit pollutant discharges. This Smart Watershed program concerns itself with targeted efforts to find, fix and eliminate discharges of sewage and other pollutants in portions of the watershed with the most severe problems.

Smart Watershed Objectives

- Implement an ongoing program to detect and eliminate any discharges of untreated wastewater and non-stormwater flows into the watershed, including sanitary sewer overflows (SSOs), combined sewer overflows, and illicit discharges.

Benchmarks

31. Possess discharge control authority
32. Discharge mapping and screening
33. Outfall reconnaissance inventory
34. Pollution hotline and response
35. Activity in eliminating discharges

National Average of Program Activity

Overall Score 63%

Large Communities 62%

Medium Communities 58%

Small Communities 71%

Case Study in Illicit Discharge Detection and Elimination

Fort Worth, Texas Dry Weather Monitoring • Population: 534,694

Fort Worth has been recognized nationally for its efforts to detect and eliminate illicit discharges to its municipal storm drain system. More than 150 dry weather field screens are performed across the city each year to help detect potential illicit discharges or improper connections using various tests. One innovative test uses luminescent bacteria as an indicator of potential toxicity at larger stormwater outfalls. The city actively performs detective work to locate and eliminate the sources of dry weather flows, and sponsors programs to prevent illicit discharges from occurring in the first place. Examples include pollutant fingerprinting, pollutant trace-backs, industrial inspections and public education. For example, the city installs more than 250 storm drain markers each year, with the location selected based on traffic volume, past dumping history, illicit discharge reports and citizen complaints. City staff routinely inspects industrial facilities considered to have a high illicit discharge potential, such as hazardous waste treatment, disposal or recovery facilities. The city also operates a permit program for mobile commercial power-washing vendors designed to limit detergents and other pollutants discharged into the storm drain system. Fort Worth also maintains a telephone hotline for reporting environmental complaints, such as illegal dumping and illicit discharges. Residents can also use an on-line complaint form to report spills or intentional violations. The city maintains a spill response team to handle spills less than 500 gallons. The team is on-call 24 hours a day, 7 days a week ready to contain and clean up chemical spills from car, truck, and train wrecks, industrial accidents, and other discharges that could impact the storm drain system. **http://www.fortworthgov.org/DEM/aboutWQ.htm**

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PROGRAM 8 ILLICIT DISCHARGE DETECTION AND ELIMINATION

Building a Better Illicit Discharge Detection and Elimination Program

Tips for Getting Started

- Most communities initially have a poor understanding of the scope and nature of their illicit discharge problem. Therefore, an adaptive approach to manage illicit discharges as outlined in Brown *et al* (2004) may be warranted.
- Once more is known about the extent of local illicit discharge problems, a community can shift resources to the most cost-effective screening, prevention and enforcement tools to solve the problem.
- The extent of local illicit discharge problems is best understood by performing rapid field assessments, reviewing past complaint files, and interviewing key inspection and utility maintenance staff.
- Continuous education is important since preventing pollution at its source is the most cost-effective method to control illicit discharges. Consider including illicit discharges as part of the overall stormwater education program in the community.
- Combine stormwater outfall screening with other rapid stream corridor assessments so streams only need be surveyed once -- and consider out-sourcing both functions to a local watershed group.

Tips for Fine-Tuning Existing Programs

- Look for patterns in outfall screening data to identify problem subwatersheds where limited resources can be effectively targeted.
- Many communities find citizen hotlines are a very cost-effective tool to detect transitory illicit discharge events.
- Work cooperatively with permit writers to ensure that IDDE program requirements are customized to deal with actual illicit discharge problems found in the community.
- Up-front desktop and field screening can characterize the severity of illicit discharge problems in different subwatersheds so that the most severe problems are addressed in each MS4 NPDES permit cycle.
- Mobile sources of illicit discharges such as industrial cleaning companies, septic pumpers, and recreational vehicles are often overlooked in many communities. Work with each sector to develop effective educational programs.

Resources for IDDE Programs

Cary, NC – Stormwater Inventory **http://www.townofcary.org/depts/dsdept/engineering/engproj/stormwaterinventoryoverview.htm**

Rouge River, MI – Illicit Discharge Detection and Elimination **http://www.rougeriver.com/proddata/catalog.cfm?category=illicit**

Washington, D.C. - Combined Sewer Overflow Abatement in Anacostia and Potomac Rivers, and Rock Creek http://**www.dcwasa.com/education/css/combined_sewer.cfm**

Greenwood, SC - Sanitary Sewer Overflow Control **http://www.epa.gov/npdes/sso/greenwood/index.htm**

Illicit Discharge Detection and Elimination: A guidance manual for program development and technical assessments. (Brown *et al.*, 2004) **http://www.cwp.org**

A007142

PROGRAM 9 MAINTENANCE, INSPECTION AND ENFORCEMENT

Communities need effective local programs to inspect and maintain existing stormwater and restoration practices. Stormwater facilities can lose their effectiveness over time without ongoing efforts to ensure their continuing function. In addition, communities should maintain active programs to enforce potential water quality violations from a range of activities.

Smart Watershed Objectives

- Routinely inspect existing stormwater treatment practices to determine their function and performance.
- Evaluate all completed watershed restoration practices on an ongoing basis to ensure they are working as designed.
- Utilize appropriate enforcement mechanisms to ensure adequate maintenance of practices and compliance with water quality ordinances.

Benchmarks

36. Inspect and maintain stormwater practices
37. Inspect and maintain restoration practices
38. Water quality enforcement activity

National Average of Program Activity

Not measured in Center survey

Case Study in Maintenance, Inspection and Enforcement

James City County Stormwater Inspection and Education Program • Population: 53,487

Virtually all new commercial and residential developments require the construction of stormwater practices in James City County, which is located near Williamsburg, Virginia. Stormwater practices require periodic maintenance to ensure that they function as designed and to prolong their useful life. Legal responsibility is typically assigned to landowners and homeowner associations through a declaration of covenants. In 2000, the County launched a comprehensive program to inventory the condition of all structural stormwater practices built to date. Field inspections were conducted and GPS coordinates were fixed at each stormwater practice, and then entered into a GIS database that contains digital photographs for each facility. Four years were needed to complete the County maintenance inventory, which, as of 2004, contained 521 stormwater practices. New stormwater practices are added to the inventory once as-built plans have been received and approved. The inventory helped the County identify critical maintenance needs and issues, and was used to expand the scope and budget of the local stormwater inspection and maintenance program. County staff continues to inspect stormwater practices on a three-year cycle, and has developed a list of third party maintenance vendors. Lastly, the County developed a watershed education website with information on how to maintain stormwater practices and a searchable database for stormwater practice ratings for individual neighborhoods. **http://www.jamescity.va.us/resources/devmgmt/environmental/div_environ_bmp.html**



A007143

PROGRAM 9 MAINTENANCE, INSPECTION AND ENFORCEMENT

Building a Better Maintenance, Inspection and Enforcement Program

Tips for Getting Started

- Work with permit writers to ensure that performance standards for maintenance, inspection and enforcement activity are explicitly included as MS4 NPDES stormwater permit conditions.
- Create a data management system to track the condition and maintenance status of stormwater and restoration infrastructure. Routine maintenance, inspection and enforcement data should be stored on a GIS so information can be quickly accessed.
- Use new technology such as GPS, digital cameras and mobile data loggers to rapidly upload field inspection data into the tracking system.
- Review local codes to ensure that they clearly define the authority and responsibilities for all maintenance, inspection and enforcement activities.
- Create an emergency contact list and distribute to inspectors and field crews so they can quickly report water quality problems, erosion control violations and emergency stormwater maintenance needs.
- Maintain a vendor list of qualified contractors that can handle emergency clean-ups and perform stormwater maintenance tasks.

Tips for Fine-Tuning Existing Programs

- Review homeowner association covenants with the local attorney office to ensure they contain adequate language on stormwater maintenance responsibilities, including right of access, charge-backs for emergency repairs and penalties for non-compliance.
- Cross-train field personnel to recognize signs of pollution problems and to know who to report them to.
- Develop an emergency response handbook for all responders that contains practical tips on how to respond to different types of pollution events.
- Consider launching an Adopt-a Pond program to educate homeowner associations about common maintenance needs for stormwater practices.

Resources for Maintaining, Inspecting and Enforcing Watershed Practices

Bellevue, WA Private Drainage Inspection Program **http://www.cityofbellevue.org/page.asp?view=1318**

Stormwater Pond and Wetland Maintenance Tool (Brown and Hoyt, 2004) at **http://www.stormwatercenter.net**

Maui County Erosion and Sediment Control Program **http://www.epa.gov/owow/nps/Section319III/innov_hi.htm**

Montgomery County, MD Stormwater Facility Maintenance Program **http://www.montgomerycountymd.gov/deptmpl.asp?url=/content/dep/SFMP/home.asp**

San Ramon, CA BMP Maintenance and Operation Verification Program – annual compliance verification. **http://www.ci.san-ramon.ca.us/engr/images/C.3appdix_K.pdf**

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PROGRAM 10 SMART SITE PRACTICES DURING REDEVELOPMENT

Smart Site practices involve eleven urban site design techniques to reduce the impacts of stormwater runoff when redeveloping existing urban areas. The purpose of Smart Site practices is to promote redevelopment as an attractive and affordable land use option while maximizing stormwater runoff controls where none were provided initially. Municipalities and their contractors are often major developers of public parking lots, roads, schools, offices, and public spaces, and can promote or require greater use of Smart Site practices during infill and redevelopment to meet restoration goals.

Smart Watershed Objectives

- Lead by example by implementing Smart Site practices on municipal construction projects such as parking lots, roads and buildings.
- Establish policies and incentives that promote Smart Site practices on private infill and redevelopment projects, and remove any barriers in existing codes and regulations.

Benchmarks

39. Conduct audit of redevelopment codes and ordinances
40. Adopt Smart Site practices for redevelopment
41. Demonstrate in municipal construction projects
42. Financial incentives for the private sector

National Average of Program Activity

Overall Score 37%

Large Communities 46%

Medium Communities 29%

Small Communities 43%

Case Study in Smart Site Practices during Redevelopment

Santa Monica, California Green Building Program • Population: 84,000 • Budget: $1,000,000

Santa Monica developed a green building program in order to improve water quality and address other environmental impacts without forcing excessive cost burdens on developers, owners or occupants. Green building guidelines apply to institutional and commercial offices, light industrial buildings, commercial retail buildings, multi-family residences, and hotels/motels in the city. The guidelines contain recommended practices to reduce stormwater runoff and conserve water featuring innovative infiltration, water reuse, and landscaping practices. An urban runoff mitigation plan is required for all new development and redevelopment projects. The purpose of the mitigation plans is to ensure each development project maximizes permeable surface area and minimizes the amount of runoff directed to impermeable areas. Compliance is measured by documenting a 20% reduction in stormwater runoff volume after the site is developed. The city code also requires the use of pollution prevention practices and spill controls. The city also provides financial incentives to promote green building projects, and adopted a streamlined plan review process that expedites the plan approval process. **http://greenbuildings.santa-monica.org**

A007145

PROGRAM 10 SMART SITE PRACTICES DURING REDEVELOPMENT

Building Better Programs for Smart Site Practices During Redevelopment

Tips for Building a Program

- Identify several municipal building projects to demonstrate Smart Site practices.
- Make sure that Smart Site practices are incorporated into green building certification programs such as the Leadership in Environmental and Energy Efficient Design (LEED) standards.
- Analyze local codes to remove barriers to redevelopment and infill.
- Offer technical information on Smart Site practices in a central location such as a kiosk or website.
- Offer financial incentives to encourage Smart Site practices, such as energy efficiency grants, cost-sharing, tax credits, and waiver or reduction of certain fees.
- Develop a local recognition program to call attention to innovative projects and developers that show leadership in Smart Site practices.

Tips for Fine-Tuning an Existing Programs

- Keep track of redevelopment projects where Smart Site practices have been successfully demonstrated to educate the local design community.
- Expedite the green building approval process so that it is faster than the standard development approval process.
- Hardwire Smart Site requirements into standard municipal building design and construction contracts.

Resources for Smart Site Practices during Redevelopment

MDE Montgomery Park: Green Building and Smart Growth **http://www.montgomerypark.com/green.html** **http://www.mde.state.md.us/AboutMDE/mp_special.ASP**

Miami River Urban Infill Plan **http://miamirivercommission.org/PDF/UIP-Final.pdf** This is a very large download. Before clicking, you may want to visit the main page to read more about the plan: **http://miamirivercommission.org**

Natural Resources Defense Council Office in Santa Monica **http://www.nrdc.org/cities/building/smoffice/walkwater05.asp#smtop**

Redevelopment Roundtable Consensus Agreement: Smart Site Practices for Redevelopment and Infill Projects (Center for Watershed Protection, 2001) at **http://www.cwp.org**

A007146

PROGRAM 11 WATERSHED EDUCATION AND PERSONAL STEWARDSHIP

Education is an important Smart Watershed program since it increases public awareness about important resident behaviors that produce or reduce stormwater pollution. Recent experience has shown that carefully targeted campaigns can be very effective in changing watershed behaviors. Community programs are also the most direct conduit to services that make it easier for individual residents to practice better watershed stewardship on their own patch of ground.

Smart Watershed Objectives

- Craft and implement watershed education programs that focus on key pollutants and behaviors with a carefully targeted message for the intended audience.
- Provide a range of direct services to help watershed residents do the right thing in terms of pollution prevention and to understand the positive and negative consequences of personal actions.
- Continuously strive to make every resident aware of available stewardship services and provide them in the most accessible and convenient manner possible.

Benchmarks

43. Watershed education and outreach activity
44. Diversity of watershed education programs
45. Convenient access to stewardship services

National Average of Program Activity

Overall Score 65%

Large Communities 77%

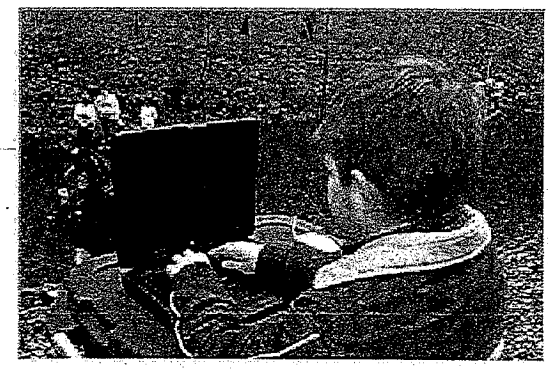
Medium Communities 63%

Small Communities 57%

Case Study in Watershed Education and Personal Stewardship

Austin, Texas Watershed Outreach and Education Programs • Budget: $825,000/year

Austin's watershed outreach and education programs are unique and diverse, ranging from Earth-wise gardening to school and community programs. Outreach activities are specifically aimed at empowering people to adopt practices and change behaviors to reduce stormwater pollution problems. The city has successfully targeted education efforts to reach specific audiences and demographic groups. For example, stormwater outreach efforts include school and camp programs, a watershed website, bilingual maps and brochures, storm drain marking, watershed cleanups, citizen monitoring, and a xeriscaping program. The city provides convenient access to services that enable residents to become good watershed stewards, such as hazardous waste and recycling drop off sites, regular yard waste collection, pet waste collection stations, discounted compost, and used oil collection. In addition, the programs are regularly evaluated and adapted to reach the greatest number of people. **http://www.ci.austin.tx.us/watershed/**





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PROGRAM 11 WATERSHED EDUCATION AND PERSONAL STEWARDSHIP

Building a Better Watershed Education and Personal Stewardship Program

Tips for Building a Program

- Target educational messages to specific audience needs.
- Determine the watershed issues that residents find most compelling, and then craft action-oriented educational tools to address them.
- Provide easy access to services that help residents become better watershed stewards.
- Develop education approaches for local elected officials – a watershed brief book can be used to compile important watershed-related information and news on a regular basis.
- Partner with the school system to build stormwater education into the curriculum.

Tips for Fine-Tuning an Existing Programs

- Survey residents before and after education efforts to document change and measure effectiveness of outreach techniques.
- Continue targeting education efforts to focus on a few new audiences each year such as real estate developers, local building industry associations, and homeowner associations.
- Understand the changing demographics of urban watersheds and adapt educational materials to address change and resident turnover.

Resources for Watershed Education and Personal Stewardship

AWRA 2000 Proceedings: **http://www.awra.org/proceedings/Alaska2000/ak04/**

Chesapeake Club Media Campaign **http://www.chesapeakeclub.org/media.htm**

EPA Section 319 Success Stories **http://www.epa.gov/owow/nps/Section319III/inform.htm**

King County, WA Water Quality Consortium Ad Campaign **http://www.psat.wa.gov/Programs/Pie_Ed/Water_Ed_Materials.htm**

Northern Virginia Stormwater Education Radio Campaign **http://www.novaregion.org/pdf/NVRCProgramHL6_05.pdf**

Portland OR – Downspout Disconnection Program **http://www.portlandonline.com/bes/index.cfm?c=31246**

Austin Hazardous Waste Facility and Reuse Store **http://www.ci.austin.tx.us/sws/hhw.htm**

Getting in Step: A Guide for Conducting Watershed Outreach Campaigns (McPherson and Tonning, 2003a) and *Getting in Step: Engaging and Involving Stakeholders in Your Watershed* (MacPherson and Tonning, 2003b) at **http://www.epa.gov/owow/watershed/outreach/documents/**

Westbrook Elementary School Stream Studies web site **http://www.mcps.k12.md.us/schools/westbrookes/streamstudies.html**

A007148

PROGRAM 12 PUBLIC INVOLVEMENT AND NEIGHBORHOOD CONSULTATION

Public involvement is critical to enlist long-term support for local watershed restoration efforts. Early public involvement in the planning process can provide important feedback on restoration goals and priorities. Communities that establish a positive relationship with residents during each step of the restoration planning process can gain support for project and program funding. This Smart Watershed program evaluates the degree to which a community enables the public to become involved and fully participate in the watershed restoration planning process.

Smart Watershed Objectives

- Provide meaningful opportunities for public involvement and participation in each step of a subwatershed restoration plan.
- Ensure that neighborhoods are fully consulted about local restoration projects.

Benchmarks

46. Stakeholder involvement in restoration planning
47. Neighborhood consultation about restoration projects
48. Public access to restoration information

National Average of Program Activity

Overall Score 71%

Large Communities 85%

Medium Communities 75%

Small Communities 50%

Case Study in Public Involvement and Neighborhood Consultation

Rockville, Maryland Watts Branch Watershed Community Charrettes • Population: 59,000

Who could possibly be against watershed restoration? Quite a few people, actually, if they haven't been involved in the design and location of restoration projects. The construction of restoration projects can have a dramatic effect on the character of neighborhoods, open space and parkland. Trees can be cleared, park uses changed, and possible water hazards created. When the City of Rockville, Maryland began an ambitious program to restore Watts Branch, they were mindful of past controversies about stormwater retrofit projects. Consequently, the city committed itself to actively involve the public in decision-making throughout the entire process. The city held more than twenty meetings (roughly four per every square mile in the watershed), posted project information on its website and community list serve and installed a watershed information kiosk in City Hall.

The city went well beyond public notification and education by forming the Watts Branch Partnership to include residents in the design and location of retrofit and stream restoration projects. The public was invited to participate in field meetings, retrofit inventories, stream assessments, and even site visits with permitting agencies. Numerous site tours were held with neighborhood and civic associations. Design charrettes were held to jointly develop a ranking system to prioritize retrofits, and raise concerns about tree clearing, loss of screening, and change in park uses. Several projects were redesigned, relocated or dropped from further consideration as a direct result of community involvement. The investment in neighborhood consultation was pivotal in getting the partnership to strongly endorse the final restoration plan. Based on the strong community support, the City Council authorized nearly $3,000,000 for final design and implementation of restoration projects.

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PROGRAM 12 PUBLIC INVOLVEMENT AND NEIGHBORHOOD CONSULTATION

Building a Better Public Involvement and Neighborhood Consultation Program

Tips for Building a New Program

- Treat the public as a partner in restoration and not as a potential foe.
- Make public involvement transparent, credible and responsive.
- Go beyond mere notification and give residents meaningful opportunities to participate in restoration planning.
- Remember that activities such as stream walks and site tours are effective ways to educate residents first hand about watershed problems that need to be addressed.
- Provide suggestions at public meetings about simple stewardship actions residents can take and how they can report water quality problems.
- Clearly indicate how public input will be used in watershed planning decisions and project implementation.
- Be prepared to defray public discontent about unrelated community issues. A few cranky citizens can derail the process, so know what hot issues are important in the neighborhood and be ready to provide contacts that can help resolve problems.
- Contact homeowners associations and civic groups to get on their agenda to describe restoration projects.

Tips for Fine-Tuning Existing Programs

- Get to know your local media and public access cable channel. Local media can help get the word out about projects and highlight the restoration program, but keep in mind that media need a lot of lead time, so plan a season ahead.
- Give restoration partners face time and speaking opportunities at public meetings.
- Manage controversial restoration projects by hiring a facilitator, utilizing a neutral spokesperson, or training key staff on facilitation skills.
- Formulate a detailed plan for the different types of public meeting formats and rehearse them in advance.
- Provide a feedback form for stakeholders to comment on projects, and provide food and fun for all stakeholders.

Resources for Public Involvement and Neighborhood Consultation

Baltimore County State of our Watersheds Conference **http://www.co.ba.md.us/Agencies/environment/watersheds/ep_watershedconference.htmlhttp://www.co.ba.md.us/News/2003/october/1027_watersheds.html**

Urban Subwatershed Restoration Manual 2: Methods to Develop Restoration Plans for Small Watersheds (Schueler and Kitchell, 2005)

Getting in Step: Engaging and Involving Stakeholders in Your Watershed (MacPherson and Tonning, 2003b) at **http://www.epa.gov/owow/watershed/outreach/documents/**

Pennsylvania Senior Environmental Corps **http://www.dep.state.pa.us/hosting/pasec/**

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PROGRAM 13 POLLUTION PREVENTION AT STORMWATER HOTSPOTS

A hotspot is defined as an urban land use or operation that generates higher concentrations of pollutants than are typically found in stormwater runoff. Simple pollution prevention practices employed at stormwater hotspots can sharply reduce pollutant loading and the frequency of spills, leaks and illicit discharges.

Smart Watershed Objectives

- Target major hotspot operations within subwatersheds with a range of carrots and sticks to promote greater pollution prevention activity.
- Provide clear and compelling pollution prevention education materials, compliance and enforcement information, and business recognition programs.

Benchmarks

49. Identify and map stormwater hotspots
50. Target businesses for education and outreach
51. Business recognition and partnerships

National Average of Program Activity

Overall Score 35%

Large Communities 39%

Medium Communities 42%

Small Communities 21%

Case Study in Pollution Prevention at Stormwater Hotspots

Seattle Pollution Control Inspection Program • Population: 572,600

The City of Seattle works with local businesses to improve the stormwater quality delivered to local creeks, lakes and the Puget Sound. Business inspections are a key element of the city's stormwater pollution prevention program required under its NPDES MS4 stormwater permit. The city inspects businesses that connect to its stormwater system that engage in activities and operations known to generate pollutant discharges, known as stormwater hotspots. Existing hotspot businesses must prepare spill prevention plans and implement operational controls to prevent runoff pollution. New hotspot businesses may also be required to install source controls or treat them with structural stormwater practices. Each business receives a notification letter sent a month before the planned inspection date. During the inspection, a water quality inspector identifies potential sources of pollutants to the storm drain system and observes whether pollution prevention practices are being maintained. If any corrective actions are needed, they are described in a letter sent to the property owner within two weeks of the inspection. The letter briefly describes the nature of the problem, recommends techniques to prevent pollutant discharge, and sets a date when the property will be re-inspected. If corrective actions are not taken, a violation notice is issued that could result in a fine of up to $500 for each day the violation continues. The city also provides financial support through the Greater Seattle Chamber of Commerce to offer local businesses free products and services that promote solid waste prevention, recycling, water conservation, stormwater pollution prevention and sustainable building. **http://www.seattle.gov/util/Services/Drainage_&_Sewer/Stormwater_Related_Inspections/Pollution_Control_Inspections/index.asp**

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PROGRAM 13 POLLUTION PREVENTION AT STORMWATER HOTSPOTS

Building Better Local Pollution Prevention Programs

Tips for Getting Started

- Target training and inspections to specific hotspot business types based on local pollutants of concern and problems found during local illicit discharge detection screening (see Program 8).
- Coordinate pollution prevention training for inspectors with adjacent communities to reduce costs.
- Create a database of hotspots for each subwatershed and make this information available to inspectors and citizen volunteer monitors.

Tips for Fine-Tuning Existing Programs

- Ensure that local inspection staff and other employees promote pollution prevention during other routine site visits and inspections.
- Develop a business recognition program for companies that do the right thing.
- Use municipal facilities to demonstrate effective pollution prevention practices.
- Conduct voluntary site audits and offer technical assistance before taking enforcement action – it is more cost-effective and can avoid litigation costs.

Resources for Pollution Prevention at Stormwater Hotspots

EPA Stormwater Management for Industrial Activities: Developing Pollution Prevention Plans **http://www.epa.gov/npdes/pubs/contents_indguide.pdf**

EPA Compliance Assistance Centers **http://www.epa.gov/compliance/assistance/centers/index.html**

King County, WA Stormwater Pollution Control Manual **http://dnr.metrokc.gov/wlr/dss/SPPM.htm**

Montgomery County Clean Water Partners – resource link to handbooks **http://www.montgomerycountymd.gov/deptmpl.asp?url=/content/dep/Epartners/home.asp**

Urban Subwatershed Restoration Manual 8: Pollution Source Control Practices (Schueler *et al.*, 2004)

Urban Subwatershed Restoration Manual 11: The Unified Subwatershed and Site Reconnaissance (USSR): A Users Manual. (Wright *et al.*, 2004).

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PROGRAM 14 POLLUTION PREVENTION AT MUNICIPAL OPERATIONS

The daily actions of public employees and municipal contractors can exert a strong influence on the quality of stormwater runoff in any watershed. In addition, public employees are also the front-line for public outreach and education and are instrumental in setting a good example. Changes in municipal operations such as street sweeping, yard waste collection, recycling of used oil and household hazardous waste, and general trash control can all help reduce stormwater, air and groundwater pollution. In addition, routine cleaning of streets and storm drains can help reduce pollutant loads delivered to local waters.

Smart Watershed Objectives

- Integrate pollution prevention in the daily operations of public employees and municipal contractors.
- Commit to continuous training of employees and municipal contractors, and employ innovative pollution reduction techniques throughout all municipal operations.
- Design a pollution prevention strategy for each municipal operational area and designate a lead local agency or operations manager to implement the pollution prevention training.

Benchmarks

52. Municipal pollution prevention operations
53. Municipal road and storm drain maintenance
54. Ongoing training of municipal employees
55. Emergency spill and discharge response
56. Environmental management system

National Average of Program Activity

Overall Score 59%

Large Communities 85%

Medium Communities 54%

Small Communities 43%

Case Study in Pollution Prevention at Municipal Operations

Los Angeles Municipal Training Program

To ensure compliance with its MS4 NPDES stormwater permit, Los Angeles initiated a training program to educate all 41,000 City employees on the actions they can take to reduce the amount of pollutants entering the municipal storm drain system. This training program includes a video entitled *Stormwater Pollution — What You Can Do* and a supplemental handbook distributed to all city divisions. The 20-minute video demonstrates good housekeeping practices, and the handbook describes actions employees can take to reduce stormwater pollution on the job and at home. Each division within the City of Los Angeles is responsible to ensure that all employees watch the video and read a copy of the handbook. The second phase of the training program provides specialized training for employees whose job duties directly impact the quality of urban runoff. In addition, all city facilities are required to develop stormwater pollution prevention plans. City employees that work in the field also receive extensive training to recognize stormwater pollution or illicit discharge problems and promptly report them to the appropriate authority.

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PROGRAM 14 POLLUTION PREVENTION AT MUNICIPAL OPERATIONS

Building Better Municipal Pollution Prevention Programs

Tips for Getting Started

- Foster an institutional mindset of going beyond compliance.
- Provide training opportunities and employee recognition programs that reward innovation and problem-solving.
- All field staff should carry emergency pollution response contact information with them at all times.
- Approach a local private industry with a good operations reputation to help train staff in doing on-site pollution prevention audits.
- Include basic pollution prevention operating procedures into municipal contract language for any contracted services that have the potential to generate pollutants.

Tips for Fine-Tuning Existing Programs

- Designate a pollution prevention coordinator to provide oversight of pollution prevention education, training, and implementation programs across all municipal operations.
- Cross-train employees, particularly field staff, in recognizing problems and how to respond appropriately as a first responder and in getting assistance on-site.
- Link municipal pollution prevention training to new employee orientation programs and performance reviews.

Resources for Pollution Prevention at Municipal Operations

National Pollution Prevention Roundtable **http://www.p2.org/**

EPA Performance Track **http://www.epa.gov/performancetrack/index.htm**

San Francisco CA – Integrated Pest Management **http://www.pesp.org/1998/birc98.htm**

Seattle Pesticide Use Reduction Program **http://www.cityofseattle.net/environment/Pesticides.htm**

Pollution Prevention/Good Housekeeping for Municipal Operations **http://cfpub.epa.gov/npdes/stormwater/menuofbmps/poll.cfm**

Stormwater Phase II Final Rule - Permitting and Reporting: The Process and Requirements **http://www.epa.gov/npdes/pubs/fact2-9.pdf**

Storm Water Phase II Compliance Assistance Guide **http://www.epa.gov/npdes/pubs/comguide.pdf**

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CHAPTER 3

THE SMART WATERSHED BENCHMARKING TOOL

This chapter presents the Smart Watershed benchmarking tool, which consists of a detailed questionnaire to measure activity and integration with 14 individual municipal watershed restoration programs. The chapter provides guidance to help program managers or watershed groups complete the tool and interpret results for their community, including alternative scoring methods for small communities and communities that lack perennial streams. Points are awarded based on answers to 56 individual benchmark questions with a total of 100 points possible (Table 4). An additional 15 extra credit points can be awarded to communities that exceed the national average level of restoration activity in a program area. The actual points awarded for each benchmark question are based on quantitative scoring criteria along with the recommended documentation to support or verify individual scoring decisions. Individual scores are then entered into a scorecard to get a total aggregate score for the community (Table 5).

Total scores for the benchmarking tool are adjusted for three different community sizes:

- Small communities: population of less than 50,000
- Medium communities: population from 50,000 to 250,000
- Large communities: population greater than 250,000

TABLE 4: OVERVIEW OF THE SMART WATERSHED BENCHMARKING TOOL

Program No.	Smart Watershed Program	Number of Benchmarks	Total Points
1	Subwatershed Restoration Planning	9	13
2	Stream and Subwatershed Field Assessment	3	7
3	Subwatershed Monitoring and Reporting	4	5
4	Watershed Restoration Financing	3	5
5	Management of Natural Area Remnants	4	10
6	Stormwater Retrofitting	3	10
7	Urban Stream Repair/Restoration	4	7
8	Illicit Discharge Detection and Elimination	5	8
9	Maintenance, Inspection and Enforcement	3	5
10	Smart Site Practices During Redevelopment	4	5
11	Watershed Education and Personal Stewardship	3	9
12	Public Involvement and Neighborhood Consultation	3	5
13	Pollution Prevention at Stormwater Hotspots	3	4
14	Pollution Prevention at Municipal Operations	5	7
	TOTAL	56	100
	Plus up to 15 extra credit points based on program implementation rates : Max Score =		115

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TABLE 5: STANDARD SMART WATERSHED BENCHMARKING TOOL SCORECARD				
Benchmark No.	Description of Benchmark	Maximum Points	Points Awarded	Extra Credit
Program 1: Subwatershed Restoration Planning				
1	Subwatershed-based restoration planning	1		
2	Subwatershed planning activity	2		1
3	Clear goals driving restoration efforts	2		
4	Comparative subwatershed analysis *	1		
5	Dedicated staffing for watershed coordination *	2		
6	Watershed management structure	1		
7	Watershed-based GIS mapping system *	2		
8	Tracking of restoration information *	1		
9	Mechanism for plan adoption	1		
	Subtotal	13		
Program 2: Stream and Subwatershed Field Assessments				
10	Rapid stream corridor assessments	2		1
11	Field evaluation of corridor restoration potential	3		
12	Field evaluation of upland restoration potential *	2		
	Subtotal	7		
Program 3: Watershed Monitoring and Reporting				
13	Subwatershed monitoring program *	2		1
14	Aquatic indicators linked to watershed goals *	1		
15	Public notification of water quality problems *	1		
16	Data management and reporting	1		
	Subtotal	5		
Program 4: Financing Watershed Restoration				
17	Total watershed restoration expenditures	2		2
18	Long-term funding for plan implementation	1		
19	Local funding for Smart watershed programs *	2		
	Subtotal	5		
Program 5: Management of Natural Area Remnants				
20	Inventory of natural area remnants	3		
21	Natural area planning and management	3		
22	Dedicated funding for restoration/reforestation *	1		
23	Subwatershed reforestation/restoration activity	3		1
	Subtotal	10		
Program 6: Stormwater Retrofitting				
24	Subwatershed retrofit inventory	4		
25	Level of stormwater retrofit implementation	4		1
26	Demonstration of innovative technology *	2		
	Subtotal	10		
Program 7: Urban Stream Repair and Restoration				
27	Systematic subwatershed approach	2		
28	Level of stream repair implementation	2		1
29	Sophistication of stream repair practice	2		
30	Postconstruction project evaluation/monitoring *	1		
	Subtotal	7		

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TABLE 5: STANDARD SMART WATERSHED BENCHMARKING TOOL SCORECARD

Benchmark No.	Description of Benchmark	Maximum Points	Points Awarded	Extra Credit
Program 8: Illicit Discharge Detection and Elimination				
31	Possess discharge control authority *	1		
32	Discharge mapping and screening *	2		
33	Outfall reconnaissance inventory	2		
34	Pollution hotline and response *	1		
35	Activity in eliminating discharges	2		1
	Subtotal	8		
Program 9: Watershed Maintenance, Inspection and Enforcement				
36	Inspect and maintain stormwater practices *	2		
37	Inspect and maintain restoration practices	2		
38	Water quality enforcement activity	1		1
	Subtotal	5		
Program 10: Promote Smart Site Practices during Redevelopment				
39	Conduct audit of redevelopment codes	1		
40	Adopt Smart Site Practices for redevelopment *	1		
41	Demonstrate in municipal construction projects	2		1
42	Financial incentives for private sector *	1		
	Subtotal	5		
Program 11: Watershed Education and Personal Stewardship				
43	Watershed education and outreach activity	3		1
44	Diversity of watershed education programs	4		
45	Convenient access to stewardship services *	2		
	Subtotal	9		
Program 12: Public Involvement and Neighborhood Consultation				
46	Stakeholder involvement in restoration planning	2		1
47	Neighborhood consultation in restoration	2		
48	Public access to restoration information *	1		
	Subtotal	5		
Program 13: Pollution Prevention at Stormwater Hotspots				
49	Identify and map stormwater hotspots	1		
50	Targeted businesses for education and outreach	2		1
51	Business recognition and partnerships *	1		
	Subtotal	4		
Program 14: Pollution Prevention at Municipal Operations				
52	Municipal pollution prevention operations	2		
53	Municipal road and storm drain maintenance	2		1
54	Ongoing employee training *	1		
55	Emergency spill and discharge response *	1		
56	Environmental management system *	1		
	Subtotal	7		
	TOTAL	100		

** benchmark may not fully apply to small communities –see Table 9 for scoring guidance for these communities*

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3.1 Steps to Complete the Benchmarking Tool

This section describes the seven steps needed to complete the benchmarking tool. The tool has been designed to take less than 40 hours of staff time in most communities, although it is prudent to schedule the time over a month to complete the entire process. In general, the tool is retrospective, and unless otherwise stated, asks for a characterization of restoration activity in the preceding one to three years.

Step 1: Decide Whether to Apply the Tool at the Community or Watershed Scale

The first key decision is whether to apply the tool across all municipal programs in a community or only apply it to a specific watershed. In the first case, the tool is used to examine how well restoration programs are integrated across an entire community. The second case evaluates individual watershed restoration plans from the standpoint of how implementation is integrated among municipal agencies. Most municipalities will apply the tool at the community scale, unless they have specifically focused limited restoration resources within a targeted watershed.

Step 2: Determine if Alternative Scoring is Needed Based on Local Conditions

While the benchmarking tool is applicable to a wide range of community sizes and geographic conditions, there are two specific situations where communities may choose an alternative scoring system to present a fair and more balanced assessment of their local restoration programs. This occurs when a community:

- Is small (population less than 50,000)
- Lacks many perennial streams (common in ultra-urban communities with greater than 75% impervious cover, and/or arid regions of the West with a very low perennial stream density)

Sections 3.2 and 3.3 provide guidance to help users choose whether it makes more sense to use an alternative scoring system in these situations.

Step 3: Find the Appropriate Local Staff to Fill Out the Benchmarking Tool

The next step is to find out who can most quickly put their hands on the right data to fill out the benchmarking tool. Ideally, local staff filling out the benchmarking tool will have the following skills:

- Understand how the community is meeting local and state water quality and stormwater management requirements
- Are broadly familiar with local restoration activity
- Understand local budget documents
- Know key restoration players and watershed education groups in the community
- Don't mind making some cold calls to get data
- Can quickly scan restoration documents to extract summary information
- Have contacts with external organizations and agencies that may be providing watershed services in the community

In some cases, it may be desirable to assemble an interagency team to work together to fill out the benchmarking tool. It may also be useful to conduct a Needs and Capabilities Assessment (Schueler and Kitchell, 2005) at the same time to help discover the right contacts, inside and outside of government, that are knowledgeable about local watershed restoration efforts.

Step 4: Review Information of Local Restoration Program Information

The real detective work involves analyzing reports, budget justifications and watershed plans to find the information to score each benchmark. For larger communities, it is always a good idea to review:

- NPDES MS4 Phase I or II stormwater permits and annual reports

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- Water quality monitoring reports
- Stream and subwatershed field assessments
- Watershed and/or subwatershed restoration plans
- Action plans/work programs of local watershed groups
- Available GIS mapping resources
- Watershed education and outreach materials
- Agency operating and capital budget documents
- Municipal facility maintenance and pollution prevention plans
- Codes and ordinances related to redevelopment
- Park management plans and/or comprehensive plans that have a natural areas component

Step 5: Compile Program Budget Information

The most difficult and tedious step is to compile Smart Watershed budget information across many local departments, agencies and organizations. A worksheet has been provided in Appendix A to simplify the job. Both annual operating and capital budgets need to be carefully scrutinized for line-item expenditures to determine total staffing and contracting dollars for each program area. In many cases, multiple agency or departmental budgets need to be examined, but start first with public works and the agency that administers the local stormwater permit. Hard decisions need to be made on how to assign actual staff effort to individual smart watershed program budget categories. Once the budget information is compiled on the worksheet, it is often surprising to see how much existing funding is available to support restoration.

Step 6: Document Scoring Decisions and Assemble Supporting Documentation in Master Binder

By now, the team has enough information to make the scoring decisions for each benchmark question and assemble the documentation to support them. It is highly recommended that the team compile supporting documentation in a three-ring master binder. The benchmarking tool provides a box after each question to justify the scoring rationale and reference the corresponding tab in the master binder where supporting documentation can be found.

Scoring is always subject to some interpretation and possible bias. Therefore, it is important to clearly document the scoring rationale, and have a second person review each scoring decision. In cases where answers to a benchmark question are unclear or difficult to ascertain, it may be helpful to review the program profile sheet and consult the resources section to see how other communities are addressing the program. Once individual scores for each benchmark are reviewed and verified, they can then be entered into the standard scorecard provided in Table 5 to determine the aggregate Smart Watershed score for the community.

Step 7: Analyze Program Strengths and Weaknesses

The final task is to total up the aggregate score for the community (or watershed), making sure to add in any extra credit points. Based on community size, the total score is converted into an overall grade based on a sliding scale. Thus, a large community must receive 90 or more points to qualify for the highest Smart Watershed grade; whereas medium and small communities must only exceed 80 and 70 points, respectively, to qualify for the same grade. Tables 6 to 8 outline the overall Smart Watershed grades that can be assigned to different-sized communities.

Communities should also analyze individual program score totals to look for their strengths and weaknesses. It is advisable to establish an interagency workgroup to study the scores and find areas to add new programs of fine-tune existing ones. In many cases, the team may want to recruit new agencies or partners to the restoration effort, and target specific program areas for greater local restoration investment, staff training or capacity building. Useful program building resources are included in the Program Profile Sheets to help build or improve Smart Watershed programs.

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TABLE 6: SMART WATERSHED BENCHMARKING GRADES FOR LARGE COMMUNITIES (POPULATION >250,000)	
A	*90 points or more.* Congratulations! Your community is a national leader in watershed restoration and is a model for other communities to follow. Your local restoration programs are integrated and aligned, and the rate of actual implementation is high.
B	*80 to 89 points.* Good work but room for improvements. A few gaps exist in your local programs, so review your scores to see if adding new programs or expanding existing ones can help you reach the next level.
C	*70 to 79 points.* Good start, but your local restoration programs are not integrated and aligned enough to realize improvements in water quality or habitat. Invest more in your weak program areas and improve interagency coordination.
D	*50 to 69 points.* While your community may technically be in compliance with your Phase I MS4 stormwater permit, you are not achieving many stormwater or watershed restoration benefits. Time for a wholesale review of most of your restoration programs.
F	*30 to 49 points.* Local watershed restoration programs need serious upgrading and additional investment in order to meet minimum Phase I MS4 stormwater permit requirements and other water quality regulations.
F	*29 or fewer points or less.* Your community needs to devote immediate attention to improving stormwater and watershed restoration programs – your score strongly suggests possible non-compliance with stormwater permits and water quality regulations.

TABLE 7: SMART WATERSHED BENCHMARKING GRADES FOR MEDIUM COMMUNITIES (POPULATION 50,000 – 250,000)	
A	*80 or more points.* Excellent. Given the size and resources available to your community, you are doing a commendable job on implementing watershed restoration projects on the ground – and are a model for comparably sized communities to follow.
B	*70 to 79 points.* Good job. While your overall program activity is high, further investments to align and integrate your watershed restoration programs can help you reach the next level and improve the health of your watersheds.
C	*60 to 69 points.* Good start, but a ways to go. Carefully review your individual program scores to look for low cost opportunities to add or expand local watershed restoration programs. Look for creative ways to engage new partners to leverage resources.
D	*40 to 59 points.* Need improvement. Your watershed restoration activity is not comprehensive enough to meet local water quality goals or the spirit of your MS4 NPDES Phase I or II permit or other looming water quality regulations.
F	*39 or fewer points.* Poor. It's time to immediately review your local stormwater and watershed restoration programs since they do not appear to comply with the minimum requirements of your MS4 NPDES Phase I or II permit.

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TABLE 8: SMART WATERSHED BENCHMARKING GRADES FOR SMALL COMMUNITIES (POPULATION <50,000)	
A	*70 or more points.* Well done. For a smaller community, your commitment to watershed restoration efforts are a model for any size community to follow, and should help to improve local water quality and habitat conditions.
B	*60 to 69 points.* Good work. Your watershed restoration programs place you well ahead of the curve compared to other small communities. Greater partnering can leverage resources that may help to add or enhance programs to get to the next level.
C	*40 to 59 points.* Decent effort, considering that few restoration programs are actually mandated for small communities. Find a few weak program areas to focus greater effort in coming years.
D	*20 to 39 points.* Significant improvement is needed in your watershed restoration program to meet local water resources goals – consider developing a broad strategy to educate citizens and elected leaders on the needs and benefits of watershed restoration.
F	*19 or fewer points.* Poor. Your program activity in watershed restoration is extremely low compared to your peers, and significantly greater program investment is needed to restore your local watersheds.

3.2 Alternative Scoring System for Small Communities

The benchmarking tool is inherently biased against small communities that have a population less than 50,000 because they lack the resources available to larger communities. When it comes to watershed restoration, small communities tend to be reliant on:

- a handful of staff (at best) that often have competing responsibilities
- extremely limited annual operating budgets and no long-term capital budgets
- state and federal grants for most of their restoration funding support
- volunteers, outside consultants, and watershed groups to provide staffing
- paper files and records, as compared to more sophisticated GIS systems
- a completely voluntary approach to watershed restoration since they are generally not regulated under current MS4 NPDES Phase II stormwater permits

Indeed, during testing and review, it became apparent that small communities with strong restoration programs might lose as many as 30 points when completing the benchmarking tool, as shown in Table 9. In some cases, benchmarks are not relevant or applicable to small communities. In other cases, the benchmarks are handled better by a larger local, regional or state authority.

A small community has two options on how to complete the benchmarking tool. The first option is to use the same scoring as larger communities, but take advantage of the lower grading thresholds shown for small communities in Table 8 (e.g., highest grade awarded if it scores 70 or more total points).

The second option is to employ the alternative scoring system for small communities presented in Appendix C. This scoring system uses more flexible and appropriate scoring criteria to define success for 24 select benchmark questions. The scoring criteria reward small communities that employ creative approaches to promote local watershed restoration such as:

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- Partnering with adjacent communities or watershed groups to leverage additional resources to support restoration programs
- Using local volunteers or watershed groups to meet restoration benchmark
- Seeking non-local sources of funding such as grants to support programs
- Piggybacking onto existing regional or state programs to provide restoration coverage

Small communities then add up points using the standard scorecard (Table 5) for the benchmark questions outlined in Appendix C, assuming they meet the more flexible scoring criteria. Small communities then tabulate their overall grade by taking their adjusted new total score, and applying it against the medium community Smart Watershed grading system shown in Table 7.

3.3 Alternative Scoring for Communities that Lack Perennial Streams

The benchmarking tool is also biased against communities that lack an extensive network of perennial streams, such as ultra-urban communities with more than 75% impervious cover and communities located in arid or semi-arid regions in the West. In these cases, the benchmarking tool penalizes them because they cannot physically do stream repairs (because their streams have been entirely piped or lack perennial stream flow). Both areas also tend to have extremely limited natural area remnant areas, such as wetlands or forests. To help these communities, the benchmarking tool has been adjusted to reflect greater focus on water quality and pollutant reduction. Under this alternative scoring system, more than 20 benchmark questions have been revised or modified within ten of the 14 program areas to better reflect restoration opportunities. A condensed summary of the alternative scoring benchmarks is presented in Table 10, and a re-

TABLE 9: BENCHMARKS THAT MAY NOT APPLY TO SMALL COMMUNITIES

No.	Name	Points
4	Comparative subwatershed analysis	1
5	Dedicated staffing for watershed coordination	2
7	Watershed-based GIS mapping	2
8	Tracking of restoration information	1
12	Field evaluation of upland restoration potential	2
13	Subwatershed monitoring program	1 of 2
14	Aquatic indicators linked to watershed goals	1
15	Public notification of water quality problems	1
19	Local funding for Smart Watershed programs	2
22	Dedicated funding for restoration/ reforestation	1
26	Demonstration of innovative retrofit technology	2
30	Post-construction project evaluation/monitoring	1
31	Possess discharge control authority	1
32	Discharge mapping and screening	2
34	Pollution hotline and response	1
36	Inspect and maintain stormwater practices	2
40	Adopt Smart Site practices for redevelopment	1
42	Smart Site incentives for private sector	1
45	Convenient access to municipal stewardship services	2
48	Public access to restoration information	1
51	Business recognition and partnerships	1
54	Ongoing employee training	1
55	Emergency spill and discharge response	1
56	Environmental performance policy	1
		32 points

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vised scorecard for communities that lacks perennial streams can be found in Appendix D.

3.4 Awarding Extra Credit Points

It is possible for a community to earn extra credit points within each program area if the level of program activity goes beyond the national norm, based on a measurable rate of implementation. Collectively, a maximum of 15 extra credit points can be earned, although it is doubtful any community can qualify for them all. In order to qualify for extra credit, a community must demonstrate that it exceeds a given level of program implementation based on a defined metric. For example, the metric used to define stream corridor assessments is based on the number of stream miles assessed. In this case, the metric also indicates different thresholds for implementation calibrated for small, medium and large communities based on the common unit of implementation.

The metrics and thresholds for implementation were based on reported levels of program activity in the 2003 survey. Only one extra credit point can be earned within each program area (with the exception of watershed financing, where up to two points can be awarded). Space has been provided in the Smart Watershed scorecard to add the extra credit points to arrive at the total community score (Table 5).

TABLE 10: SUMMARY OF REVISED SCORING BENCHMARKS FOR COMMUNITIES THAT LACK PERENNIAL STREAMS

- Program 2: Upland assessments such as outfall surveys, storm drain mapping and stream daylighting investigations are substituted for stream assessment methods
- Program 3: Water quality monitoring at stormwater outfalls replaces instream monitoring
- Program 5: Management of Natural Area Remnants is changed to Management of Vacant Lands and Open Space to reflect greater emphasis on land reclamation, brownfields and urban forestry, and reduced emphasis on forest and wetland conservation
- Program 6: More emphasis on implementation of on-site stormwater retrofits compared to storage retrofits
- Program 7: Stream Repair is changed to Stormwater Pollution Source Assessment, with points awarded for source area modeling, pollutant load analysis, behavior surveys and water quality simulation modeling
- Program 8: More points are awarded to illicit discharge screening and pollution hotlines
- Program 9: More points are awarded to water quality enforcement activity, fewer points awarded for maintenance of stormwater practices
- Program 13: More points awarded for pollution prevention at stormwater hotspots
- Program 14: More points awarded for pollution prevention at municipal operations

Note: Consult Appendix D to see revised scorecard for communities that lack perennial streams.

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TABLE 11: MEASURING EXTRA CREDIT WITHIN EACH PROGRAM AREA

#	Benchmark	Metric Used to Define Extra Credit	Points
2	Subwatershed planning activity	Plans completed based on community size	1
10	Rapid stream corridor assessments	Stream miles assessed based on community size	1
13	Subwatershed monitoring program	Number of stations based on community size	1
17	Per-capita watershed restoration expenditures	Per capita restoration program expenditure	2
23	Subwatershed reforestation activity	Implementation rate based on community size	1
25	Level of stormwater retrofit implementation	Storage retrofits implemented based on community size	1
28	Level of stream repair implementation	Linear feet of stream repair based on community size	1
35	Activity in eliminating discharges	Response time to repair or correct illicit discharges and overflows	1
38	Water quality enforcement activity	Number of effective watershed enforcement programs	1
41	Demonstration in municipal construction projects	Number of projects, based on community size	1
43	Watershed education and outreach activity	Number of innovative program features	1
46	Stakeholder involvement in restoration planning	Number of innovative program features	1
50	Targeted business education and outreach	Number of innovative program features	1
52	Municipal pollution prevention activity	Type of municipal operations with active pollution prevention plans	1
		Total Possible Extra Credit Points	15

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3.5 The Smart Watershed Benchmarking Tool

This section presents the 56 individual benchmark questions that comprise the Smart Watershed benchmarking tool. The basic scoring criteria are described for each benchmark question, along with suggested documentation to support the answer.

PROGRAM 1 SUBWATERSHED RESTORATION PLANNING

1. Subwatershed-based restoration planning (1 point):
Do you conduct watershed restoration planning based on subwatersheds less than ten square miles in area?

Scoring Criteria: Award one point if answer to the question is YES. Communities doing plans at a larger watershed scale may be awarded a ½ point if their plans provide subwatershed detail.

Suggested Documentation: Provide copy of a community map that depicts watershed and subwatershed boundaries.

Score	Rationale and Corresponding Tab in Master Binder

2. Subwatershed planning activity (2 points):
How many subwatershed restoration plans have been initiated and/or completed in your community in the last three years?

Scoring Criteria: are based on community size up to a maximum of 2 points, as follows:

- *Small Community:* Award one point for each restoration plan initiated or completed in last three years
- *Medium Community:* Award ½ point for each restoration plan initiated in last three years and one point for each plan completed over the same time-span
- *Large Community:* Award ½ point for each 5% of total community area that is covered by a restoration plan completed in the past 3 years

Extra credit: Add one extra credit point for each completed plan above the thresholds indicated above.

Suggested Documentation: Attach the title page and executive summary of each completed plan, and compile a list of ongoing watershed planning efforts with an estimated time-line for completion.

Score	Rationale and Corresponding Tab in Master Binder

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PROGRAM 1 SUBWATERSHED RESTORATION PLANNING

3. Clear goals driving restoration efforts (2 points):
Have you clearly articulated the goals that guide your watershed restoration efforts?

Scoring Criteria: Award one point if written restoration goals and objectives exist to guide the restoration process. Award a second point if the goals and objectives are time-based and linked to measurable indicators.

Suggested Documentation: List restoration goals and objectives developed to drive local watershed planning efforts and briefly describe the process by which they were developed.

Score	Rationale and Corresponding Tab in Master Binder

4. Comparative subwatershed analysis (1 point):
Have you systematically screened all the subwatersheds in your community (e.g., using desktop GIS analyses) to prioritize the ones with the greatest restoration potential or most severe impacts?

Scoring Criteria: Award one point if answer to the question is YES.

Suggested Documentation: Attach your priority subwatershed list and supporting documentation on the screening or ranking methods used to develop it.

Score	Rationale and Corresponding Tab in Master Binder

5. Dedicated staffing for watershed coordination (2 points):
Do you have dedicated staff to coordinate your watershed planning process?

Scoring Criteria: Award one point if an individual has been designated to coordinate local restoration efforts, with greater than 50% of their time allocated to this task. Award a second point if more than one full-time employee exists to coordinate watershed planning.

Suggested Documentation: Provide contact information and copy of position description for watershed planning coordinator. If watershed groups or consultants provide this function, please provide a copy of their scope of work and budget.

Score	Rationale and Corresponding Tab in Master Binder

6. Watershed management structure (1 point):
Does an interagency workgroup or watershed group exist to guide the subwatershed planning process?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Provide a current list of members involved in the watershed management structure and briefly describe its decision-making powers.

Score	Rationale and Corresponding Tab in Master Binder

A007166

PROGRAM 1 SUBWATERSHED RESTORATION PLANNING

7. Watershed-based GIS mapping system (2 points):
Do you utilize a watershed-based GIS mapping system that integrates all the data layers needed to support watershed restoration planning efforts?

Scoring Criteria: Award one point if a watershed-based GIS has been created to support planning efforts. Award a second point if the system is currently operational and accessible by the core restoration team.

Suggested Documentation: List the major data layers included in the GIS system and attach the most recent copy of watershed and subwatershed delineations.

Score	Rationale and Corresponding Tab in Master Binder

8. Tracking of restoration information (1 point):
Is a watershed-based geographic information system used to track cumulative restoration project implementation?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested documentation: Provide maps or spreadsheets that track project implementation and show cumulative effects of restoration efforts.

Score	Rationale and Corresponding Tab in Master Binder

9. Mechanism for plan adoption (1 point):
Have you defined the process by which subwatershed plans will be adopted, budgeted and implemented in your community?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Briefly describe the anticipated political process in your community to formally adopt, finance and implement subwatershed plans.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 1: _____

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PROGRAM 2 STREAM AND SUBWATERSHED FIELD ASSESSMENTS

10. Rapid stream corridor assessments (2 points):
Have you conducted stream corridor assessments within priority subwatersheds in the last three years?

Scoring Criteria: Maximum of two points based on community size and implementation rate, as follows

- *Small Communities:* Award one point for each subwatershed in which a stream corridor assessment has been completed
- *Medium Communities:* Award one point for each 25 miles of stream corridor assessed
- *Large Communities:* Award one point for each 50 miles of stream corridor assessed

Extra credit: Add one extra credit point if your community exceeds these stream corridor assessment thresholds.

Suggested Documentation: Provide a map describing the location and approximate mileage of all stream corridor assessments conducted in the past three years.

Score	Rationale and Corresponding Tab in Master Binder

11. Field evaluation of restoration potential in the stream corridor (3 points):
Does your rapid assessment methodology employ parameters that assess stream impacts and restoration potential?

Scoring Criteria: Award ½ point for each parameter that you routinely measure during your stream corridor assessments as shown in the list below. Maximum score: 3 points.

- ❑ Wetland assessment
- ❑ Channel stability
- ❑ Aquatic insect diversity
- ❑ Stream habitat
- ❑ Water quality
- ❑ Stream corridor restoration needs
- ❑ Riparian buffer quality
- ❑ Stormwater outfall screening
- ❑ Flow regime
- ❑ Other Indicator (please specify) _____

Suggested Documentation: Provide a sample copy of the field forms used in your most recent stream corridor assessment.

Score	Rationale and Corresponding Tab in Master Binder

A007168

PROGRAM 2 STREAM AND SUBWATERSHED FIELD ASSESSMENTS

12. Field evaluations of upland restoration potential (2 points):
Do you conduct any field assessments in upland areas of subwatersheds to evaluate restoration potential?

Scoring Criteria: Award ½ point for each type of field assessment routinely conducted in upland subwatershed areas. Maximum score: 2 points.

- ❑ Neighborhood source assessment
- ❑ Upland reforestation surveys
- ❑ Streets and storm drain survey
- ❑ Assessment of natural area remnants
- ❑ Stormwater hotspot survey
- ❑ Stormwater retrofit inventory
- ❑ Other assessment (please specify)

Suggested Documentation: Provide sample copy of field forms used to assess upland restoration potential at the subwatershed level.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 2: _____

PROGRAM 3 SUBWATERSHED MONITORING AND REPORTING

13. Subwatershed monitoring program (2 points):
Do you have a monitoring program that measures key aquatic indicators at the subwatershed level?

Scoring Criteria: Award two points if your community conducts monitoring at subwatershed level. If monitoring is conducted at a broader scale, award only one point.

Extra credit: Award one extra credit point if your community operates long-term sentinel monitoring stations to track trends in specific subwatershed indicators.

Suggested Documentation: Provide map that shows locations of monitoring stations and indicate the frequency that monitoring data is collected.

Score	Rationale and Corresponding Tab in Master Binder

A007169

PROGRAM 3 SUBWATERSHED MONITORING AND REPORTING

14. Aquatic indicators linked to watershed goals (1 point):
Does your monitoring program employ aquatic indicators that reflect the goals and objectives of your watershed restoration effort so that progress can be quantified?

Scoring Criteria: Award one point if your monitoring program measures indicators directly linked to watershed goals.

Suggested Documentation: List the primary aquatic indicators you currently sample and then cross-reference them to the goals outlined earlier in Benchmark 3.

Score	Rationale and Corresponding Tab in Master Binder

15. Public notification of water quality problems (1 point):
Does your program provide timely notification to the public about spills, sewage discharges and other water quality problems that make it unsafe for the public to swim, recreate or consume fish from local waters?

Scoring Criteria: Award ½ point if a notification system exists to warn the public about water quality problems. Award another ½ point if the system has been tested and/or used in last three years.

Suggested Documentation: Briefly describe the warning system and provide examples of signs, press releases or media announcements used to notify the public.

Score	Rationale and Corresponding Tab in Master Binder

16. Data Management and Reporting (1 point):
Has your community analyzed monitoring data and reported results to the public and other stakeholders in the last three years?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Attach a copy of your most recent monitoring report.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 3: _____

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PROGRAM 4 FINANCING WATERSHED RESTORATION

17. Total watershed program expenditures (2 points):

How much does your community spend on a per capita basis for watershed restoration programs in comparison to other municipal programs?

Scoring Criteria: Award one point if total annual restoration program expenditures covering the 14 Smart Watershed programs are at least $10 per capita. Award second point if restoration expenditures exceed $15 per capita.

Extra credit: Add one extra credit point for each additional $3 per capita spent on local watershed restoration above $18, for a maximum of two points.

Suggested Documentation: Estimate your total annual operating and capital expenditures directly related to watershed restoration program efforts for most recent fiscal year using the budget worksheet provided in Appendix A, and then divide by total population.

Score	Rationale and Corresponding Tab in Master Binder

18. Long-term funding for plan implementation (1 point):

Does your community have a long-term capital budget that extends beyond the current budget year to provide dedicated funding for design and construction of watershed restoration projects?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Attach a summary of approved capital budget line items for watershed restoration projects (or dedicated funding allocation from a local stormwater utility, if applicable).

Score	Rationale and Corresponding Tab in Master Binder

A007171

PROGRAM 4 FINANCING WATERSHED RESTORATION

19. Local funding for Smart Watershed programs (2 points):
Does your local budget include operating and/or capital funding to support Smart Watershed programs?

Scoring Criteria: Mark the following boxes where operating or capital funds are dedicated for the current budget year. Award one point if at least seven boxes are checked. Award a second point if more than ten boxes are checked.

- ☐ Program 1. Subwatershed Restoration Planning
- ☐ Program 2 Stream and Subwatershed Field Assessment
- ☐ Program 3 Subwatershed Monitoring and Reporting
- ☐ Program 4 Financing Watershed Restoration
- ☐ Program 5 Management of Natural Area Remnants
- ☐ Program 6 Stormwater Retrofitting
- ☐ Program 7 Urban Stream Repair/Restoration
- ☐ Program 8 Illicit Discharge Detection and Elimination
- ☐ Program 9 Maintenance, Inspection and Enforcement
- ☐ Program 10 Smart Site Practices During Redevelopment
- ☐ Program 11 Watershed Education and Stewardship
- ☐ Program 12 Public Involvement and Neighborhood Consultation
- ☐ Program 13 Pollution Prevention at Stormwater Hotspots
- ☐ Program 14 Pollution Prevention at Municipal Operations

Suggested Documentation: Estimate your total annual operating and capital expenditures directly related to each of the 14 Smart watershed programs for most recent fiscal year using the budget worksheet provided in Appendix A.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 4: _____

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PROGRAM 5 MANAGEMENT OF NATURAL AREA REMNANTS

20. Inventories of natural area remnants (3 points):
Does your community have a current inventory or map of natural area remnants available at the watershed level to prioritize their management?

Scoring Criteria: Award one point for each of the following natural areas that have been mapped or inventoried within the last three years (maximum score: 3 points).

- ❑ Steep Slopes
- ❑ Wetlands
- ❑ Forest Cover or Canopy
- ❑ Vegetative Cover in Stream Corridor (Buffers)
- ❑ Open Space
- ❑ Vacant Lands
- ❑ Other RTE Habitat (please specify)

Suggested Documentation: Provide an example map showing distribution of natural area remnants.

Score	Rationale and Corresponding Tab in Master Binder

21. Natural area planning and management (3 points):
Does your subwatershed planning approach address conservation, restoration and reforestation of natural areas?

Scoring Criteria: Award one point for each of the following natural area planning and management activities that apply in your community (maximum score: 3 points).

- ❑ Watershed or community forest cover/canopy goals are established
- ❑ Upland public lands are reforested
- ❑ Existing natural remnants are actively restored or managed
- ❑ High quality natural remnants are conserved
- ❑ Stream corridors are reforested
- ❑ Vacant lands/brownfields are reclaimed
- ❑ Invasive species are removed from natural areas
- ❑ Other (please specify)_____

Suggested Documentation: Provide excerpts from subwatershed plans that demonstrate actual implementation of each of the boxes checked above.

Score	Rationale and Corresponding Tab in Master Binder

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PROGRAM 5 MANAGEMENT OF NATURAL AREA REMNANTS

22. Dedicated funding for natural area restoration and reforestation (1 point):
Do you have an annual budget of at least one dollar per capita for on the ground implementation of natural area restoration and reforestation projects?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Derive from restoration budget worksheet provided in Appendix A.

Score	Rationale and Corresponding Tab in Master Binder

23. Subwatershed restoration and reforestation activity (3 points):
How many acres has your community restored/reforested to improve subwatershed conditions in the last three years?

Scoring Criteria: A maximum of 3 points can be awarded based on community size and level of restoration activity, as follows: Award one point for each restoration activity that exceeds minimum area thresholds provided in the table below:

RESTORATION ACTIVITY	COMMUNITY SIZE		
	Small	Medium	Large
Natural Area Restoration	5 acres	15 acres	30 acres
Stream Corridor Reforestation	5 acres	15 acres	30 acres
Upland Reforestation	5 acres	15 acres	30 acres

Extra credit: Add an extra credit point if your community can report some activity in all three restoration areas shown in the table above.

Suggested Documentation: Provide project descriptions and photo documentation, if available.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 5: _____

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PROGRAM 6 STORMWATER RETROFITTING

24. Subwatershed retrofit inventory (4 points):
Has your community conducted stormwater retrofit inventories within priority subwatersheds within the last three years?

Scoring Criteria: Up to four points, based on the scope of retrofit inventories undertaken, as follows:

- Award one point if a retrofit inventory has been conducted on municipal properties and at existing stormwater practices
- Award second point if inventory has been conducted in at least one priority subwatershed
- Award third point if full inventory has been completed in two priority subwatersheds
- Award fourth point if more than 25% of developed area in your community has been systematically evaluated for retrofit opportunities

Suggested Documentation: Provide map showing subwatersheds in your community where retrofit inventories have been undertaken, and provide a sample retrofit inventory field sheet.

Score	Rationale and Corresponding Tab in Master Binder

25. Level of stormwater retrofit implementation (4 points):
What is the level of activity in retrofit design and/or construction in the last three years?

Scoring Criteria: Up to four points, based on the number of retrofit projects installed, as follows:

- Award one point if at least one retrofit project is currently under design or construction
- Award second point if at least three retrofit projects are currently under design or construction
- Award third point if five or more retrofit projects have been completed or if completed retrofit projects have a combined drainage area of more than 250 acres
- Award fourth point if more than ten retrofit projects have been completed or if completed retrofit projects have a combined drainage area of more than 500 acres

Extra credit: Add one extra credit point if more than 15 retrofit projects have been completed in last three years.

Suggested Documentation: Provide list and brief description of retrofit projects designed and/or constructed. Note: credit is given for storage retrofit projects only.

Score	Rationale and Corresponding Tab in Master Binder

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PROGRAM 6 STORMWATER RETROFITTING

26. Demonstration of innovative retrofit technology (2 points):
Do your retrofit projects incorporate innovative stormwater technologies?

Scoring Criteria: Award one point if storage retrofit designs employ more advanced or sophisticated practices than the "average" stormwater design submitted for new development in your community. Award a second point if innovative on-site retrofits are employed in your retrofit program such as green rooftops, rain gardens, and bioretention areas.

Suggested Documentation: Provide photos of innovative retrofit designs or practices.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 6: _____

PROGRAM 7 URBAN STREAM REPAIR AND RESTORATION

27. Systematic subwatershed approach (2 points):
Are stream repair practices explicitly designed to address restoration objectives at the subwatershed level?

Scoring Criteria: Award one point if the answer to the question is YES. Award second point if stream repair projects are integrated with other subwatershed restoration practices such as storage retrofits and riparian reforestation.

Suggested Documentation: Briefly describe the methods used to assess stream restoration priorities at subwatershed scale and the primary objectives driving stream restoration in your community.

Score	Rationale and Corresponding Tab in Master Binder

PROGRAM 7 URBAN STREAM REPAIR AND RESTORATION

28. Level of stream repair implementation (2 points):
How many stream miles have been covered by urban stream cleanup and stream repair practices in the last three years?

Scoring Criteria: Are based on community size and type of stream repair implemented, as follows:

Award one point if the length of stream cleanup projects undertaken in the last three years exceeds the thresholds in the following table. Award second point if the length of stream repair projects implemented exceeds the minimum length thresholds shown below.

PROJECT ACTIVITY	COMMUNITY SIZE		
	SMALL	MEDIUM	LARGE
Stream cleanup/adoption	1000 feet	1 mile	5 miles
Stream repair projects	500 feet	2500 feet	10,000 feet

Extra credit: Add one extra credit point if your community has exceeded the stream repair length thresholds by a factor of two or more.

Suggested Documentation: Briefly list the type and length of stream cleanup and repair projects conducted in the last three years.

Score	Rationale and Corresponding Tab in Master Binder

29. Sophistication of stream repair practices (2 points):
Do you apply a variety of stream repair practices to improve stream habitat, structure and aquatic diversity?

Scoring Criteria: Award ½ point for each of the following practices that have been installed in the last three years. Maximum score: 2 points.

- ❑ Instream habitat enhancement
- ❑ Fish barrier removal
- ❑ De-channelization
- ❑ Natural channel design
- ❑ Reintroduction of native fish
- ❑ Baseflow channel creation
- ❑ Comprehensive stream restoration projects
- ❑ Other (please specify) _____

Suggested Documentation: Provide before and after photos of innovative stream repair projects.

Score	Rationale and Corresponding Tab in Master Binder

A007177

PROGRAM 7 URBAN STREAM REPAIR AND RESTORATION

30. Post-construction project evaluation and monitoring (1 point):
Have you conducted any post-construction monitoring to evaluate the effectiveness of the stream repair installations?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Provide copy of post-construction monitoring evaluation reports.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 7: _____

PROGRAM 8 ILLICIT DISCHARGE DETECTION AND ELIMINATION

31. Possess discharge control authority (1 point):
Does your community possess adequate legal authority to prohibit non-stormwater discharges to the storm drain system, including access to private property to investigate and enforce compliance?

Scoring Criteria: Award one point if your community has adopted a local ordinance that explicitly defines and regulates illicit discharges into the storm drain and stream system.

Suggested Documentation: Provide copy of illicit discharge ordinance and briefly describe how the public is made aware of its provisions.

Score	Rationale and Corresponding Tab in Master Binder

32. Discharge mapping and screening (2 points):
Have you conducted desktop analysis to screen the potential risks of illicit and/or sewage discharges at the subwatershed level?

Scoring Criteria: Award one point if your community has an up-to-date map of stormwater and sanitary sewer systems. Award second point if a desktop analysis has been conducted to identify priority areas to investigate potential discharges in the field.

Suggested Documentation: Provide map showing priority areas for field investigations.

Score	Rationale and Corresponding Tab in Master Binder

A007178

PROGRAM 8 ILLICIT DISCHARGE DETECTION AND ELIMINATION

33. Outfall reconnaissance inventory (2 points):
Have you performed a field inventory of stormwater outfalls to look for potential or suspected illicit discharges?

Scoring Criteria: Award one point if at least 50% of stormwater outfalls in your community have been field screened in the last three years. Award a second point if all stormwater outfalls in your community have been screened in the field.

Suggested Documentation: Provide sample copy of outfall screening field forms.

Score	Rationale and Corresponding Tab in Master Binder

34. Pollution hotline and response (1 point):
Have you established and advertised a hotline to report spills, discharges and water quality problems?

Scoring Criteria: Award one point if answer to above question is YES.

Suggested Documentation: Provide the hotline number and describe how it is advertised to the public.

Score	Rationale and Corresponding Tab in Master Binder

35. Activity in eliminating discharges (2 points):
How quickly are illicit discharges and sewer overflows eliminated after they are discovered?

Scoring Criteria: Award one point if typical discharges are repaired within 60 days of discovery, including any needed repairs or enforcement actions. Award two points if discharges are enforced and corrected within 30 days of discovery.

Extra credit: Add extra credit point if discharges are corrected within 10 days of discovery.

Suggested Documentation: Provide excerpt from annual NPDES MS4 report or other documentation on progress made in detecting and eliminating illicit discharges.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 8: _____

A00179

PROGRAM 9 MAINTENANCE, INSPECTION AND ENFORCEMENT

36. Inspect and maintain stormwater practices (2 points):
Does your community regularly inspect stormwater treatment practices to assess ongoing maintenance needs?

Scoring Criteria: Award one point if your community has inspected more than half of all existing stormwater practices within the last three years. Award a second point if your community has a maintenance budget to perform critical maintenance tasks or has otherwise exercised authority to compel maintenance on privately owned practices.

Suggested Documentation: Briefly describe the inspection and maintenance components of your local stormwater program, with an emphasis on maintenance performed at privately-owned stormwater practices.

Score	Rationale and Corresponding Tab in Master Binder

37. Inspect and maintain watershed restoration practices (2 points):
Do you regularly inspect the condition of all restoration projects after they are installed to ensure they meet project objectives?

Scoring Criteria: Award one point if a tracking system is in place to inspect, maintain and evaluate restoration projects constructed to date. Award a second point if your community has actually inspected and taken corrective action at existing restoration projects.

Suggested Documentation: Provide sample inspection and maintenance reports for a typical restoration practice.

Score	Rationale and Corresponding Tab in Master Binder

A007180

PROGRAM 9 MAINTENANCE, INSPECTION AND ENFORCEMENT

38. Water quality enforcement activity (1 point):
Do you actively enforce local ordinances that help protect local water quality?

Scoring Criteria: are based on the extent of local enforcement activity. Check the boxes for which you have actually undertaken enforcement action in the last year. Award one point if at least three boxes are checked.

- ❑ Erosion and sediment control violations
- ❑ Illegal dumping
- ❑ Illegal storm drain discharges
- ❑ Clearing of stream buffers
- ❑ Swimming pool discharges
- ❑ Pet waste
- ❑ Littering
- ❑ Other (please specify) _____

Extra credit: Add an extra credit point if more than three boxes are checked.

Suggested Documentation: Briefly describe the nature and extent of enforcement actions for each checked box.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 9: _____

PROGRAM 10 PROMOTE SMART SITE PRACTICES DURING REDEVELOPMENT

39. Conduct audit of redevelopment codes and ordinances (1 point):
Has your community assessed its codes and ordinances to identify barriers to implementation of Smart Site practices during redevelopment?

Scoring Criteria: Award one point if answer to question is YES.

Suggested Documentation: Briefly describe the process you used to evaluate local codes and ordinances to promote Smart Site practices.

Score	Rationale and Corresponding Tab in Master Binder

A007181

PROGRAM 10 PROMOTE SMART SITE PRACTICES DURING REDEVELOPMENT

40. Adopt Smart Site practices to redevelopment projects (1 point):
Has your community actually revised or modified existing codes to promote Smart Site practices for infill and redevelopment projects in highly urban watersheds?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Indicate the specific changes made to redevelopment and infill codes to promote Smart Site Practices.

Score	Rationale and Corresponding Tab in Master Binder

41. Demonstrate in municipal construction projects (2 points):
Have Smart Site practices been incorporated in any municipal construction projects in your community in the last three years?

Scoring Criteria: projects may include innovative site design and stormwater practices applied to schools, community centers, libraries, road construction and other construction projects. Award up to two points based on the following community size thresholds:

- *Small Communities:* Award one point for each municipal construction project built that demonstrates innovative stormwater treatment and site design techniques
- *Medium Communities:* Award ½ point for each municipal construction project incorporating Smart Site practices built in the last three years
- *Large Communities:* Award ½ point for each municipal construction project incorporating Smart Site practices built in the past three years

Extra credit: Add one extra credit point if the number of municipal demonstration projects exceeds the indicated thresholds.

Suggested Documentation: Provide a summary list of municipal construction projects that have incorporated Smart Site practices, and provide photos if possible.

Score	Rationale and Corresponding Tab in Master Binder

A007182

PROGRAM 10 PROMOTE SMART SITE PRACTICES DURING REDEVELOPMENT

42. Financial incentives for the private sector (1 point):
Does your community provide financial incentives to the private sector to encourage Smart Site Practices during redevelopment? (e.g., financial and technical assistance, streamlined plan review, tax credits)

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Briefly describe the nature and effectiveness of the private sector incentives offered.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 10: _____

PROGRAM 11 WATERSHED EDUCATION AND PERSONAL STEWARDSHIP

43. Watershed education and outreach activity (3 points):
Does your community have a watershed outreach and education program?

Scoring Criteria: are based on scope and sophistication of local programs, based on the following: Check each of the following boxes that apply to your watershed education and outreach program.

- ❑ Has a full-time watershed outreach coordinator
- ❑ Focuses on pollutants of concern (as defined in local restoration goals)
- ❑ Presents clear and simple education messages
- ❑ Advertises message through newspapers, radio or television
- ❑ Has annual budget of more than $50,000 for outreach materials
- ❑ Conducts surveys to determine key watershed behaviors
- ❑ Targets specific pollution sources and outreach populations
- ❑ Produces local stormwater and watershed education materials
- ❑ Other (please specify)_____

Award ½ point for each box checked, up to a maximum of three points.

Extra credit: Add extra credit point if more than six boxes are checked.

Suggested Documentation: Provide typical examples of education and outreach materials produced and distributed by your program.

Score	Rationale and Corresponding Tab in Master Binder

A007183

PROGRAM 11 WATERSHED EDUCATION AND PERSONAL STEWARDSHIP

44. Diversity of watershed education programs (4 points):
Do your watershed education efforts include diverse opportunities for involvement among many sectors of the public?

Scoring Criteria: Award ½ point for any of the following that apply to your education and outreach program, up to a maximum of 4 points.

- ❑ Kids and schools (e.g., art contests, schoolyard habitat projects)
- ❑ Adopt a stream programs
- ❑ Watershed website
- ❑ Community directory of watershed services
- ❑ Distribution of brochures and fact sheets
- ❑ Watershed maps or posters
- ❑ Storm drain marking
- ❑ Watershed fair/cleanup activity day
- ❑ Community tree-planting projects
- ❑ Downspout disconnection kits
- ❑ Citizen monitoring
- ❑ Other (please specify) _____

Suggested Documentation: Provide examples of each watershed education program checked.

Score	Rationale and Corresponding Tab in Master Binder

45. Convenient access to municipal stewardship services (2 points):
Does your community provide convenient access to direct services that enable residents to become good watershed stewards?

Scoring Criteria: Award ½ point for each municipal stewardship service offered by your community, up to maximum of two points.

- ❑ Household hazardous waste collection
- ❑ Yard waste collection
- ❑ Lawn soil testing
- ❑ Natural lawn care consultation
- ❑ Septic system inspections
- ❑ Pet waste collection stations
- ❑ Technical assistance for stormwater pond maintenance
- ❑ Homeowner retrofits such as rain gardens and rooftop disconnection
- ❑ Free/discounted compost, seedlings, rain barrels, or compost bins
- ❑ Used oil collection
- ❑ Other (please specify) _____

Suggested Documentation: Briefly summarize how each checked municipal service is advertised to the public.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 11: _____

A007184

PROGRAM 12 PUBLIC INVOLVEMENT AND NEIGHBORHOOD CONSULTATION

46. Stakeholder involvement in restoration planning (2 points):
Does your small watershed restoration program involve stakeholders in restoration plan development and implementation?

Scoring Criteria: Award ½ point for each of the following boxes checked, up to a maximum of two points:

- ❑ At least three outreach methods are used to recruit stakeholders
- ❑ Stakeholders participate in restoration goal setting process
- ❑ Stakeholders are drawn from diverse constituencies
- ❑ At least two stakeholder meetings are conducted during each plan
- ❑ A current stakeholder management database is maintained
- ❑ Stakeholders receive at least two communications per year
- ❑ Several opportunities are provided for stakeholders to comment on restoration plans

Extra Credit: Award an additional point if more than four stakeholder management elements are checked above.

Suggested Documentation: Provide list of the names and affiliations of stakeholders involved in your most recent restoration plan.

Score	Rationale and Corresponding Tab in Master Binder

47. Neighborhood consultation about restoration projects (2 points):
Are adjacent residents and landowners routinely consulted about major restoration projects to solicit their feedback?

Scoring Criteria: Award one point for each of the following boxes that apply, up to a maximum of 2 points.

- ❑ Adjacent residents are consulted in advance about major restoration projects
- ❑ At least two outreach methods are used to notify them about projects
- ❑ Meetings are scheduled at convenient times for residents to attend
- ❑ Agency is willing to modify or drop projects based on resident concerns

Suggested documentation: Provide a typical agenda for a neighborhood consultation meeting.

Score	Rationale and Corresponding Tab in Master Binder

A007195

PROGRAM 12 PUBLIC INVOLVEMENT AND NEIGHBORHOOD CONSULTATION

48. Public access to restoration information (1 point):
Does your community make watershed plans and mapping products available to the public through web-based tools?

Scoring Criteria: Award ½ point if basic restoration documents/maps are made available upon request to the public free of charge. Award additional ½ point if restoration information and maps are provided on interactive websites.

Suggested Documentation: Provide sample copies of restoration documents and indicate website address.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 12: _____

PROGRAM 13 POLLUTION PREVENTION AT STORMWATER HOTSPOTS

49. Identify and map stormwater hotspots (1 point):
Have you developed a list or map of potential hotspot operations to aid in tracking and inspecting these sites?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Provide a map or list of hotspot operations in your community.

Score	Rationale and Corresponding Tab in Master Binder

50. Target businesses for education and outreach (2 points):
Does your community target specific local businesses to educate them on stormwater impacts and basic pollution prevention practices?

Scoring Criteria: Award one point for each of the following boxes that apply in your community (maximum two points):

- ❑ Specific hotspot operations are targeted that produce water quality problems
- ❑ Educational materials are distributed to business target groups
- ❑ Training classes are provided for businesses on pollution prevention practices
- ❑ On-site audits or other technical assistance are provided to business owners

Extra Credit: Award an extra credit point if more than two boxes are checked above.

Suggested Documentation: Provide list of hotspot operations that are targeted in your community and attach examples of outreach and educational materials distributed to them.

Score	Rationale and Corresponding Tab in Master Binder

A007186

PROGRAM 13 POLLUTION PREVENTION AT STORMWATER HOTSPOTS

51. Business recognition and partnerships (1 point):

Does your community recognize businesses that employ good pollution prevention and stewardship practices?

Scoring Criteria: Award one point if the answer to the question is YES.

Suggested Documentation: Describe the nature of your business recognition program and the type of business partners that are recognized.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 13: _____

PROGRAM 14 POLLUTION PREVENTION AT MUNICIPAL OPERATIONS

52. Municipal pollution prevention operations (2 points):

Does your community have current pollution prevention plans for its own municipal facilities and operations?

Scoring Criteria: Check all municipal operations in your community that have current stormwater pollution prevention plans:

- ❑ Public works yard
- ❑ Landfills
- ❑ Wastewater treatment plants
- ❑ Recycling/solid waste transfer stations
- ❑ Maintenance depots
- ❑ School bus and fleet storage areas
- ❑ Public golf courses
- ❑ Road maintenance yard
- ❑ Marinas or ports
- ❑ Airports
- ❑ Other operations (please specify)

Award one point if at least three operations are checked. Award a second point if six or more municipal operations are checked.

Suggested Documentation: Provide a sample pollution prevention plan for at least two municipal operations checked above. Certify that an on-site inspection has occurred in the last year to verify plans are being implemented.

Score	Rationale and Corresponding Tab in Master Binder

A007187

PROGRAM 14 POLLUTION PREVENTION AT MUNICIPAL OPERATIONS

53. Municipal road and storm drainage system maintenance (2 points):
Does your community maximize pollutant reduction and/or prevention during its routine road and storm drain maintenance operations?

Scoring Criteria: Check any of the following maintenance operations that are performed to improve water quality in your community:

- ❑ Street sweeping
- ❑ Catch basin cleanouts
- ❑ Reduced road salting/sanding and de-icing chemicals
- ❑ Integrated pest management in road right-of-way
- ❑ Pollution prevention during routine road maintenance operations
- ❑ Other (please specify)

Award ½ point for each box checked above for a maximum of two points.

Extra Credit: Award additional point if more than four boxes are checked above.

Suggested Documentation: Briefly justify how each checked maintenance operation has been modified to improve water quality.

Score	Rationale and Corresponding Tab in Master Binder

54. Ongoing employee training (1 point):
Does your community offer routine pollution prevention training to all appropriate municipal staff?

Scoring Criteria: Award one point if your answer to the question is YES.

Suggested Documentation: Generally describe the nature of employee training programs and estimate the number of employees receiving training in the past year.

Score	Rationale and Corresponding Tab in Master Binder

A007188

PROGRAM 14 POLLUTION PREVENTION AT MUNICIPAL OPERATIONS

55. Emergency spill and discharge response (1 point):
Does your community have the capability to rapidly respond to contain spills that occur during transport and industrial accidents?

Scoring Criteria. Award one point if emergency responders in your community have tested or employed spill response and containment procedures for highway or other spills into the storm drain system.

Suggested Documentation: Indicate which agencies or emergency responders are responsible for emergency spill response planning and when the last time the plan was tested or used.

Score	Rationale and Corresponding Tab in Master Binder

56. Environmental Management System (1 point):
Does your community have an Environmental Management System (EMS) or other institutional policy governing environmental performance of municipal operations and practices?

Scoring Criteria: Award one point if answer to the question is YES.

Suggested Documentation: Provide a copy of your community's environmental performance policy.

Score	Rationale and Corresponding Tab in Master Binder

TOTAL SCORE FOR PROGRAM 14: _____

CONGRATULATIONS!

You have reached the end of the Smart Watershed benchmarking tool.

Enter your scores on the scorecard provided in Table 5 to assess your progress.

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A007192

GLOSSARY

Aquatic indicators: Biological, chemical, physical, and community indicators used to measure biotic or abiotic attributes that can provide quantitative information on ecological condition, structure and function.

Discharge control authority: legal authority of a community to prohibit non-stormwater discharges to the storm drain system, including authority to investigate and enforce compliance (under MS4 stormwater permitting).

Environmental Management System: An EMS is a set of management processes and procedures that allows an organization to analyze and reduce the environmental impact of its activities. First adopted by private industry, the EMS approach is increasingly common in the public sector. For example, it can be used to help design, operate and maintain municipal wastewater treatment facilities.

Illicit discharge: Any discharge to a municipal separate storm sewer system that is not composed entirely of storm water, except for discharges allowed under an NPDES permit or waters used for certain emergency situations. Includes dry weather flows.

MS4: A municipal separate storm sewer system consisting of a conveyance or system of conveyances designed or used for collecting or conveying stormwater (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains). Stormwater discharges associated with MS4s are regulated through the use of National Pollutant Discharge Elimination System (NPDES) permits.

Municipal stewardship services: Community provided direct services that can improve stewardship by residents and businesses. Examples include: household hazardous waste collection, yard waste collection, lawn soil testing, natural lawn care consultation, septic system inspections, pet waste collection stations, technical assistance for stormwater pond maintenance, free/discounted compost, seedlings, rain barrels, or compost bins, and used oil collection.

Natural area remnants: Small parcels or fragments of forest, wetland, parks, stream corridors and open space in a subwatershed that could be expanded, restored or linked to other remnants to improve ecological structure and function of remaining natural areas, improve groundwater infiltration and restore habitat to a subwatershed.

Needs and Capabilities Assessment (NCA): a checklist of 47 questions that helps a restoration team understand its strengths and weaknesses, and identifies programs and resources to build an effective watershed restoration program.

NPDES: As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System permit program was established to improve the quality of the nation's streams, rivers, lakes, and estuaries by regulating point sources that discharge pollutants into waters of the United States and includes managing stormwater runoff from urban and suburban areas, construction projects, and industrial sites. Point sources are discrete conveyances such as pipes or man-made ditches and include municipal separate storm sewer systems (MS4s). NPDES Phase I, promulgated by EPA in 1990, covered medium and large municipalities (i.e., populations over 100,000), construction sites over 5 acres in size, and 10 categories of industrial activity. The Phase II program became law in 1999 and covers smaller municipalities, urban areas adjacent to some municipalities, and construction sites over 1 acre.

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New development: New development activities on previously undeveloped land.

Outfall reconnaissance inventory: A field inventory to screen problem outfalls to find suspected illicit discharges.

Pollutants of concern: Pollutants that have been identified in TMDLs, and/or local watershed monitoring assessments to be causing impairments to local water quality and aquatic life. Watershed and subwatershed planning and implementation efforts should be tailored to specifically address these pollutants.

Pollution prevention: Pollution source reduction practices that reduce or eliminate pollutants in stormwater runoff through prevention practices such as stormwater management and better housekeeping, improved materials storage, and covered fueling operations that municipalities, institutions and commercial operations can apply to their activities.

Redevelopment: New development activities on previously developed land. The process by which an existing developed area is adaptively reused, rehabilitated, restored, renovated and/or expanded.

Regulatory Drivers: Federal regulations, mandates, and strategies designed to improve water quality. These include Total Maximum Daily Loads (TMDLs), National Pollutant Discharge Elimination System (NPDES) stormwater permits, Combined Sewer Overflow (CSO) and Sanitary Sewer Overflow (SSO) control practices, brownfields, and others.

Retrofits (stormwater retrofits): A stormwater management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other watershed restoration objectives. The installation of a new stormwater practice or the improvement of an existing one in a previously developed area.

Small Watershed: Refers to subwatersheds as defined below.

Smart Site practices: Site design parameters that are encouraged in urban restoration, redevelopment and infill projects that use innovative measures to reduce impervious surfaces, improve the site function in terms of water quality, and promote integrated urban design to improve site runoff.

Stakeholder: Defined as any agency, organization or individual involved in or affected by the decisions made in a subwatershed restoration plan. The four broad groups of stakeholders include agencies, the public, watershed partners, and potential funders.

Storage retrofit: Stormwater management practice that detains water for a period of time and provides for the gradual release of a volume of water in order to increase settling of pollutants and protect downstream channels from frequent storm events. Good examples are stormwater ponds and wetlands with extended detention time.

Stormwater hotspots: Commercial, industrial, institutional, municipal, or transport-related operations that produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks or illicit discharges.

Stormwater retrofit inventory: A subwatershed-wide examination of areas where stormwater management practices can be implemented in previously developed areas to better regulate stormwater flow and create a more predictable hydrologic regime, and improve water quality. Retrofits are broken into three major categories - offsite storage, onsite nonresidential, and onsite residential.

Stream corridor: The active stream channel and its adjacent riparian area that has a direct effect on water quality, physical habitat and biological integrity.

Stream repair: Activities undertaken to address damage to stream channels typically stemming from uncontrolled runoff and other stream channel alterations resulting from development activities in a subwatershed.

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Subwatershed: A smaller geographic area of a larger watershed unit with a drainage area of between 2 to 10 square miles with boundaries to include all the land area draining to a common point. Subwatersheds are the primary unit for the analysis, design and implementation of stream repair and other restoration practices and provide a more manageable scale at which to educate residents and foster direct citizen involvement to improve their local neighborhood streams.

Subwatershed restoration: Subwatershed-wide activities conducted as part of a comprehensive plan that includes multi-faceted stream corridor and upland watershed practices to meet subwatershed restoration objectives chosen by the community.

Urban runoff: All surface discharges from an urban area, including stormwater flows, illicit discharges and dry weather flows.

Watershed: All the land area that contributes runoff to a particular water body, composed of multiple order stream systems and the subwatersheds draining to these streams and the larger tributary, water body or river system.

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APPENDIX A

SMART WATERSHED PROGRAM BUDGET WORKSHEET

Providing adequate financing for the 14 Smart Watershed programs is perhaps the area where most communities face their greatest challenge. The budget worksheet provides a tool for computing individual program and overall community budgets for Smart Watersheds. In general, the worksheet should be filled out for the most recent fiscal year. Alternatively, you can provide the average for the three most recent fiscal years.

Smart Watershed Program	Operating Budget For Most Recent Fiscal Year	Capital Improvement Program (CIP) Budget For Most Recent Fiscal Year	Other Funding Sources (Grants, Donated Services, Etc.)	Annual Program Totals
Program 1 Subwatershed Restoration Planning	$	$	$	Program 1 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include funding for watershed planning studies, staff costs for a watershed coordinator and/or planners, proportion of overall GIS budget allocated to watershed programs.			
Program 2 Stream and Subwatershed Field Assessment	$	$	$	Program 2 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include funding for field staff, consultant studies for watershed assessments, field equipment.			

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Smart Watershed Program	Operating Budget For Most Recent Fiscal Year	Capital Improvement Program (CIP) Budget For Most Recent Fiscal Year	Other Funding Sources (Grants, Donated Services, Etc.)	Annual Program Totals
Program 3 Subwatershed Monitoring and Reporting	$	$	$	Program 3 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include monitoring staff and/or seasonal consultants/interns, monitoring equipment including any permanent recording equipment or gages, lab costs, etc.			
Program 4 Financing Watershed Restoration	$	$	$	Program 4 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include administrative costs associated with managing restoration programs and procuring funds/grants, etc.			
Program 5 Management of Natural Area Remnants	$	$	$	Program 5 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include staff costs for an urban forester, project costs for reforestation planting, wetland restoration, etc. Activities conducted by watershed partners and community groups should be included.			
Program 6 Stormwater Retrofitting	$	$	$	Program 6 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include engineering staff and/or consultants for stormwater retrofit inventories and project design, and retrofit construction costs.			

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Appendix A: Smart Watershed Program Budget Worksheet

Smart Watershed Program	Operating Budget For Most Recent Fiscal Year	Capital Improvement Program (CIP) Budget For Most Recent Fiscal Year	Other Funding Sources (Grants, Donated Services, Etc.)	Annual Program Totals
Program 7 Urban Stream Repair and Restoration	$	$	$	Program 7 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include engineering staff and/or consultants for field assessments, design and construction specifically related to stream repair practices.			
Program 8 Illicit Discharge Detection and Elimination	$	$	$	Program 8 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include inspection and enforcement staff, response equipment, hotline administration, maintenance activities specific to pollution prevention such as periodic videoing of lines, and costs to repair/upgrade aging lines.			
Program 9 Maintain, Inspect and Enforce Watershed Practices	$	$	$	Program 9 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include municipal staff and/or contractors for stormwater pond inspection and maintenance program, post-construction inspection of restoration practices, annual maintenance budget to address problems identified during inspections, and sediment control inspectors.			

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Smart Watershed Program	Operating Budget For Most Recent Fiscal Year	Capital Improvement Program (CIP) Budget For Most Recent Fiscal Year	Other Funding Sources (Grants, Donated Services, Etc.)	Annual Program Totals
Program 10 Promote Smart Site Practices During Redevelopment	$	$	$	Program 10 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include staff costs to administer a Smart Site program, financial incentives such as cost-share programs or tax credits as incentives to the building community , and construction costs for water quality components of municipal demo projects.			
Program 11 Watershed Education and Personal Stewardship	$	$	$	Program 11 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include staff costs for a watershed educator, costs to produce and deliver educational materials, and the operating costs for municipal services directly related to watershed stewardship such as household hazardous materials collection, grass/lawn trim collection, etc.			
Program 12 Public Involvement and Neighborhood Consultation	$	$	$	Program 12 Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include specific outreach and website costs for advertising watershed restoration activities, and staff or consultant costs to manage stakeholder facilitation activities.			

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Smart Watershed Program	Operating Budget For Most Recent Fiscal Year	Capital Improvement Program (CIP) Budget For Most Recent Fiscal Year	Other Funding Sources (Grants, Donated Services, Etc.)	Annual Program Totals
Program 13 Pollution Prevention at Stormwater Hotspots	$	$	$	Program 13 Total: $'
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include costs for education materials targeted to pollution hotspots such as automotive service stations, dry-cleaners, and costs for business recognition and incentive programs.			
Program 14 Pollution Prevention at Municipal Operations	$	$	$	Program Total: $
	# staff (FTE) and Funding Source:	Funding Source:	Funding Source:	Percent of 14 Program Total:
	Budget items include staff costs for a pollution prevention coordinator, development and administration of P2 plans for municipal operations, spill response training and response kits, street-sweeping operations, storm drain clean-out, and construction costs for municipal operation upgrades specifically targeted to water quality improvements.			
Budget Category Totals	**Operating:** $	**CIP:** $	**Other:** $	**Total Annual Budget** $
Current Population:				**Per Capita Budget:** $

Notes:

Personnel costs should be reported based on full time equivalent (FTE) units for a forty–hour week (e.g. if a staff person spends one-third of their time on watershed coordination, then show .3 FTE times a salary). If one staff person is responsible for a number of program elements, then estimate the proportion of time to be applied to the various program areas.

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APPENDIX B

EXCERPTS FROM THE CONSENSUS DOCUMENT OF THE NATIONAL REDEVELOPMENT ROUNDTABLE

What Is the Redevelopment Roundtable?

The Redevelopment Roundtable represents a one-of-a-kind effort to engage a diverse spectrum of national and local stakeholders in a consensus process to address site level redevelopment and infill issues. The Roundtable was created to assure local communities that stakeholders in the redevelopment arena can agree on specific practices and programs that can help protect our existing natural resources and help build better communities. The Redevelopment Roundtable reached consensus on the 11 Smart Site Practices for Redevelopment and Infill.

What Are the 11 Smart Site Practices?

The term "Smart Site Practices" refers to site planning practices that can be used to mitigate watershed impacts in highly urban watersheds. Designed primarily with the developer in mind, the smart site practices represent the best techniques for protecting water quality and habitat in the highly constrained setting of urban infill and redevelopment. These practices are intended to complement municipal actions under the Smart Watersheds plan.

What Type of Redevelopment and Infill Projects Do Smart Site Practices Address?

The Redevelopment Roundtable recognizes that a vast array of redevelopment and infill projects exist. For the purposes of this project, redevelopment is defined as the process by which an existing developed area is adaptively reused, rehabilitated, restored, renovated and/or expanded. Infill, on the other hand, is development that occurs on smaller parcels that remain undeveloped but are within or very close to existing urban areas. In both cases, the development relies on existing infrastructure, and does not require an extension of water, sewer or other public utilities. In addition, the project must be located in a highly developed watershed, encouraged by the public sector, and water quality limited or biologically impaired. Example of redevelopment and infill projects are listed in the table below.

Various Types of Redevelopment and Infill Projects

- Historic preservation
- Waterfront development
- Brownfields
- Residential infill
- Adaptive reuse
- Downtown business district
- Multifamily
- Suburban commercial
- Mixed use development
- Roadway expansion

How Can the Smart Site Practices Be Applied?

While the Smart Site Practices were developed primarily as a tool for designers, they can be used by developers, local government officials, planners, and environmentalists alike. For example, developers who are concerned about larger community environmental issues can refer to the Smart Site Practices for guidance on how their projects might be better designed to address watershed impacts. Local governments can utilize the Smart Site Practices to develop better criteria on which to gauge the potential impact of a development site. Lastly, communities can utilize the Smart Site Practices

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to gain insights on redevelopment and infill from a watershed protection perspective.

The Smart Site Practices

Practice #1: Redevelopment and infill planning should include environmental site assessments that protect existing natural resources and identify opportunities for restoration where feasible.

Rationale: Requirements under existing brownfields and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) legislation, as well as bank purchase and loan requirements, help to mitigate the impact of some pollution sites by requiring basic site history investigation and surface soil and water testing and cleanup. A more thorough environmental site assessment, which includes the production of a base map that outlines existing buildings, transportation networks, utilities, floodplains, wetlands, streams, and other natural features, can help address existing environmental constraints and highlight opportunities for restoration and reclamation at a site.

Practice #2: Sites should be designed to utilize impervious cover efficiently and to minimize stormwater runoff. Where possible, the amount of impervious cover should be reduced or kept the same. In situations where impervious cover does increase, sites should be designed to improve the quality of stormwater runoff at the site or in the local watershed.

Rationale: The amount of impervious cover is known to have a direct impact on annual runoff volume, and consequently affects annual pollutant loads, flooding frequency, stream channel degradation, and a host of other impacts. Some of these impacts can be mitigated by making efficient use of the existing impervious cover and reducing or keeping it the same when possible. Managing stormwater runoff can also help to reduce these impacts.

Practice #3: Plan and design sites to preserve naturally vegetated areas and to encourage revegetation, soil restoration and the utilization of native or non-invasive plants where feasible.

Rationale: Remaining natural areas have particular value in the urban environment, but are also strongly influenced by adjacent uses. Often found in small fragments, these areas can also suffer from poor quality soils, invasive plant species, dumping and extensive alteration by past development. Collecting and mapping natural features, working toward preserving these areas in a consolidated manner, and evaluating the site for potential stormwater management, revegetation, and passive recreational benefits can provide environmental, economic and aesthetic benefits.

Practice #4: Establish mechanisms to guarantee long term management and maintenance of all vegetated areas.

Rationale: Guaranteed long-term management, financing and maintenance plans can assure continuous enjoyment and function of vegetated areas over the long run. Innovative partnerships, conservation easements, or donations to land trusts can help land owners ensure that intensively used vegetated areas on urban lands are actively kept up.

Practice #5: Manage rooftop runoff through storage, reuse, and/or redirection to pervious surfaces for stormwater management and other environmental benefits.

Rationale: Reducing the runoff generated from urban rooftops can reduce pollutant loads, flooding, channel erosion, and many other stream impacts. In addition, many rooftop runoff management practices can help conserve water and improve aesthetics. Examples of rooftop runoff management techniques include green rooftops, rooftop gardens, rain barrels and downspout disconnection. The design, slope and architecture of rooftops can reduce the volume of rooftop runoff as well.

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Practice #6: Parking lots, especially surface lots, should be minimized and designed to reduce, store and treat stormwater runoff. Where site limitations or other constraints prevent full management of parking lot runoff, designers should target high use areas first.

Rationale: While adequate parking is often considered a critical ingredient to the success of most infill and redevelopment projects, parking lots are often one of the greatest sources of stormwater runoff. In addition, many older parking lots that are being redeveloped were designed with little regard to landscaping, actual parking demand, or effective stormwater treatment. Some of the techniques that can be utilized for managing parking lot runoff include making parking lots incrementally smaller, providing more functional landscaping, and where possible, treating the quality of stormwater runoff.

Practice #7: Utilize a combination of Better Site Design techniques with infill projects to minimize stormwater runoff and maximize vegetated areas.

Rationale: Many single lot or small multi-lot infill projects contribute to "impervious creep," which is defined as the increase in impervious cover seen over time in highly developed areas. On-site improvements, such as house additions, expanded driveways, new housing, and sidewalks all contribute to impervious creep. Typically, there are few or no requirements to manage stormwater runoff or preserve or restore natural features associated with these small and incremental projects. Better Site Design refers to a design approach that seeks to reduce the amount of impervious cover associated with development, increase the natural lands set aside for conservation, use pervious areas for more effective stormwater treatment, and achieve a marketable, cost-effective product. Better Site Design consists of a series of benchmarks that fall under three categories: parking lot and street design, lot development, and natural areas conservation. Many of these benchmarks are applicable to infill development that can be described as: 1) single lot or small multi-lot infill (up to 3 lots) and 2) larger infill subdivisions (10 to 30 lots). While infill development occurs on smaller lot sizes (10,000 square feet or less), it is often still possible to effectively cluster lots to provide more open space and reduce impervious cover.

Practice #8: Utilize proper storage, handling and site design techniques to avoid the contact of pollutants with stormwater runoff.

Rationale: Opportunities exist to improve water quality by preventing contact of rainfall with pollutant sources stored or handled at the site of redevelopment and infill projects. Controlling pollutants at the site (source control) is usually the simplest and most cost-effective way to reduce stormwater pollution at many commercial sites. Source control measures include: 1) proper handling and storage of pollutants and 2) site design practices. Handling and storage practices focus on the storage of materials and vehicles in outdoor areas, while site design practices include designing better loading docks, covering materials stored outdoors, and containing dumpsters and fueling areas. Other source control opportunities exist at fleet parking areas, outdoor maintenance areas, landscaping areas and above ground storage tanks.

Practice #9: Design the streetscape to minimize, capture and reuse stormwater runoff. Where possible, provide planting spaces to promote the growth of healthy street trees while capturing and treating stormwater runoff. In arid climates, xeriscapes should be used to achieve similar benefits.

Rationale: With proper design and consideration, the interface between the street, sidewalk and other structures, known as the streetscape, can provide opportunities to manage stormwater runoff while providing many other environmental and aesthetic benefits. For example, streets can be made more narrow, and landscaped areas and/or

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trees can be incorporated into the street front and created so that they function to treat stormwater runoff. In addition, when tree pits are provided along with adequate soil and rooting space, street trees can provide additional stormwater capture and other numerous environmental benefits. Alternatively, xeriscaping (the practice of landscaping to conserve water) can be an important tool in more arid climates.

Practice #10: Design courtyards, plazas, and amenity open space to store, filter or treat rainfall.

Rationale: Much of the open space found in redevelopment and infill projects consists of hard surfaces that are impervious to rainfall. Using creative site plans, these courtyards, plazas, and other hard open spaces can be designed to store, filter and treat rainfall. Examples include the use of alternative pavers, bioretention areas, and planting boxes.

Practice #11: Design sites to maximize transportation choices in order to reduce pollution and improve air and water quality.

Rationale: Designing redevelopment and infill sites to increase connections to adjacent land uses, parks and public spaces through non-automotive related transportation choices (bike paths, pedestrian walkways, etc.) can improve environmental quality. Sites should also seek to provide links to mass transit when available, and provide commuter amenities such as bus shelters or bike racks. In addition, site designers may also wish to explore alternate pathway options for pedestrian movement, rather than the traditional sidewalk on both sides of the street.

Consensus Statement

As members of the Redevelopment Roundtable, we acknowledge the Smart Site Practices as sound and practical redevelopment and infill techniques that can help maintain natural areas, reduce the effects of stormwater runoff, and protect local streams, lakes, wetlands and estuaries. We believe that the technical and case study information provided in these Smart Site Practices are based on sound research and encourage developers, environmental organizations, government agencies and the general public to utilize and promote the dissemination of the practices. The recommendations of the Redevelopment Roundtable reflect our professional and personal experience with redevelopment and infill and do not necessarily carry the endorsement of the organizations and agencies represented by their members.

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APPENDIX C

ALTERNATIVE SCORING GUIDANCE FOR SMALL COMMUNITIES

ALTERNATIVE SCORING GUIDANCE FOR SMALL COMMUNITIES		
No.	**Name**	**Guidance**
4	Comparative subwatershed analysis	Award one point if community has used GIS maps generated by regional or state agency as part of its planning process.
5	Dedicated staffing for watershed coordination	Award one point if staffing for watershed coordination is handled by local volunteer or watershed group
7	Watershed-based GIS mapping	Award one point if paper maps are used or community can access GIS information from another jurisdiction or agency
8	Tracking of restoration information	Award one point if information is stored in paper files that are publicly accessible
12	Evaluation of upland restoration potential	Award one point if field evaluations are conducted by volunteers/ watershed group
13	Subwatershed monitoring program	Award one point if any volunteer citizen monitoring is conducted in the community or watershed
14	Aquatic indicators/ watershed goals	Award one point if community utilizes regional or state agency water quality monitoring data in its watershed planning
15	Public notification of water quality problems	Award one point if this function is effectively handled by a larger regional or state agency
19	Local funding for Smart watershed programs	May check boxes even if grants or non local funds are sole source of funding support
22	Dedicated funding for restoration/reforestation	Award points if reforestation is routinely funded through grants or state assistance
26	Demonstration of innovative technology	Benchmark may not apply to small communities
30	Post-construction project evaluation	Benchmark may not apply to small communities
31	Possess discharge control authority	Does not apply, unless community is regulated as MS4 stormwater NPDES Phase II community
32	Discharge mapping and screening	Does not apply unless community is regulated as MS4 stormwater NPDES Phase II community
34	Pollution hotline and response	Point may be awarded if the community piggybacks onto existing regional or state hotline
36	Inspect and maintain stormwater practices	May not apply to non-MS4 small communities that lack a post-construction stormwater ordinance
40	Smart Site practices for redevelopment	May not apply to small communities that experience little or no redevelopment activity

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ALTERNATIVE SCORING GUIDANCE FOR SMALL COMMUNITIES		
No.	**Name**	**Guidance**
42	Financial incentives for private sector	May not apply to small communities that experience little or no redevelopment activity
45	Convenient access to municipal stewardship	Award one point for each checked box for municipal service offered
48	Public access to restoration information	Award one point if staff person is designated as public liaison on local watershed issue
51	Business recognition and partnerships	Award one point if community conducts watershed outreach to business community or chamber of commerce in last year
54	Ongoing employee training	Award one point if at least one staff attends a watershed training/ workshop each year
55	Emergency spill and discharge response	Award point if community coordinates with regional or state authority to effectively handle this function
56	Environmental performance policy	Benchmark does not generally apply to small communities

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APPENDIX D

REVISED SMART WATERSHED SCORECARD FOR COMMUNITIES THAT LACK A PERENNIAL STREAM NETWORK

ALTERNATIVE SCORING SYSTEM FOR COMMUNITIES THAT LACK PERENNIAL STREAMS				
Benchmark No.	Description of Benchmark	Maximum Points	Points Awarded	Extra Credit
Program 1: Subwatershed Restoration Planning				
1	Subwatershed-based restoration planning	1		
2	Subwatershed planning activity	2		1
3	Clear goals driving restoration efforts	2		
4	Comparative subwatershed analysis *	1		
5	Dedicated staffing for watershed coordination *	2		
6	Watershed management structure	1		
7	Watershed-based GIS mapping system *	2		
8	Tracking of restoration information *	1		
9	Mechanism for plan adoption	1		
	Subtotal	13		
Program 2: Outfall and Subwatershed Field Assessments				
10	**Field surveys of outfalls (1) and updated mapping (1)**	**2**		
11	**Field evaluation of upland restoration potential ***	**3**		**1**
12	**Assessment of stream daylighting opportunities**	**1**		
	Subtotal	6		
Program 3: Watershed Monitoring and Reporting				
13	**Stormwater outfall monitoring program ***	**2**		**1**
14	Aquatic indicators linked to watershed goals *	1		
15	Public notification of water quality problems *	1		
16	Data management and reporting	1		
	Subtotal	5		
Program 4: Financing Watershed Restoration				
17	Total watershed restoration expenditures	2		2
18	Long-term funding for plan implementation	1		
19	Local funding for Smart watershed programs *	2		
	Subtotal	5		
Program 5: Management of Vacant Lands and Open Space				
20	**Inventory of vacant lands and natural area remnants**	**3**		
21	**Brownfield and land reclamation efforts**	**2**		
22	**Dedicated funding for reforestation ***	**1**		
23	**Activity in urban stormwater forestry practices**	**2**		**1**
	Subtotal	8		
Program 6: Stormwater Retrofitting				
24	**Onsite retrofit and rooftop disconnection inventory**	**3**		
25	**Level of on-site stormwater retrofit implementation**	**3**		**1**
26	Demonstration of innovative technology *	2		
	Subtotal	8		

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ALTERNATIVE SCORING SYSTEM FOR COMMUNITIES THAT LACK PERENNIAL STREAMS				
Program 7: Stormwater Pollution Source Assessment				
27	**Pollution source area monitoring**	**1**		
28	**Subwatershed pollutant loading analysis**	**1**		**1**
29	**Survey of watershed behavior and attitudes**	**1**		
30	**Water quality simulation modeling**	**1**		
	Subtotal	4		
Program 8: Illicit Discharge Detection and Elimination				
31	Possess discharge control authority *	1		
32	**Discharge mapping and screening ***	**3**		
33	Outfall reconnaissance inventory	2		
34	**Pollution hotline and response ***	**2**		
35	Activity in eliminating discharges	2		1
	Subtotal	10		
Program 9: Watershed Maintenance, Inspection and Enforcement				
36	**Inspect and maintain stormwater practices ***	**1**		
37	Inspect and maintain restoration practices	2		
38	**Water quality enforcement activity**	**2**		**1**
	Subtotal	5		
Program 10: Promote Smart Site Practices during Redevelopment				
39	Conduct audit of redevelopment codes	1		
40	Adopt Smart Site Practices for redevelopment *	1		
41	Demonstrate in municipal construction projects	2		1
42	Financial incentives for private sector *	1		
	Subtotal	5		
Program 11: Watershed Education and Personal Stewardship				
43	Watershed education and outreach activity	3		1
44	Diversity of watershed education programs	4		
45	Convenient access to stewardship services *	2		
	Subtotal	9		
Program 12: Public Involvement and Neighborhood Consultation				
46	Stakeholder involvement in restoration planning	2		1
47	Neighborhood consultation in restoration	2		
48	Public access to restoration information *	1		
	Subtotal	5		
Program 13: Pollution Prevention at Stormwater Hotspots				
49	**Identify and map stormwater hotspots**	**3**		
50	**Targeted business education and outreach**	**4**		**1**
51	Business recognition and partnerships *	1		
	Subtotal	8		
Program 14: Pollution Prevention at Municipal Operations				
52	**Municipal pollution prevention operations**	**3**		
53	**Routine street sweeping and catch basin cleanouts**	**3**		**1**
54	Ongoing employee training *	1		
55	Emergency spill and discharge response *	1		
56	Environmental management system *	1		
	Subtotal	9		
	GRAND TOTAL	100		

* *benchmark may not fully apply to small communities –see Table 9 for scoring guidance for these communities*

Items in bold identify scores that have been adjusted.

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GREEN Engineering *Promote* Low-

Applying the principles of green engineering can help create more sustainable development.

ALLEN P. DAVIS
UNIVERSITY OF MARYLAND

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Principles Impact Development

As human populations increase, relocate, and spread from existing urban areas, pressures to build on undeveloped lands have become severe. Unfortunately, traditional development practices put the environment at risk by creating large tracts of impervious area, thereby destroying natural infiltration and buffer zones. Altering the land in these ways can devastate local water bodies by increasing erosion; mobilizing sediment; and dispersing nutrients, toxic substances, and other pollutants. The large amounts of polluted water that run off urbanized land areas can destroy habitats and disrupt entire ecosystems. However, proper attention to land development methodology and engineering can minimize these adverse environmental impacts.

The concept of low-impact development (LID) integrates environmental concerns with land development, focusing on water and pollutant balances. Also known by other names, such as environmentally sensitive design, LID represents a fundamental change in the way residential, commercial, and institutional properties are developed and minimizes negative impacts on the environment and local ecology.

How land is developed deserves increased attention, especially as nonpoint-source pollution concerns move to the forefront in many water-quality evaluations, and total maximum daily load (TMDL) regulations inch closer to reality. In a fundamental sense, LID represents the application of pollution prevention and waste minimization concepts to land development. LID meshes with the principles of green engineering as applied to land development for environmental benefit (*1*).

Consequences of urbanization

Converting "natural" land, such as forest, to residential or commercial use drastically changes its hydrological characteristics. Vegetation is uprooted and replaced by impervious surfaces—rooftops, driveways, roadways, parking lots, and sidewalks. Even the remaining vegetated areas in residential developments tend to be smoothed, and small water storage depressions are eliminated. Diverse plant species are replaced with monoculture grasses that are regularly cut short and may be inundated with fertilizers and pesticides.

Sacrificing open land for impervious surface alters the water balance by promoting polluted run-

IMAGES FROM THE MARYLAND STATE HIGHWAY ADMINISTRATION, RHONDA SAUNDERS, AND PHOTODISC

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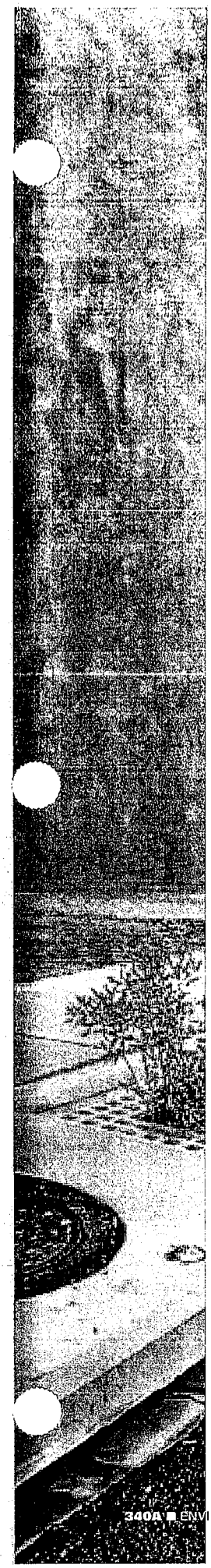

off at the expense of infiltration (*2*). Development negatively impacts water quality in two ways. First, many of the new materials and components used in land development contribute higher pollutant loads during rainfall and subsequent storm-water runoff. Second, the natural filtering action of wild vegetation (trees, bushes, tall grasses) is replaced by concrete, asphalt, and rooftops, which offer little means for water-quality improvement.

Conventional management of urban storm water aims to move runoff away from a developed area as quickly as possible—from impervious surfaces to gutters to storm drains and finally to stream discharge. Water is not permitted to pool. Although this approach minimizes ponding and flooding, it tends to lower water quality. Larger impervious areas lead to higher levels of more diverse pollutants, diminished pollutant removal during overland flow, reduced infiltration, and greater runoff peak flows, which, in turn, can increase stream erosion.

TABLE 1

Typical pollutant concentrations in urban storm-water runoff for different land uses

	Median event mean concentration for land use		
Pollutant (units)	**Residential**	**Mixed**	**Commercial**
Biological oxygen demand (mg/L)	10	7.8	9.3
Chemical oxygen demand (mg/L)	73	65	57
Total suspended solids (mg/L)	101	67	69
Total lead (μg/L)	144	114	104
Total copper (μg/L)	33	27	29
Total zinc (μg/L)	135	154	226
Total Kjeldahl nitrogen (μg/L)	1900	1288	1179
Nitrate and nitrite (μg/L)	736	558	572
Total phosphorus (μg/L)	383	263	201
Soluble phosphorus (μg/L)	143	56	80

Source: Reference 12.

Initially, storm-water management regulations tended to focus primarily on controlling quantity, with minimal provisions for improvement of water quality. Retention ponds constructed to store runoff from large storm events allowed water to gradually enter the stream environment. Little improvement in water quality was expected. Meanwhile, municipal and industrial point-source water pollution discharges have been increasingly reduced. With continuing urbanization in sensitive watershed areas, the emphasis must now shift to controlling pollutants originating from nonpoint sources, such as urban storm-water runoff.

However, not only are nonpoint sources more difficult to manage than point discharges, but the sources, mobilization, and transport of pollutants are also much more complex. The complexity arises from the interdependence of pollution, accumulation, and mobilization factors with hydrological behavior. The kinetic energy of rainfall and the momentum of flowing water provide sufficient shear stresses to mobilize deposited pollutants. With the higher volumes and velocities of sheet flow over rooftops, driveways, sidewalks, and roadways, water can dissolve deposited pollutants and mobilize solids and oils that have accumulated on these surfaces between rainfall events. Because of these mechanisms, the fraction of area that is impervious is considered as a primary measure linked to water-quality decline in urban areas. Studies have indicated that modifications in stream ecology occur when the proportion of impervious area is only a few percent. Once the impervious fraction reaches 10–30%, researchers see major declines in habitat and water-quality indicators (*3*).

Pollutant sources

Most traditional pollutants, including suspended solids, nutrients, and heavy metals, are found at fairly high levels in urban and roadway runoff (Table 1). Any disturbance that creates bare soil provides the potential for rain or runoff to mobilize sediments. In addition, greater overland flows from compacted and impervious areas increase erosion rates of nearby soils. Loss of vegetation eliminates the possibility of attenuation of suspended solids and results in total suspended solids levels from tens to hundreds of milligrams per liter in urban runoff. Fertilizers are applied to managed lawns and other landscaped areas, possibly several times per year. If not administered appropriately, nitrogen and phosphorus compounds readily wash from these lawns and from spillover onto paved areas. Nitrate deposition from automobile NO_x emissions becomes part of the runoff flows. In high-density residential areas, wastes from pets (if not cleaned up), birds, squirrels, and other urban animals are washed away by rainfall and add significant organic and pathogen loadings.

Moreover, a soup of toxic compounds exists in urban storm-water runoff. Heavy metals, such as copper, lead, and zinc, are released from automobiles, from fluid leaks; brake and tire wear; and corroded and weathered paints, coatings, decorative flashing, galvanized materials, and structural components (*4–6*). Motor oil, fuel, gear fluids, and coolants from vehicles are readily washed from impervious surfaces, cause oil sheens, and can directly impact aquatic life. Numerous toxic hydrocarbons and their oxidized products, which may persist in the environment, are also present in these fluids. PAHs may be found in leaking fluids, incompletely combusted fuel in atmospheric deposits, and as-

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phaltic products used in roofing and pavements. Various herbicides and insecticides are frequently used to control weeds and damage from insects in green urban areas. Again, without careful control of application, excess pesticides will leach from the application areas.

Collectively, pollutants derived from large developed areas can have major impacts on water bodies and their supported ecosystems during wet-weather flows, resulting in habitat degradation and loss, biological species shifts, and aquatic mortality. Receiving water bodies used for swimming or as a drinking-water supply may be compromised. Some of these pollutant sources are unavoidable with current practices, but development focused on water runoff issues can reduce impacts on the environment.

Elements of LID

LID is a philosophy for development that focuses on specific sustainable water conservation goals. Its aim is land use and management that minimize adverse environmental impacts. This process begins with planning at the watershed level. Various factors affect the flow and quality of water as it leaves the watershed; these include development densities; the placement and mixing of developed and undeveloped lands; and how residential, commercial, and other land uses are combined. However, our current understanding of the effects of these "smart-growth" planning features is incomplete and difficult to quantify. The environmental consequences of these planning decisions are very likely to be site-specific and will be influenced by regional development goals.

LID designs attempt to replicate pre-development hydrologic conditions as closely as possible. The desired result is not only a reduction in stormwater runoff from the site but improvements in water quality as well. LID is primarily focused on design characteristics at the individual lot level, and improvements are expected as a cumulative impact integrated over the entire developed area. LID objectives incorporate as little impervious surface as possible and keep any runoff on site as long as possible with natural approaches.

Design. LID design begins with site preparation. Rather than completely clear-cutting and leveling sites, designers leave as much wooded area on each lot as possible and try to avoid disturbing natural topographic depressions. Lots are designed with narrow driveways and minimal sidewalks. Streets are kept as narrow as local zoning and building codes will allow. To minimize soil compaction, the use of heavy equipment is discouraged. Vegetated swales and filter strips are encouraged, instead of elaborate curb-and-gutter systems that rapidly convey runoff. Rooftop downspouts are directed into vegetated areas, and rain barrels capture water for later use. Permeable paving materials are used rather than traditional asphalt and concrete.

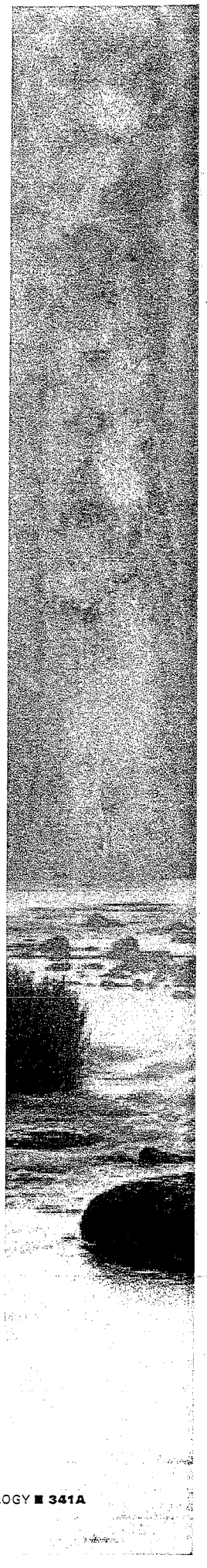
Collectively, these actions assist in keeping precipitation and runoff on the lot. Fewer impervious surfaces create less runoff. Swales and natural depressions allow for some on-lot storage, thus promoting infiltration and evapotranspiration. Preventing compaction of soils encourages natural infiltration. Overland water flow is slowed by vegetation, depressions, and meandering; this gives water time to seep into the ground, mobilizes fewer pollutants, and allows particulate matter to settle or be filtered. Keeping trees or small, forested areas promotes infiltration, lowers ambient temperatures, and reduces lawn use, which, in turn, decreases applications of fertilizers and pesticides.

These ideals follow several of the principles of green engineering (*1*). Foremost, when land is not paved, roofed, or even converted to lawn, these areas cannot create excess runoff and contribute pollutants from autos and lawn chemicals; this demonstrates Principle 2 (prevention instead of treatment). Care in the land development process, especially with driveways and sidewalks, both with the final design and with the construction phase, falls under Principle 8 (meet need, minimize excess). "One size fits all" designs must be avoided to minimize runoff and maximize on-site water collection and infiltration. Designs to direct downspouts onto lawns and store roof runoff in rain barrels follow Principle 10 (integrate local material and energy flows). Integrating natural areas into land development plans allows ecosystem maintenance and sustainability to be considered and emphasizes Principles 6 (entropy and complexity must figure into design) and 12 (materials should be renewable, not depleting).

Management practices. Of course, some impervious area cannot be avoided. Nonetheless, excess runoff can still be managed with LID and green engineering considerations. When some land is sacrificed to impervious cover, the remaining land surface can be engineered for greater infiltration by increasing overland flow time on the lot, creating storage, and modifying soils to promote infiltration. Specific vegetated runoff management practices can be incorporated within individual lots and also used to collect runoff from larger areas, such as several lots, roadways, or parking lots.

Vegetated areas are used in LID wherever overland flow is expected. Sheet flow is directed over vegetated filter strips, which include grass or, better yet, wild grass, shrubs, or trees. Vegetated swales are used to convey concentrated flows. Soils should be engineered and managed to encourage infiltration. Studies on grassed swale's efficiency in removing pollutants emphasize the importance of infiltration, because small flows may be completely infiltrated during transport through the swale (*7*).

Bioretention is a vegetated management practice designed to collect, store, infiltrate, and treat runoff. Bioretention areas, also known as rain gardens, may be concave flower gardens or landscaped areas. The rain garden is placed near the boundary of an individual lot to accumulate and manage escaping water. The depression is several centimeters deep, provides storage, and promotes evapotranspiration and infiltration. In a property with multiple lots, runoff from parking areas is conveyed into the bioretention facility. These facilities may be constructed in a parking island or linearly along a roadway



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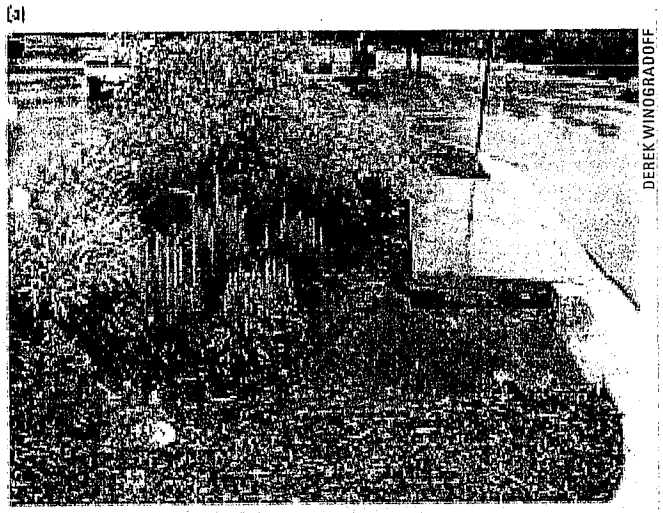
with curb-cut inlets (Figure 1). Overflow drains or swales leading into the adjacent traditional storm-drain infrastructure handle large flows or pooling that exceeds depths of ~15–30 cm. An engineered porous soil mixture encourages infiltration. Larger facilities are generally designed with an underdrain, which is typically a perforated plastic pipe that sits ~75 cm below the soil's surface.

FIGURE 1

Bioretention facilities

Also known as rain gardens, bioretention facilities use planted landscapes that are designed to collect, store, filter, and treat runoff. For example, these gardens may be constructed (a) in an island of a parking lot or (b) parallel to a roadway.

(a)



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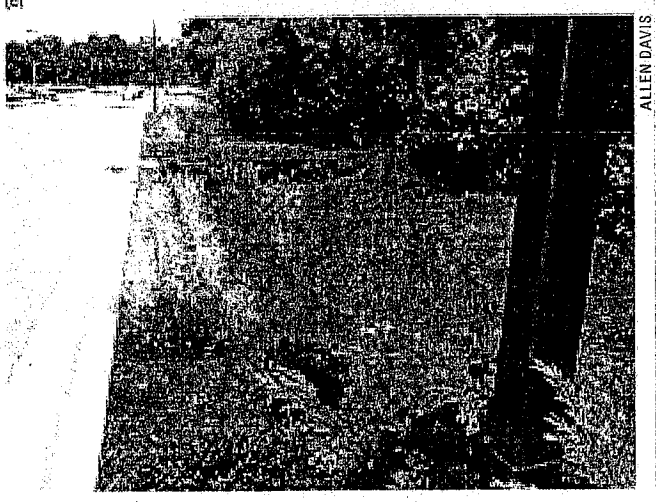
(b)



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Some studies have documented significant water-quality improvement through bioretention and infiltration processes. Bench-scale, pilot-scale, and some limited full-scale studies generally show nearly complete removal of suspended solids, oil and grease, and several heavy metals (*8*, *9*). Moderate removal of phosphorus, total Kjeldahl nitrogen, and ammonium has also been noted (*8*). Vegetation in the bioretention facility is expected to promote evapotranspiration, contribute to the capture and degradation of pollutants, and help maintain the soil infiltration capacity.

Impervious rooftops are one of the most difficult runoff problems to address. Green roof technology has significantly advanced in the past decade, and these roofs are now commonplace in Europe. Green roof design generally includes a layer of several centimeters of soil, sand, or another medium to capture the first few centimeters of rainfall. Sedum plants, which have simple growth needs and high evapotranspiration rates, can thrive on rooftops. Through the actions of the plants and soil media, flow volumes and velocities are minimized. Green roofs are an example of applying the principles of green engineering to LID (*10*).

Incorporating simple LID concepts into a site design can significantly reduce runoff flow and pollutant loads (*11*). For example, ammonia (80–85%), nitrate (66–79%), suspended solids (91–92%), copper (81–94%), iron (92–94%), lead (88–93%), manganese (92–93%), and zinc (75–89%) annual loads were decreased significantly by incorporating porous paving and swales into a parking lot of the Florida Aquarium in Tampa, Fla. The entire water volume was kept on-site during small storm events and eventually infiltrated or evapotranspired; this resulted in no release of water or associated pollutants from the site boundaries. With large storms and saturated soils, however, runoff is not greatly influenced by the LID techniques.

Anywhere green space is present, some innovative thought and application of green engineering principles can make it functional for water management. Even "nonfunctioning" space can be made functional. For example, grass swales or bioretention areas can be constructed along the edge of traditional parking spaces (Figure 2). The landscaped area is placed where the front or back of the car would overhang. Generally, this space is not used for wheel contact; thus, no valuable parking space is sacrificed.

Obstacles. Unfortunately, several logistic issues hinder complete implementation of the LID philosophy around the world. For example, some LID concepts are not allowed or are highly restricted under many current zoning and regulatory statutes. Easy access for school buses, garbage trucks, and emergency equipment requires a minimum street width. Concrete curbs and gutters may be required to rapidly convey runoff because of safety concerns from ice formation. Runoff collection and ponding may be discouraged because of public-health concerns about mosquito breeding. Continued research, development, and case-study information are needed to address these issues.

Economic concerns will always be important in driving LID implementation. LID construction may be more costly than leveling the land, because crews must work around trees and natural vegetated areas. On the other hand, narrower streets, the absence of curbs and gutters, and smaller stormwater management infrastructure may reduce

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costs. In the end, builders will desire the same return on investment through LID as with traditional development. If LID landscaping were to become accepted and commonplace, costs could be similar to those of traditional landscaping.

Public education and an understanding of public perception will be critical to the success of LID. Environmental managers must demonstrate to the public the importance of "environmentally friendly" land development and management. Will the public accept and maintain LID lots and subdivisions? Economics and social issues are linked: Landowners will look to the aesthetics, ease of maintenance, and return on investment with owning LID properties.

Benefits and drawbacks

Because of the dispersed nature of the pollutant fluxes and the focus on small, dispersed practices, environmental benefits from LID can be difficult to prove. Careful monitoring studies must be implemented so that expected improvements in water quality can be documented within the wide variability in rainfall, runoff flows, background water-quality characteristics, and development options. Both modeling and monitoring programs can assist in determining designs that truly produce the lowest impact.

Using LID solves some environmental issues but unfortunately raises others. For example, one particularly prominent aspect of nonpoint-source water-quality improvement practices is the "ownership" of pollutants after they are captured. The traditional development infrastructure encourages the flushing of pollutants from developed lands into the local waterways; thus, these pollutants are transported and diffused throughout the aqueous environment. Capture, however, creates ownership.

Toxics such as heavy metals are a particularly tough challenge. For example, data suggest that these metals are efficiently captured via bioretention. Over the lifetime of a facility, the accumulating metals must be periodically removed, or owners must face the unattractive notion of completely excavating contaminated media every few decades. One possible management option is to periodically remove layers of the bioretention mulch and media surface. Another attractive alternative is to carefully manage the vegetation and cut it on a regular basis, thereby creating a controlled pathway for the removal of many pollutants. In addition, novel hyperaccumulating plants could be incorporated into a traditional landscape management program.

For sustainable LID systems, natural pollutant degradation mechanisms must be integrated into the design and operation. Nutrient cycling must be emphasized, and opportunities for biological degradation of captured pollutants must be optimized. Biological processes could include "traditional" environmental engineering microbial processes that degrade captured pollutants, such as fuel hydrocarbons and organic pesticides. However, the role of macrophytes (larger plants and trees) must be considered when phytoremediation tools are incorporated into the LID environment. Vegetation plays an important role in the water balance and the fate and cycling of many pollutants, including nitrogen, phosphorus, and metals. Worms and insects can also affect pollutant fates through tunneling, soil digestion, and other processes. Because suspended solids are accumulated by LID practices, it is important to encourage biological processes that allow the natural integration of these particulates into the soil media structure to prevent clogging of infiltration areas.

FIGURE 2

Making use of nonfunctional space

In a parking lot, grass swales or bioretention landscapes can be constructed along the edge of traditional parking spaces. No valuable parking area is lost, because the landscaped area is placed where the front or back of the car would overhang.



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Infrastructure materials also demand some discussion within the LID philosophy—even if the land designer has minimal control over what is used to create the developed watershed or subsequently transported within it. Ultimately, we must look to the substitution of building materials and automobile components with those that leach less and are less toxic but still meet their respective performance requirements. Principle 1 of green engineering states that all material inputs should be as inherently nonhazardous as possible.

Ultimately, LID plays a role in larger, long-term development philosophies. Pollutant reduction via LID may be less costly than complex structural management practices, and future development in an area may be predicated on lower pollutant loads via new TMDL requirements. Who is responsible for funding pollutant reduction and who benefits from these practices remain to be determined. In the end, local

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governments or homeowners' associations may have to regulate and enforce LID design, construction, and maintenance and subsidize the costs.

From a regional development perspective, incorporating LID should not encourage urban sprawl. A forced overimplementation of infiltration practices could propel the development beyond its initial boundaries and result in more land being consumed. The cumulative environmental impact may be greater than that of traditional approaches if more undeveloped land is used and more roadway infrastructure is created to connect the sprawl development. LID practices should be carefully integrated into all development densities without forcing density reduction. High-density LID represents a formidable challenge.

Certainly, other important issues exist. Clearly, acceptance of LID will require continued research, performance monitoring, demonstration, and study. Fundamental studies will need to be coupled with practical applications. Expertise from many different disciplines is needed to address important issues, and cooperation among impacted parties is necessary. Conscientious land development decisions based on the best available supporting science are the best ways to protect our aquatic ecosystems.

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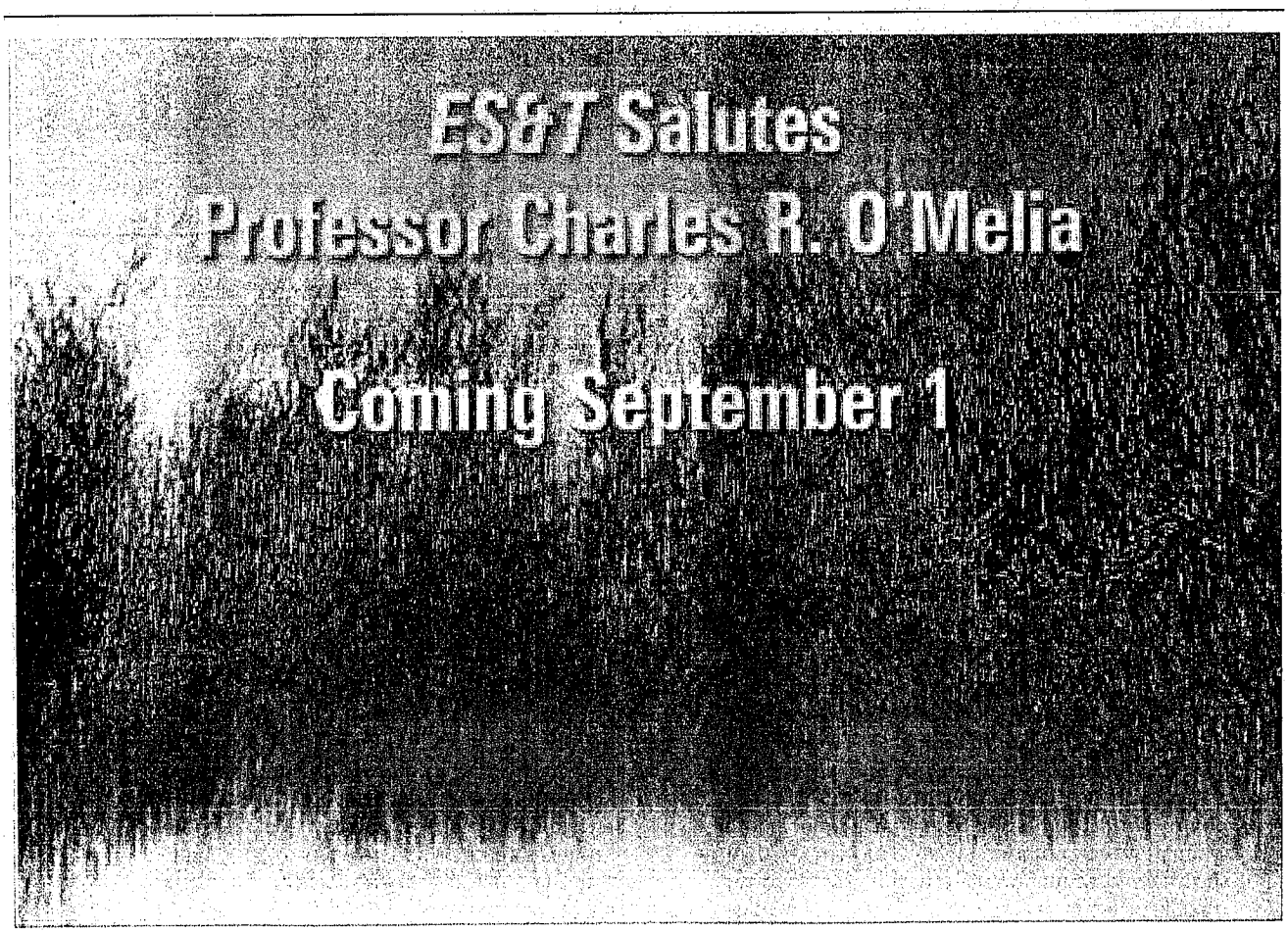

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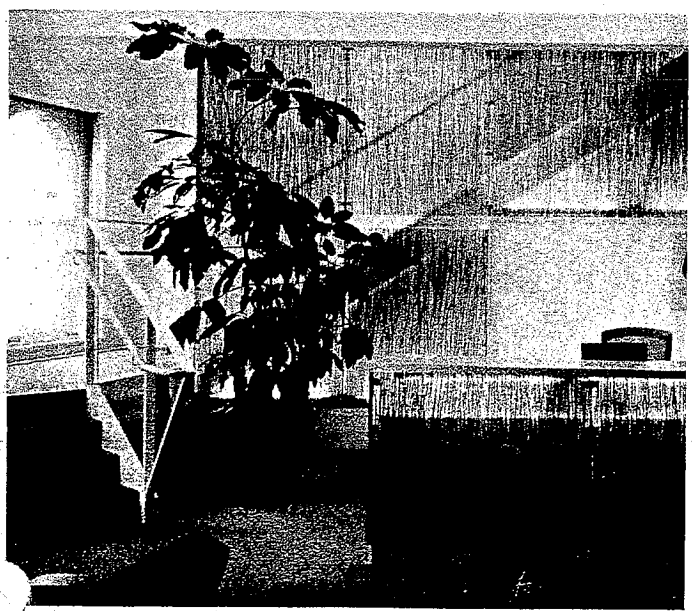
By Andrew J. Hall and Edward A. Belden, LEED Accredited Professional

Green Building and the LEED Rating System: The Next Logical Step for CEQA

The rapid rise in the demand for green buildings in the United States, and particularly in California, indicates a growing awareness that conventional approaches to building and development contribute to unnecessary and excessive levels of environmental degradation, habitat destruction, and resource depletion. The United States Green Building Council (USGBC) has developed a green building rating system, LEED (Leadership in Energy and Environmental Design), as the instrument to lessen those environmental impacts. In 2005, the USGBC registered 2,069 LEED new construction projects; of these projects, 358 were in California, a substantial increase from the 10 projects registered and certified in the program's first version released in 2000. The recognition of the importance of green building is quickly redefining construction best practices. Yet despite substantive overlap and shared goals, the California Environmental Quality Act (CEQA), the virtual precursor to this movement, has not yet embraced LEED as a tool for reducing environmental impacts.



Natural Resources Defense Council (NRDC) continues to lead the way with a LEED Gold certification for their San Francisco offices.

The LEED rating system is the most comprehensive program available to help design teams implement sustainable development practices. LEED evaluates environmental performance from the perspective of five categories:

1. Sustainable sites
2. Water efficiency
3. Energy and atmosphere
4. Materials and resources
5. Indoor environmental quality

Although LEED places primary emphasis on architecture and design, many of its categories overlap or influence CEQA issue areas.

The possibility of integrating LEED and CEQA is illustrated in the Draft Environmental Impact Report (EIR) of the University of California at Berkeley 2020 Long-Range Development Plan, which commits future buildings to be LEED certified in order to "minimize energy and water consumption and wastewater production" associated with cumulative significant impacts. The Berkeley Draft EIR represents a beginning; but it does not take advantage of LEED's ability to quantify environmental impact reductions. LEED credit requirements could be used as mitigation to address specific CEQA issue area impacts, as well as lessen cumulative impacts.

For example, CEQA's Appendix G, Utilities and Services Question A, specifically seeks reductions of wastewater to treatment facilities that can be directly addressed through the use of LEED, New Construction Water Efficiency Credit 2, which calls for a 50-percent reduction of the generation of wastewater or 100-percent treatment on site. The Audubon Nature Center, located at Debs Park in Los Angeles, implemented a groundbreaking on-site treatment for 100 percent of its

[1]University of California, Berkeley, Office of the Chancellor. 2004. *Draft Environmental Impact Report. UC Berkeley 2020 Long Range Development Plan & Chang-Lin Tien Center for East Asian Studies.* Available at: http://www.cp.berkeley.edu/LRDP_2020draft.htm.

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wastewater, which earned the center a Water Efficiency Credit 2 (Innovative Wastewater Technology) and a LEED Platinum Certification. The design includes a custom treatment system that treats, stores, and reintroduces clean water back to the environment, while meeting modern health code standards. The design technology used by the Audubon Nature Center is readily available for a multitude of applications, but yet remains underutilized.

The LEED system, through its credit-based framework, encourages the use of environmentally friendly products, technologies, and planning that demonstrably reduce negative environmental impacts, such as the wastewater treatment example demonstrated by Audubon Nature Center. The initial step toward achieving LEED recognition is LEED registration through the USGBC. LEED credits are obtained by meeting specific requirements, with additional prerequisites required to obtain LEED Certification. An additional example is a Sustainable Sites Credit that calls for a reduction of project footprint through the preservation or restoration of green space to 50 percent of the project development area. Depending on the amount of credits accumulated, a LEED–New Construction (NC) project can attain one of the following designations:

- LEED Certification: . . .26 to 32 points
- Silver Level: . . . . . .33 to 38 points
- Gold Level: . . . . . .39 to 51 points
- Platinum Level: . . . . . .52 to 69 points

LEED
LEADERSHIP IN ENERGY & ENVIRONMENTAL DESIGN

LEED-NC Version 2.1 Registered Project Checklist
Project Name
Project Location

Yes	?	No			
			Sustainable Sites		14 Points
Y			Prereq 1	**Erosion & Sedimentation Control**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity and Carpooling	1
			Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
			Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
			Credit 6.1	**Stormwater Management**, Rate and Quantity	1
			Credit 6.2	**Stormwater Management**, Treatment	1
			Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
			Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
			Credit 8	**Light Pollution Reduction**	1
Yes	?	No			
			Water Efficiency		5 Points
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1
Yes	?	No			
			Energy & Atmosphere		17 Points
Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
			Credit 2.1	**Renewable Energy**, 5%	1
			Credit 2.2	**Renewable Energy**, 10%	1
			Credit 2.3	**Renewable Energy**, 20%	1
			Credit 3	**Additional Commissioning**	1
			Credit 4	**Ozone Depletion**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

figure 1 continued on page 6

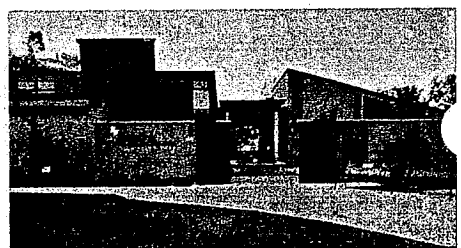
An example of the LEED–NC checklist utilized for projects is included in Figure 1, *LEED–NC Version 2.1 Registered Project Checklist.*

Three LEED rating systems are currently in use: LEED–NC, LEED–Existing Building (EB), and LEED–Commercial Interiors (CI). All three of these systems are geared to large commercial and municipal buildings. Three other LEED rating systems are in development to address buildings' core and shell, homes, and neighborhood developments. LEED–EB focuses on operations and maintenance of buildings two years or older. LEED–CI addresses materials, products, and resources utilized by tenants of a building.

Even with a tight budget, a LEED Certification can be achieved with minimal upfront costs. Despite the higher initial costs of adopting the LEED rating system, developers are generally receptive to green building because of the long-term savings they will ultimately enjoy on the design and construction impacts of new developments or major renovations to existing buildings.



Huge saving are projected for the ABD office building, a LEED Silver project located in Sacramento.



The Audubon goes for broke with a beautiful LEED Platinum nature center at Debs Park in Los Angeles.

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Green Building

continued from page 5

figure 1 continued from page 5

?	No		
		Materials & Resources	13 Points
Y		Prereq 1 **Storage & Collection of Recyclables**	Required
		Credit 1.1 **Building Reuse**, Maintain 75% of Existing Shell	1
		Credit 1.2 **Building Reuse**, Maintain 100% of Shell	1
		Credit 1.3 **Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
		Credit 2.1 **Construction Waste Management**, Divert 50%	1
		Credit 2.2 **Construction Waste Management**, Divert 75%	1
		Credit 3.1 **Resource Reuse**, Specify 5%	1
		Credit 3.2 **Resource Reuse**, Specify 10%	1
		Credit 4.1 **Recycled Content**, Specify 5% (post-consumer + ½ post-industrial)	1
		Credit 4.2 **Recycled Content**, Specify 10% (post-consumer + ½ post-industrial)	1
		Credit 5.1 **Local/Regional Materials**, 20% Manufactured Locally	1
		Credit 5.2 **Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
		Credit 6 **Rapidly Renewable Materials**	1
		Credit 7 **Certified Wood**	1
Yes	?	No	
		Indoor Environmental Quality	15 Points
Y		Prereq 1 **Minimum IAQ Performance**	Required
Y		Prereq 2 **Environmental Tobacco Smoke** (ETS) **Control**	Required
		Credit 1 **Carbon Dioxide** (CO_2) **Monitoring**	1
		Credit 2 **Ventilation Effectiveness**	1
		Credit 3.1 **Construction IAQ Management Plan**, During Construction	1
		Credit 3.2 **Construction IAQ Management Plan**, Before Occupancy	1
		Credit 4.1 **Low-Emitting Materials**, Adhesives & Sealants	1
		Credit 4.2 **Low-Emitting Materials**, Paints	1
		Credit 4.3 **Low-Emitting Materials**, Carpet	1
		Credit 4.4 **Low-Emitting Materials**, Composite Wood & Agrifiber	1
		Credit 5 **Indoor Chemical & Pollutant Source Control**	1
		Credit 6.1 **Controllability of Systems**, Perimeter	1
		Credit 6.2 **Controllability of Systems**, Non-Perimeter	1
		Credit 7.1 **Thermal Comfort**, Comply with ASHRAE 55-1992	1
		Credit 7.2 **Thermal Comfort**, Permanent Monitoring System	1
		Credit 8.1 **Daylight & Views**, Daylight 75% of Spaces	1
		Credit 8.2 **Daylight & Views**, Views for 90% of Spaces	1
Yes	?	No	
		Innovation & Design Process	5 Points
		Credit 1.1 **Innovation in Design**: Provide Specific Title	1
		Credit 1.2 **Innovation in Design**: Provide Specific Title	1
		Credit 1.3 **Innovation in Design**: Provide Specific Title	1
		Credit 1.4 **Innovation in Design**: Provide Specific Title	1
		Credit 2 **LEED™ Accredited Professional**	1
Yes	?	No	
		Project Totals (pre-certification estimates)	69 Points

Certified 26-32 points Silver 33-38 points Gold 39-51 points Platinum 52-69 points

through lower operating costs. Expenses can be recuperated by green building benefits, such as improving occupant health, comfort, and productivity. The LEED approach encourages an integration of green systems and materials and ensures that a project is designed as one dynamic system rather than a collection of standalone systems. The LEED checklist helps builders prevent and reduce potential negative environmental impacts, thus providing a natural extension of CEQA.

Updaating CEQA Through LEED

The LEED reference manual, while as voluminous as a well-documented EIR, provides in-depth approaches for new environmental analysis and mitigation measures. The integration of LEED and CEQA could result in many positive outcomes, including the prevention of negative impacts in the design phase, the development of alternative mitigation measures, the generation of public support for projects, the encouragement of green technology and products, the reduction of project costs, and the revival of enthusiasm in the environmental consulting field.

Mitigation measures pursuant to CEQA must provide performance standards and are developed by a CEQA-approved agreement, such as an EIR, to reduce impacts to below the level of significance. The LEED certification process involves third-party verification of compliance and culminates in an award of certification from the USGBC. Through the LEED rating system, credits are used to reduce potential impacts. As with CEQA requirements for mitigation measures, an applicant's claim of credit fulfillment must be clear, concise, verifiable, measurable, and thoroughly documented. A list of the LEED credits that may be utilized as mitigation measures to reduce or prevent potential significant impacts from a proposed project is provided in Table 1, *Integration of CEQA Issue Areas and LEED Credits.* Table 1 indicates the issue areas and questions specified in Appendix G of the CEQA Guidelines. Table 2, *Description of LEED Credits*, presents a summarization of the links between specific LEED credits and the CEQA issue areas to which they apply. For example, LEED credits could be used as mitigation measures incorporated into an EIR in which certain buildings would be earmarked for conformity to specific LEED credits, such as requiring Water Efficiency Credit 3 to reduce and quantify water usage. Utilizing such credits would directly reduce the time, effort, and financial commitments dedicated to environmental analysis. In addition, Appendix F, Energy Conservation, of the CEQA Guidelines requires that project planners assess energy usage and take steps to reduce inefficient uses of electricity—another issue that can be directly addressed by LEED energy and atmosphere credits, which require reductions in energy use and promote renewable sources of energy.

Including provisions for green buildings in environmental documents can serve as a public support mechanism by demonstrating specific steps taken to reduce environmental

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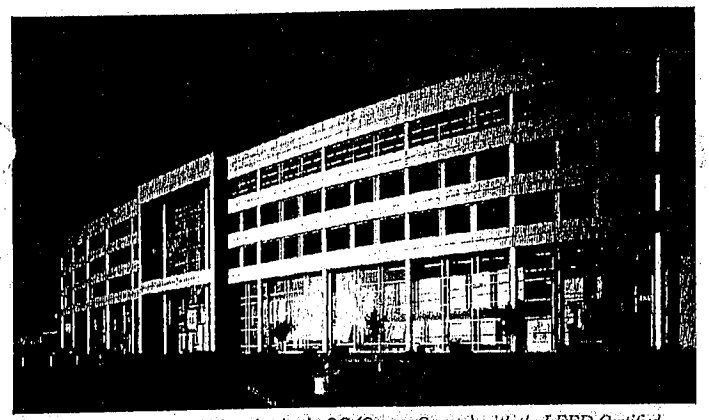

Ford Motor Company is trend-setting in the OC (Orange County) with the LEED Certified Premier Auto Group North American Headquarters.

impacts in a project's development phase. The USGBC has created widespread recognition of LEED, and the phrase "LEED Certification" is readily accepted by the public as a desired attribute for a project. Consequently, green building projects often enjoy faster acceptance from civic leaders, who readily welcome the positive perception of supporting a certified green building. Thus, the inclusion of LEED credit requirements in CEQA documents can garner support for a project during public review periods.

The recommendation and use of LEED credits in environmental documents can help promote green technologies that have the potential to reduce impacts in the immediate project area, as well as pare down the energy and impacts embodied during product manufacturing and transportation. The number of green products developed every year is growing rapidly; the exhibitor space at the 2005 Greenbuild Conference in Atlanta, Georgia, USGBC's annual conference, was sold out with 381 exhibitors. The conference was attended by more than 8,000 people interested in green building. By promoting green products, LEED directly and indirectly fulfills the legislative intent behind CEQA's Section 21000, which calls upon public and private interests to demonstrate a "concerted effort" to "manage natural resources and waste disposal...to enhance environmental quality and control environmental pollution."

LEED buildings have been estimated to increase initial project costs by 2 to 5 percent, but result in payback of premium in less than 10 years. In addition, the costs of preparing environmental documentation and litigation may be reduced through the adoption of a LEED-certified project. By decreasing time for obtaining permits and by reducing costly CEQA litigation, green building can reduce overall project costs.



The Inland Empire Utilities Agency (IEUA) headquarters in Chino State Park received a LEED Platinum for it outstanding design and forward-thinking site plan.

Policy Recommendations

One of the intents of CEQA is to incorporate planning early in the design phase as an instrument to reduce negative environmental impacts. Environmental consultants shoul embrace the use of LEED-registered projects as a new planning instrument. LEED's planning strategy requires the comparison of a LEED building with a standard building early in the design phase, allowing for an easy quantification of differences in impacts. This strategy has the ability to refine current environmental analysis techniques—in particular, in the comparison and quantification of impacts of project alternatives in an EIR. A LEED-certified building would serve as a measurable Environmentally Superior Alternative.

In response to the common concern over the high premium for green building, Santa Monica and other progressive municipalities have developed a preferential system for LEED-registered projects to proceed through the city planning department's approval process. This approach saves time and reduces costs to project proponents. The time and money savings can also be accomplished through CEQA exemptions or streamlining for LEED-registered projects. One option would be a categorical exemption for LEED–EB registered projects, since these projects only affect modifications to existing buildings.

A second option is for municipalities to adopt a streamlined CEQA process for LEED–NC or LEED–EB registered projects. This streamlined process would only evaluate those

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Table 1, **Integration of CEQA Issue Areas and LEED Credits***

CEQA Issue Area	Question	LEED Credit
Aesthetics	d	SS Credit 8
Agriculture Resource	a	SS Credit 1
Air Quality	a, b, & c	EA Credit 4
Biological Resources	a & c	SS Credit 1
Cultural Resources	a	MR Credit 1
Geology and Soils	b	SS Prerequisite
Hazards and Hazardous Materials	d	SS Credit 3
Hydrology and Water Quality	a & b c & d e f g & h	WE Credit 3 SS Credit 6 SS Credit 6, WE Credits 1 & 2 SS Credit 6, WE Credits 1, 2, 3 SS Credit 1
Land Use and Planning	c	SS Credit 1
Population and Housing	a	SS Credit 4
Pubic Services	a, Parks	SS Credit 1
Transportation and Traffic	a, b, f, & g	SS Credit 4
Utilities and Services	a, b, c, & e d f g	WE Credits 2 & 3, SS Credit 6 WE Credits 1 & 3 MR Prerequisite, Credit 2, 1-6 MR Credits 1-6

Note: The LEED credits utilized for this table are based on the LEED-NC rating system, version 2.1.

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Green Building

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CEQA issue areas not specifically covered by a preapproved LEED checklist. An additional component could be the development of standard mitigation measures to address those CEQA issue areas not addressed in the preapproved LEED checklist. Streamlining of CEQA is a controversial issue, but LEED-certified projects incorporate the intent of CEQA to seek project alternatives that reduce impacts to natural resources and protect the health of humans and other species. Furthermore, LEED-certified projects demonstrate some of the most innovative approaches to incorporating sustainable principles in project design. If the suggested streamlining is adopted, CEQA's influence on projects could be propelled beyond its current level and into a project design leadership position.

LEEDing CEQA Into the Future

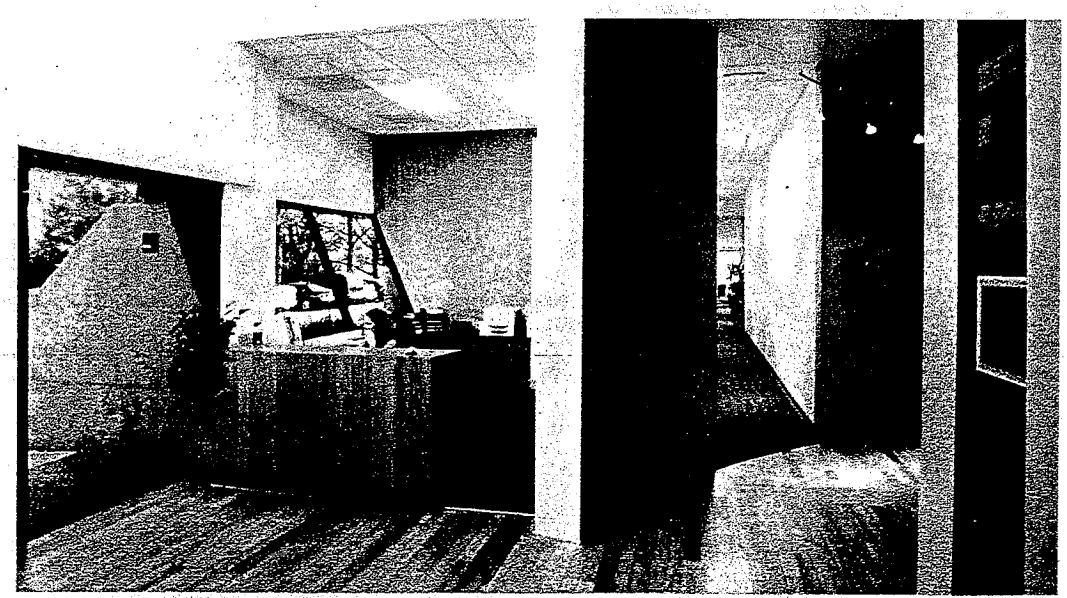
The integration of LEED and CEQA would ensure that negative environmental impacts are reduced before, during, and after a project has been completed. The inclusion of LEED credits in environmental analysis may provide a spark for new thinking, new language, and new approaches to CEQA. Looking forward to LEED-certified neighborhood developments in 2007, an integrated LEED and CEQA system would have the opportunity to promote smart growth and sustainable principles in California's preferred planning approach, the master plan.

The integration of LEED into environmental analysis also holds promise for the environmental consulting field. To date, architects dominate the LEED field, but environmental consultants are amply qualified to perform many of the required LEED credit calculations. In fact, the combination of LEED and CEQA may allow architects, other design team members, and environmental consultants to work more collaboratively to create inspired design solutions to environmental issues.

Andrew J. Hall is an environmental analyst with Sapphos Environmental, Inc. and is currently working to complete his LEED accreditation. Edward A. Belden is a LEED accredited professional and an environmental analyst with Sapphos Environmental, Inc.

Green Building in California

In 1993, the USGBC realized that in order to create a measurable green building standard, the concept of sustainability needed an organized format. In response, the USGBC created the LEED building rating system, which intends to balance environmental responsiveness, resources efficiency, and cultural sensitivity. The recent development of the LEED rating system has helped fuel the development of green buildings throughout California. California has the highest number (250) of LEED-registered and -certified projects, followed by Pennsylvania with 95 projects. The large number of LEED-certified projects has been encouraged throughout California through the establishment of green building ordinances, subsidies for developers, and streamlined planning review. Green building ordinances have been established in the California cities of San Diego, San Francisco, Davis, and Santa Monica, and in the County of San Mateo. In addition, municipalities are adopting creative subsidies for LEED-certified buildings. Pasadena offers $30,000 toward LEED Platinum certification. Santa Monica offers monetary subsidies and recently adopted accelerated plan checks for LEED-registered projects. Encouragement of LEED certification outside of California is expanding as well, with Portland, Oregon recently adopting a LEED Gold Standard for city buildings. In addition, the U.S. General Services Administration, which provides oversight for the construction and operation of most federal buildings, has mandated that future projects be LEED certified.



TKG Consulting Engineers, Inc. built a LEED Gold building for their offices in Oberlin, San Diego County. Photo courtesy of Ted Walton Photography.

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TABLE 2 DESCRIPTION OF LEED CREDITS

The following provides a brief description of the LEED credits discussed:

SUSTAINABLE SITES (SS)

Prerequisite: Erosion and Sedimentation Control controls erosion in order to reduce the negative impacts to water and air quality. Example strategies include temporary and permanent seeding, earth dikes, silt fencing, sediment trap, and sediment basins **(required)**.

SS Credit 1: Site Selection adopts the CEQA standard in its avoidance of converting to nonagricultural use or placing a building atop Prime Farmland, Unique Farmland, or Farmland of Statewide Importance **(1 point)**.

SS Credit 3: Brownfield Redevelopment does not tolerate the presence of, or the negligent building atop, harmful hazardous waste sites. The LEED credit requires the site to be effectively remediated before any building begins. The up tick here is that many cities already have in place brownfield redevelopment policies or grant programs that offer economic incentives for rehabilitating contaminated sites **(1 point)**.

SS Credit 4: Alternative Transportation requires the inclusion of an alternative transportation component that focuses on reducing pollution and land development impacts from increased automobile use. Examples of strategies range from providing accessible public transportation, bicycle and storage facilities, and increased parking capacity to the development of ernative fuel vehicles and technologies **(up to 4 points)**.

SS Credit 6: Stormwater Management requires projects that have an existing imperviousness less than or equal to 50 percent to implement a stormwater management plan that prevents the postdevelopment 1.5-year, 24-hour peak discharge rate from exceeding the predevelopment 1.5-year, 24-hour peak discharge rate. Alternatively, if existing imperviousness on site ater than 50 percent, the project is required to implement a stormwater management plan that results in a 25 percent decrease in the rate and quantity of stormwater runoff **(up to 2 points)**.

SS Credit 8: Light Pollution Reduction intends to eliminate light trespass from the buildings and site, as well as improve night sky access and reduce development impact on nocturnal ments. The LEED guidelines are very rigorous and ire a lighting engineer to develop a lighting plan **(1 point)**.

WATER EFFICIENCY (WE)

WE Credit 1: Water Efficiency Landscaping requires the limited use, or elimination of, potable water for landscape irrigation **(2 points)**.

WE Credit 2: Innovative Wastewater Technologies requires the reduction of the use of municipally provided potable water for building sewage conveyance by a minimum of 50 percent, or the treatment of 100 percent of wastewater on site to tertiary standards. This credit is far more aggressive and challenging to fulfill than the CEQA requirement, which merely requires that the wastewater treatment provider have sufficient capacity for a project's projected greywater output **(1 point)**.

WE Credit 3: Water Reduction offers points to projects that use 20 to 30 percent less water than the calculated baseline **(up to 2 points)**.

ENERGY AND ATMOSPHERE (EA)

EA Credit 4: Ozone Protection strategies include installing base building level heating, ventilation, and air conditioning (HVAC) and refrigeration equipment and fire suppression systems that do not contain hydrochlorofluorocarbons (HCFCs) or halons **(1 point)**.

MATERIALS AND RESOURCES (MR)

Prerequisite: mandates the facilitation of the waste generated by building occupants to proper landfills **(required)**.

MR Credit 1: Building Reuse offers points for maintaining at least 75 to 100 percent of existing building structure and shell (i.e., exterior skin and framing, excluding window assemblies) and at least 50 percent of non-shell areas **(up to 3 points)**.

MR Credit 2: Construction Waste Management requires that 50 to 75 percent of construction waste materials to be diverted from landfills **(up to 2 points)**.

MR Credit 3: Resource Reuse requires that 5 percent of total building material costs be dedicated to the use of salvaged materials **(1 point)**.

MR Credit 4: Recycled Content requires that 5 to 10 percent of total building material costs be dedicated to the use of post-consumer recycled content materials. Post-industrial recycled content materials can also be used, but it will be credited at only 50 percent of post-consumer recycled content materials **(up to 2 points)**.

MR Credit 5: Regional Materials requires that 20 to 50 percent of building materials be manufactured within a 500-mile radius of the project **(up to 2 points)**.

MR Credit 6: Rapidly Renewable Materials requires that 5 percent of total building material costs and products be spent on rapid renewable materials **(1 point)**.

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Message

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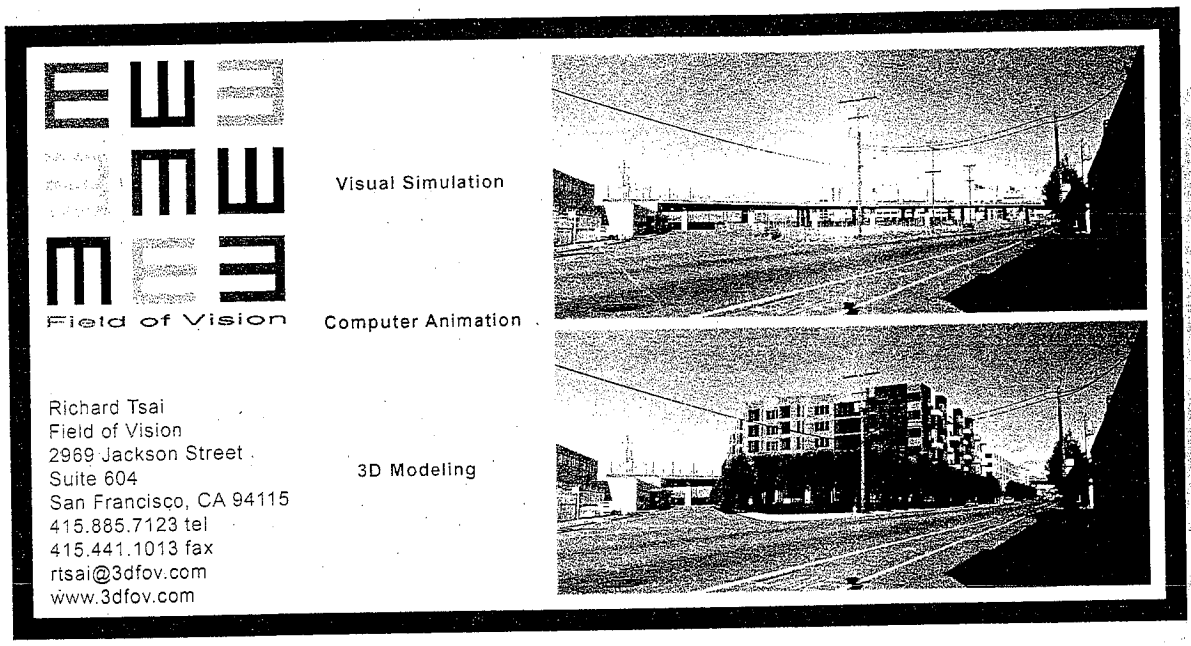
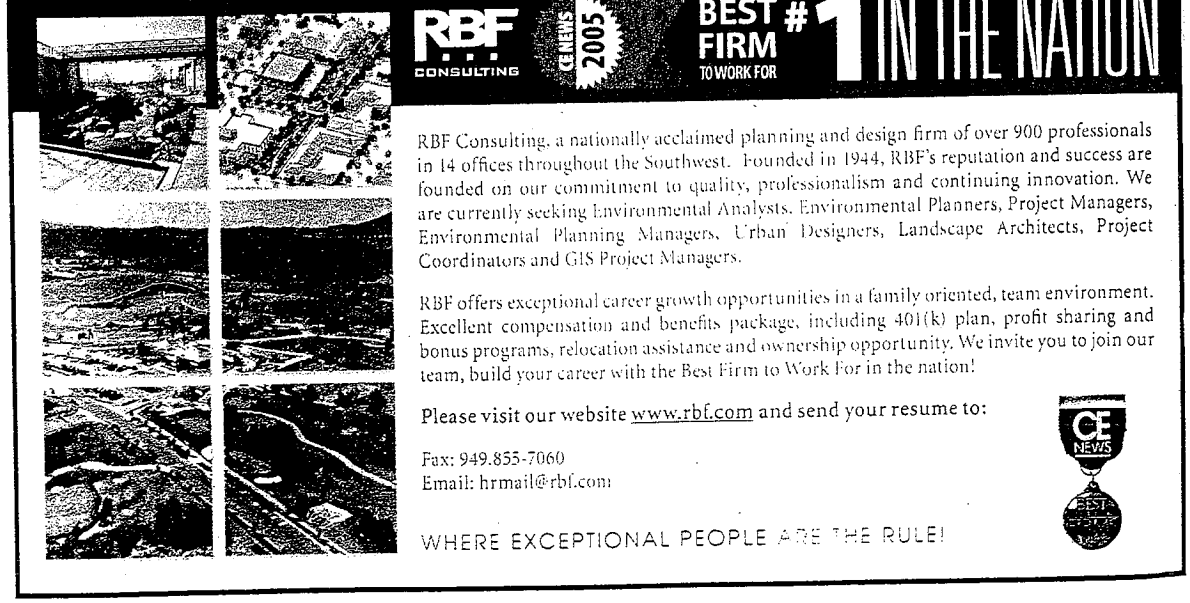
- Annual Conference
- NAEP Logo Products
- Educational Courses and Seminars
- Regional meetings and events
- Opportunities to advance personally and professionally through leadership positions in NAEP working groups, committees and the National Board of Directors
- Access to a Career Center specifically targeted to the Environmental Professional
- Confidential search profile
- Online Management tools
- Automatic new job e-mail notification
- Avenues to network with professional contacts in industry, government, academia and the private sector

These are exciting but challenging times for the environmental profession, whether you are interested in state or in national issues. We are facing continued pressure from the building community, state legislators, and the governor's office to reform or weaken CEQA and the Endangered Species Acts. We will also work with our NAEP colleagues as we watch potential challenges to NEPA, the federal ESA, etc. CalAEP will work diligently and proactively on meaningful legislative reform through our Legislative Committee. I hope you will continue to support our efforts to improve CEQA and services to our members, and our future efforts in the NEPA arena as well. Please let us on the state Board or the officers on your local chapter Board if you have concerns or suggestions for improving AEP. Thank you and I look forward to continued service for and with you on behalf of AEP.





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The Ahwahnee Water Principles for Resource Efficient Land Use

Cities, counties and organizations that have adopted the Ahwahnee Water Principles:

Recently Adopted: City of Ukiah, CA; City of Sunnyvale, CA

Town of Windsor, CA; Marin County, CA; Marin Municipal Water District, CA; Menlo Park, CA; Morgan Hill, CA; Palo Alto, CA; Petaluma, CA; Port Hueneme, CA; Richmond, CA; Rohnert Park, CA; Rolling Hills Estates, CA; San Luis Obispo, CA; Santa Paula, CA; Santa Rosa, CA; Ventura, CA; Ventura County, CA.

Organizations that have endorsed the Ahwahnee Principles:

Bay Area Water Forum and Association of Bay Area Governments (CalFed Task Force); League of California Cities; Southern California Association of Governments Water Policy Task Force.

*Want to adopt the Ahwahnee Water Principles? A **model water resolution** is available.*

*Recently adopted or endorsed all, or part, of the Ahwahnee Water Principles? **Let us know!***

Preamble

Cities and counties are facing major challenges with water contamination, storm water runoff, flood damage liability, and concerns about whether there will be enough reliable water for current residents as well as for new development. These issues impact city and county budgets and taxpayers. Fortunately there are a number of stewardship actions that cities and counties can take that reduce costs and improve the reliability and quality of our water resources.

The Water Principles below complement the Ahwahnee Principles for Resource-Efficient Communities that were developed in 1991. Many cities and counties are already using them to improve the vitality and prosperity of their communities.

Community Principles

1. Community design should be compact, mixed use, walkable and transit-oriented so that automobile-generated urban runoff pollutants are minimized and the open lands that absorb water are preserved to the maximum extent possible. (See the **Ahwahnee Principles for Resource-Efficient Communities**)
2. Natural resources such as wetlands, flood plains, recharge zones, riparian areas, open space, and native habitats should be identified, preserved and restored as valued assets for flood protection, water quality improvement, groundwater recharge, habitat, and overall long-term water resource sustainability.
3. Water holding areas such as creek beds, recessed athletic fields, ponds, cisterns, and other features that serve to recharge groundwater, reduce runoff, improve water quality and decrease flooding should be incorporated into the urban landscape.
4. All aspects of landscaping from the selection of plants to soil preparation and the installation of irrigation systems should be designed to reduce water demand, retain runoff, decrease flooding, and recharge groundwater.
5. Permeable surfaces should be used for hardscape. Impervious surfaces such as driveways, streets, and parking lots should be minimized so that land is available to absorb storm water, reduce polluted urban runoff, recharge groundwater and reduce flooding.
6. Dual plumbing that allows graywater from showers, sinks and washers to be reused for landscape irrigation should be included in the infrastructure of new development.
7. Community design should maximize the use of recycled water for appropriate applications including outdoor irrigation, toilet flushing, and commercial and industrial processes. Purple pipe should be installed in all new construction and remodeled buildings in anticipation of the future availability of recycled water.
8. Urban water conservation technologies such as low-flow toilets, efficient clothes washers, and more efficient water-using industrial equipment should be incorporated in all new construction and retrofitted in remodeled buildings.
9. Ground water treatment and brackish water desalination should be pursued when necessary to maximize locally available, drought-proof water supplies.

Implementation Principles

1. Water supply agencies should be consulted early in the land use decision-making process regarding technology, demographics and growth projections.
2. City and county officials, the watershed council, LAFCO, special districts and other stakeholders sharing watersheds should collaborate to take advantage of the benefits and synergies of water resource planning at a watershed level.
3. The best, multi-benefit and integrated strategies and projects should be identified and implemented before less integrated proposals, unless urgency demands otherwise.
4. From start to finish, projects and programs should involve the public, build relationships, and increase the sharing of and access to information.
5. Plans, programs, projects and policies should be monitored and evaluated to determine if the expected results are achieved and to improve future practices.

Authors: Celeste Cantu, Martha Davis, Jennifer Hosterman, Susan Lien Longville, Jeff Loux, John Lowrie, Jonas Minton, Mary Nichols, Virginia Porter, Al Wanger, Robert Wilkinson, Kevin Wolf

Editor: Judy Corbett

(Adopted in 2005)

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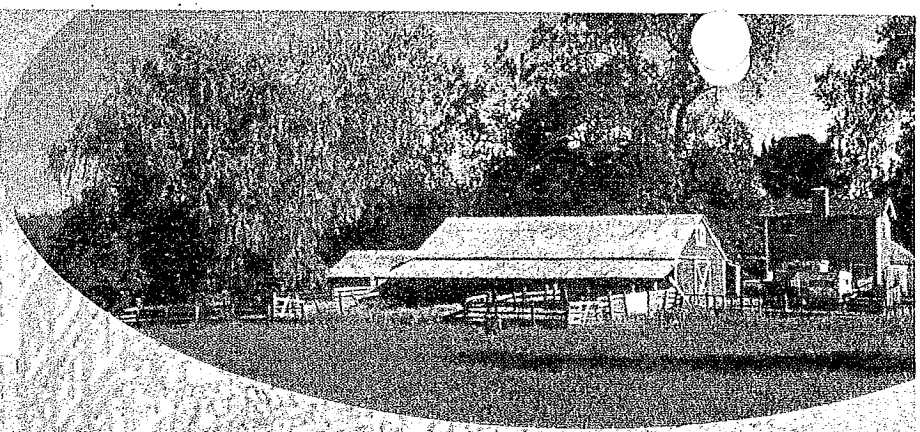
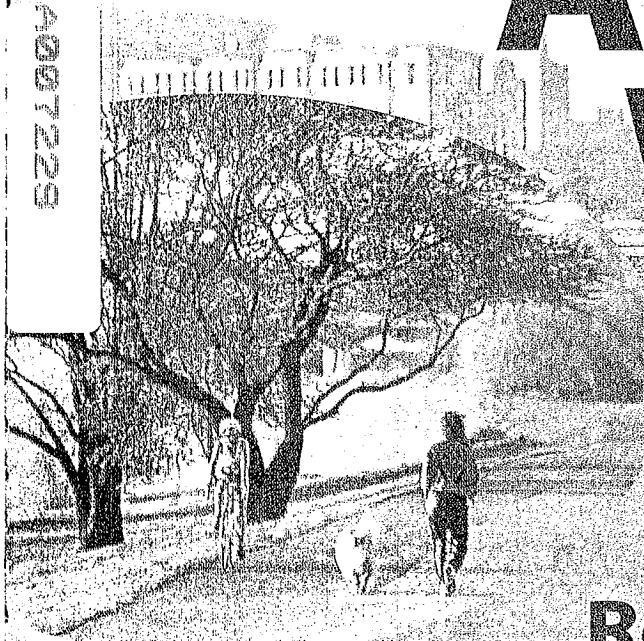


The Ahwahnee Water Principles

A Blueprint for Regional Sustainability



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Local Government Commission



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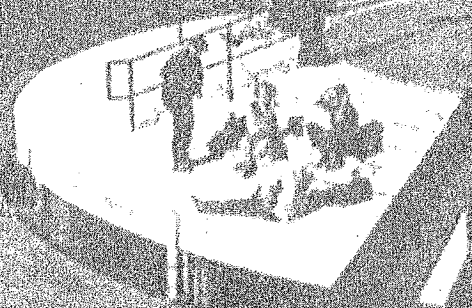
The Ahwahnee Water Principles

A Blueprint for Regional Sustainability



July 2006

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"Watersheds not only connect our land and water, they connect our communities. We cannot sustain vibrant, livable communities if we cannot sustain clean and reliable water supplies."

– Mary Jane Griego, Yuba County Board of Supervisors

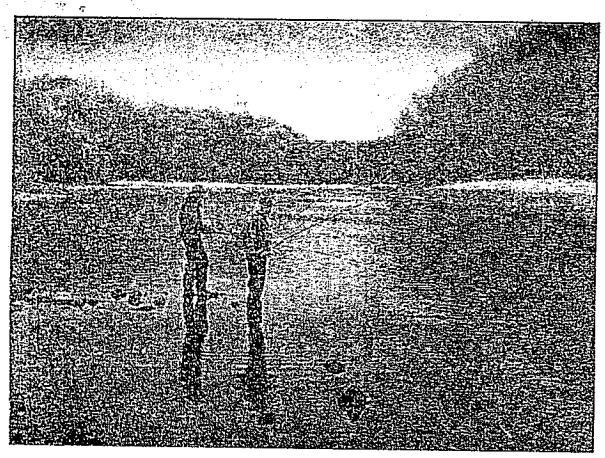
Introduction

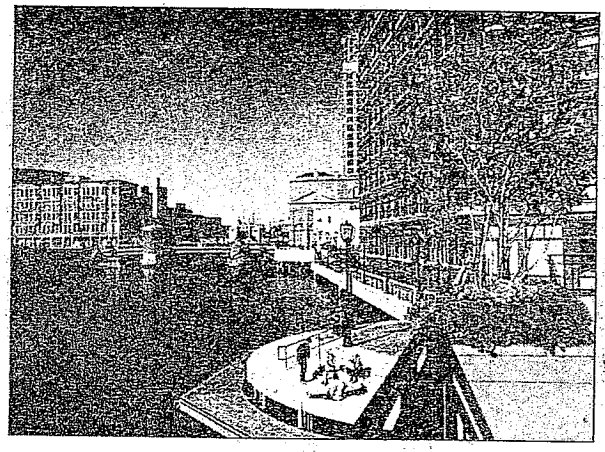
While in California in the later part of the 19th century, Mark Twain observed, "Whiskey is for drinking... water is for fighting." The tensions and concerns over sufficient water to meet the needs of California reflected in Twain's humorous comment are as true today as they were over 100 years ago.

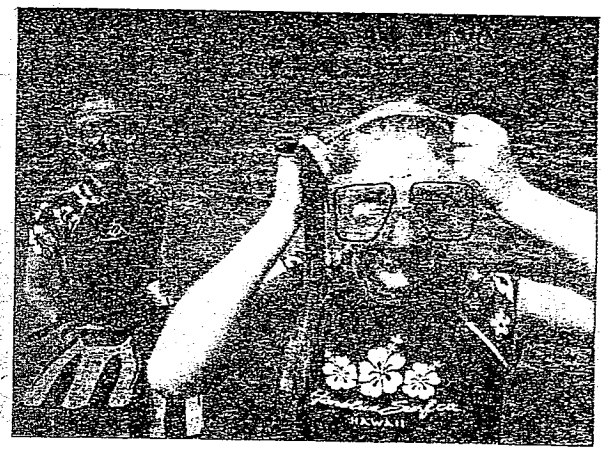
Safe, clean water is essential to California, its nearly 37 million residents, its vibrant and diverse economy, and its cherished quality of life. However, accessible quantities of clean water adequate to meet California's current and projected future needs are limited and relatively finite. It is becoming increasingly evident to policy-makers that to accommodate the often competing needs of various end-users, while providing for continued demographic and economic growth, requires careful, forward-thinking management of California's water resources.

Responsibility for balanced, effective water management in California is increasingly borne by government at the local level. In 2001, state legislators recognized the need to tie future development to the availability of water in enacting Senate Bills 221 and 610. This legislation, sometimes referred to as the "show me the water laws," requires that before local jurisdictions can approve new, large residential and commercial projects, the project must receive written verification from the local water agency that there are sufficient water resources to sustain the growth projected by the project.

However, the reverse is also true. The loss of water resources forces the loss of population and businesses. For example, in in west Fresno County where several towns are now facing diminishing water resources, a lack of water is causing some residents to move out of the area. This population loss is presenting formidable economic challenges for these communities. [1]







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New responsibilities for managing California's water supplies

In addressing the state's population growth, predicted to jump another 12 million people by 2030, community and regional land use decision-making by local jurisdictions will directly impact the distribution of California's water resources. [2]

Competition for adequate supplies of water has long-produced tensions between rural and agricultural California and rapidly growing urban, suburban and exurban California. This competition and the resulting tensions will almost certainly intensify unless local governments mitigate these competing interests by looking to cost-effective, long-term policies that efficiently manage and distribute available water resources.

Furthermore, responsibility for the safety and protection of California's water is now increasingly placed with local and regional government agencies. Federal and state laws mandate regulatory oversight at the local level, including water supply and safety, stormwater management, pollution mitigation and flood control.

However, the responsibility for meeting these requirements is accompanied by growing concerns over legal and financial liabilities that city and county governments may face.

Taken together, the requirements of the new water supply laws and regulatory programs are pushing California's local governments to see the need to coordinate their planning and development processes with water management efforts.

Local governments' increasing concern about adequately managing water resources also extends to protecting and preserving California's precious quality of life. The demands of increasing population, agricultural and commercial operations, changing land use and expanding urbanization affect and, in some cases, threaten California's ecology, natural places and resources. Shortsighted land use planning threatens the state's natural treasures, including aquifers, lakes, rivers, streams and watersheds.

Sound, thoughtful management of our water resources – how water is captured and controlled, how it is treated, used and released – is an issue that local governments cannot afford to ignore. Around the United States, local officials are embracing new land use policies that protect and maximize local water resources, reduce the cost of stormwater permits,

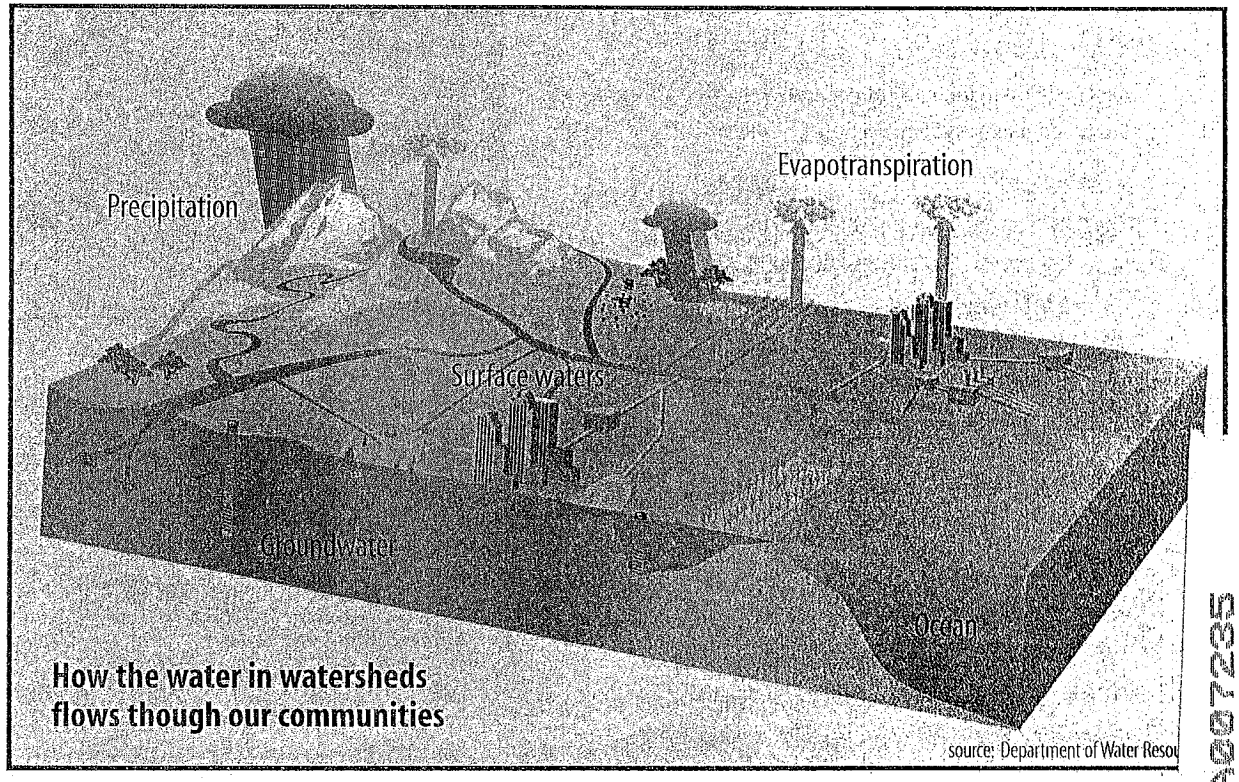
lessen the possibility of fines for violating water quality standards, and limit the impacts of flooding on rapidly developing floodplains. Communities are looking ahead, and planning and investing to meet current and projected future demands for water supply, quality and the environmental health needed to sustain them. They understand that their land use decisions seriously impact those water resources. This guidebook is intended to help officials at the local and regional level become active partners in protecting local water resources and watersheds.

Thinking regionally – The watershed

Every river we see is part of an area of land – a watershed – that catches and drains the water that falls within it. A watershed is a network of water, a geographic area in which water, solids, sediments and dissolved materials drain and flow to a common outlet – a point on a larger stream, a lake, an underlying aquifer, an enclosed bay, an estuary or, in California, the Pacific Ocean.

All land, developed or not, is part of a watershed. When rain falls, it becomes a part of the watershed it falls in. The water in a watershed is connected by the streams, lakes and wetlands we see on the surface, which are also tied to groundwater basins below the ground.

Watersheds are critical to the health and welfare of our communities. They are the source of our water; they maintain our forests, agriculture and fisheries; they feed our rivers, lakes, groundwater and estuaries; and they provide essential wildlife habitat and innumerable natural services we depend on.



How the water in watersheds flows though our communities

source: Department of Water Resou

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In addition to providing our drinking water, California's watersheds sustain economic and recreational activities throughout the state, including tourism, commercial and recreational fishing, boating and rafting.

Of course, the natural boundaries that define watersheds are not the same as the political boundaries of cities and counties. Watersheds may span multiple jurisdictions, which means separate communities and their water supplies are connected by the watershed they share.

In hydrologic terms, California can be broken into 10 watershed regions – North Coast, San Francisco, Central Coast, South Coast, Sacramento River, San Joaquin River, Tulare Lake, North Lahontan, South Lahontan and Colorado River – each with its own climate, ecology and geographic characteristics. From a regulatory perspective, California's watersheds are arranged into nine Regional Water Quality Control Boards.

Meeting our future water needs

Because watersheds are dynamic and fragile systems, the challenges to maintaining and sustaining vital watersheds are becoming increasingly complex.

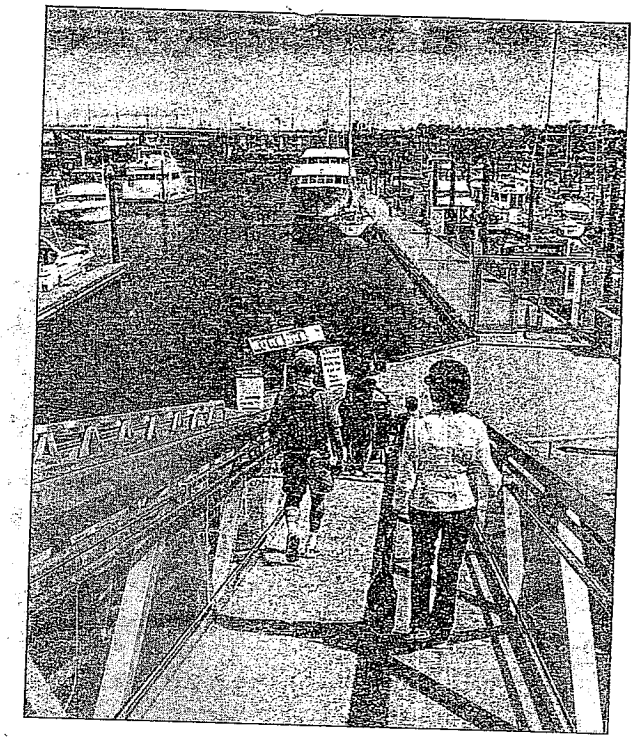
Population increases and economic growth will be accompanied by more housing and commercial development. This means that previously open land will be covered by asphalt, concrete and similar impervious surfaces, impairing water from percolating into the ground and replenishing underground aquifers. This will reduce available water supplies at a time when the demand for water will be increasing.

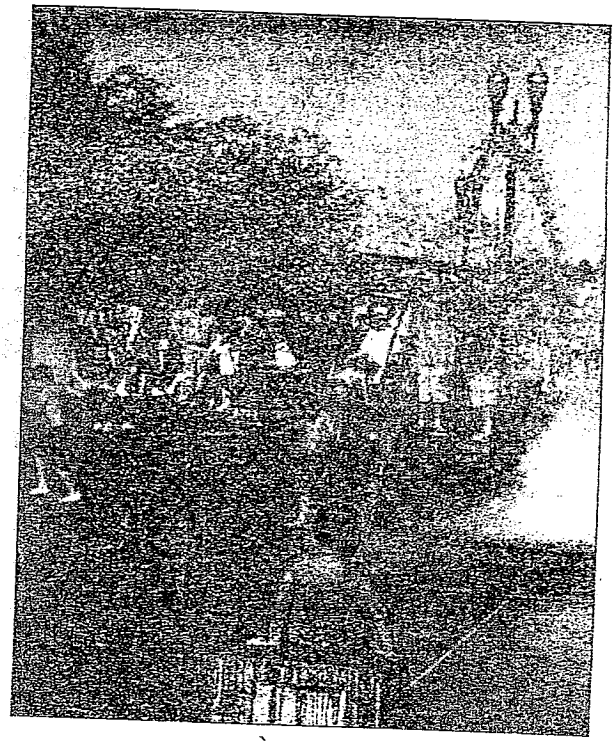
To make matters worse, as it flows across parking lots and streets, runoff water will gather up refuse, oil and other contaminants and pollute our local water supplies.

Unless the relationships between water supply, growth and development are better managed, California's watersheds will become increasingly polluted. Their vital natural functions to collect and cleanse our water supplies, provide commercial and recreational opportunities and wildlife habitat will be impaired and possibly permanently destroyed.

Global warming represents yet another challenge to California's future water supplies. Warmer temperatures will produce a smaller snowpack and more winter runoff. This means more floodwaters to manage in the winter followed by less snow melt to bank in reservoirs for drinking water, summer lawns and crop irrigation.

It cannot be stressed enough that California's available water resources are limited and unpredictable. Much of California is arid and prone to drought; in the past 75 years, in fact,





California has experienced three major droughts – from 1929-34, 1976-77 and, most recently, 1987-92.

The way most California communities supplement local supplies is by importing water. Unfortunately, the principal sources of imported water are becoming increasingly unavailable. Today, most of Central and Southern California's water comes from the San Francisco Bay-San Joaquin River Delta, which provides water for two-thirds of California residents. This water also irrigates a substantial portion of California's farms, is the state's most important fishery habitat, and is home to more than 10,000 species of migratory fowl. But the Delta itself is under severe strains.

Nor can California, especially the southern part of the state, continue to rely so heavily on water imported from the Colorado River. Currently, it is California's other major source of imported water. But regulatory requirements limit California's claim on water from the Colorado River. The needs of other states in the Colorado Basin, the impact of severe, prolonged drought, and questions of water quality limit the Colorado River as a reliable source of water for California's future needs.

Still, the picture of water resource management in California is not entirely bleak. There are practical actions that cities and counties can take that will ensure a future water supply for their communities.

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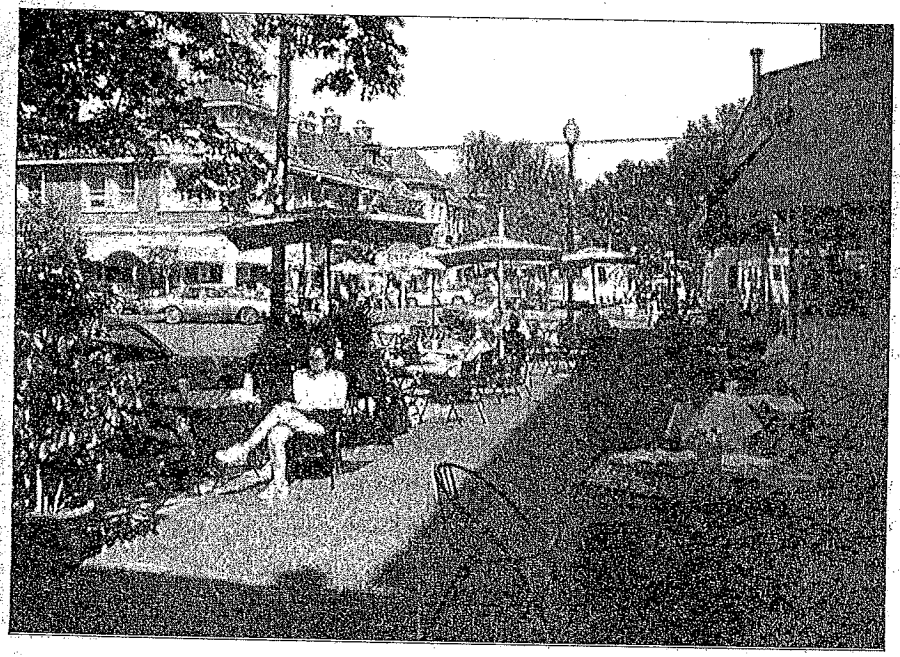
The Ahwahnee Water Principles for Resource-Efficient Land Use



In 2004, the Local Government Commission set out to identify effective, least-cost economically and politically viable options for sustainable water resources management at the local level. The LGC invited respected water resource policy, management and planning professionals – with experience at the federal, state and local levels – to craft a set of land use principles which would provide guidance to local officials and communities concerned about sustaining future water supplies.

The process of developing the Ahwahnee Water Principles mirrored the LGC's earlier Ahwahnee Principles for Resource-Efficient Communities, which were released in 1991. The Ahwahnee Principles presented a blueprint for elected officials to create compact, mixed-use, walkable, transit-oriented developments in their local communities, and have since paved the way for growing acceptance and inclusion of "smart growth" and the "New Urbanism" in local and regional land-use policies and practices.

In March 2005, the Ahwahnee Water Principles for Resource-Efficient Land Use, in a format that could be incorporated into a community's general plan, were presented to an audience of more than 100 mayors, city councilmembers and county supervisors at the Ahwahnee Hotel in Yosemite, where they were enthusiastically received.

The Ahwahnee Water Principles – comprised of nine community principles and five precepts to implement these community objectives – provide a practical blueprint for sustainable land-use practices that can improve the reliability and quality of water resources and reduce some of the financial liabilities that new development places on local government.

These principles are practical actions that cities and counties can take as good stewards of California's water resources by ensuring that new development and redevelopment minimize the risks and impacts of stormwater runoff, ground and surface water contamination and flooding.

At the same time, these steps can help ensure that communities will have water resources adequate to serve existing and new businesses and residents. These strategies are efficient, effective, least-cost options, which can help avoid communities being dependent on expensive and potentially unreliable imported supplies of water from outside their area, or undertaking costly cleanup or water treatment measures. Implementation rests with county boards of supervisors and city councils exercising their planning and land use authorities.

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The Ahwahnee Water Principles

Preamble

Cities and counties are facing major challenges with water contamination, stormwater runoff, flood damage liability, and concerns about whether there will be enough reliable water for current residents as well as for new development.

These issues impact city and county budgets and taxpayers. Fortunately there are a number of stewardship actions that cities and counties can take that reduce costs and improve the reliability and quality of our water resources.

The Water Principles complement the Ahwahnee Principles for Resource-Efficient Communities that were developed in 1991. Many cities and counties are already using them to improve the vitality and prosperity of their communities.

Community Principles

1 Community design should be compact, mixed use, walkable and transit-oriented so that automobile-generated urban runoff pollutants are minimized and the open lands that absorb water are preserved to the maximum extent possible. *[See the Ahwahnee Principles for Resource-Efficient Communities]*

2 Natural resources such as wetlands, floodplains, recharge zones, riparian areas, open space and native habitats should be identified, preserved and restored as valued assets for flood protection, water quality improvement, groundwater recharge, habitat and overall long-term water resources sustainability.

3 Water holding areas such as creek beds, recessed athletic fields, ponds, cisterns and other features that serve to recharge groundwater, reduce runoff, improve water quality and decrease flooding should be incorporated into the urban landscape.

4 All aspects of landscaping from the selection of plants to soil preparation and the installation of irrigation systems should be designed to reduce water demand, retain runoff, decrease flooding, and recharge groundwater.

5 Permeable surfaces should be used for hardscape. Impervious surfaces such as driveways, streets and parking lots should be minimized so that land is available to absorb stormwater, reduce polluted urban runoff, recharge groundwater and reduce flooding.

6 Dual plumbing that allows graywater from showers, sinks and washers to be reused for landscape irrigation should be included in the infrastructure of new development.

7 Community design should maximize the use of recycled water for appropriate applications including outdoor irrigation, toilet flushing, and commercial and industrial processes. Purple pipe should be installed in all new construction and remodeled buildings in anticipation of the future availability of recycled water.

8 Urban water conservation technologies such as low-flow toilets, efficient clothes washers and more efficient water-using industrial equipment should be incorporated in all new construction and retrofitted in remodeled buildings.

9 Groundwater treatment and brackish water desalination should be pursued when necessary to maximize locally available, drought-proof water supplies.

Implementation Principles

1 Water supply agencies should be consulted early in the land use decision-making process regarding technology, demographics and growth projections.

2 City and county officials, the watershed council, LAFCO, special districts and other stakeholders sharing watersheds should collaborate to take advantage of the benefits and synergies of water resource planning at a watershed level.

3 The best, multi-benefit and integrated strategies and projects should be identified and implemented before less integrated proposals, unless urgency demands otherwise.

4 From start to finish, projects and programs should involve the public, build relationships, and increase the sharing of and access to information. The participatory process should focus on ensuring that all residents have access to clean, reliable and affordable water for drinking and recreation.

5 Plans, programs, projects and policies should be monitored and evaluated to determine if the expected results are achieved and to improve future practices.

Authors: Celeste Cantú, Martha Davis, Jennifer Hosterman, Susan Lien Longville, Jeff Loux, Jake Mackenzie, Jonas Minton, Mary Nichols, Virginia Porter, Al Wanger, Robert Wilkinson and Kevin Wolf. Editor: Judy Corbett.

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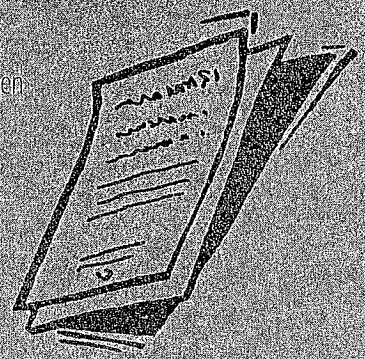
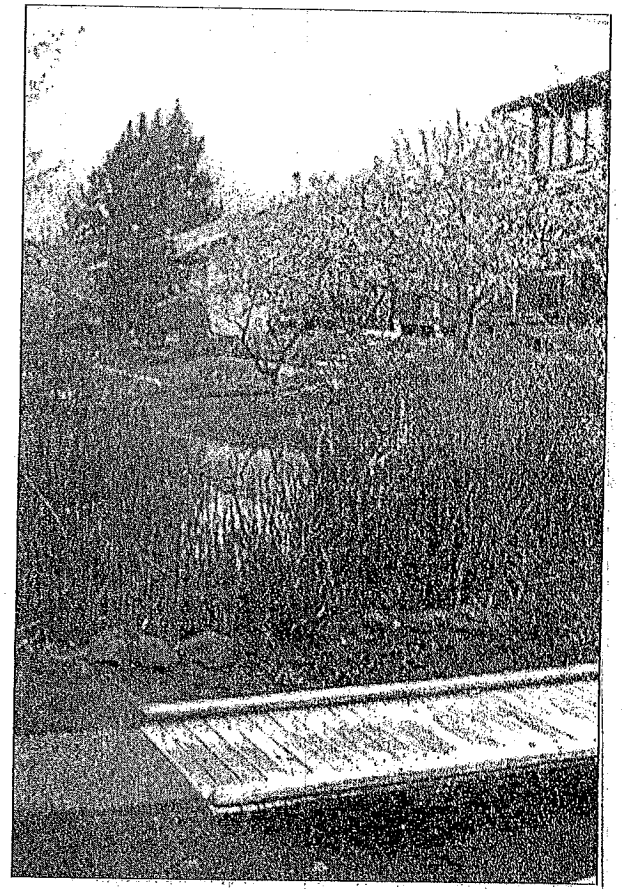
Model Water Element for General Plans

In conjunction with the Ahwahnee Water Principles, a Model Water Element has been drafted. A compilation of some of the best general-plan language available, drawn from existing city and county general plans, this model element can be tailored to fit any community plan once the individual characteristics of the watershed have assembled (see Appendix A). This model element can also help cities and counties examine the interconnections within watersheds in the hope that it will guide the way for new partnerships with other entities for their mutual benefit.





The Ahwahnee Water Principles can be grouped into four categories:

I. Growing in a water-wise manner [Principles 1-2]: Forms that new development should, and should not, take to accommodate population growth and accompanying development and transportation needs without destroying watersheds – including the natural infrastructure of wetlands, floodplains, recharge zones, riparian areas, open space and native habitats that supply our water.

II. Water-friendly site design [Principles 3-5]: Neighborhood and site-scale planning and design strategies that can be used to protect water quality, maximize existing supplies, reduce flood risks, and handle runoff more wisely.

III. Stretching our water supplies [Principles 6-9]: To ensure reliable water supplies in the future, communities need to make the most efficient use of existing supplies. This includes graywater for reuse in the home, office or landscaping, use of water-efficient technologies and designs, and stretching groundwater supplies through treatment and desalinization.

IV. Implementation principles: These five precepts can help local governments put the Ahwahnee Water Principles into action through strategies for implementing compact growth patterns, water-friendly site design and water conservation. They provide practical steps to make the physical changes necessary to ensure water sustainability.

As a follow-up to the Ahwahnee Water Principles, the State Water Board is developing a model letter that regional water boards can use in commenting on general plan Environmental Impact Reports. The letter asks cities and counties to fully consider how their general plan updates will affect water quality, encourages planning to avoid adverse effects, and cites the Ahwahnee Water Principles as a source of policy level principles to address water supply/quality problems stemming from urban development.

The League of California Cities and the California State Association of Counties have adopted resolutions that encourage their members to consider the Ahwahnee Water Principles, and individual jurisdictions have begun to adopt them as local policy.

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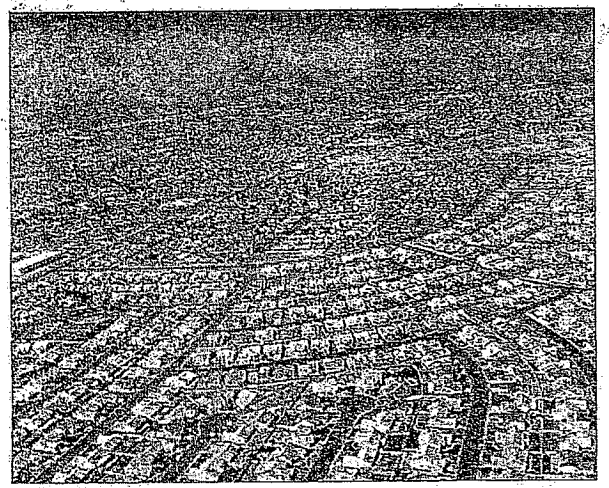



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I. Growing in a Water-Wise Manner

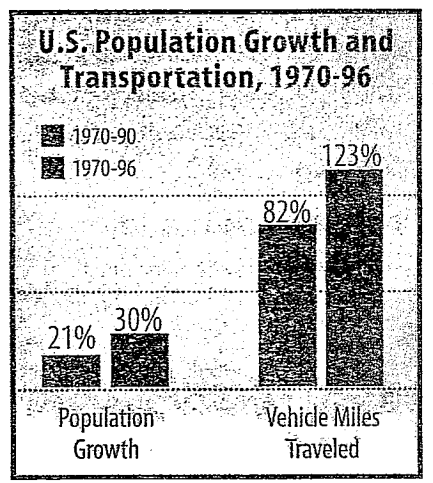
To accommodate growth and maintain strong economic vitality, California communities need to provide adequate housing, opportunities for commerce and good services. But communities also need water, and because land development can degrade water resources, communities must also ensure that they grow in ways that do not jeopardize the very water that will be needed to accommodate growth.

Local government decisions – neighborhood and city-/county-wide planning strategies that specify how and where development occurs – affect future water supplies.

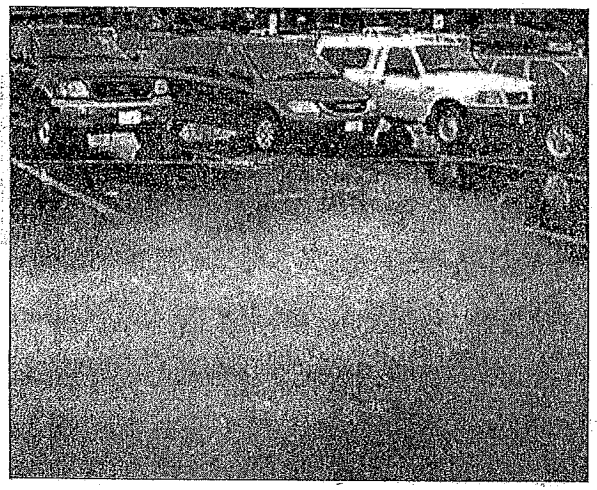
Water for our increasing population

The U.S. population is projected to grow by 18%, or 50 million people, between 2000 and 2020. California will absorb a large portion of that growth – adding some 12 million people by 2030. [3]

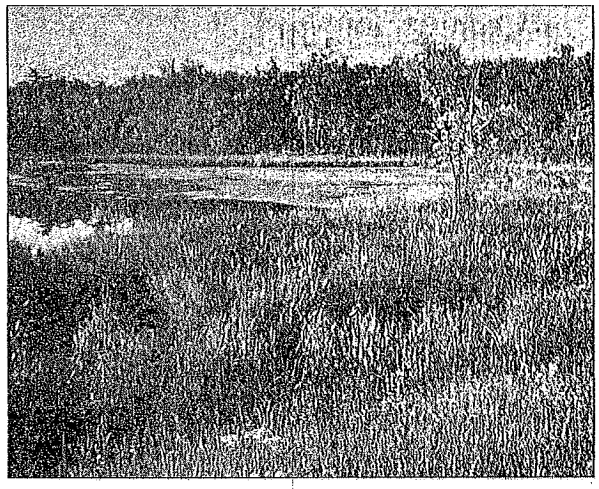
Where will this growth be located? Where will water come from for this growth? The answers to these questions are linked because the water we need for future growth depends upon how we develop the land to accommodate it.



...and the rate of car travel has increased even faster than the population growth.



Ninety-one percent of California's original five million acres of wetland have been drained or filled. It is estimated that the state is currently losing 5,000 acres of wetlands per year.



Today's growth patterns

How we are growing

Between 1982 and 1997, developed land in the U.S. grew by 34%, far outpacing the 15% population growth that occurred over the same period. [4] This pattern is the result of land use patterns that are spread out, resulting in what many refer to as "sprawl."

The root cause of sprawl is zoning and development that encourage large lots and the separation of land uses. Since the end of World War II, we have been separating housing, work places, retail, government services and even schools. The assumption that everyone wants to live in a large-lot, residential-only subdivision has led to near-complete dependence on the auto as a method of travel.

The result is that urbanizing communities are mostly covered in pavement, which effectively rules out walking and biking as transportation options. Wide roads and acres of parking lots make for unappealing, hot, polluted and unsafe places for pedestrians and bicyclists. Anyone not in a car is viewed as out-of-place. Furthermore, low densities make transit infeasible. It takes a density of at least seven units per acre to make frequent bus service viable and 16 units per acre to accommodate rail. In urban sprawl, densities are generally far below these minimums. [5]

Pollutants from automobiles are deposited on parking lots and roads. Stormwater collects those pollutants and deposits them in our streams, rivers, lakes, beaches and other bodies of water. Urban runoff is a chief cause of nonpoint source pollution that, according to the U.S. EPA, is the most significant threat to water quality.

In its 2000 National Water Quality Inventory, the U.S. EPA reported that the leading sources of impairments across all water body types – including streams and rivers, lakes, ponds and estuaries – are nonpoint sources such as agriculture and land-based activities in urban areas. [6]

Where we are growing

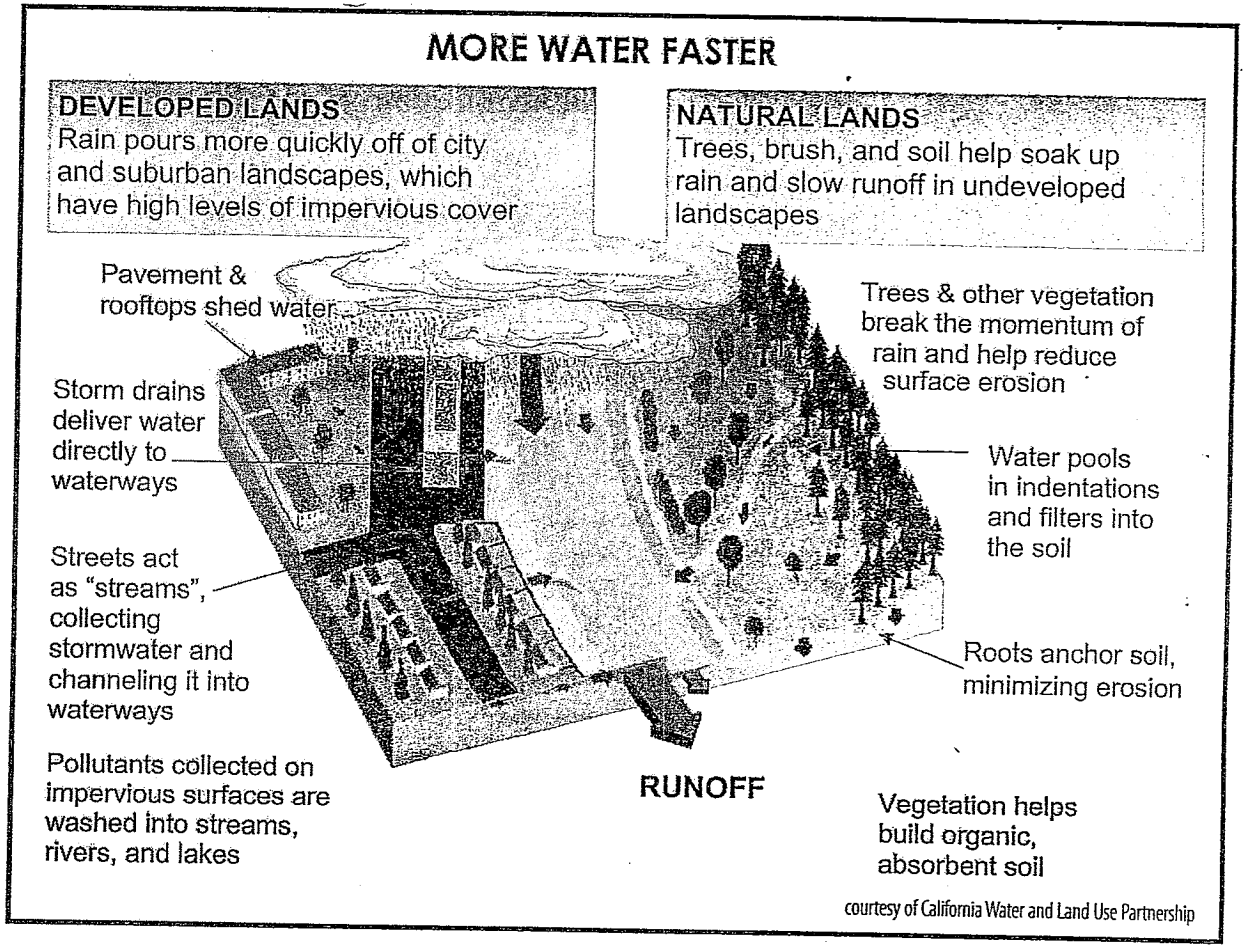
A related issue is that most new growth is occurring on undeveloped natural areas called "greenfield" sites. A recent analysis showed that 95% of all building permits in 22 metropolitan areas were for development on previously undisturbed lands. [7] Urban areas are expanding onto forests, wetlands, agriculture and rangeland, floodplains, riparian zones and other natural areas. These development patterns tend to consume valuable farm, range, recreational and forest land that drive important economic sectors.

The water supply impact of growing on greenfields

Today's growth patterns are troubling to water management professionals because they are reducing the amount of land that filters, transports and stores our water. Activities associated with increased development on greenfield sites such as construction, increased traffic and the use of chemical treatments in lawns, impair the quality of water resources as well.

As the diagram shows, developing land in undisturbed areas interferes with natural drainage processes and impairs water quality through:

- The loss of undeveloped natural areas that absorb runoff and filter pollutants;
- The expansion of impervious surfaces that prevent natural infiltration of runoff;
- The subsequent alterations to flow regimes that result in the loss of groundwater recharge, and increased localized flooding and nonpoint source pollutant loads carried by urban runoff.



courtesy of California Water and Land Use Partnership

It has long been understood that impervious surfaces affect water quantity by diverting groundwater flow to surface runoff, but the impacts to watersheds and water quality have become clear as well. Numerous studies show that by virtually every measure of ecosystem health, the streams, creeks, marshes and rivers in watersheds where over 10% of the land has been paved over are less diverse, stable and productive than those in natural watersheds. [8]

As the amount of impervious cover increases, the magnitude and velocity of runoff from urban areas increase resulting in erosion and instability of stream banks, changes to channel structure, loss of natural vegetation and increased sedimentation. These effects damage habitat and property, and often require expensive structural fixes to prevent damage to roads, bridges and property, which cause further degradation and compounded effects down stream.

Recent research indicates that in California, many rivers and streams appear to be even more susceptible to the effects of impervious cover than experts initially thought. These studies indicate that initial impairment actually occurs at levels as low as 3% to 5% impervious cover. [9]

Water management professionals have responded with stronger regulatory controls intended to reduce the impacts of development on water quality, water supplies and the natural environment.

Understanding water quality regulations in California

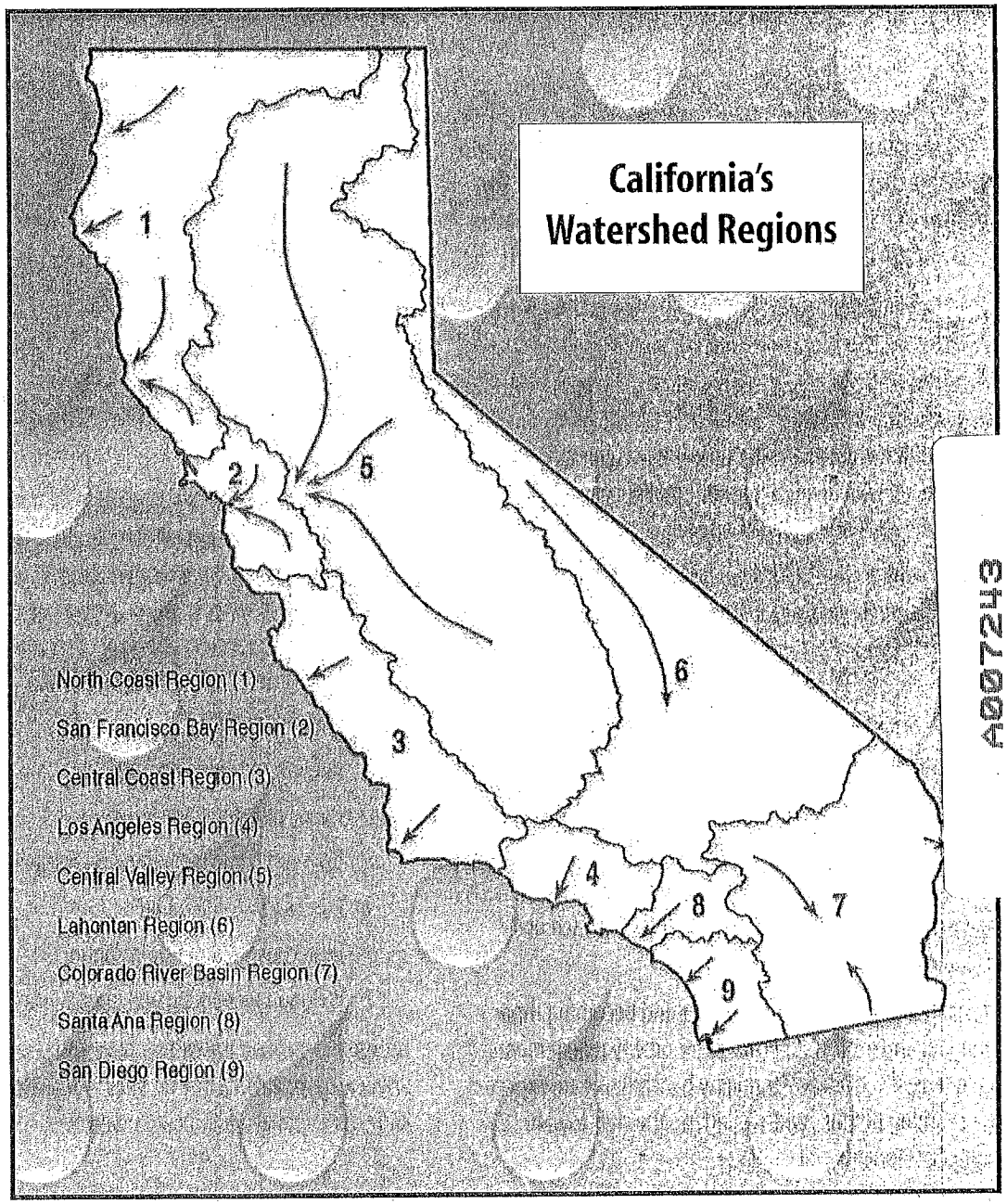
The Clean Water Act gives the U.S. EPA authority to set water quality standards for all contaminants in surface waters. The act makes it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.

In California, the Porter-Cologne Water Quality Control Act gives the State Water Board ultimate authority over State water rights and water quality policy, and establishes the nine Regional Water Quality Control Boards to oversee water quality on a day-to-day basis at the local/regional level.

In 1972, the federal government established the National Pollutant Discharge Elimination System program (NPDES) to regulate point sources of pollution (attributable to specific outflows) from municipal sanitary sewers and industries. The program was effective but significant water quality problems, stemming from "nonpoint source" pollution, remained. Nonpoint source pollution results when contaminants from many diffuse sources are carried to water bodies.

In 1987, amendments to the Clean Water Act expanded the NPDES program to address nonpoint source pollution in urban runoff by determining that discharges from stormwater systems were point sources of pollution.

This change brought cities and counties, as operators of municipal separate storm sewer systems (MS4s), under the regulatory provisions of the NPDES Municipal Stormwater Program. Compliance with municipal stormwater permits



required by the NPDES can be costly and burdensome to local governments.

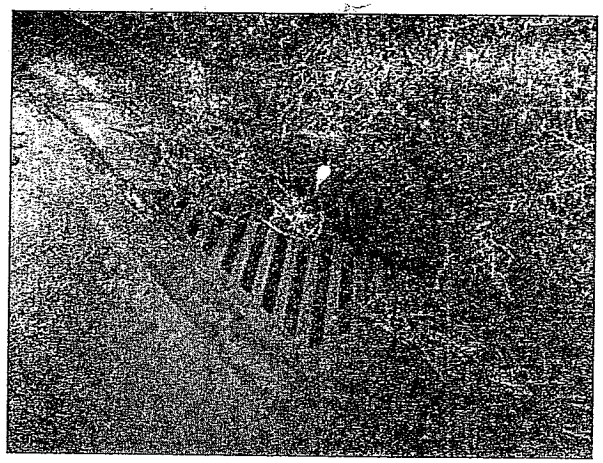
The NPDES MS4 permit program was instated in two phases. Phase I regulations were directed at MS4s serving a population of 100,000 or more, including interconnected systems and stormwater discharges associated with industrial operation and construction activities.

Phase II regulations were issued in 1999 to expand permit coverage to MS4 dischargers not covered in Phase I, including small MS4s (those serving a population of less than 100,000). In general, municipalities of over 10,000 residents require a permit, but the regional water boards have ultimate authority to designate who needs a permit. Smaller communities with exorbitant discharges may also be regulated.

ermits are issued every five years to allow for
g conditions, evolving pollution control practices,
lifications to discharge/performance standards and
ns. The water-quality protection strategies in this
ok apply to both phases.

rs want to see that the practices that communities
r their stormwater programs will lead to measurable water quality improvements, but they do not yet set specific numeric standards. Instead, they use performance standards that establish minimum levels of execution in each of six required program areas of the permit.

The standards are evolving, however, and becoming more stringent and explicit. Specific water quality requirements are not used yet, but water quality benchmarks are expected in upcoming permits, which suggests the shift toward numeric standards will continue.



NPDES permits require regulated MS4 operators to develop a Storm Water Management Program that implements appropriate best management practices to reduce the discharge of pollutants to the maximum extent practicable. Small MS4s permits prescribe a set of six minimum control measures that must be implemented along with evaluation and assessment efforts:

1. Public education and outreach
2. Public participation
3. Illicit discharge detection and elimination
4. Construction site runoff
5. Post-construction runoff control
6. Pollution prevention and good housekeeping

For more details on the NPDES program, please visit www.waterboards.ca.gov for links to more information and your regional water board's web site.

Water supply legislation

Legislation requiring adequate water supplies prior to development approval was passed in 2001. The so-called "show me the water laws" are Senate Bills 221 and 610. SB 221 requires a city or county to provide written verification of sufficient water supplies by the water agency for proposed development projects of 500 units or more.

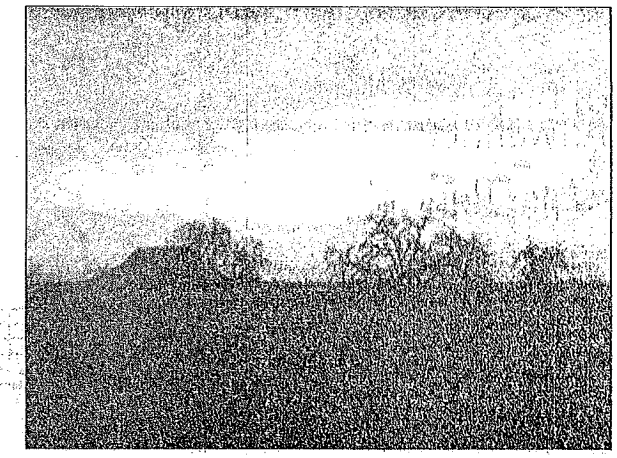
A sufficient supply is defined as enough to meet the needs of the proposed development project in normal years as well as during a drought. Approval of the subdivision map or parcel map is prohibited unless and until such supplies are documented. Meeting the terms of this legislation is solely the responsibility of the city or county, even though it is the water agency that documents the availability of water for the new project.



Old stormwater solutions like these did not address water quality, but now they must.







SB 610 provides the process for implementing SB 221. This measure requires that a water supply assessment be included in the Environmental Impact Report of any large development project that exceeds certain specified thresholds.

Both the NPDES program and new water supply laws are pushing local governments to coordinate their planning and development processes with water management efforts.

Economic implications

The costs related to water issues, from managing stormwater to securing supplies, is great. To reduce serious impacts to their budgets, communities should address the basic land use practices that create those costs.

A study of 27 diverse watershed types revealed that in areas where less than 40% of the land in a watershed was developed, the treatment cost of water was about $30 per million gallons. Where the land was completely paved over or dedicated to intensive agriculture, the cost to supply drinking water to the community was $140 per million gallons. [10]

California's economy also depends on clean water and beaches – coastal employment represents more than 80% of employment in California, and 58% of the state's ocean economy is from tourism and recreation – watershed protection is not only a water quality issue, it is an economic imperative.

The solution is to grow in the form of compact, walkable communities that concentrate growth and preserve watersheds. Doing so may also increase property tax revenues. Investors expect that real estate values over the next 25 years will rise fastest in communities that have a "pedestrian-friendly configuration." [11]

"Local land use decisions have significant impact on our wat resources. We must work develop our communities ways that protect and enhan rather than degrade, th natural and precious resources."

– Kathy Long, Ventura County Board of Supervisors

Ahwahnee Water Principle 1 – How we grow

Community design should be compact, mixed use, walkable and transit-oriented so that automobile-generated urban runoff pollutants are minimized and the open lands that absorb water are preserved to the maximum extent possible.

(see the Ahwahnee Principles for Resource-Efficient Communities)

"The biggest influence on future water supplies and water quality in California is local land use planning."

– Celeste Cantú, Executive Director, California State Water Resources Control Board

Planning that assures compact, walkable and transit-oriented communities while preserving important open lands is touted by both the U.S. EPA and the state as one of the most effective steps that can be taken to minimize the water pollution created by urban runoff and assure future water supplies.

In 2002, the U.S. EPA modeled the impacts of stormwater from new development at densities of one, four and eight residential units per acre. The results revealed that, assuming that our communities will continue to grow, it is better to concentrate the development in a smaller land area using higher densities.

"Lower-density development always requires more land than higher densities to accommodate the same amount of growth." When more land is disturbed, more of the watershed is damaged, according to the U.S. EPA's "Protecting Water Resources with Higher Density Development."

Figure 1 – One-acre scenarios

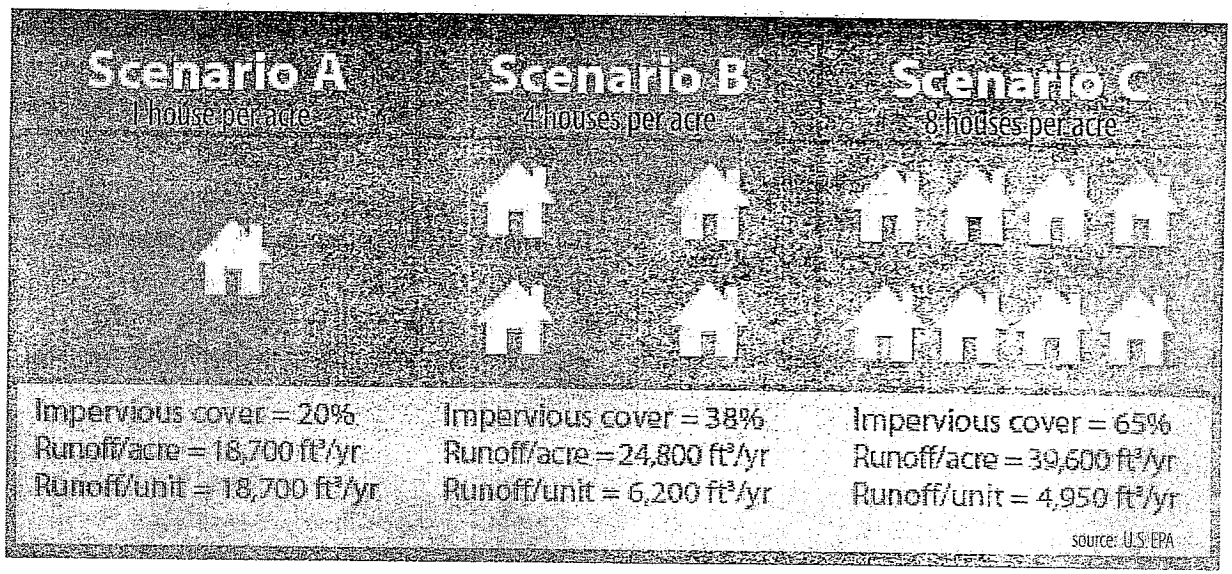


Figure 1 demonstrates that the amount of runoff – per housing unit – is higher at lower densities, and lessens as more units are accommodated per acre.

In Figure 2, overall impervious cover for the watershed decreases as site density increases. The lowest-density scenario (Scenario A) covers the entire watershed and generates 187 million cubic feet per year of stormwater runoff. At four houses per acre, Scenario B consumes less land and generates less than half as much stormwater runoff as Scenario A. At the highest density, Scenario C consumes the least land and produces just 49.5 million cubic feet per year of stormwater runoff. Scenario A generates approximately three times the runoff of Scenario B and four times as much as in Scenario C.

Purdue University researchers came to the same conclusion when they examined two potential project sites in the Chicago area – one in the city, the other on the urban fringe. Their study revealed that placing low-density development on the urban fringe would produce 10 times more runoff than a higher-density development in the urban core. These results are consistent with other studies completed in the past decade. [12]

Today, a significant number of developers are interested in developing and redeveloping vibrant downtowns that include townhouses, lofts and apartments in addition to retail, entertainment and government services. Others are attempting to develop New Urbanist, sustainable or smart-growth compact, mixed-use and mixed-income neighborhoods. The market is responding very positively to these walkable, bikeable and transit-friendly developments.

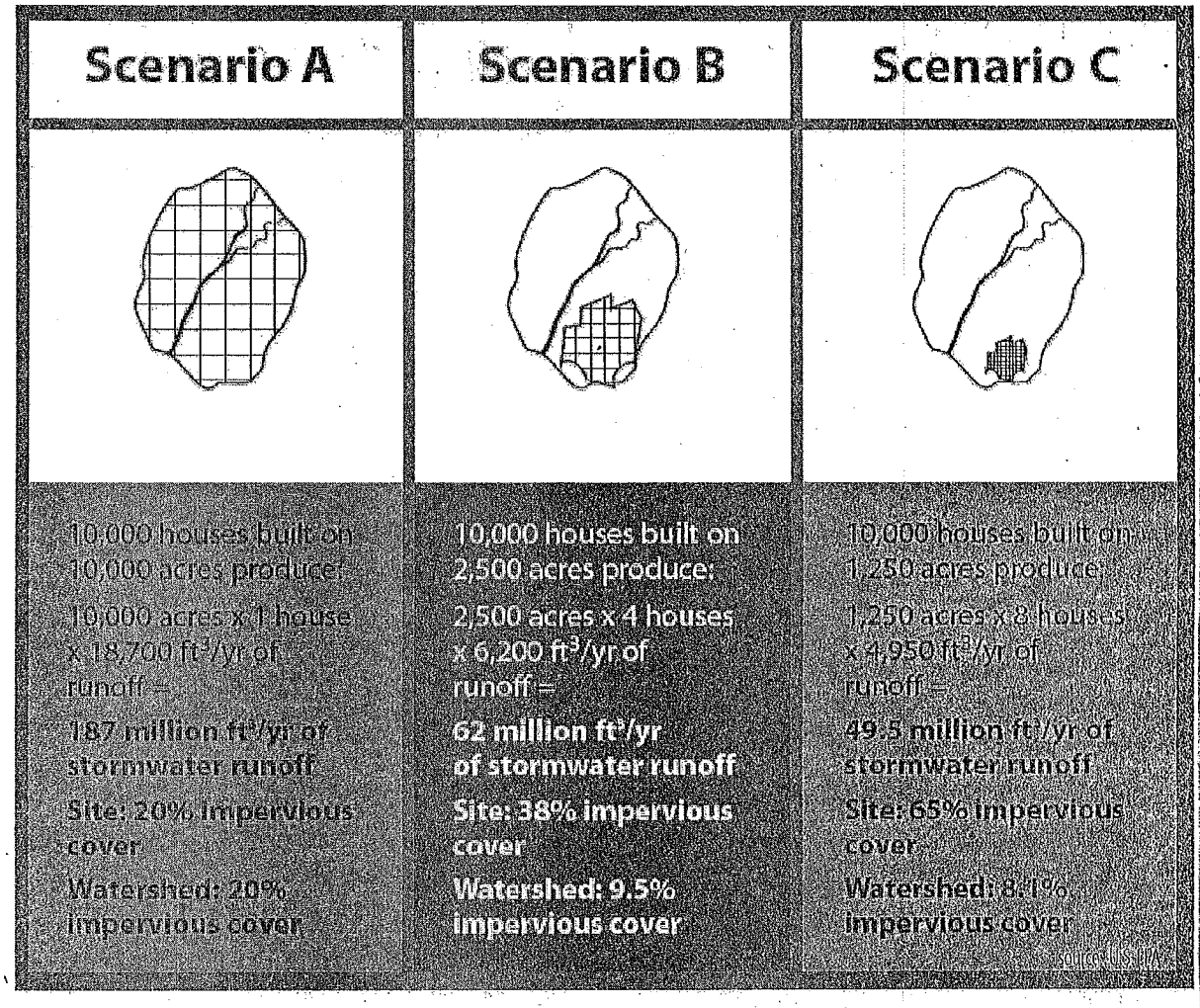


Figure 2 – A 10,000-acre watershed accommodating 10,000 houses

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Redevelopment and infill development

Infill can reduce the impact of development on water resources by focusing growth into already developed areas instead of on more sensitive lands at the urban fringe. Infill also takes advantage of existing infrastructure and transportation options.

One of the best ways to protect natural areas and prevent the spread of impervious cover is to maximize the use of land that is already paved. Using land that is already developed conserves greenfields by absorbing growth that would otherwise be sited in undeveloped areas. This means growth is accommodated without increasing impervious cover and urban runoff.

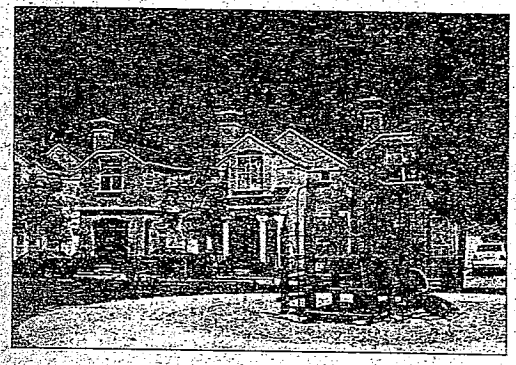
These strategies can also lead to a greater mix of uses and higher densities, which create other benefits including increased transportation options and vibrant neighborhoods.

For example, if an old shopping center is replaced by mixed-use development, growth is accommodated with no net increase in impervious surface cover.

Many stormwater management strategies focus on new development. Redevelopment projects also provide opportunities to incorporate on-site stormwater strategies, such as swales, green roofs and permeable hardscapes that can readily be retrofitted into urban areas (see Section II). Cities can partner with the private sector to encourage redevelopment and identify ways to retrofit stormwater management practices into projects.

Strip mall transformed into pedestrian-oriented community

The Crossings is a transit-oriented redevelopment project in Mountain View that transformed a 1960s auto-oriented strip mall into a mixed-use and pedestrian-oriented community. Located adjacent to a new CalTrain commuter station, The Crossings provides a range of housing and retail opportunities (359 housing units at about 21 units per acre) located within a short walk of shopping and transit. An interconnected network of tree-lined streets and paths encourages pedestrian mobility and provides easy access to an existing grocery store.



The project's multi-story design reduces its footprint and provides sufficient density to support transit. The project also incorporates on-site stormwater management with permeable "turf-blocks" used for fire lanes and roof spouts that drain into landscaped areas to infiltrate rooftop runoff. Community parks and open spaces are distributed throughout the 18-acre site to provide an amenity as well as areas that can absorb stormwater.

For more information: Eric Anderson, City of Mountain View, (650) 903-6225 or eric.anderson@ci.mountainview.ca.us

To make use of infill and redevelopment as water protection strategies, communities may need to revise local zoning ordinances to allow for greater density and mixed uses. Both infill and redevelopment tend to be more complex and pose more barriers to developers than greenfield development. Communities should consider incentives that facilitate redevelopment and infill projects.

Density bonuses provide incentives for developers who agree to incorporate certain desired features into their projects. For example, a developer could be allowed to develop at higher densities if they integrate on-site stormwater practices. The City of Portland provides density bonuses for the use of green roofs.

The EPA's model Phase II stormwater permit provides language on the use of infill, redevelopment, and other specific smart growth strategies as stormwater best management practices (www.epa.gov/npdes/pubs/modpermit.pdf).

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Walkable, well-connected streets and paths

Land use patterns that create a network of well-connected streets and paths that support walking, biking and transit have many water resource benefits. Reducing auto use minimizes auto-related pollutants in urban runoff.

Narrower streets translate into water resource benefits as well because they reduce the amount of pavement covering a community. The fifth Awhahnee Water Principle offers more information on the benefits of narrow street designs.

Need for improved zoning

Sadly, the vast array of codes and ordinances that we have produced over the past 50 years are holding up the progress of better land use patterns. Existing zoning codes and ordinances, focused on density and use, often make more water-friendly developments difficult or impossible to do.

Fortunately, tools and strategies are available to local governments to level the playing field or even provide advantages to those developers attempting to build less auto-oriented places to live, work and play.

Form-based codes

Form-based codes are increasingly being used by cities and counties across the country to achieve the walkable, aesthetically pleasing neighborhoods that residents and policy-makers have envisioned for their general plans. Rather than zoning by use and density, the form-based code allows the community to specify exactly what they want new development and redevelopment to look like – including public spaces and streetscapes. There is less emphasis on use and more on form – thus the name, "form-based" code.

This zoning tool involves community residents in design charettes very early in the process. It provides accurate graphics so that residents can see exactly what they are going to get. It also lets developers know exactly what the community wants. It speeds up the development approval process, gives certainty to developers, and saves them money.

A form-based code can be incorporated into a specific plan, a Planned United Development or other planning document. The Local Government Commission's web site (www.lgc.org) has more information on this tool and the communities that have implemented it.

Green stormwater design improves redevelopment

The City of Emeryville is combining extensive redevelopment and on-site stormwater best management practices for an integrated water protection strategy. Long a pioneer in reclaiming and redeveloping industrial areas, Emeryville is now incorporating stormwater management strategies to comply with NPDES permit requirements.

Strategies range from shared structured parking to green roofs and landscaped areas designed to capture stormwater. The City's "Guidelines for Green Dense Redevelopment" provides developers and designers with a vision for integrating green stormwater treatment into site planning and building design.

The guidelines show how such techniques can be designed to match Emeryville's unique densely urbanized development context. Using green dense redevelopment, Emeryville's urban infill projects maximize existing impervious surfaces and direct growth away from the undeveloped portions of the watershed.

For more information: Peter Schultze-Allen, Emeryville Public Works Department, (510) 596-3728.

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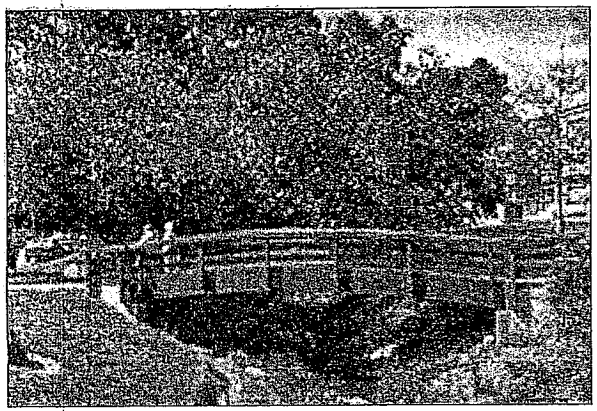

ource-efficient land use means
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works with natural processes –
gainst them. Water resource-
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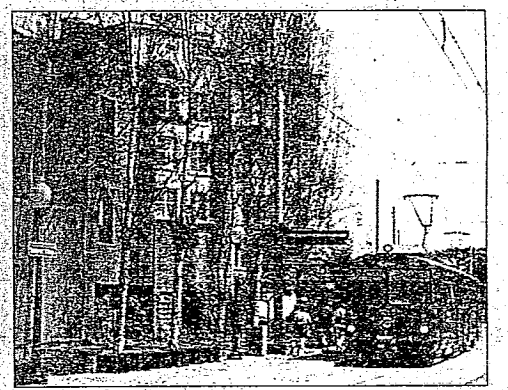
understand how the watershed works and we work with it.”

– Susan Lien Longville, Director, Water Resources Institute, CSU-San Bernardino

Transit-oriented developments add water management

City of Villages demonstrated in San Diego



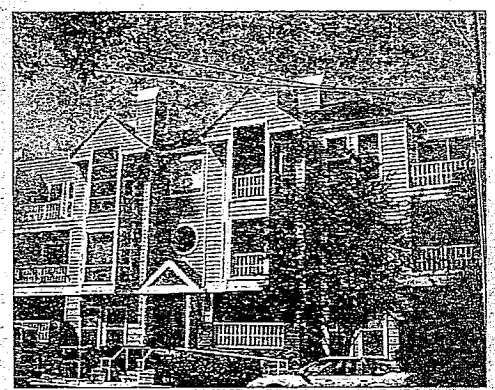
The City of San Diego is encouraging smart growth development through its City of Villages pilot demonstration project, a strategy encourages development that mixes housing, retail, jobs, schools and civic uses within walkable communities that have easy access to transit.

The San Diego City Council approved five innovative projects to become pilot villages by a unanimous vote in February 2004. The projects are meant to inspire developers and communities to create similar neighborhood centers throughout the city.

Notably, the City of Villages plan coordinates infill and redevelopment with stormwater management; and the stormwater plan identifies the City of Villages infill plan as a water protection strategy.

For more information: San Diego Planning Department, (619) 235-5200 or planning@sandiego.gov

Rooftop runoff in San Jose

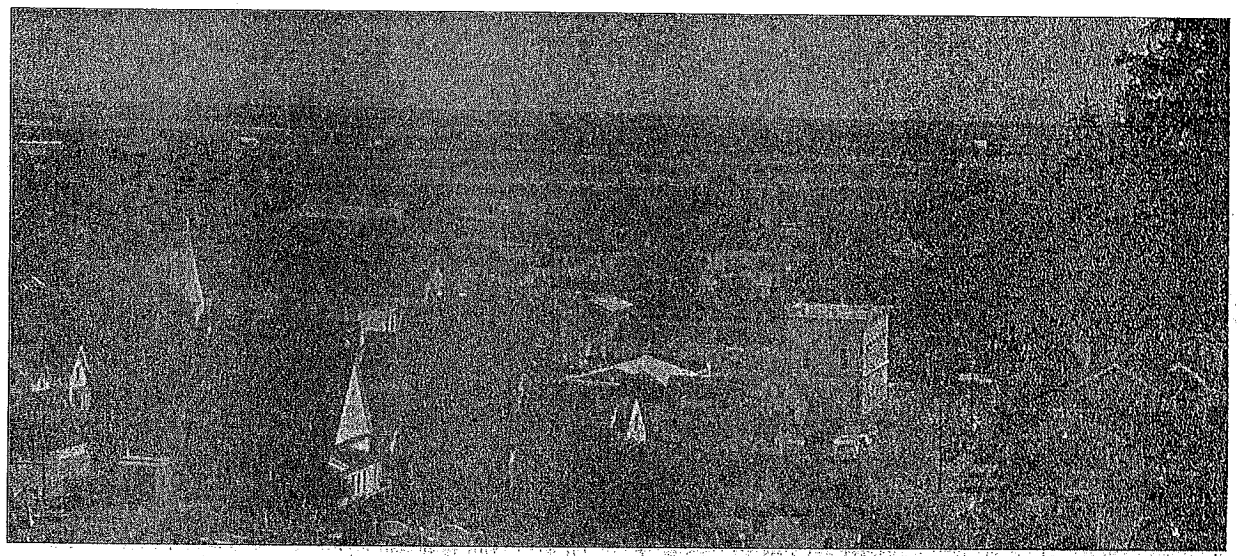


The Ryland Mews transit-oriented development in San Jose provides high-density housing on an existing light rail line within walking distance of downtown. Its multi-story buildings reduce the footprint of the development, while its setting facilitates pedestrian mobility to reduce transportation-related pollution and hardscape. The project also directs rooftop runoff to landscaping, allowing infiltration to control stormwater on-site.

For more information: Jenny Nusbaum, City of San Jose, (408) 277-4576 or jenny.nusbaum@sanjoseca.gov

Ahwahnee Water Principle 2 – Where we grow

Natural resources such as wetlands, floodplains, recharge zones, riparian areas, open space and native habitats should be identified, preserved and restored as valued assets for flood protection, water quality improvement, groundwater recharge, habitat and overall long-term water resource sustainability.



"The water in a watershed is essential for supporting all life."

– Mary Nichols, Director, UCLA Institute of the Environment

Natural resources, such as our drinking water supplies, riparian habitat and aquatic ecosystems, are linked together and function as an integrated whole in a watershed. The water within watersheds – above and below ground – is connected. This means the quality of both surface and groundwater supplies is dependent upon the land cover within a watershed.

Watersheds act as the plumbing system that ultimately delivers rainwater from the place it lands in the watershed to our kitchen sinks. "Undisturbed" areas are important to this natural plumbing system because they filter, transport and store our water; provide natural flood control; and maintain fisheries, timber, agriculture and other natural resources.

Preserving the watershed

The U.S. EPA has been advocating the use of watershed protection approaches since 1991. Watershed protection, which emphasizes preservation of valuable natural areas to protect water resources, is an approach that is recognized for providing long-term benefits to water quality and supplies.

Local government can align development with long-term water resource goals by making wise land use decisions that protect watershed functions rather than degrade them. The second Ahwahnee Water Principle is designed to:

- Protect and restore large, continuous natural areas as open space;
- Preserve important and sensitive ecological areas such as wetlands, floodplains and riparian corridors;
- Preserve and enhance the value of these natural areas as community assets.

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Preserving open space and farm land in the watershed

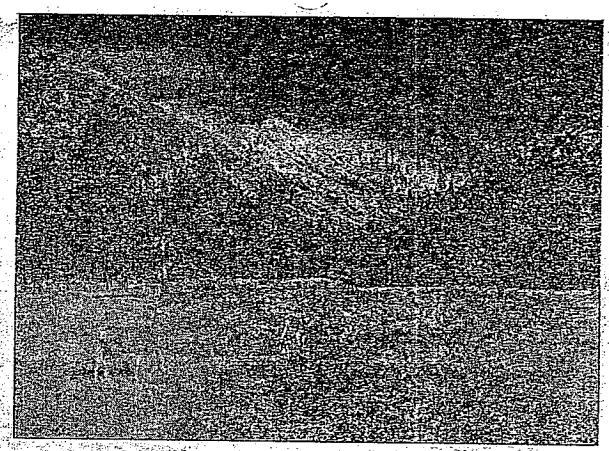
Livermore Specific Plan curbs sprawl

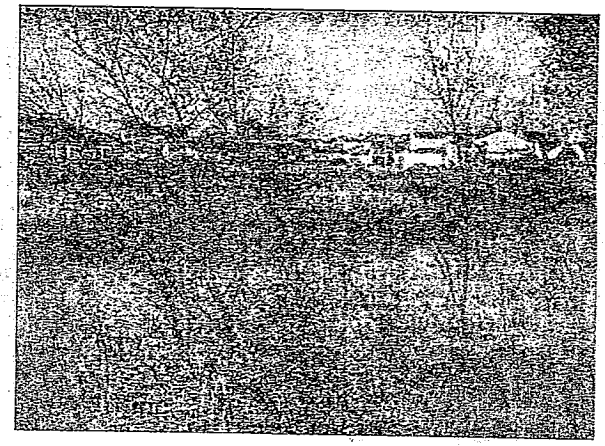
The City of Livermore's South Livermore Valley Specific Plan received the 2006 Outstanding Planning Award for Implementation from the American Planning Association. For each acre of land developed in the plan area, one acre of agricultural land is placed into a conservation easement. This helps curb sprawl while preventing the loss of prime agricultural land. For more information: Livermore Community Development Office (925) 960-4400

Conservation easements create balance

In Placer County, one of California's fastest-growing areas, the Placer Land Trust is using collaboration and conservation easements to balance rapid growth and land conservation.

The trust crafted the West Placer Habitat Protection Program with developers, conservation groups, and local, state and federal agencies to protect 3,500 acres of critical habitat in western Placer County over 25 years. Real estate transaction fees in the West Roseville Specific Plan area fund the program. To date, 2,000 acres of valuable land have been protected. For more information: (530) 887-9222 or info@placerlandtrust.org





Efforts to preserve valuable natural areas work best when coordinated with the strategies outlined in the first Awhahnee Water Principle that create compact forms of development, encourage a mix of uses and maximize the utility of existing infrastructure. The combination of compact community forms and preservation of critical environmental areas is a powerful tool that communities can leverage to protect the water resources needed to sustain future growth.

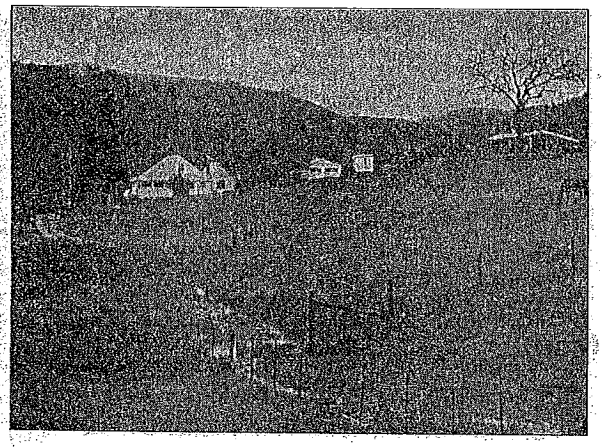
Identify and prioritize

Many tools are available to local officials ready to initiate, or improve upon, efforts to protect and restore natural areas. Not all land is of equal value for water resources and watershed protection. Taking inventory of areas that remain undeveloped and assessing their value allows communities to prioritize and protect those areas that are the most valuable and vulnerable.

To get started, communities must:

- Identify – Determine areas that are still undeveloped.
- Prioritize – Rank areas according to their natural resource value.
- Protect – Use local and regional planning, incentive and acquisition programs, and land use regulations to protect valuable areas and direct future growth.

Geographic Information Systems (GIS) mapping can help communities with these steps. Mapping existing land uses, open space areas and key natural resources can help communities know what they have to work with, and how these areas relate to each other spatially. Mapping can also help communities rank sites in terms of their conservation priority, and target areas most suitable for growth. Communities can use this information to create and compare different development scenarios as well. These methods can combine good data and expert analysis with public participation.



Once identified, the community(s) involved must determine ways to protect and restore those areas that are the most important, and then implement them through local and regional planning policies and plans. Ways to do this include conservation easements, transfers of development rights, buffer zones and greenbelts, urban growth boundaries, open space districts and habitat conservation districts.

Conservation easements

A conservation easement is a legal agreement that permanently limits uses of a piece of land to protect its conservation value. Local land trusts work with landowners to create conservation easements as an alternative to subdividing or selling the land for development. The easement spells out the rights retained by the landowner and the restrictions on use of the property.

In return for putting their land under easement, landowners typically receive monetary compensation, can stay on their land, and can receive significant tax benefits. To be eligible for federal tax deductions, conservation easements must be dedicated in perpetuity so that the easement remains in force forever and "runs with the land," meaning that all subsequent landowners are also bound by the easement.

Easements on private lands have become an effective means of protecting large expanses of natural and working landscape without having to purchase the land outright or needing to manage it over the long term. Cities and counties can partner with local land trusts as funding partners and integrate easements into local planning efforts.

Transfer of development rights

In a Transfer of Development Rights program, landowners living on valuable land worthy of protection are able to trade their rights to develop that land for the right to develop in designated growth areas.

This allows a community to shift development away from land it wants to protect but cannot afford to purchase. At the same time, development is focused in designated growth areas. The result benefits both the landowner, who receives just compensation, and the community, which can protect important natural areas, agricultural lands or open space.

Development rights credits help to direct good growth

The County of San Luis Obispo passed an ordinance to allow the Land Conservancy of San Luis Obispo County to sell development credits in areas that the County has designated for growth.

A $200,000 State Coastal Conservancy grant was used to establish a revolving fund for purchasing environmentally sensitive properties, record deed restrictions on those properties, and sell the resulting Transfer of Development Rights credits to people wishing to develop at higher densities or add square footage above allowed levels within designated "receiving" areas.

The proceeds from these sales provide capital for the acquisition of additional property from willing sellers to be preserved as open space. The program costs the county nothing since the sale of credits is administered by the State Coastal Conservancy. The Land Conservancy of San Luis Obispo County has preserved more than 230 properties to date and doubled the amount of money in the revolving fund.

For more information: Land Conservancy of San Luis Obispo County (805) 544-9096 or lc@special-places.org

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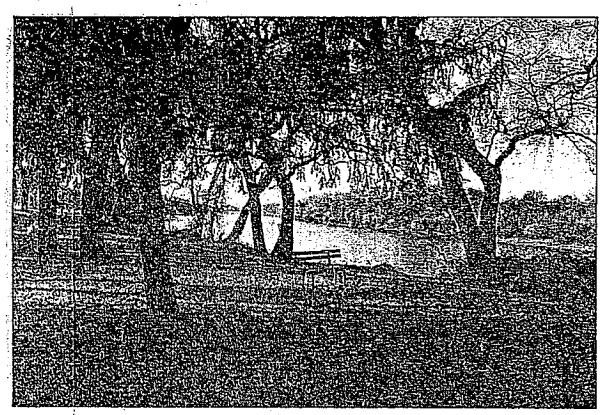

Buffer zones and greenbelts

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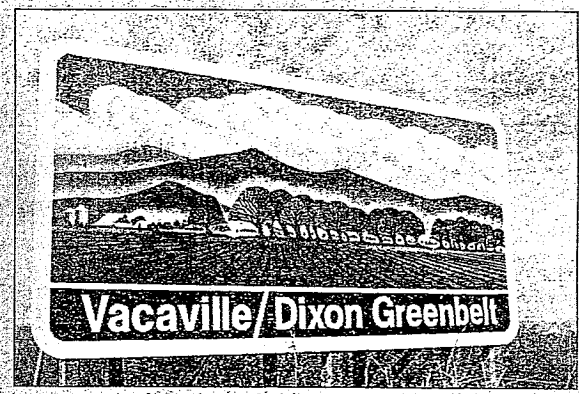
ıes create a transition or barrier of open space potentially conflicting land uses. Placing buffers development and sensitive natural resource areas is er-protection strategy. These water-specific buffers ıonly used along rivers and streams, around wet- akes, or to protect known groundwater recharge ey provide flood protection, reduce erosion, protect ality, and create/protect habitat. Studies have shown that forested buffers are highly effective in removing particulate pollutants from runoff. [13]

Communities can establish setback requirements that create buffers by specifying how far a development must be built from a stream, wetland or other water body. The U.S. EPA recommends a minimum of 100 feet to protect water quality and at least 300 feet if a habitat corridor is also needed.

Regional greenbelts protect some of world's best farmland

The cities of Yolo and Solano Counties are working together to protect some of the world's most productive farmland by creating a regional greenbelt to distinguish each city, focus development into built areas, and preserve natural and working lands.



For example, the City of Davis' Farmland Preservation Ordinance is helping to create a greenbelt around the city. It requires mitigation for development that alters zoning from agricultural to any other use. The mitigation can come in the form of conservation easements or other land-protection practices, or developers can pay into a farmland preservation fund established by the City.

The City of Davis' Right to Farm Ordinance is another tool for developing greenbelts. It requires that developers create a buffer of at least 150 feet between existing agricultural land and new development. A portion of the buffer can be used for native landscaping, trails, stormwater drainage swales or retention basins, and other natural or recreational amenities. For more information: (530) 757-5610 or pbweb@ci.davis.ca.us

In Solano County, the Cities of Dixon and Vacaville are working hand-in-hand to create an agricultural greenbelt to separate the two cities and protect the cultural, natural and economic values of the land between them. They jointly purchased the land that now creates a greenbelt between the two cities. It is leased to local farmers and is under an easement that ensures the land will never be developed. (www.ci.dixon.ca.us)

And in 2002, the Cities of Davis and Woodland, in conjunction with Yolo County, signed a memorandum of understanding establishing a greenbelt between the cities. The MOU makes official the intent of all three jurisdictions to provide a permanent area of open space and agriculture between Davis and Woodland. (pbweb@ci.davis.ca.us)

Urban growth boundaries

Urban growth boundaries confine growth to a designated zone by creating a boundary around a municipality or developed area outside of which urban development is prohibited. These boundaries are not meant to stop or restrict the amount of growth, but to contain outward urban expansion.

Typically, the area inside the boundary – the growth zone – provides enough land and infill/redevelopment potential to accommodate projected growth over a 20-year period. Zoning ordinances usually need to be changed to allow and encourage higher densities inside the boundary.

A similar approach is to limit the extension of infrastructure, thereby forcing development to occur in areas that are already served by existing public services and facilities. These controls are meant to limit "leapfrog" development patterns.

More and more localities are employing urban growth boundaries to protect open space and encourage development in already developed areas. These programs can be highly effective in ensuring that growth does not occur in natural areas, but they must be coordinated with regional efforts to ensure that growth is accommodated in a fair manner, and that uncontrolled forms of development do not simply end up in nearby communities.



Urban boundaries "curb" growth so open space can "soar"

Ventura County and eight of the county's municipal jurisdictions have passed Save Open-Space and Agricultural Resources (SOAR) ordinances that share the goal of preventing development outside of designated areas. For the cities, the ordinances establish a boundary called a "City Urban Restriction Boundary" (CURB). Development outside a city's CURB lines requires city voter approval. At the county level, a countywide vote is required to approve any change to existing open space, agricultural or rural designations or to change any element of the general plan related to those designations. Most of the SOAR ordinances were passed by initiative. For a copy of Ventura County's ordinance: www.ventura.org/planning/ordinances_regs/ords_regs.htm

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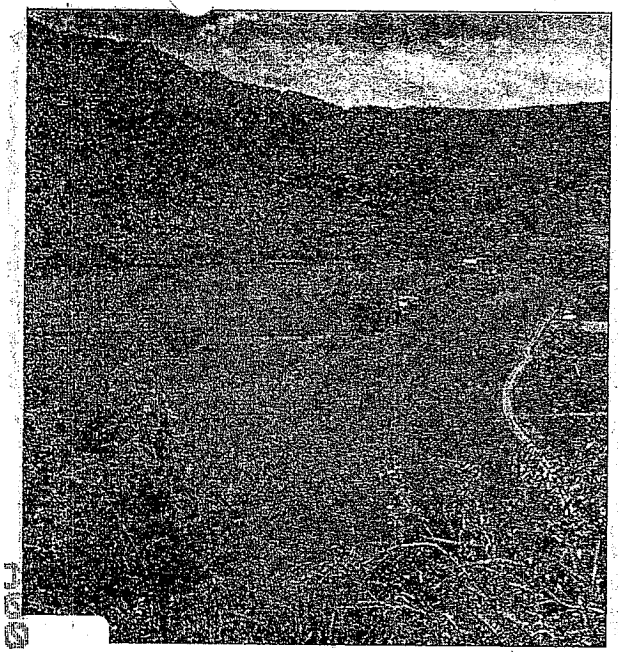

space districts

ıce districts are independent special districts within
ernments with the role of protecting and acquiring
ce in and around the community. They are often
ed by local ballot measures through which local
...cide to tax themselves for the purpose of protecting
open space.

Since 1994, voters around the nation have approved more than 1,200 local conservation measures generating more than $30 billion in new public funds for land conservation. In 2005, 80% of such measures passed, as voters approved another $1.7 billion for open space protection. Cities and counties can take the lead in establishing or increasing funds for local open space districts.

Voters support preservation measures, fund land acquisition

Marin County creates open space district to protect wetlands and natural habitats



In 1972, Marin County voters approved the creation of the Marin County Open Space District. Since then, the district has worked to protect more than 14,000 acres in 33 preserves, including native habitats, important natural resource areas and sensitive wetlands.

The district has worked with local partners to purchase land, obtain conservation easements, and establish transfer of development rights programs. The protected acreage – ranging from wetlands to oak woodlands and redwood groves – provides a host of public benefits including recreation, water resource protection and habitat protection.

For more information: parksandopenspace@co.marin.ca.us

Sonoma County voters approve sales tax to fund conservation efforts

Sonoma County voters created the Sonoma County Agricultural Preservation and Open Space District in November 1990 and funded it with a quarter-cent sales tax. The tax currently generates more than $17 million annually.

The district works with local government, landowners and public agencies to acquire land for each of four program areas: agriculture, greenbelts, natural resources and recreation. Employing several methods of land acquisition, this program is using public-private partnerships to protect valuable natural resources, working lands and community amenities.

The program has protected nearly 70,000 acres of land by conservation easement or fee title purchase, at a cost of $168.7 million for land worth $221.6 million – a net savings to the district of nearly $53 million.

For more information: Sonoma County Open Space District, (707) 565-7360 or openspace@sonoma-county.org

Conservation plans – local opportunities for regional planning

Habitat Conservation Plans (HCP) and Natural Community Conservation Plans (NCCP) are locally developed plans that are completed to satisfy federal and state species protection laws. The plans are developed under California's Natural Community Conservation Planning Program Act and the federal Endangered Species Act for the protection of species and habitat. The California Department of Fish and Game administers the NCCP program.

The program is not focused on single species, instead the goal is to conserve natural communities at the ecosystem scale while accommodating compatible land uses. This helps reduce conflict between conservation efforts and reasonable uses of natural resources. The U.S. Fish and Wildlife Service administers the HCP program that works hand-in-hand with the state program resulting in joint NCCP/HCPs.

The state program is generally more expansive than the federal equivalent because it focuses on protecting whole ecosystems rather than single species. All NCCPs are completed in concert with HCPs, which are funded under the Endangered Species Act. An adequate NCCP/HCP will likely receive implementation funding from state and federal sources.

NCCP/HCP plans allow local governments to coordinate their natural resource planning at a regional level and to determine how and where growth should occur over a longer timeframe. Developers benefit through streamlined permitting processes that clarify allowable types and locations of development in the plan area.

Regional planning balances growth and habitat conservation

Yolo County's regional agency secures largest HCP planning grant in California

In 2004, Yolo County and the Cities of Davis, Winters, Woodland and West Sacramento entered into a collaborative planning agreement with the California Department of Fish and Game to develop a county-wide NCCP/HCP. A joint powers agency was established to act as the lead agency on the project.

The conservation planning process coincides perfectly with other local/regional planning efforts including Yolo County's General Plan update and Integrated Regional Water Management Plan, according to Maria Wong, the agency's executive director. She believes that this provides an opportunity to develop plans with mutually supportive goals and solutions that can help Yolo County communities to balance conservation with working landscapes and regional growth before remaining habitat is lost or degraded.

The project is supported by grant funding from state and federal sources. Last year, it received the largest HCP planning grant awarded in California. For more information: Maria Wong, (530) 666-8834.

San Diego County's regional plan provides large-scale ecosystem and habitat protection

In 1997, San Diego County adopted a Multiple Species Conservation Program to provide large-scale ecosystem and habitat protection, as opposed to individual species preservation. The regional plan covers 900 square miles that designates areas suitable for development and those that must be preserved. Large areas of continuous habitat and natural lands are protected under the plan, which has assisted landowners and developers with a simpler, more streamlined development process. Under the program, developers and local agencies benefit from the localized permit process, pre-established mitigation requirements based on development area, and cost-sharing with state and federal agencies.

The program is a 50-year plan that was developed by species advocates, developers and local/state agencies. Though the plan does not place a moratorium on development, it requires County review of all projects within the plan area to determine compliance with mitigation and regulations of the program. The County also negotiates with property owners in the plan area to acquire more land for preservation.

Since its inception, thousands of acres have been acquired for protection. The program's goal is to acquire or permanently protect a total of 172,000 acres, 98,379 of which are in unincorporated areas. For more information: www.sandiego.gov/planning/mscp or Betsy Miller, City of San Diego Planning Department's MSCP Section, (619) 533-4543 or bmiller@sandiego.gov.

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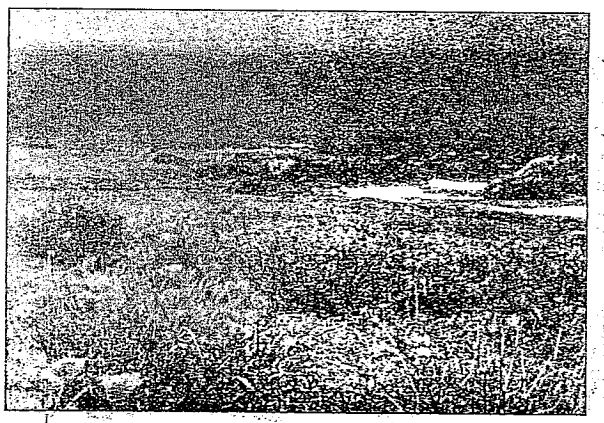

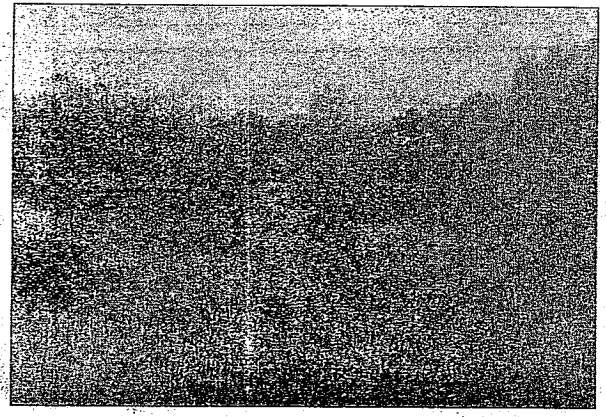

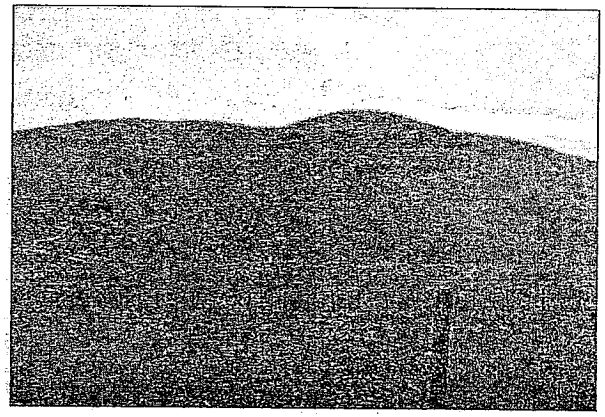

West's largest restoration

The Vic Fazio Wildlife Area, dedicated in 1997, created a wetland preserve of more than 16,000 acres — the largest public/private restoration project west of the Florida Everglades. The area provides protection from seasonal floods, the most significant natural hazard in Yolo County. The wetlands also provide natural habitat and agricultural use during the summer and fall.

The Vic Fazio Wildlife Area is considered a model of public-private partnership that illustrates the potential for communities to meet shared goals through regional collaboration. The project's stakeholders included landowners, conservation organizations, recreation groups, farmers and representatives of local, state and federal resource and planning agencies.

The plans reduce risk and conflict because all parties know what to expect and what is required. The plans must specify a strategy for achieving the required objectives of natural community conservation and compatible land use and economic activity. The strategy might include such techniques as land acquisition, developing wildlife reserves or watershed management.

For more information: California Department of Fish and Game, www.dfg.ca.gov/nccp; and "A Local Official's Guide to Habitat Conservation Laws," www.ilsg.org/habitat

Restoration strategies

Restoration is to natural resource management what redevelopment is to community planning; it takes damaged "natural" infrastructure and turns it into a community asset.

Restoration practices re-establish the "working parts" of a site's ecology, so it can function properly again. Restored areas such as wetlands, floodplains and riparian areas can provide water storage, purification and infiltration to reduce flood risks, improve water quality and enhance supplies.

Local watershed councils and resource conservation districts are often engaged in restoration work and can be valuable partners for local government. Resource conservation districts also provide important links to local landowners, which is especially valuable since agricultural and pasture lands often contain sites that can be restored and maintained to serve double-duty as working lands and water protection areas. (Section IV provides more information on entities with whom local government can partner.)

Wetland restoration is especially important. Wetlands are the workhorses of our watersheds. They filter water, detain flood flows, recharge aquifers, feed surface waters, provide prime habitat and aesthetic and recreational value for people.

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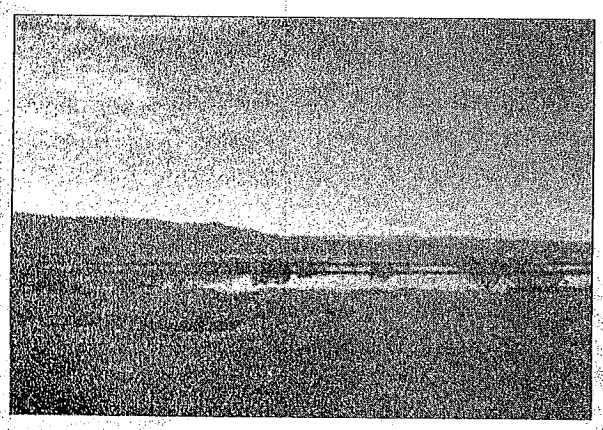

The Arcata Marsh and Wildlife Refuge (above) takes partially treated wastewater and finishes the process.

In recent decades, urbanization and development of roadways have caused the loss of significant amounts of wetland areas. Ninety-one percent of the five million acres that once made up California's wetlands have been drained or filled. It is estimated that California is currently losing 5,000 acres of wetlands per year. [14]

This creates a serious shortage of land areas that can recharge groundwater, absorb excess flood flows, filter pollutants and deliver the array of ecosystem services – including purifying water supplies – that wetlands provide.

One way to recoup the essential work that wetlands perform is to restore or create wetland areas in and around a community. This practice has been used successfully for flood protection, stormwater control, wastewater treatment and habitat creation.

Man-made wetlands remove pollutants from urban runoff

The San Diego Creek Watershed Natural Treatment System (NTS), developed by the Irvine Ranch Water District, is a watershed-based approach to solving regional water quality problems. It strategically places man-made wetlands throughout the watershed to remove pollutants from urban runoff – particularly from chemical lawn treatments that wash off people's yards.

The project is expected to remove 126,000 pounds of nitrogen and 21,000 pounds of phosphorus annually, and reduce fecal coliform levels by 26%. It also provides wildlife habitat and open space, and is expected to cost significantly less than new or existing wastewater and stormwater infrastructure systems.

Project Manager Norris Brandt says the project is cost-effective and notes that it has been well received because "it uses existing public lands and natural processes to clean the creek water instead of expensive man-made structures like treatment plants."

The natural treatment system will use plants and soils, including bulrush, cattails and peat to eliminate pollutants in urban runoff. Sediments, nutrients and pathogens



that would otherwise enter Upper Newport Bay – and eventually flow into the ocean – are instead settled out and assimilated though natural processes.

While its primary goal is to improve water quality, other benefits include creating habitat and providing an aesthetic and educational amenity. The natural treatment system is a model for the way wetland restoration can solve multiple problems, create community assets, and cut costs.

For more information on this and other Irvine Ranch Water District Urban Runoff projects, www.irwd.com

II. Water-Friendly Site Design

"Fines for violating new EPA runoff regulations are costly; traditional treatment methods are expensive. But there is another approach."

– Art Baggett, Boardmember, State Water Resources Control Board



Natural systems have the ability to filter and cleanse water, then collect it in lakes, rivers and underground aquifers. For the sake of our water supplies, it is best to leave much of a watershed undeveloped. Practically speaking, however, we will be developing an increasing acreage of watershed lands to accommodate our growing population.

A community's water resources are only as healthy as the areas through which they flow. By retaining or restoring natural drainage and landscape systems within development, we create a natural infrastructure that filters, stores and distributes water resources, ensuring their quality and quantity for our use. We can also create systems that naturally manage stormwater generated by development.

Much of our urban areas are now covered with hard surfaces, mostly streets and parking lots. Dangerous pollutants accumulate on these surfaces including heavy metals from auto parts and oil leaking from cars, only to be washed into local waters by stormwater and runoff from irrigation systems.

Impervious surfaces also prevent water from soaking in the ground to recharge aquifers, and this leads to flooding since the water has nowhere else to go. During the 20th century, stormwater management in developed areas was highly engineered and lead to extensive paving and impervious surfaces. Today, underground pipes and aboveground concrete channels collect the polluted runoff and deliver it into surface waters. The unfortunate result is decreased water quality, diminished groundwater supplies and flooding.

Ahwahnee Water Principles 3, 4 and 5 are design strategies that reduce development impacts by minimizing impervious surface cover and integrating natural runoff controls in a project's site design. Together, the strategies aim to emulate predevelopment conditions in the built environment. They call for areas to be incorporated into the urban environment that will temporarily hold water during periods of heavy rain. They call for landscapes designed to reduce water demand. And they call for a reduction in hard surfaces in the urban environment, with the substitution of pervious pavement and other surfaces that allow water to penetrate the soil and flow to groundwater systems.

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Low impact development

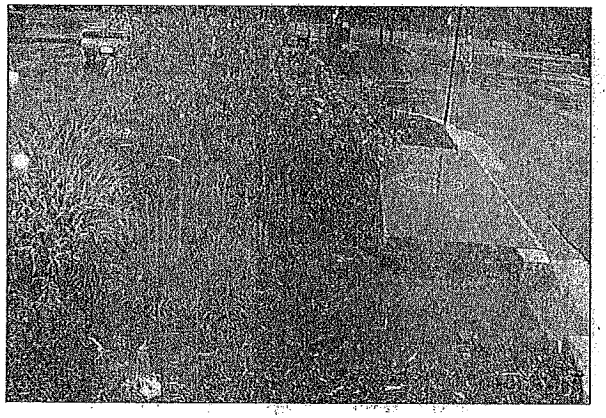
Water resource professionals refer to the use of these ecologically based design techniques as "Low Impact Development." Low impact development promotes the integration of stormwater best management practices that mimic natural hydrology into all aspects of development and community design, including streets and parking, homes and buildings, and parks, public spaces and landscaped areas.

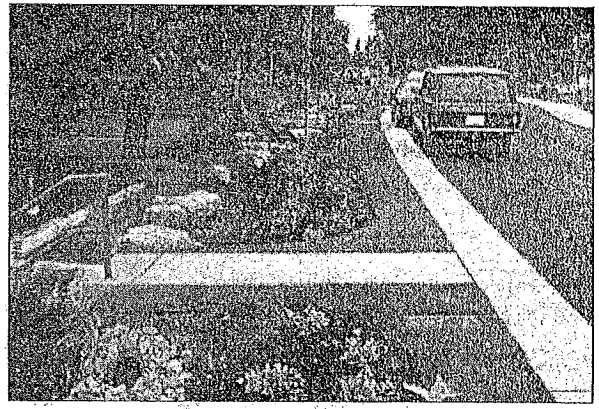
The State Water Board and nine regional water boards are encouraging the use of low impact development by incorporating it into post-construction performance criteria for municipal stormwater permits.

A primary goal of low impact development is to reduce runoff volume by infiltrating rainfall into the ground where it can be taken up by plant roots or enter groundwater systems. Another key goal is to treat runoff by allowing pollutants to be filtered or settle out as the runoff is conveyed through and stored in vegetation and soils.

Low impact development is economical, costing less than conventional stormwater management systems to install and maintain, in part, because of fewer pipe and below-ground infrastructure requirements.

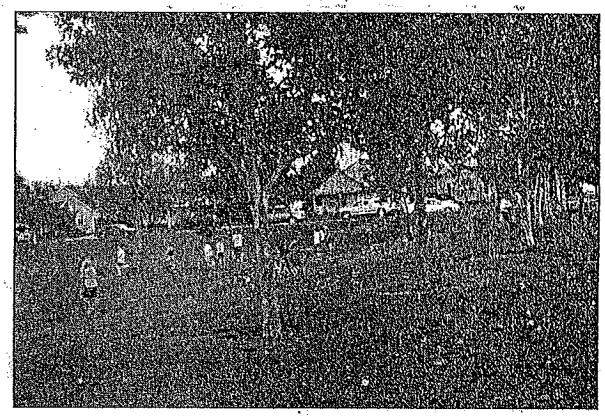
The landscape areas used in low impact development also create "quality of life" benefits that contribute to livability, property values, community vitality and aesthetics. Low impact development has also emerged as a cost-effective tool for helping communities comply with post-construction elements of their National Pollutant Discharge Elimination System (NPDES) permit requirements.





The enforcement of the federal requirements has been somewhat lax during the early years of its implementation, according to Celeste Cantú, the State Water Board's executive director.

However, she warns, "The regulations are going to keep getting tougher. It's going to be expensive to NOT get it right." Cantú is a strong advocate for implementing the Ahwahnee Principles in new development as a mechanism for assuring water quality.



"The days of catch it, pipe it, and send it are gone. We now have effective planning and design solutions that allow us to manage stormwater as a valuable resource. We have the tools to design urban development in a way that respects the hydrologic cycle."

– Jeff Loux, Director, UC Davis' Extension Land Use and Natural Resources Program

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Ahwahnee Water Principle 3 – Maximize permeability in developed areas

Water holding areas such as creek beds, recessed athletic fields, ponds, cisterns and other features that serve to recharge groundwater, reduce runoff, improve water quality and decrease flooding should be incorporated into the urban landscape.

We can improve the land's capacity to handle the water it receives when it rains. The measures described in the third Ahwahnee Principle mimic naturally occurring systems that hold and drain water in a safer manner.

They can take many forms such as swales, rain gardens and depressed turf areas, and can be used in parking areas, along road sides, in traffic islands, below roof gutter downspouts, and in public areas, parks, greenbelts and residential landscaping.

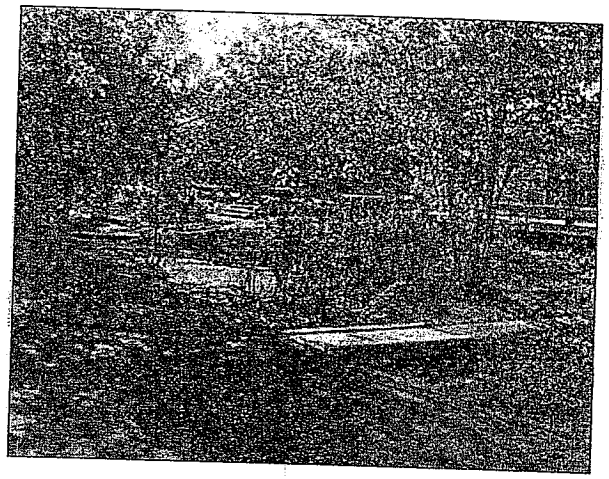
Site design and natural drainage

Infiltration is the natural drainage process through which water is absorbed into the ground. It allows physical, chemical and biological processes to occur that purify water as it travels through soils into groundwater basins.

Retention is another important component of the natural drainage process. Here, runoff is temporarily held in place allowing for evaporation, infiltration into the ground and slower, controlled rates of drainage to take place.

These processes can effectively attenuate flood flows and replenish our rivers, lakes and groundwater. They can also be designed into stormwater best management practices to control drainage and capture pollutants suspended in runoff.

Bioretention is a common low impact development practice that directs runoff from impervious areas into a highly permeable area to treat and control on-site runoff close to its source. Bioretention practices not only provide water storage and facilitate infiltration, they also improve water quality. A study of six bioretention systems showed greater than 99% removal efficiency for oil and grease. Removal of total suspended solids – a measure of the amount of pollutants in an amount of water – ranged from 72% to 99%. Lead removal ranged from 80% to 100%. [15]



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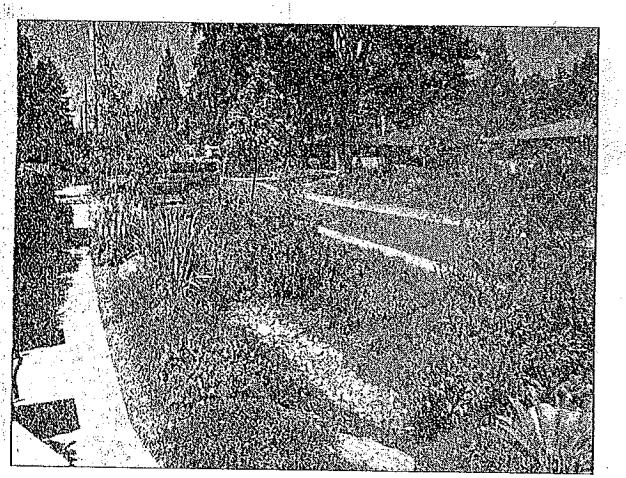
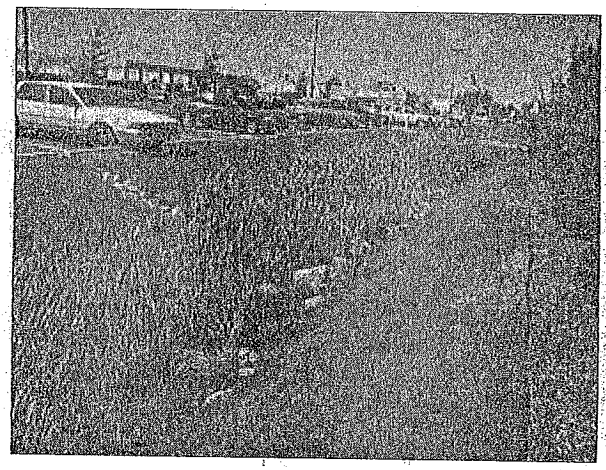
A number of communities are now creating recessed parks, baseball fields and similar features that temporarily hold water during excessively rainy periods. Some are also daylighting urban creeks and creating or restoring ponds.

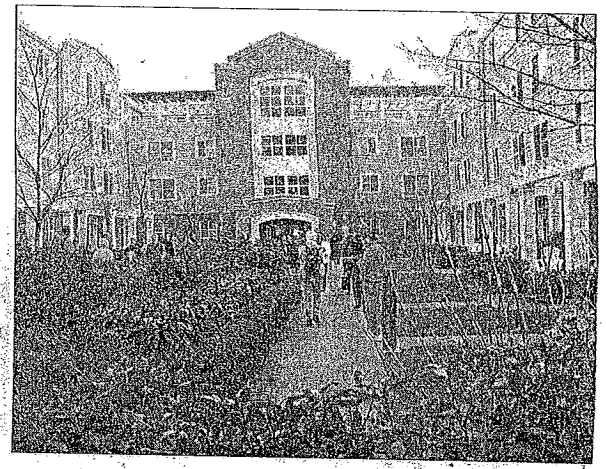
Vegetated swales and rain gardens

Swales are drainage areas that are designed and maintained to slowly transport runoff through a vegetation-lined channel. The vegetation helps to slow the flow of the runoff and promotes the filtration and settling of pollutants. Biophysical interactions between the vegetation, soils and soil organisms serve to digest most contaminants.

Rain gardens are another example of bioretention practices. These low-tech treatment systems look like nicely landscaped







areas, but are in fact engineered systems to manage stormwater runoff. They can be designed to fit a range of needs and areas, and are often combined with other low impact development practices to create a stormwater treatment system.

Capturing the rain to protect water

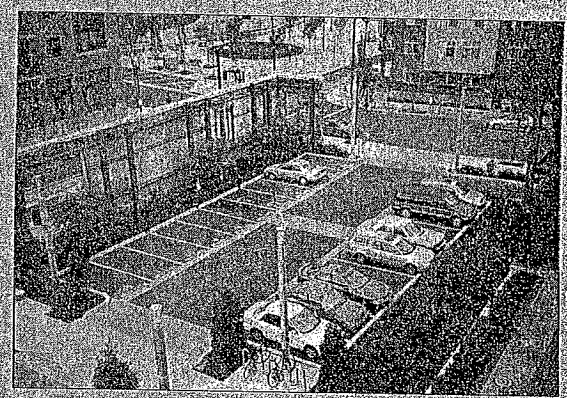
Rain barrels and cisterns are low-cost, effective and easily maintainable water storage systems that can be used at residential, commercial and industrial sites to manage rooftop runoff. They are designed to capture runoff that comes off buildings, which reduces stormwater runoff and provides a source of water for landscapes or other uses. "Rainwater harvesting" practices help manage stormwater, turning it from nuisance into a resource.

For example, University of California-Davis' Department of Environmental Horticulture and the Center for Urban Forest Research have integrated a rainwater harvesting system that uses cisterns and rain barrels to capture water, a vegetated filter strip to treat surface runoff, a swale that enhances infiltration into soils, and drought-tolerant landscaping that strategically uses trees to shade smaller vegetation. The water stored in the rain harvesting system is used for landscape irrigation. (www.fs.fed.us/psw/programs/cufr)

Portland's "Green Streets" link transportation planning and stormwater management, reduce impervious hardscape

Portland's "Green Streets" links the city's transportation planning and stormwater management into a program that actively reduces runoff and removes pollutants, using strategically placed best management practices throughout the city's transportation network.

Sidewalks, streets, medians and parking areas are all designed to maximize infiltration and reduce overall imperviousness. For more information: www.portlandonline.com/bes/index.cfm?c=34601



Stormwater management: Working with developers

Best practices and swale guidelines assist compliance with regulations, reduce runoff

The City of Livermore relies on the legal authority of its stormwater ordinance to implement its stormwater program and ensure that new development is compliant with NPDES permit requirements. The ordinance cross-references the permit, instructing developers to follow its provisions. Keys to the program include early communication with developers, extensive review of project planning, design and installation, and rigorous monitoring and enforcement.

Developers have flexibility to select best management practices consistent with those outlined in the City's stormwater permit. However, City staff also provide guidance to ensure that developers have adequate information to properly design, install and maintain their best management practices. The City's "Swale Guidelines" help developers in this process. Today, swales are a common feature in development throughout Livermore.

For more information: Livermore Public Works Department, (925) 960-8000.

City worksheet helps developers comply with stormwater quality requirements

The City of Emeryville has generated a simple but effective worksheet to help builders and developers comply with local stormwater quality requirements. It explains the importance of controlling stormwater quality, summarizes requirements, and offers best management practices for construction site controls, site design for water quality and stormwater treatment measures.

The worksheet provides developers with a guideline for completing the required form detailing the stormwater treatment measures on their development site. It also encourages developers to include stormwater treatment measures in their plans early in the design process.

For more information: Peter Schultze-Allen, Environmental Analyst, Emeryville Public Works Department, (510) 596-3728.

Economic implications

Natural drainage systems are economical, costing far less than conventional stormwater management systems to install, in part because they require fewer pipes and other below ground infrastructure, and because they often reduce the need for off-site detention basins. The landscaped areas that are created also provide aesthetic benefits and increase property values.

A 2003 study modeled the economic benefits of on-site runoff storage and revealed that this design option could save $17,540 to $36,000 per acre, due to reduced flood liability on property value. Avoided costs for storm drainage infrastructure were estimated at $247 to $836 per acre. [16]

A recent analysis of flood control costs in Los Angeles County estimated that $400 million in flood insurance costs could be avoided by installing a comprehensive natural drainage system that retains water and promotes infiltration. [17]

Other research indicates that developers are not as opposed to these solutions as people assume. As long as the rules are clear and the project can be completed without excessive delays, developers are open to using the practices, particularly as the cost savings and environmental-permitting benefits from low impact development practices become clear.

Coordinating local development codes and stormwater management creates a more streamlined process and ensures that effective, lasting stormwater controls are implemented.

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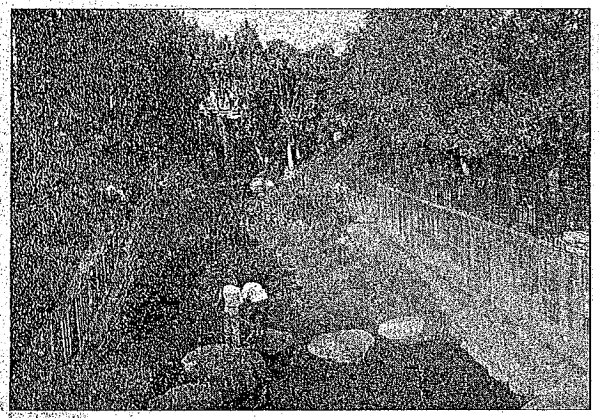
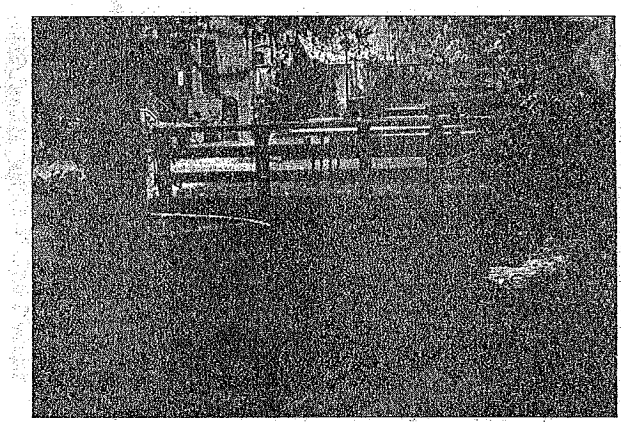




Daylighting urban streams

The rivers and streams that flow through our communities are among our most highly valued resources. They add community character, recreational opportunities, economic stimulus, habitat and environmental and water resource benefits.

Unfortunately, since the early parts of the 20th century, many of the rivers and streams in our communities have been buried in culverts under pavement or encased in concrete channels. These degraded waterways provide little benefit for human or natural communities and serve to quickly funnel polluted water to healthy rivers and streams they flow into.

Restoring urban creeks is important to watershed-based stormwater management. A recent study reports that streams do much of the heavy lifting when it comes to filtering pollutants from urban runoff. Some streams process more than 50% of the inorganic nitrogen – common in household lawn treatments – entering the stream system. [18]

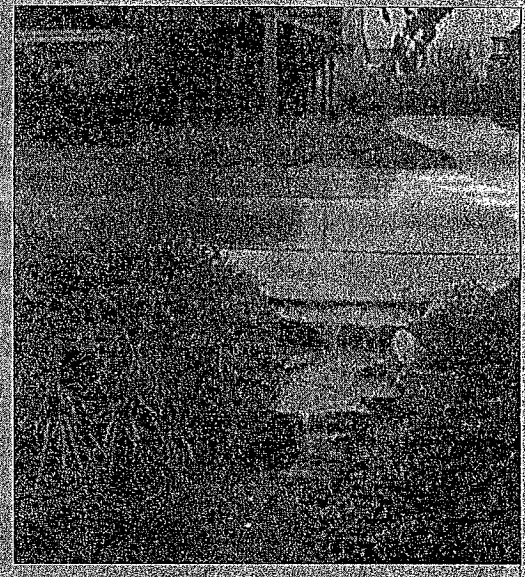
Public partnerships bring a Sonoma urban creek back to life

Santa Rosa Creek is a model of urban creek restoration. A diverse group of stakeholders worked together to restore the creek after it had been channelized and lined with concrete for flood-control purposes in the 1960s. The stream had become an urban eyesore and a haven for vandalism and transients. The Committee for Restoring Santa Rosa Creek involved partners in the development of the Santa Rosa Creek Master Plan, which was adopted by the City of Sonoma, the County of Sonoma and the Sonoma County Water Agency. Today, the creek has been restored as part of a community greenway. Through a participatory process, the creek was brought back to life and now provides a range of benefits to the community including restored steelhead habitat. For more information: Nancy Adams, transportation planner, Santa Rosa Department of Public Works, (707) 543-3910

Natural drainage can save money, boosts home values

Village Homes, a 60-acre development built in the late 1970s in Davis, provides a real-life example of the infrastructure savings of a natural drainage system. Runoff water is held and absorbed on-site through a system of natural-looking creeks and holding ponds that run throughout the development. The developer saved $700 per unit (in 1978 dollars) over the cost of installing a concrete storm drain.

Property values in the area are also the highest per square foot of any in Davis, although the initial selling prices of the homes were not above average. This is due, in part, to the aesthetics of the landscape design. [19]



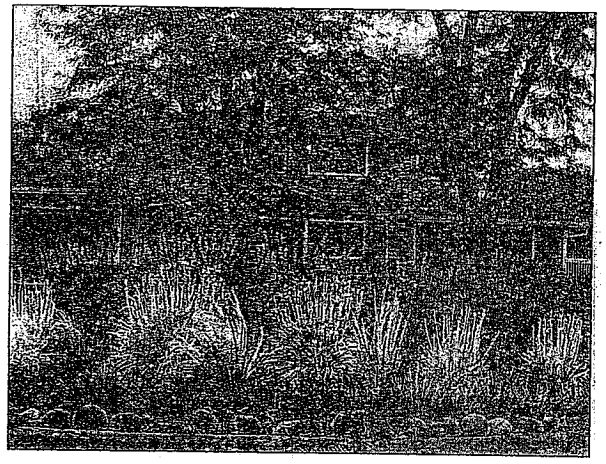
Ahwahnee Water Principle 4 – Water-wise landscaping

All aspects of landscaping from the selection of plants to soil preparation and the installation of irrigation systems should be designed to reduce water demand, retain runoff, decrease flooding, and recharge groundwater.

The fourth Awhahnee Water Principle addresses how we employ landscape design in our communities to improve stormwater management and maximize existing supplies, from the scale of an entire subdivision down to an individual property. The goal is to develop a natural "green" infrastructure that communities can depend on to protect water resources.

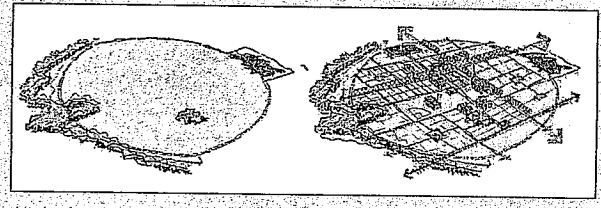
Water infrastructure in new development and redevelopment

Water-sensitive landscape design should begin at the scale of the subdivision, planned unit development or specific plan. During construction and grading, the natural topography, vegetation and soils are usually scraped away or degraded.



The loss of plants and natural streams, and the compaction of soils, leads to urban runoff problems and reduced infiltration.

Preserving Coyote Valley



In the beginning (l), there is canvas of environmental features. Smart planning (r) will design the community around these features.

The City of San Jose is planning a new community of 25,000 homes and 50,000 jobs in the six square-mile Coyote Valley. Rather than look at the valley as a blank slate, project consultant Ken Kay started by studying the natural landscape. "We looked for ways to not only preserve, but also reclaim nature by restoring wetlands and transforming sterile ditches into living streams," Kay said. "Only after key pieces of nature are identified and connected do we begin to plan interconnected roads and possible transit lines, and then identify building sites. The final element is compact development – all kinds of homes near jobs and transit, including some homes and offices over stores."

Residents of the future community will be able to walk from their front doors into thousands of acres of natural open space. A short stroll in another direction will take them to work, school, out for coffee, or to a train station. A specific plan and form-based code are under preparation to assure that future development maintains the green and blue infrastructure and compact form as originally planned. For more information: www.sanjoseca.gov/coyotevalley

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A development proposal for undisturbed land should catalog the water resource features of the natural landscape, including plants, trees, streams and water holding sites, small ponds, soils and natural drainage patterns. These features have played an important role in the natural watershed and should be incorporated in the landscape of the new development to the maximum extent possible.

Local governments should have ordinances in place that require protection of large-stature trees and native vegetation and encourage minimal grading and excavation of undisturbed soils.

Appropriate plant selection and xerisecapes

On average, more than half of the water consumed in both single-family and multi-family residences goes to landscape maintenance. Californians use about 977 billion gallons of water for landscape irrigation each year. Improved landscape techniques can reduce this amount up to 75%. [20]

Water-efficient landscaping (sometimes called xeriscaping) includes the selection and use of appropriate plants, limiting water-hungry turf, proper grading and soil preparation, use of mulches and composting, and hydro-zoning that groups plants with similar water needs. To further reduce water demand, we can also collect and recycle rainwater and household graywater, and use better water management and landscape maintenance practices.

Water-efficient landscapes benefit communities, water supply agencies and the environment by reducing:

- Average daily water demand.
- Seasonal peak water demand.
- The need for taking water from environmental uses.
- Runoff and soil erosion, as well as the need for chemical treatments.
- The production of green waste.
- Air pollution from lawn mowing.
- Costs of energy use, stormwater controls, water treatment and wastewater treatment.

While there are many benefits to water-efficient landscapes, the most obvious is lower water bills. A study of condominiums and townhouse complexes in Marin County found that traditional landscaping used 126 to 216 gallons daily for landscaping per dwelling unit. Water-conserving landscapes at similar complexes reduced water use by greater than 50%. [21]

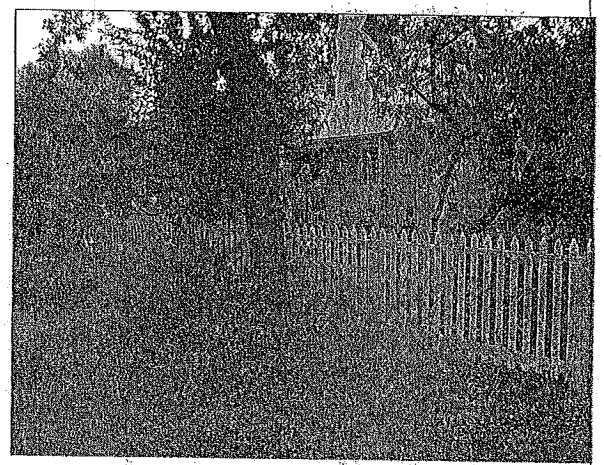
Water-efficient landscaping can reduce costs, maintenance

Palm Desert cut water use by one-seventh using drought-tolerant plants

Water-efficient plants don't grow as rapidly, so maintenance requirements are reduced. The City of Palm Desert replaced lawns in street medians with drought-tolerant species. The City now uses only one-seventh as much water. Maintenance costs have also been reduced by two-thirds. Water-efficient landscaping also reduces pests, weeds and disease. Thus, less money is spent on fertilizers and pesticides. Reducing the use of these substances also reduces water pollution. For more information: www.cityofpalmdesert.org/PublicWorks.asp

Water district pays residents to reduce size of their lawn, install water-efficient irrigation

The North Marin Water District offers residential customers a cash rebate for reducing the amount of lawn area in their landscapes. The district offers $25 per 100 square feet of regularly irrigated lawn area removed. The removed turf must be replaced with water-conserving plants, vegetable gardens or other low water-using plants. Water-efficient irrigation systems must also be installed. The district offers to pay for 50% of the cost of approved irrigation supplies. For more information: www.nmwd.com/c4g.html



Water-wise irrigation systems

Most irrigation systems apply water on an arbitrary schedule rather than on the actual needs of the plants. Automatic "smart irrigation controllers" are now available that use on-site sensors to evaluate soil moisture, temperature and weather conditions. The newest models (ET irrigation controllers) also measure "evapotranspiration" – to irrigate based on how much water the plant is actually using. These ultra-sophisticated sprinkling systems provide exactly the amount of water needed to keep plants healthy.

State legislation

The State of California passed the Water Conservation in Landscaping Act in 1990 requiring municipalities to adopt the State's Model Landscaping Ordinance (www.owue.water.ca.gov/docs/WaterOrdIndex.cfm) or an equivalent policy. While few adopted the ordinance and most failed to enforce it, this tool is ready for use by local governments.

New policies for efficient landscaping

Assembly Bill 2717, authored by Assemblymember John Laird and signed by Governor Arnold Schwarzenegger in 2004, charged the California Urban Water Conservation Council with developing a task force to make recommendations for improving the efficiency of water use in new and existing urban irrigated landscapes in California.

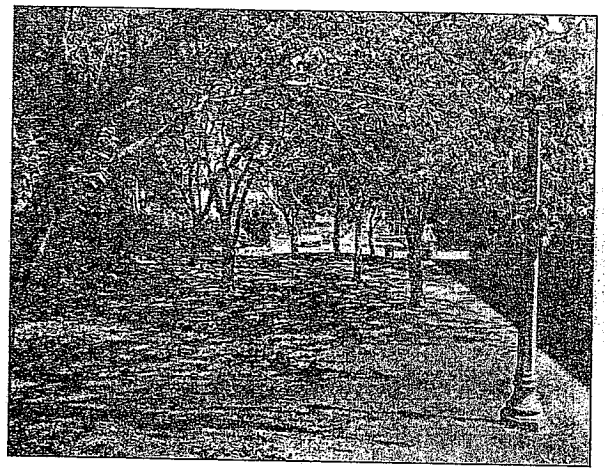
Many of the legislative, regulatory and administrative changes proposed by the task force have implications for local governments. One immediate effect is that local governments would be required to update their landscaping ordinances. The recommendations also call for stronger enforcement of these local ordinances.

Some of the recommendations that would most affect cities and counties include:

- Adopt water-conserving rate structures as defined by the task force.
- Enforce and monitor compliance with local ordinances and the state model ordinanceincluding an enforcement mechanism to ensure effective irrigation system installation and efficiency.
- Require dedicated landscape meters.
- Promote the use of recycled water in urban landscapes.
- Require that local ordinances be at least as effective as the state model ordinance.
- Require smart controllers.
- Adopt and enforce statewide prohibitions on overspray and runoff.

The Landscape Task Force estimates that implementing these recommendations and corresponding set of actions would save 600,000 to one million acre-feet of water annually from improved landscape water use efficiency – enough water to meet the needs of up to two million households annually.

For a copy of the report: www.cuwcc.org/ab2717_landscape_task_force.lasso or the California Urban Water Conservation Council, (916) 552-5885



The important role of trees

Trees play several roles in urban stormwater management. Their leaves and bark surfaces intercept and hold water to slow and reduce runoff during rainstorms. A portion of would-be runoff is effectively "held back" by the tree, allowing some to evaporate, some to infiltrate, and the remainder to run off in a slower and more controlled fashion. Computer simulations of deciduous trees in California's Central Valley estimate that for every 1,000 trees, stormwater runoff is reduced nearly one million gallons. Cost savings from these reductions total about $7,000 per year. [22]

As a tree's roots grow, they break up and loosen soils, which makes the ground capable of absorbing more water at faster rates. The increased infiltration reduces flooding and helps replenish groundwater. Tree roots interact with soils to assimilate pollutants in the runoff they capture. Trees also prevent erosion because their roots hold soil in place. [23]

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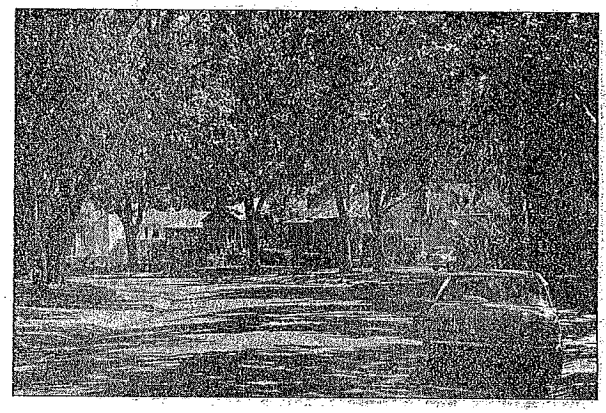
Economic benefits of trees

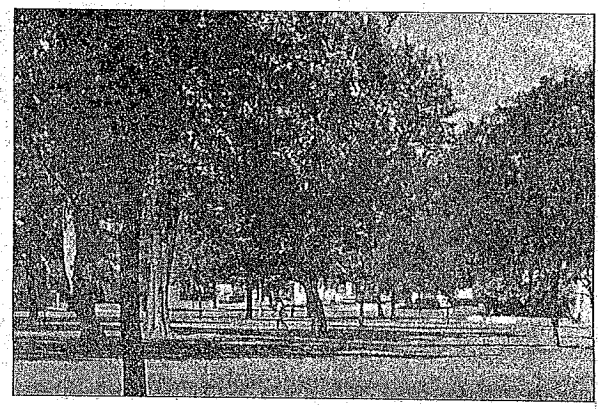
A recent study modeled rainfall interception and runoff reduction by trees in Santa Monica. The study found that, through reductions in runoff, the City avoided costs for stormwater treatment and flood control costs worth $110,890 annually or $3.60 per tree. [24]

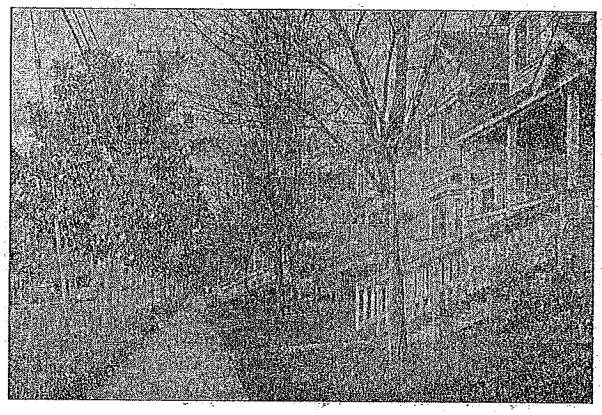
A GIS-based model developed by the U.S. Geological Survey and American Forests calculated the costs of losing existing tree cover and replacing it with impervious cover. For the Oakland area, the model predicted replacing the stormwater services provided by existing tree cover would cost the City approximately $242 million. [25]

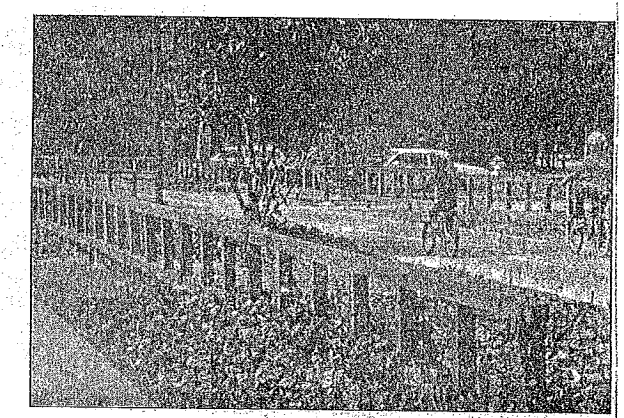
Trees increase residential property values. Recent research comparing residential sale prices shows that people are willing to pay 3% to 7% more for property with ample trees versus those with fewer or no trees. An analysis of prices in one city found that each large front-yard tree added about 1% to a home's sale value and an estimated increase of $100,000 (in 1978 dollars) in property tax revenues. [26]

Trees also help merchants enjoy greater sales and cities reap greater tax revenues. University of Washington studies found that consumers shop more often and longer in downtowns that have street trees and landscaping. They are also willing to pay more for parking and up to 11% more for goods and services. [27]









A community forest for Los Angeles

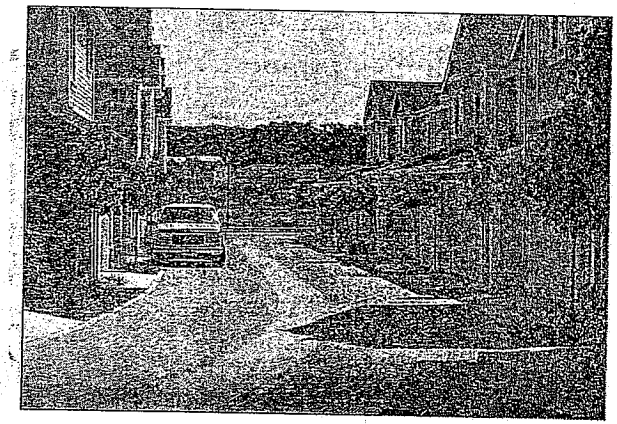
In Los Angeles, Mayor Antonio Villaraigosa is working with TreePeople to move forward on a initiative to plant one million new trees throughout the city. The plan is in keeping with TreePeople's vision of creating a functioning community forest in every square mile of Los Angeles. "Trees are more than ornamental," said TreePeople founder Andy Lipkis. "They can be our partners in making Los Angeles a healthier place to live." For more information: www.treepeople.org



Ahwahnee Water Principle 5 – Minimize impervious surface cover

Permeable surfaces should be used for hardscape. Impervious surfaces such as driveways, streets, and parking lots should be minimized so that land is available to absorb storm water, reduce polluted urban runoff, recharge groundwater and reduce flooding.





Automobile-related hardscapes generally account for more than 60% of the total imperviousness in suburban areas. Streets account for the lion's share of this – about 40% to 50% in residential areas alone. [28] Parking lots take up around 10% of the land in U.S. cities and can occupy as much as 20% to 30% of downtown core areas. [29]

Impervious surfaces inflict more damage to the watershed than any other aspect of development. When rainwater cannot infiltrate, it runs off the surface and carries with it whatever has accumulated there.

When impervious surfaces are linked via a network of streets, parking areas, storm drains and drainage channels, they create an "expressway" for runoff that leads to higher concentrations of pollutants and fast-moving "bursts" of polluted water that is damaging and erosive to local streams and habitat.

Brake wear releases nickel, chromium, lead and copper. Tires shed zinc, lead, chromium, copper and nickel. Engine wear releases nickel, chromium, copper and manganese. All of these toxins accumulate on paved surfaces used by cars, and are carried into storm drains and water bodies in urban runoff. [30]

For most local governments, increasingly strict NPDES urban runoff regulations will be sufficient to persuade a serious look at the way impervious surfaces are used and designed into the built environment.

However, an even greater incentive may be the improved quality of life achieved by reducing the dominance of streets and parking lots in a downtown or neighborhood. Cities that narrow their streets and put cars in smaller lots or parking structures are far more attractive, safe and pleasant places to be.

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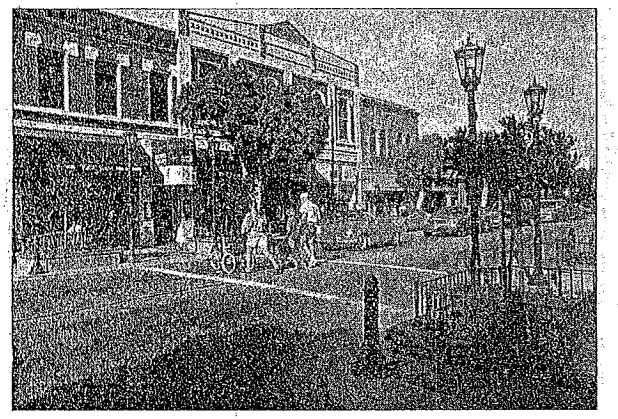
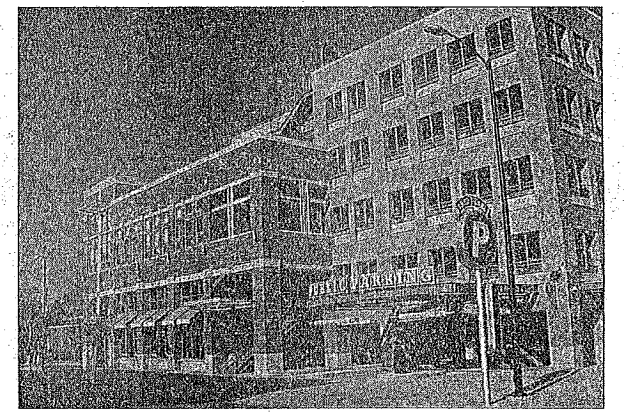




Downsizing streets

It is generally acknowledged among urban designers and health professionals that most residential streets are too wide. Many communities are now narrowing the street widths in newer developments and redesigning existing streets to devote less space to the car. This technique is known as a street-diet. In places where it has been implemented, it has successfully accommodated the same amount of traffic while creating a more pleasant urban environment.

Arterials are also coming under scrutiny. The Institute of Transportation Engineers, in partnership with the Congress for the New Urbanism, has released a draft guide that will change the design of arterial streets. Rather than focusing on capacity, speed and topography alone, as is currently the case, this new guide (available at www.cnu.org) will change widths and street design to accommodate pedestrians.

Reducing expansive parking lots

Local governments have a tendency to require more parking spaces than are needed. One study of 10 California cities revealed that, even at peak times, lots were filled to only 56% of their capacity. Nevertheless, it is the usual practice to set minimum parking requirements to satisfy maximum parking demand.

Development density, design and use influence parking needs: Each time residential density doubles, car ownership falls 32% to 40%. If transit is available, neighborhood stores are close by, and streets are walkable, even less parking will be required. If daytime uses leave spaces unfilled in the evening, they can be shared with theater-goers. A wise planner will take time to look at these factors rather than simply pull a book of outdated standards off the shelf. [31]

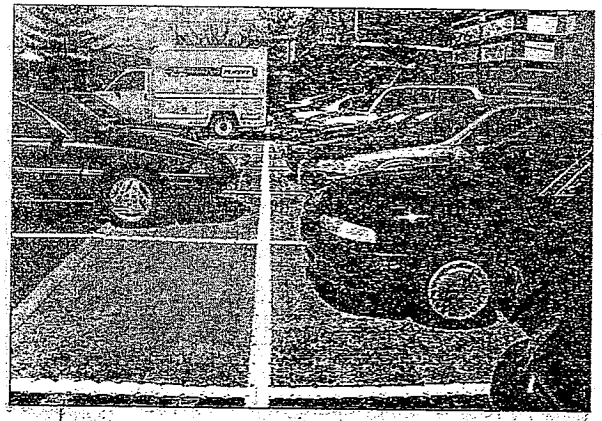
Reducing parking pays off

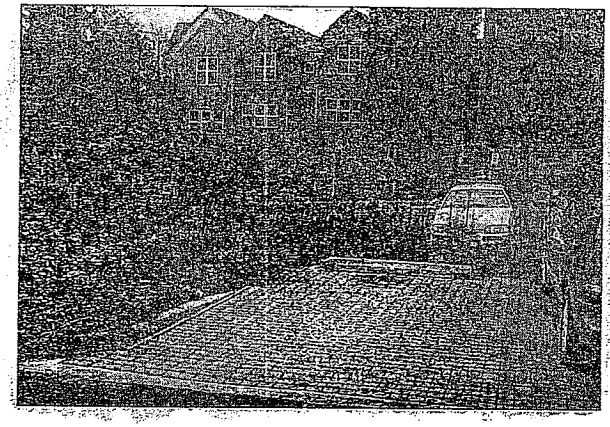
The City of Palo Alto will defer up to 50% of the required parking spaces as a landscape reserve where the need for parking is not clear. One apartment development deferred 22 of the 95 parking spaces required by the city code, turning the land into a family play lot, a barbeque area and picnic benches. After 15 years, the landscaped area remains – no new parking proved necessary. For more information: cityofpaloalto.org/planning-community

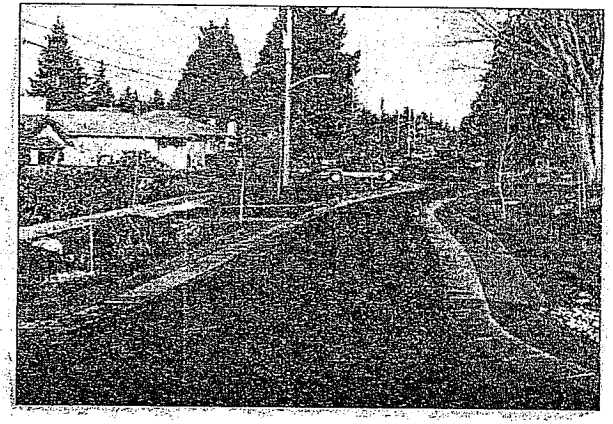
The City of Santa Clara allowed a reduction in parking spaces at a NASA research park, a mixed-use development with housing, retail and office space in close proximity and connected by a network of bicycle and pedestrian paths. Reducing 7,542 parking spaces to 5,200 saved $3 million a year.

The design of the Los Padres and Homestead Condominiums in Santa Clara minimizes impervious surfaces with higher-density housing and narrow streets. The design incorporates pervious areas that allow for the absorption of stormwater and the recharge of groundwater.

The 20-foot-wide streets are supplemented by permeable concrete (turf block) fire lanes. The permeable turf blocks allow natural filtration of stormwater and provide a place for children to play while also allowing for emergency vehicle access. For more information: Judith Silva, jsilva@ci.santa-clara.ca.us







Pervious materials and techniques

Recently, the market has responded by creating pervious materials suitable for sidewalks and other uses. These new products are designed to let water flow through, reducing the water-related problems with impervious hardscapes.

Permeable paving reduces runoff and allows water to infiltrate into the ground where it can be stored and slowly released over time. If conditions are right, it can infiltrate completely to augment groundwater supplies.

Various kinds of permeable paving are available. The costs, benefits and functionality vary. Other pervious products include paving stones or unit pavers – blocks of brick, stone or concrete laid on top of a prepared sand base. Water can travel through gaps between the blocks.

Grass pavers or turf blocks are similar to unit pavers except that the gap between the blocks is designed to allow grass or other appropriate planting to grow there. This system not only allows water to percolate into the ground, but it also slows runoff and filters pollutants.

Permeable pavements are not suitable for high-traffic areas such as busy roads and highways. They are very appropriate for use in places like parking lots, driveways, access roads, public plazas and sidewalks. New porous asphalt and pervious concrete surfaces now on the market look just like conventional asphalt or concrete, but have tiny spaces that allow water to percolate through.

Each of these products usually overlays a base of crushed stone that stores runoff during a rainstorm. The water percolates the upper paving surface and is stored temporarily so it can gradually seep into soils to replenish groundwater, or drain at a controlled rate from the storage area.

The strategies in this section are often part of integrated policy solutions that combine the reduction of impervious surfaces with the use of water-sensitive landscaping.

Narrow streets, more creeks mean less runoff

In Village Homes in Davis, streets are narrow – 20 to 24 feet in width – and parking spaces are downsized. Natural drainage is incorporated in the form of creeks and ponds that act as temporary holding areas. Abundant trees provide shade, reduce runoff and enhance infiltration.

With the exception of playfields, lawns are eliminated and drought-tolerant plants and food-producing vegetation are used extensively. Conservation site design was used to plan the development which allowed the developers to make use of existing natural features and incorporate multi-functional open space throughout. [32]

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III. Stretching Our Water Supplies

"Every time water is wasted, money and a precious resource go down the drain."

– California Water Plan Update 2005

Based on current per-capita use, the water demand generated by California's future residents will require a 40% increase in supplies. While our population is growing rapidly, our water supplies are limited, and there is no way to make "new water" to meet increasing demand.

Communities need to look to under-utilized local resources to fill future needs. They also need to develop a portfolio of water supplies, rather than relying on a single conventional source. Conservation, reclamation, the reuse of graywater and recycled water, and the treatment of contaminated groundwater supplies are all potentially viable "supply" options available to local communities.

By employing water conservation, recycling water and treating contaminated groundwater, California could make another four million acre-feet available to meet future needs. [33]

Reduced reliability of future water supplies

In the past, many communities have looked to far away sources to provide the water they needed. In the future, it is likely that those sources will be increasingly difficult to secure and less reliable, and bear heavy economic, social and environmental costs. Communities that now have excess water are likely to need it to supply their own growing populations. Water supplies to Southern California coming from the Colorado River are already being reduced, as other states are using their full-supply rights to serve their own growing populations. This provides a forecast of what is likely to pass in California as our own communities grow in population.

While some interests still support new surface water reservoirs, none of the proposals in the CALFED Record of Decision has been found to be cost-effective or environmentally acceptable. [34]

The conventional water supply systems – dams, aqueducts and pumping stations that move water around the state – are also dependent upon an aging infrastructure. As the financial costs of maintaining and updating the extensive infrastructure required by these systems – and the environmental costs they create – become increasingly apparent, damming rivers and building aqueducts to move water wherever it is needed will no longer be viable strategies.

Global warming may also play into this scenario. California depends on the Sierra snow pack as a massive natural storage system. Global warming experts warn that snow levels will rise and winters become shorter, effectively shrinking our largest storage system.

Community self-reliance

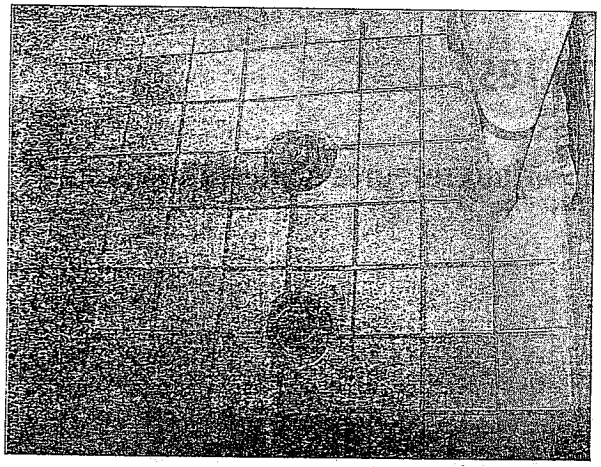
When a gallon of water is conserved, it's as good as a gallon of water supplied. In fact, it can be better. Conserving that gallon not only makes it available for other uses, it means less wastewater is generated. The potential of water conservation is immense and offers the greatest and most-affordable single source for meeting future needs.

We can design infrastructure and buildings to greatly increase the efficiency with which we use our water supplies. Requiring dual plumbing in all new development – even if recycled water is not yet locally available – will make future use of recycled supplies a viable option. Enabling expanded use of household graywater systems will give consumers an opportunity to reduce their water costs and play a role in decreasing demand on potable supplies. Low-flow and dual-flush toilets, water efficient appliances and "smart" water-saving irrigation technology are practical and available.

Developing these strategies can provide local and reliable sources of water that communities will need to meet California's "show me the water" laws. Conservation, recycling and groundwater treatment meet the criteria of "no regrets actions." They are sustainable strategies that make sense whatever the impacts of global climate change.

Ahwahnee Water Principle 6 – Graywater reuse

Dual plumbing that allows graywater from showers, sinks and washers to be reused for landscape irrigation should be included in the infrastructure of new development.



Water inside, reused outside: Dual drains installed in a second-story shower allow water to be diverted to the garden.

Reuse of domestic graywater is a simple and affordable practice that individual families or entire communities can employ to use water more wisely. Any water that has been used in the home – except water from toilets – is called "graywater." Shower, sink and laundry water comprise 50% to 80% of residential "waste" water, which may be reused for other purposes, especially landscape irrigation. [35]

During droughts, some people resorted to using buckets to transfer bath water to the garden. This practice can be made more convenient by putting two drains in a bathtub or sink – one drains to the garden, the other to the sewer.

Key facts about water reuse

More than half of the water used within the home, typically 60 gallons a day per person, is suitable for reuse. [36]

Using graywater instead of drinking quality water for landscape irrigation can keep lawns and gardens green – eve in times of drought – and alleviate water demand in areas prone to water shortages.

Graywater can also be better for a garden than using treated drinking water. Soap and other products in wastewater are rich in compounds that can pollute waterways, wear out septic systems, and overburden wastewater facilities. However, these same pollutants – phosphorous, nitrogen, potassium and proteins – are sources of nutrients for fruit trees, landscaping and gardens. [37]

State law (California Water Code, Section 14875-14877.3) permits cities and counties to allow the sanitary reuse of graywater.

Graywater systems are affordable and simple to install, especially if done at the time of construction. A workable, code-compliant, graywater irrigation system sends water from showers, sinks and other graywater sources away from blackwater before they mix and go to a sewage system.

Economic implications

Graywater reuse allows water suppliers to purchase less water for their customers. This water will become even more expensive as California's population increases.

Reusing graywater for irrigation means wastewater treatment facilities will have less volume to treat, and can delay expansion of those facilities. It can also extend the life of residential septic systems.

Individual customers save money on their metered water bills when water is used more than once.

Environmental benefits

Reusing water may allow communities to leave fresh water in rivers and streams to protect fish and wildlife. This can be critical during times of drought when river and stream flows can become low and warm, leading to fish-kills.

What local government can do

Cities and counties can require that dual drains be installed in new construction for the purpose of reusing water. As an incentive, the water saved can be counted as a source of water to meet the requirements of new state "show me the water" laws that require developers to prove that enough water is available to serve proposed new housing.

Taking steps to require and encourage graywater

Malibu adds graywater to its General Plan, develops guidebook to aid installation

The City of Malibu inserted graywater installation requirements in its general plan: "New development shall include a separate graywater treatment system where feasible" (Policy 3.123). As a result, numerous sites have graywater systems in use. Malibu also developed a "Graywater Handbook" to complement the City's policy. The handbook provides guidelines, resources and techniques to help homeowners and developers integrate graywater systems into their projects.

The handbook is available at www.ci.malibu.ca.us. For more information about Malibu's graywater law and permit process: Deputy Building Official Craig George, (310) 456-2489 x229

Santa Monica uses financial incentives to promote graywater projects

The City of Santa Monica has an incentive-based program to encourage graywater projects. The City provides discounts on sewage bills for installing graywater systems and has implemented a grant program to provide partial funding for innovative landscaping projects that incorporate graywater systems and other innovative water-saving features.

The City also provides fact sheets about graywater regulations and additional resources about constructing graywater systems, requesting rebates or receiving general assistance. For more information: Kim O'Cain or Bob Galbreath, Santa Monica Water Resources Management Office, (310) 458-5408

LA County recycled water manual provides wide range of tips and resources

The Los Angeles County Recycled Water Advisory Committee has developed an extensive 48-page "Recycled Water Manual" that provides information on goals, general provisions, design and construction, operations and maintenance, marking and equipment, agency contacts and resources for users and site providers. (www.watereuse.org/ca)

Los Angeles military base serves as graywater model for others to follow

The Los Angeles Air Force Base in El Segundo uses graywater in toilets and urinals in seven buildings and irrigates their five-acre landscape with graywater. The Los Angeles Air Force Base is serving as a template for bases throughout the world though its innovative use of recycled water. For more information: Office of Public Affairs, (310) 653-1132

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Ahwahnee Water Principle 7 – Water recycling

Community design should maximize the use of recycled ...er for appropriate ...lications including ...door irrigation, toilet ...hing, and commercial ...industrial processes. Purple pipe should be installed in all new construction and remodeled buildings in anticipation of the future availability of recycled water.

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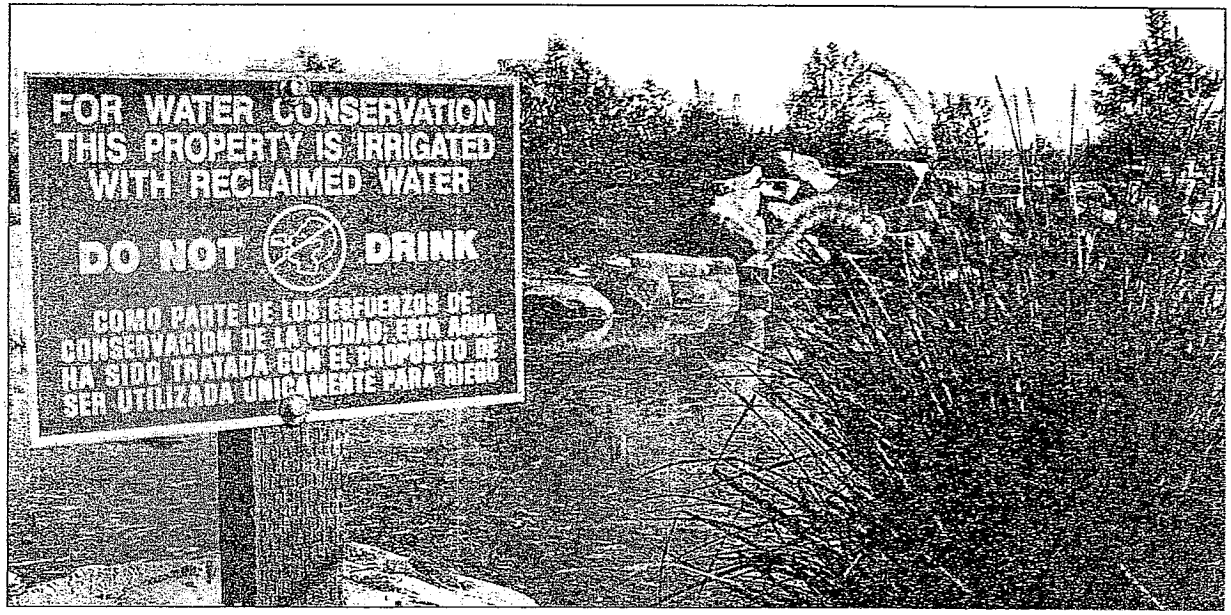


"California has the potential to recycle enough water to meet 30-50% of the household water needs of our projected population growth."

– California Recycled Water Task Force

Water recycling is an umbrella term that encompasses the treatment, storage, distribution and reuse of municipal wastewater. Recycling wastewater provides communities an opportunity to develop and diversify their water portfolios with a reliable source of water to meet a range of needs.

Recycled water is municipal and/or industrial wastewater that is treated for reuse. The recycled wastewater generally used in urban settings has undergone biological, physical and chemical treatment processes to bring it up to a standard appropriate for use in fire fighting, toilets, sprinkler systems, landscape irrigation, agriculture, cooling towers, commercial laundries, car washes and artificial snow making. Recycled water is the fastest-growing water supply in California. [38]

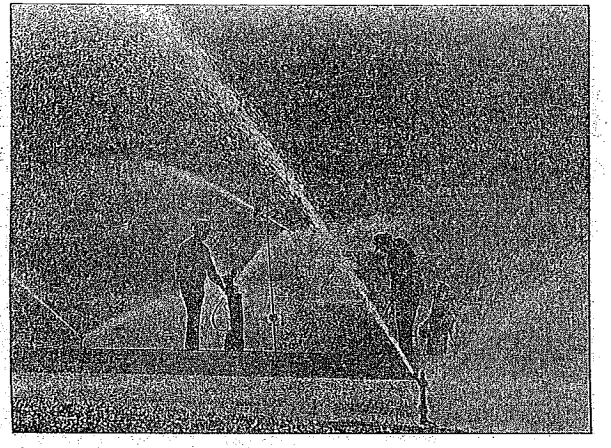
Potential contribution to our water supplies

California generates about five million-acre feet of municipal wastewater per year. Currently, 500,000 acre-feet of recycled water is being used around the state. An acre-foot is roughly enough to cover a football field with one foot of water or the amount needed by one or two families for one year.

According to the California Recycled Water Task Force, California has the potential to recycle up to 1.5 million acre-feet per year, saving potable water to satisfy the needs of 1.5 million homes annually. [39]

Safety

The safety of recycled water is well-established: it has been used by California communities since 1929 without any reported health problems. California's regulations governing the production, distribution and use of recycled water are some of the most stringent in the world. The California State Department of Health Services sanctions the use of recycled water for a variety of uses. These include, but are not limited to landscape irrigation, agricultural irrigation, construction water, water for industrial purposes, fountains, and indoor toilet and urinal flushing. Recycled water may also be used in cooling systems for buildings.



Many golf courses are using recycled water for irrigation.

Working with non-potable recycled water is safe if common sense is used and appropriate regulations are followed. There has never been a documented case of disease or other public health effect in the United States related to the use of recycled water that meets established standards, according to the Department of Health Services.

Purple pipes to assure safety

Recycled water, although highly treated, is considered non-potable. A dual-plumbing system is used, with the recycled water carried in purple-colored pipes to prevent the unintentional misuse of recycled water or cross-connection with the potable water system.

Regulations and guidelines have been developed to address public-health concerns with such misuse. State law prohibits a connection between the recycled water and the potable water systems. Tests are conducted before connecting new sites to recycled water supplies to ensure this does not happen.

Look for the purple pipes

To avoid confusion, pipes, valves and other equipment carrying recycled water are colored purple to make sure that recycled water does not get mixed with potable water.

Purple pipe is just like other PVC piping except that it carries reclaimed, rather than fresh, water.

The pipe usually has a continuous banding of lettering on both sides reading, "RECYCLED WATER – DO NOT DRINK."



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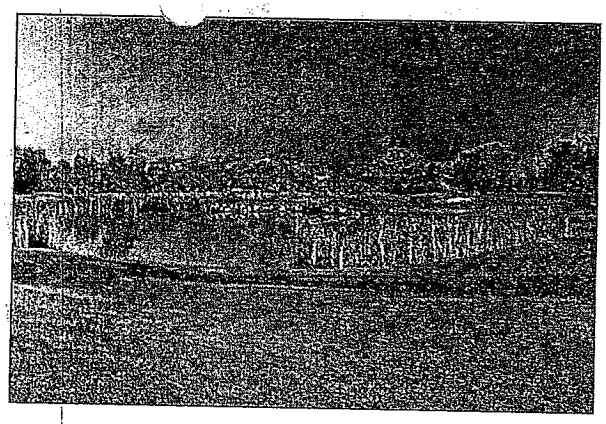


Matching the quality with the use

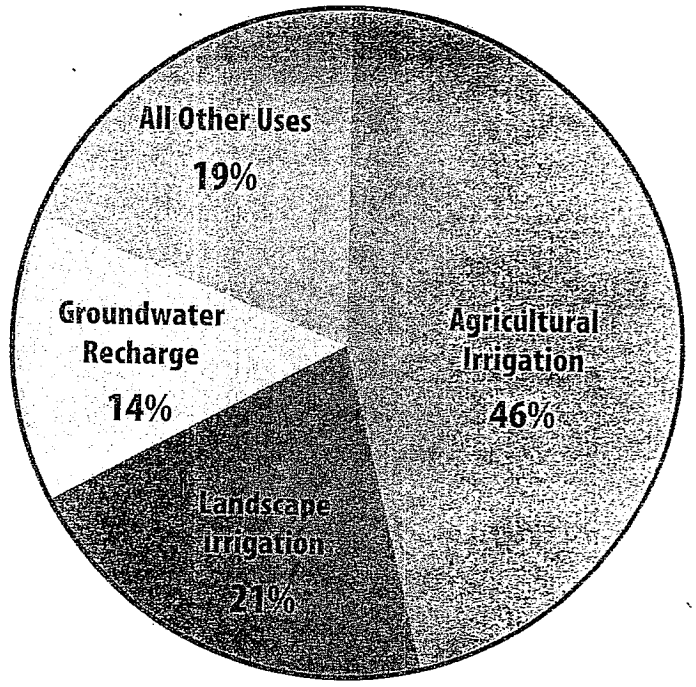
Industrial and commercial users of recycled water are sometimes served by their own pipeline from a wastewater ment plant. Uses for recycled water cleaned to a lower- ty standard include aquaculture, concrete manufacture ooling tower operation. Urban irrigation uses include ife-habitat maintenance, irrigation of cemeteries and way landscaping, and nursery irrigation.

me cases, wastewater from a building's sinks and toilets may also be carried to a separate holding tank in the basement, where it undergoes multi-stage processing similar to that of large-scale wastewater treatment plants. Many of these systems are currently on the market. The resulting water is then recycled through the building's toilet system via the purple pipes. These systems require permits both as providers and users of recycled water.

Large quantities of recycled water are used in California for agricultural purposes. The quality of that water varies based on the degree to which the water may come in contact with food crops or dairy cows. Recycled water supplies can also be used as a part of groundwater storage projects.

California has more than 300 water recycling plants in operation. The Department of Water Resources reports that, as of 2004, California communities were using recycled water at 4,800 sites. [40]

How recycled water is used in California



Notable recycled water venues

- The San Francisco 49ers' practice field in Santa Clara
- The Pebble Beach and Spyglass golf courses
- Ernest and Julio Gallo Winery's vineyards

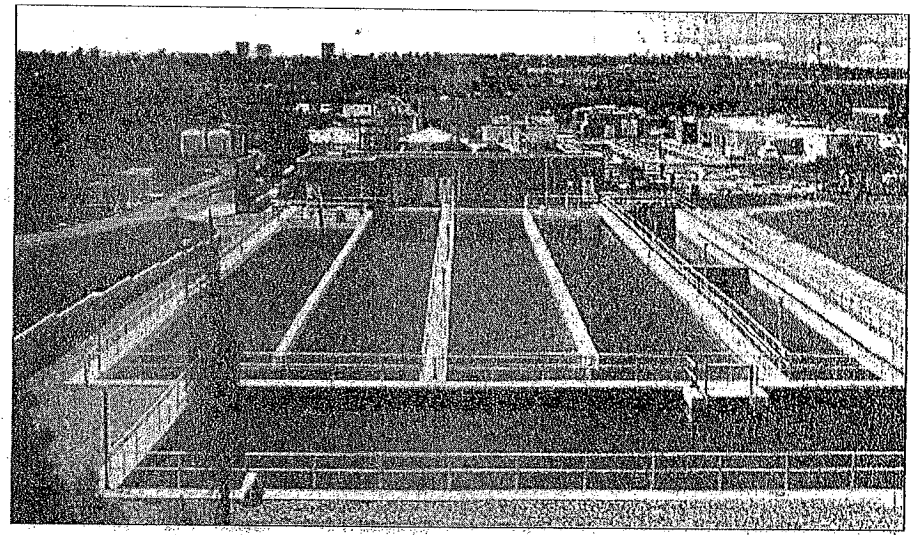
State law about recycled water

State law indirectly requires the use of recycled water. California Water Code Section 13550-13556 states that the use of potable domestic water for non-potable uses, including cemeteries, golf courses, parks, industrial and residential irrigation uses, and toilet flushing, is an unreasonable use of water if recycled water is available.

California regulates the use of recycled water as directed under Title 22. Each use of recycled water must have a permit from the local authority administering the recycled water program, which has the responsibility of enforcing the rules and regulations. The local authority is usually the retailer of recycled water to the site. Permit requirements typically include construction, inspection, cross-connection certification, site-supervisor training and a schedule of the hours that recycled water can be used. These local authorities can specify what sites and/or uses of recycled water are to be used in their service area, as long as they comply with state requirements.

The Regional Water Quality Control Boards require that recycled water customers conduct an inspection at least once a year while the recycled water system is in use. The results of this inspection must be documented and submitted in a written report. According to Department of Health Services regulations, at dual-plumbed use sites the customer is responsible for conducting a periodic cross-connection test every four years, unless visual inspections reveal a requirement for more frequent testing. The agency operating the recycled water program also promulgates rules and regulations determining the way recycled water systems are implemented and operated, and how records are to be kept.

Plans for projects using recycled water should indicate all water sources and the locations and specifications of all pipes and devices. Design standards must be set to protect public health and the integrity of the overall water supply, setting minimum separations for recycled and potable water pipes, minimum standards to protect drinking fountains and eating areas from overspray, and restrictions on runoff and ponding to protect domestic well water.



Recycled water systems also require regular preventative maintenance, including inspections, making certain that pipe markings remain level, monitoring of spray patterns and runoff from irrigation, and accurate recordkeeping of maintenance.

Economic implications

While the economics of recycled water depend upon the place and the use, recycled water can be less expensive than purchasing new supplies. As water supplies grow more scarce, the economic advantages of recycled water will continue to increase.

In Southern California in particular, recycling water reduces the enormous cost of energy required to import water. Orange County's Groundwater Replenishment System treats water so that it can be safely pumped into potable groundwater supplies, creating water for 144,000 families annually. Despite $486.9 million in construction costs, studies found that the system produced greater benefits for its cost than any of the alternatives. It will also use 50% less energy than importing water, resulting in additional savings. [41]

Environmental benefits

Recycled water can be used to enhance or restore wetlands that provide wildlife habitat, flood protection, improved water quality and recreational amenities. It also reduces the volume of potable water that must be withdrawn from rivers, lakes and groundwater to maintain the natural ecology of those bodies of water.

Recycled water projects and programs make a difference in communities across California

Recycled water saves supply and money in Rohnert Park

The City of Rohnert Park has been using recycled water to reduce demand on potable water supplies since 1988. Approximately 510 acres of land are irrigated with recycled water, saving more than three million gallons per day of potable city water. An extensive distribution system distributes recycled water to golf courses, city parks, school grounds and commercial properties.

The lead developer of 1,610 homes planned along Rohnert Park's eastern border has requested approval from the Santa Rosa Board of Public Utilities to build three waste-water storage ponds capable of storing up to 10 million gallons of recycled water. If the $18 million project is built, it will be the largest reuse project in Sonoma County since the $205 million Geysers' wastewater-to-electricity project went operational in December 2003. The ponds, which would be filled during the winter, would be drained during the spring and summer to irrigate the front yards of 880 homes, the front and back yards of 730 multifamily units, and several acres of commercial development planned within the nearly 300-acre area. For more information: Brookfield Homes, (925) 743-8000

Marin water district expanded recycled water for new uses

The Marin Municipal Water District was the first water supplier in California to use recycled water for car washes, air conditioning cooling towers and commercial laundries. Since the early 1980s, the district has pioneered the use of recycled water for non-agricultural purposes in northern California. Up to two million gallons a day are recycled and distributed in a separate pipeline system to more than 250 customers in northern San Rafael. Recycled water is used for irrigation, toilet flushing and other non-drinking purposes.

The water that the district recycles is wastewater that has been treated by the Las Gallinas Valley Sanitary District. To recycle this water, the district filters it and treats it further at its recycled water treatment plant, meeting the most stringent standards in the country. The finished recycled water is crystal clear, odorless and free of harmful bacteria. It is similar in quality to water in swimming pools. The district also manages the demand for water by encouraging efficient water use through various conservation programs. For more information: Marin Water District Conservation Department, www.marinwater.org or (415) 945-1520

Downtown Oakland high-rise incorporates dual plumbing

In 2001, the Shorenstein Company altered its plans for 555 City Center – a premier office building in an infill, redevelopment area of downtown Oakland – to include dual plumbing for recycled water for toilet and urinal flushing. It has become the first dual-plumbed high-rise building in Northern California, with a savings of 11.2-acre feet of drinking water per year. For more information: Shorenstein Company, www.shorenstein.com or (415) 772-7000

Recycled water a big part of Irvine Ranch Water District's supply

Recycled water now makes up about 20% of the Irvine Ranch Water District's total water supply: 18 million gallons a day are treated, providing water for 80% of all business and community landscaping needs including parks, golf courses, school grounds and gardens.

In 2000, the Lakeshore Towers' dual-plumbed office complex became the 15th building within the Irvine Ranch Water District's service area to convert to recycled water for toilet flushing. The conversion is the second one at Lakeshore Towers and one other building is slated for future conversion to recycled water for toilets. For more information: Lakeshore Towers, www.lakeshoretower.com/pages/Profile.html or (949) 955-5253

What local government can do

- Amend the local building code to require the installation of dual-purpose pipes (purple pipes) in new construction. Where recycled water is available, this step will implement state law. Where it is not, communities will be building the infrastructure for when recycled water is available in the future.
- Amend the building code to require the installation of purple pipes in remodeled buildings.
- Adopt a water recycling ordinance. The California section of the WateReuse Association web site provides a model water recycling ordinance (www.watereuse.org/ca/modelwrord.htm). The ordinance's intent is to maximize resource conservation and streamline implementation of water recycling projects in conformance with state law. The ordinance can also be tailored to conform with local rules and regulations.
- Work with wastewater management authorities to develop the necessary reclamation and treatment facilities.
- Work with local water suppliers to add water recycling to their Urban Water Management Plan and consider sharing resources for a joint public-private venture.
- Work with developers to create incentives or otherwise streamline the deployment of dual-plumbing systems.
- Initiate or join a public outreach and education program to educate the community about the benefits of using recycled water and address their concerns.

Recycled water works in many different settings

Recycled watering part of master-planned community in Placer County

The Serrano development in Placer County is one of the first master-planned communities to use recycled water for large-scale residential lawn watering. Recycled water is used to water common areas, golf courses, an elementary school's landscaping and the front and back lawns of more than 3,400 homes.

Due to the success of Serrano, the El Dorado Irrigation District – which is now saving millions in treatment costs and reduced discharges – is asking that new developments adopt programs similar to Serrano's whenever feasible. Homeowners reap savings in their water bills as well.

For more information: Parker Development Company, www.serranoeldorado.com/about-1b.html or (916) 939-3333.

Windsor finds big irrigation savings in recycled water

The Town of Windsor is saving approximately 275 million gallons of drinking water a year by irrigating 400 acres of golf course, vineyard, parks, pasture and fodder croplands with recycled water. A new housing development uses recycled water to irrigate front yards and offers residents the option of using reduced-cost water that is recycled to irrigate backyards.

For more information: Windsor Water Department, www.windsorgov.com/townwater.html, (970) 686-7476.

"It is not a question of whether or not we grow, but how. This is about the future of our communities; the decisions we make need to reflect our commitment to protecting the water resources we depend on."

– Jennifer Hosterman, City of Pleasanton Mayor

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Ahwahnee Water Principle 8 – Water conservation

Urban water conservation technologies such as low-flow toilets, efficient clothes shers, and more efficient ter-using industrial ipment should be rporated in all new struction and retrofitted in remodeled buildings.

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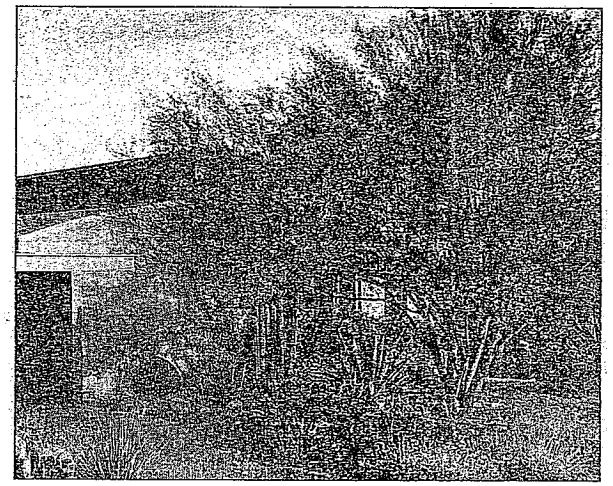


Projections by the California Department of Water Resources indicate that urban water conservation will be the leading source of water for California's growing population. Water conservation is one of the main reasons that urban areas have been able to accommodate the last 20 years of growth with approximately the same amount of water that they consumed in the 1990s. [42]

Existing conservation technologies include low-flow toilets and showerheads, efficient clothes washers, weather-based irrigation controllers, and more efficient commercial and industrial cooling equipment.

To meet the supply demands of California's growing population at the lowest cost and protect against droughts, local governments should expand the use of water conservation. The urban sector, and residential use in particular, provide the greatest opportunities for cost-effective water savings through conservation.

Potential contribution to water supply

It is estimated that urban water conservation can contribute 2.0 to 2.3 million-acre feet a year to our water supplies – enough to supply the current household demands of more than two million new families. (One acre-foot is roughly the amount needed by two families for one year.) [43]

State laws that encourage or require conservation

Article X of the California Constitution prohibits waste and unreasonable use of water.

California's Water Code Section 375 allows any public entity that supplies water to adopt and enforce a water conservation program that requires installation of water-saving devices.

The Urban Water Management Planning Act (Water Code Section 10620-10621 and 10644) requires urban water suppliers with more than 3,000 customers to adopt water management and conservation plans in five-year increments. These plans must be filed with local land-use planning agencies and are a key resource for water planning and coordination between water agencies and local government.

In 2001, SB 221 (Government Code Section 66473.7) and SB 610 (Water Code Section 10910-10915) were enacted to ensure adequate supplies prior to approval of development projects with 500 homes or more, and encourage better coordination between water suppliers and local land use agencies. Water conservation is a low-cost way to meet the water needs of new development.

Economic implications

Conservation is the least expensive strategy available to us. According to the Pacific Institute, more than half of the urban water conservation strategies can be achieved at $200 per acre-foot or less. By comparison, the Metropolitan Water District of Southern California currently charges its members over $400 per acre-foot. [44]

Approximately 33% of the energy budget of city governments in California is used for pumping water and 23% is used for treating wastewater. [45] Water conservation has the potential to significantly reduce local government energy costs because it reduces the need to pump water and to treat wastewater.

The State Water Project is the largest single user of energy in California, consuming an average of 5 billion kWh of electricity each year. [46] Assuming a relatively low rate of 8 cents/kWh, the electricity cost to move this water is $400 million per year.

Investing in improved water efficiency creates local jobs and local benefits. By contrast, investment in distant supplies sends money out of the community.

Environmental benefits

Water-conserving activities are key to sustainable development because they help protect water as a natural resource, minimize the use of chemicals needed to treat water and wastewater, and reduce energy use and pollution associated with pumping and transporting water.

Water conservation reduces demand, which in turn reduces the need to expand water storage projects and allows more water to remain in our rivers and streams for recreation, fisheries and natural habitat.

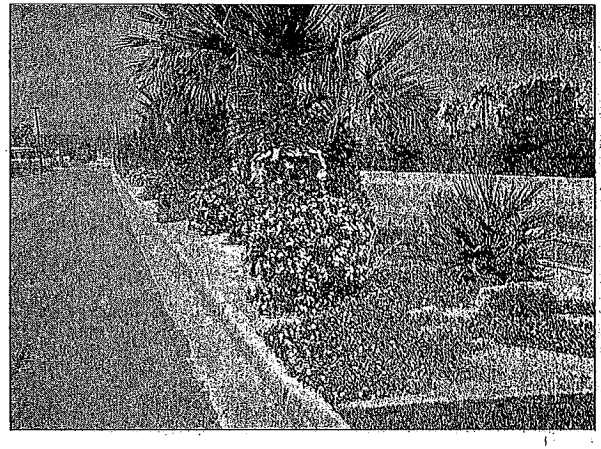
Conventional methods of increasing supplies, building more or larger dams, transporting water long distances, and excessive pumping, have harmed the state's aquatic resources. Using conservation, we can supply enough water to meet our needs without further damaging the natural heritage of California.

Reducing water use, and consequently wastewater generation, lessens environmental damage resulting from withdrawals, wastewater discharge and overuse of surface or groundwater.

Working with others at a regional level to improve water-use efficiency

Although many conservation efforts are local in scope, their effects are regional because the supplies that communities depend on are shared at the regional, state and inter-state levels. There is enormous potential for cities, counties, water districts, state and regional agencies, and developers to work together under the current regulatory context.

The recent "show me the water" laws and Urban Water Management Plans raise the bar for developing locally reliable supplies because without proof of adequate supplies, communities and developers are unable to engage in growth needed to accommodate future residents.



Because the supply of housing is also a regional issue, improving regionally based sources of water will give communities in the region greater self-sufficiency and more control over how they develop.

What local government can do

- Local building codes can be amended to require the use of low-flow toilets, showerheads and efficient irrigation technologies."
- Local retrofit ordinances can require the retrofit of water-conserving technologies in both residential and industrial facilities upon resale.
- Local governments can work with water suppliers to develop incentives, rebates and outreach programs to help residents, property managers and developers incorporate more efficient technologies into their homes and projects.

A007283

California communities find innovative ways to encourage the public to conserve water

New fee structure has rewards for Irvine Ranch Water District

When rapid population growth led to dwindling supplies and increased wholesale water charges, the Irvine Ranch Water District implemented a new fee structure that rewards water efficiency and identifies waste when it occurs. The long-term goal was to develop a water-wise conservation ethic within the community while maintaining stable utility revenues. Within a year, water use declined by 19%. Over the next six years, the district saved an estimated $33 million in water purchases. For more information: Irvine Water District Conservation Office, (949) 453-5325 or www.irwd.com/Conservation

Santa Monica uses outreach, loans in its conservation program

Groundwater contamination and rapid growth created a dual threat to the City of Santa Monica's water supplies. The City was forced to increase water purchases and decided to take a multi-faceted approach. It developed a conservation program that includes education and outreach, water-use surveys, landscaping measures, toilet retrofits and a loan program. The result was a 14% reduction in water use, a 21% reduction wastewater flow and a net savings of $9.5 million between 1990 and 1995. For more information: City of Santa Monica Environmental Programs Division, www.santa-monica.org/epd or (310) 458-2213

Metropolitan Water District offers free conservation workshops

The Metropolitan Water District of Southern California – a consortium of 26 cities and water districts that provides drinking water to nearly 17 million people – works with local communities to provide free water conservation workshops to community members as well as landscaping firms. The workshops cover topics including how to detect wastewater, maintain sprinkler systems properly, and develop landscape designs appropriate to the climate. The workshops are offered in both English and Spanish. For more information: www.bewaterwise.com/pda.html or Diane Harrelson, (213) 217-6167 or dharrelson@mwdh2o.com

Santa Barbara County water suppliers launch media campaign

Cities and counties can be involved in educating the community on water conservation practices. The water suppliers of Santa Barbara County joined forces to launch the Santa Barbara County Be Water Wise Media Campaign. Campaign sponsors included the Santa Barbara County Water Agency, the Cities of Buellton, Santa Barbara, Santa Maria and Solvang, the Carpinteria Valley, Goleta and Montecito water districts, and the Cuyama Los Alamos and Vandenberg Village community services districts.

The campaign used materials developed and shared by the Metropolitan Water District of Southern California to run ads in local media outlets. To view ads and materials from the campaign: sbwater.org/Programs.htm#Media. For more information: Helena Wiley, Santa Barbara County Water Agency, (805) 568-3451 or hwiley@cosbpw.net

The City of Santa Barbara also offers residents a free "water-checkup" on how to read their water meters and use water efficiently, check for indoor and outdoor leaks, measure the efficiency of irrigation systems, and develop an irrigation schedule. City water customers can call the Water Conservation Hotline for assistance. For more information: www.santabarbaraca.gov/Government/Departments/PW/WCHome.htm

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Ahwahnee Water Principle 9 – Cleaning up groundwater supplies

Groundwater treatment and brackish water desalination should be pursued when necessary to maximize locally available, drought-proof water supplies.

In rural areas and along the state's central coast, 90% of the drinking water is supplied by groundwater. Nearly one in three Californians – more than 9 million people – rely solely on groundwater for their water needs. In fact, California's groundwater supply is 20 times greater than the amount of water stored behind all our dams. [47]

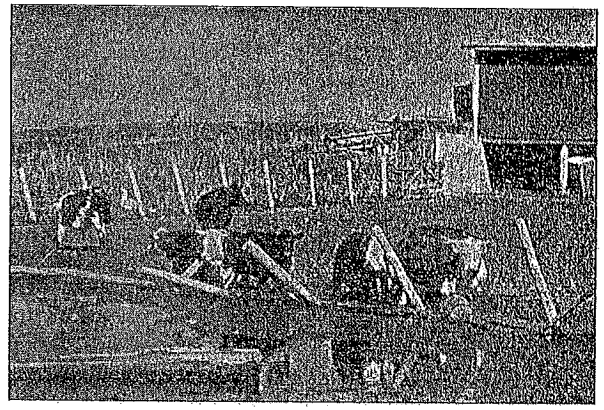
Groundwater resources are particularly valuable in California because – unlike surface supplies – they are widely distributed throughout the state. Groundwater also has the benefit of year-round reliability, unlike surface supplies that are available from rain in the winter and snow melt in the spring but can be scarce in the summer and fall when they are most needed.

Sadly, in many areas, groundwater is already over tapped and/or contaminated. In some cases, desalination can treat these supplies to meet local needs.

Threats to groundwater

Groundwater is being contaminated by a number of sources, but salts, stemming from urban, agricultural, wastewater and seawater intrusion, have become one of the greatest threats to California's groundwater resource.

Seawater intrusion is a growing problem due to the over-drafting of coastal groundwater basins. As groundwater is pumped from the aquifer, seawater flows inland through permeable ground. Under normal conditions, the fresh water acts as a buffer by leaving no space in the aquifer. When too much fresh water is drawn, the sponge-like aquifer can soak up the seawater.



In the Salinas Valley, for instance, 50 years of overdraft has allowed seawater to move five miles inland, contaminating local groundwater aquifers that provide water for the region's $3-billion agricultural economy and the public water supply for local communities.

Saltwater contamination of groundwater is not only a coastal phenomenon. In the Central Valley, ancient pockets of isolated saltwater have been drawn into nearby freshwater aquifers as a result of overdraft.

Since management of groundwater is primarily a local responsibility, cities and counties are positioned to make important decisions that protect groundwater as a long-term, sustainable supply for local water needs. The first step is to protect these resources with land use practices based on the first five Ahwahnee Water Principles that help protect surface waters and recharge groundwater supplies. When that fails, the more costly step of desalination is an option.

AGW7295

Groundwater desalination

Desalination is a process that removes salt from brackish (low-salinity) water or seawater so it is available for beneficial use. Reverse osmosis, the principal method used for desalination in California, can be used to remove salt as well as specific contaminants in water such as chemicals, volatile organic carbons, nitrates and pathogens.

Groundwater desalination has been used in California since 1965. Dramatic improvement in the treatment technology has resulted in a significant rise in desalination capacity. Currently, 17 groundwater desalination plants operate in California, with six new plants in the design and construction phase.

Desalination is an important component of water recycling (Awhahnee Water Principle 7). Desalting wastewater expands the range of beneficial uses of recycled municipal wastewater. Roughly 150,000 acre-feet of the 1.2 million acre-feet per year of the recycled water expected by 2030 will be desalinated.

AGL 286

Potential contribution and economics

The State of California Desalination Task Force found that there is a potential for 290,000 acre-feet of additional groundwater desalination at costs ranging from $130 to $1,250 per acre-foot. The benefits of desalination include:

- Increased water supply.
- Decreased diversion from environmental uses.
- Increased water supply reliability during drought periods.
- Reclamation and beneficial use of waters of impaired quality.
- Diversification of water supply sources.
- Improved water quality.
- Protection of public health.

Desalination has historically been prohibitively expensive. However, recent technological advances have made it more efficient, less energy-demanding and less expensive. These advances have reduced desalination costs to levels that are comparable to, and in some instances, competitive with the cost of purchasing outside water supplies. [48]

Chino Basin desalination project serves fast-growing region

The Chino Desalter Authority was formed as a joint powers authority in February 2002 to manage the production, treatment and distribution of highly treated potable water to cities and water agencies throughout its service area. The authority and the Inland Empire Utilities Agency are advancing groundwater desalination as part of their Optimum Basin Management Plan. They have installed pumps and filters to remove nitrates from groundwater supplies in the Chino Basin, one of the fastest-growing areas in the nation. About 27,000 acre-feet has been restored so far, with the goal of reducing dependence on expensive imported water supplies and providing a local drought-proof supply of new water for local communities.

The desalination project is also linked to other efforts to maximize local supplies. The Chino Basin Recycled Water Groundwater Project is part of the comprehensive Water Supply Enhancement Program jointly sponsored by the Inland Empire Utilities Agency, Chino Basin Watermaster, the Chino Basin Water Conservation District and the San Bernardino County Flood Control District. Combined, these efforts aim to improve the quality of local drinking water wells, enhance water supply reliability and lower the cost of water to residents throughout the Chino Basin. For more information: Chino Basin Watermaster, www.cbwm.org, or Inland Empire Utilities Agency, www.ieua.org

What local government can do

- Allow developers to fund groundwater cleanup as a condition of approval as a way of meeting California's "show me the water" laws.
- Work with water suppliers to include groundwater treatment in Urban Water Conservation Plans.

IV. Implementing the Ahwahnee Water Principles



The five implementation principles are designed to provide guidance to local leaders and their staff members to ensure the most effective application of the measures suggested by the nine community principles.

In brief, these implementation principles suggest involving key watershed stakeholders in the decision-making process, and they point out that the best projects have more than one benefit and that evaluating the effectiveness of our policies once they are implemented is a very good idea.

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Implementation Principle 1 – Coordination is key

Water supply agencies should be consulted early in the land use decision-making process regarding technology, demographics, and growth projections.

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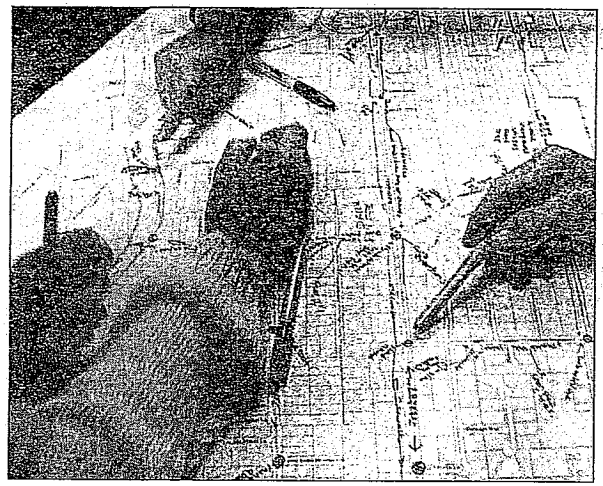

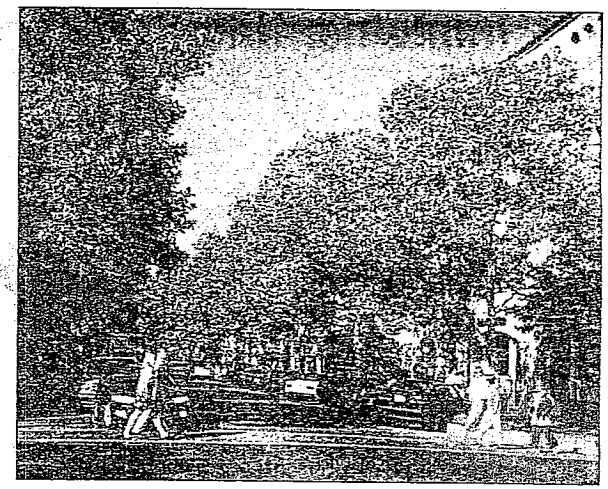

The Ahwahnee Water Principles are suitable for implementation by individual cities or counties through their land use processes. However, to maximize their effectiveness, local jurisdictions need to engage water suppliers as partners. Recent legislation has made this even more important.

Lack of coordination between water agencies and land use agencies can lead to the approval of development projects that lack water to meet projected needs. This problem led to legislation in 2001 that encourages greater coordination between water suppliers and local government planning agencies.

"Show me the water laws"

Senate Bills 221 and 610 are the so-called "show me the water laws." SB 221 requires a city or county to obtain written verification that sufficient water supplies are available before approving proposed development projects of larger than 500 residential units, retail projects larger than 500,000 square feet, and office projects larger than 250,000 square feet. The water agency must provide verification of a sufficient supply – defined as enough water to meet the needs of the proposed development project in normal years as well as during a drought.

SB 610 provides the process for implementing SB 221. This measure requires that a water supply assessment be included in any environmental documentation for projects subject to the California Environmental Quality Act, that also meet the size thresholds above.

The SB 610 supply assessment does not preclude development, SB 221 prohibits approval of a proposed subdivision map or parcel map unless and until sufficient supplies are documented.

Responsibility for meeting the requirements of this legislation lies solely with the city or county, even though it is the water agency that documents the availability of water for the new project.

Urban Water Management Plans

Municipal water agencies are required to prepare an Urban Water Management Plan every five years. The plan must evaluate supplies and demands over a 20-year horizon, including wet, dry and normal years, and specify measures for ensuring future water supplies. Urban Water Management Plans provide a foundation for satisfying the specific requirements of the "show me the water" laws.

Cities, counties, developers and water agencies share an interest in the information these planning documents provide. They should work in concert to ensure that plans are complete and to identify water management options that make the most of existing water supplies. That way the plan can be used in development planning and approval to ensure that statutory requirements are met.

The community's future water needs will be a function of population growth and the location and design of new development. Water agencies and planning departments will both benefit if plans reflect input from the cities and counties supplied by the water agencies.

The land use agency must provide an accurate picture of planned land uses to forecast and plan for future water needs. Water agencies must provide a clear picture of available sources of water supply and the various costs and benefits of those sources so that local land use agencies can plan for future growth in a manner that includes a careful evaluation of the water supplies available to meet future needs.

Once completed, water agencies are required by state law to provide copies of their Urban Water Management Plans to the cities and counties they serve. Planning staff should review the plans of water suppliers in their jurisdiction to see if they contain sufficient supply and demand analysis to meet the provisions of the "show me the water" laws.

Coordinating the analyses needed for land use and water planning facilitates sustainable development practices, such as the following:

- To advance the use of recycled water, a community needs to ensure that the water agency identifies and analyzes recycled water as a source in their Urban Water Management Plan. The water agency will also need to be certain that the city or county will be requiring purple pipes in new development.
- To be certain that conservation measures will maximize the efficient use of existing water supplies, the water agency can work with the cities or county in its service area to develop programs that require or incentivise the installation of water-efficient technologies such as low-flow toilets, shower heads and smart irrigation systems.
- To count on groundwater supplies as a source, water agencies need to know that land use policies are in place to protect groundwater supplies from contamination and loss of infiltration for recharge.



All of the above measures can be included in development agreements.

General Plans

It is also advisable for local governments to perform a water supply and demand analysis when preparing a general plan update. This should be done in cooperation with the water agency to ensure that the general plan does not designate properties for future growth where there is no available water supply.

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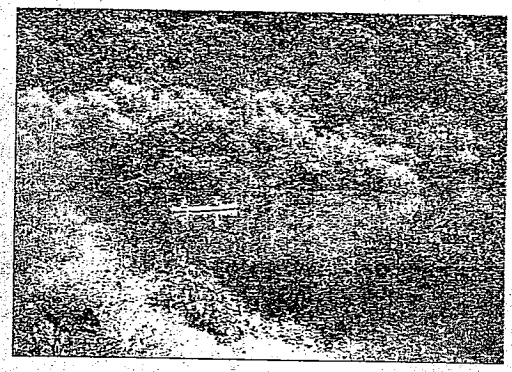
Conserving water makes more of it available for agriculture and environmental uses.

nproved efficiency and increased
ıservation are the cheapest,
iest and least destructive
vs to meet California's future
ter needs."

– Peter Gleick, President, The Pacific Institute

Water coordination is crucial for regional self-sufficiency

Sonoma County thinks regionally to implement water conservation programs



Acting regionally, the Sonoma County Water Agency – which includes the County, the Cities of Santa Rosa, Petaluma, Sonoma, Cotati and Rohnert Park, and the water districts of Forestville, North Marin and Valley of the Moon – is the first water wholesaler in the state to make a 100% commitment to water conservation and recycling as supply sources on behalf of all of its retailers.

Notably, the agency is requiring that all of its retailers join the California Urban Water Conservation Council and commit to implementing the 14 best management practices of urban water conservation. The agency oversees planning and implementation of regional water conservation programs for its eight retail water contractors and has developed a self-sustaining funding mechanism to support those programs.

Collaboration between the eight-member Water Advisory Committee brings together city council and county board members, city and district managers, and senior-level staff. The North Coast Water Conservation Group has also been established as an clearinghouse for information on current issues and coordination of regional programs and events.

Sonoma's regional goal is to achieve a combined yearly water savings of 6,600 acre-feet by 2015. The agency developed a Water Conservation Plan as a guide to achieve this goal and has reduced the contractual water entitlements of each contractor to reflect these savings, further demonstrating their commitment to water efficiency. For more information: Cristina Goulart, Sonoma County Water Agency, (707) 523-1010 or www.scwa.ca.gov

East Bay Municipal Utility District coordinates with local planners

The East Bay Municipal Utility District (EBMUD) worked with 22 local land use agencies in its service area to complete "District Wide Update of Demand Projections." EBMUD developed a geographic information system to complete the analysis, which calculated demand based on land uses in the service area. Accurate land use-based analysis required coordination with local planning departments to identify the phasing of future growth and accommodate for the variation in water demand from different land uses. For more information: www.ebmud.com

Implementation Principle 2 – Regional collaboration

City and County officials, the watershed council, LAFCO, special districts, and other stakeholders sharing watersheds should collaborate to take advantage of the benefits and synergies of water resource planning at a regional level.

"Regional efforts are needed to effectively coordinate local approaches to development and achieve better watershed-wide results."

– U.S. Environmental Protection Agency

Successful integration of water into land use planning is achieved through a watershed-wide perspective. A single community within a watershed can enact measures to protect water quality or prevent flooding but they won't be as effective as when neighboring communities enact similar measures. Coordination is needed because watersheds do not tend to follow jurisdictional boundaries.

Fortunately, there are numerous venues for city and county elected officials to affect planning on a watershed level.

Important opportunities are also available to local representatives who serve on a LAFCO or Council of Government.

Local elected officials as conveners

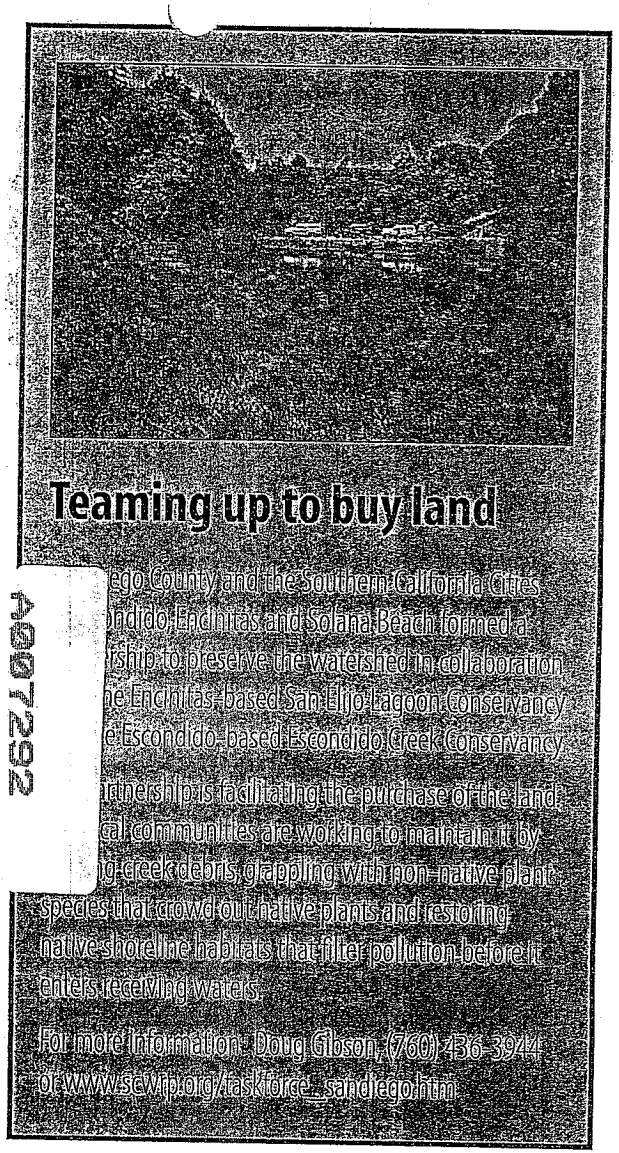
Mayors, city councilmembers and county supervisors an excellent position to bring together key players w watershed to focus on its preservation.

A007291

Water collaboration produces more fish for North counties

In 1997, Del Norte, Humboldt, Mendocino, Siskiyou and Trinity Counties agreed to work collaboratively to boost declining salmon and steelhead populations in Northern California. This commitment led to the development of the Five Counties Salmonid Conservation Program (www.5counties.org), which seeks to protect the region's economic and social resources through the conservation and restoration of salmonid populations to healthy, sustainable levels. Through this effort, they agreed to base decisions on watershed rather than county boundaries. The partnership has led to on-the-ground restoration projects, the development of regional policy guidelines and ongoing collaborative resource management.

The program is also becoming more involved in land use planning. Water quality and quantity can be drastically improved by providing incentives to private landowners to maintain riparian setbacks, as well as working with county planning departments to integrate specific ordinances into their general plans that combine a watershed-based approach with private land development.



Teaming up to buy land

...ego County and the Southern California cities ...ondido, Encinitas and Solana Beach formed a ...rship to preserve the watershed in collaboration ...he Encinitas-based San Elijo Lagoon Conservancy ...e Escondido-based Escondido Creek Conservancy. ...rtnership is facilitating the purchase of the land ...cal communities are working to maintain it by ...g creek debris, trapping with non-native plant species that crowd out native plants and restoring native shoreline habitats that filter pollution before it enters receiving waters.

For more information: Doug Gibson, (760) 436-3944 or www.scwrp.org/taskforce_sandiego.htm

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Local Agency Formation Commission

Local Agency Formation Commissions (LAFCOs) review proposals for the formation of new local governmental agencies and for changes in the organization of existing agencies (such as annexations). There are 58 LAFCOs working with nearly 3,500 governmental agencies. LAFCO decisions strive to balance the competing needs for efficient services, affordable housing, economic opportunity and conservation of natural resources.

The composition of LAFCOs varies from county to county, but nearly all have two members from the board of supervisors and two members from city councils within the county. Many LAFCOs also have two members from independent special districts in the county and a representative from the public.

A 1995 law added section 10910 to the California Water Code that permits LAFCOs to require cities, when applying to expand their sphere of influence, to provide information for determining whether existing and planned water supplies are sufficient to meet current and new demands.

LAFCOs cannot demand conditions for their approval of a project – they can only say "yes" or "no" to an expansion request. However, LAFCO boardmembers can base their decision on the impact of the proposed expansion on the watershed. For instance, a LAFCO denied an annexation request by the City of Folsom because the local water agency maintained that there were not adequate water supplies to serve the new development.

LAFCOs can also offer guidelines such as the Ahwahnee Water Principles to potential applicants.

Councils of Government

A Council of Government (COG) has responsibility for producing transportation plans within its region. A COG in a region with poor air quality must also address air pollution or be threatened with the loss of its transportation funds.

COGs representing 80% of California residents have recently undertaken visioning exercises that address where and how their communities should grow. All have adopted a growth strategy that includes preservation of existing open space and a vision for compact, walkable, mixed-use communities.

Their legal mandate does not include water in the visioning process, but these processes offer an ideal opportunity to apply a regional approach to managing water resources.

Metropolitan Planning Organizations

Metropolitan Planning Organizations (MPOs) are the entities that administer federal transportation dollars. COGs often serve as the regional MPO. The Metropolitan Transportation Commission in the San Francisco Bay Area and the Sacramento Area Council of Governments (which serves as that region's MPO) provide financial incentives to cities and counties in their regions for concentrating growth around transit and for planning and building compact, mixed-use development. These same strategies are found in the first Ahwahnee Water Principle.

Resource conservation districts

Resource conservation districts are formed as independent local liaisons between local, state and federal government and landowners. California has more than 100 resource conservation districts, funded largely through grants and occasionally through county property tax revenues.

California's resource conservation districts are "special districts" organized under the state Public Resources Code, Division 9. Each district has a locally elected or appointed volunteer board of directors composed of landowners in the district. The districts address a wide variety of conservation issues, including watershed protection and water management.

Resource conservation districts can facilitate cooperation between local government and farmers, ranchers and other landowners. They have an expanding role in linking land use planning and water management. Several are extending their focus on agricultural issues in primarily rural areas to address a growing slate of concerns related to urban areas.

Many are also engaged in local land-use planning activities and watershed management. Many watershed coordinators are housed in local resource conservation districts, which make them a valuable resource for getting stakeholders to the table in planning and management processes.

Regional visions help planning for growth and water needs

Sacramento region uses visioning process to create a water-demand "blueprint"

The Sacramento Area Council of Governments (SACOG) has completed water-demand projections for the areas covered in the Sacramento Blueprint visioning process. SACOG planners worked with local water agencies to model water-demand projections for each of the different scenarios that were envisioned.

The results indicate that the SACOG-preferred Blueprint Scenario, which advocates smart growth for the region, would generate less water demand than the status quo. In fact, analysis found that implementing smart-growth land use practices in the Sacramento region would net a 31% reduction in needs for the increment of anticipated growth. For more information: sacregionblueprint.org/sacregionblueprint.

Northwest Colorado uses "natural" boundaries for regional water quality plan

Other COGs in the West are explicitly integrating water into their work. For example, the Northwest Colorado Council of Governments (NWCCOG), whose planning region includes portions of the Colorado River and the North Platte River watersheds, is taking a regional approach to developing a regional water quality plan. It became involved because the natural and planning boundaries of the region's watersheds "do not neatly correspond to the planning regions with respect to the Water Quality Management Plans." [49] For more information: www.nwcog.co.us/Programs/Water/water_quality_quantity_committee.htm

"California's regions cannot meet all of their objectives with a single water strategy. Integrated regional water management is the future for California because it will help regions diversify their water portfolio strategies and get the most from local, state and federal resources and funding."

– Lester Snow, Director, California Department of Water Resources

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Many benefits grow out of watershed partnerships

Sun Valley watershed group creates flood protection and water supply solutions



The Sun Valley Watershed Stakeholders Group began meeting in 1998 under the leadership of the Los Angeles County Department of Public Works' Watershed Management Division, which was formed to create integrated solutions for flood protection, water supply and stormwater quality in the county.

The Sun Valley Watershed Management Plan was initiated "to solve the local flooding problem while retaining all ...water runoff from the watershed, increasing water ...rvation, recreational opportunities, wildlife habitat ...educing stormwater pollution."

...planning process developed a set of alternatives that were evaluated according to the costs and benefits they provided ...od control, water quality, water conservation and total cost. The plan provides data and analysis to take a watershed-... approach to solving water management problems in one of California's most urbanized watersheds. For more ...mation: www.sunvalleywatershed.org.

San Diego County groups band together for collaborative watershed management plan

In 1998, a group including foundations, two conservancies and a resource conservation district signed a formal agreement to protect and improve the Carlsbad Hydrologic Unit through a collaborative watershed management plan. San Diego County and seven cities joined the effort, along with federal, state and regional government entities and nonprofit organizations. The project has been working to restore habitat and raising funds to acquire watersheds to protect them from development.

Watershed partnerships

Watershed partnerships, often called watershed councils, are formed when local watershed stakeholders come together to protect their watershed. These groups are engaged in a wide range of efforts to protect and restore the state's water resources and the watersheds that sustain them. These include local restoration efforts, data collection and monitoring, local education and outreach efforts, and providing a conduit between local government, landowners and citizens interested in protecting the watershed. Many are also involved in long-range planning and assessment projects to provide information that can affect policy and management decisions.

Not every community has an active watershed group, but there are currently more than 300 watershed groups in California.

Watershed groups are funded through local, state and federal sources. Most depend on state and federal grants matched by local funds. Recent state funding to promote community-based watershed efforts has come through CALFED's Watershed Program.

Propositions 40 and 50 (administered by the State Water Boards and the Department of Water Resources), the Non-

Point Source program 319 funds (as part of the Clean Water Act's Section 319) and the State Water Boards' revolving fund and community assistance grants are the primary funding sources supporting local watershed management efforts.

Many watershed councils and state officials are worried about future support for watershed projects as these funding sources end.

Federal funding has been available through the Department of Conservation's Watershed Coordinator Grant Program, which funds watershed coordinators through local resource conservation districts.

Watershed management plans have been developed over the years by watershed partnerships.

Integrated water management efforts

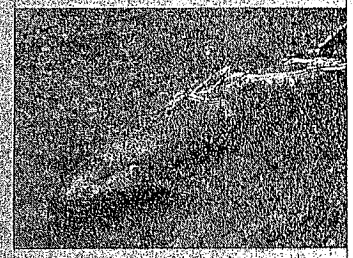
The State of California has developed an Integrated Regional Water Management Grant program, which has encouraged integrated regional strategies for managing water resources and provided grant funding or projects that protect communities from drought, protect and improve water quality, and reduce dependence on imported water. Several impressive regional projects have grown out of this effort.

Integrated Regional Watershed Management Plans

Southern California region eyes making its watershed drought-proof

The Santa Ana Watershed Project Authority covers a Southern California region projected to grow by 5-10 million residents in the next 50 years. The agency developed the Southern California Integrated Watershed Program as a series of projects that would be needed to achieve its goal of making the watershed drought-proof (by requiring no imported water during drought years). The intent is to complete this program within 10 years, providing that sufficient funding is acquired. The program includes a message to the planning community to "integrate watershed thinking into the everyday planning process." For more information: www.sawpa.org

North Coast develops comprehensive plan to meet the region's shared water goals



The North Coast Integrated Regional Water Management Program is developing a comprehensive plan to increase cooperation between regional stakeholders in meeting shared water management goals. The program encourages projects that offer multiple benefits, are integrated with other regional efforts, and address water supply, water quality, wastewater, stormwater, flood control, watershed planning and aquatic habitat protection and restoration.

Improving coordination and collaboration among agencies responsible for managing water-related issues, including local land use agencies, is a key to achieving greater efficiencies. Additional benefits include the enhancement of public services and building of public support. The joint effort will also help to improve regional competitiveness for state and federal grant funding.

"The North Coast IRWMP's unique, multi-jurisdictional approach has brought together agencies dealing with water supply, water quality and land use planning," said Rohnert Park Councilmember Jake Mackenzie, the North Coast program's vice chair. "The process relies heavily on the leadership of local elected officials, as well as extensive critical review by an advisory board representing all seven counties. It has brought about an amazing amount of communication between the counties and water management agencies." For more information: www.northcoastirwmp.net

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Implementation Principle 3 – Integrated solutions achieve multiple benefits

…t, multi-benefit and …ted strategies and …s should be identified …plemented before less …ated proposals, unless …y demands otherwise.

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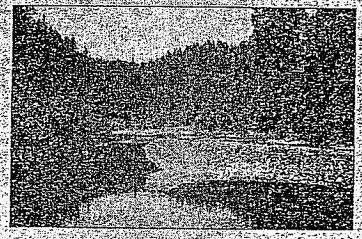
Many of the strategies outlined in the Ahwahnee Water Principles have more than one benefit. Whenever possible, strategies should be chosen that provide two-fers, or better.

For example, putting up a levee will help prevent flooding, but it is not effective as an Ahwahnee Principle strategy that both prevents flooding and replenishes groundwater supplies.

The first community water principle suggests that we develop our cities in a compact manner so that automobile-generated urban runoff pollutants are minimized and open lands are preserved. This strategy is not only better for the community water supply, it also reduces air pollution and provides the walking and biking opportunities that help our populations incorporate healthy physical activity into their daily lives.

Ideally, planners and developers will apply all the Ahwahnee Water Principles, including natural drainage systems, the use of permeable surfaces, water-conserving landscapes, and water-conserving toilets. Integrating these measures achieves the maximum benefit.

Less expensive recycled water reduces threat of floods



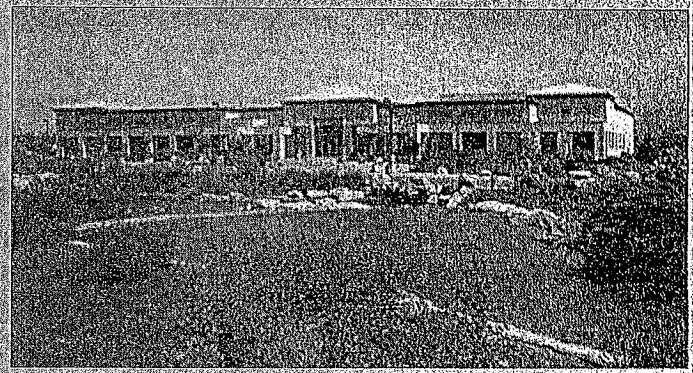
Communities whose treated sewage empties into the Russian River – a Northern California river that is very prone to flooding – have accomplished two community benefits by using recycled water to irrigate landscapes. First, recycled water is less expensive than potable water, so the community and its residents save money. Second, by keeping wastewater out of the river, the threat of flooding during heavy periods of rain is reduced. While beefing up the area's levees may be effective in an emergency, diverting water from the area for productive uses also has more benefits in the long term.

Combining smart growth and low-impact development

The City of Ventura uses an infill-first strategy to avoid urban sprawl and minimize the impacts of development on local watersheds. Mixed-use, multi-story buildings replace small, dilapidated buildings currently surrounded by large parking lots. Underground parking lots, retail on street level and residences or offices on the upper floors now serve to reduce the development's impervious footprint. New developments are also conditioned with the goal of mimicking a site's pre-development hydrology. Design techniques manage runoff throughout the development. These structures retain, infiltrate, filter, store and evaporate, and detain runoff close to its source. Preferred conditions emphasize the use of grassy swales and depressed landscape areas. The result provides a range of benefits to the community and the environment. Landscaped areas help capture runoff and recharge groundwater, open space and agriculture remain intact, and pedestrian activity increases while fewer car trips are made. For more information: Vicki Musgrove, City of Ventura, (805) 652-4518

Inland Empire headquarters combines a variety of water- and energy-efficient measures

The Inland Empire Utilities Agency's LEED Platinum headquarters, located in Chino, integrates components of all of the community Ahwahnee Water Principles. The 22-acre Chino Creek Park, which abuts the agency's headquarters, serves as a regional community park dedicated to reestablishing the river's ecological function and native wildlife ecosystem.



The centerpiece is the restoration of approximately 16 acres of riparian habitat and wetlands, which will improve runoff water quality and benefit endangered species. Minimal grading during the construction of the building also helped preserve natural landscape features and promote natural drainage capacity. The two-acre headquarters site was planted with native, drought-tolerant trees and shrubs to create a natural setting for songbirds and other species.

Designed to manage a 25-year storm on-site, the project integrates sustainable stormwater solutions including permeable paving, bioretention basins, swales and disconnected roof sp Using these low-impact development techniques instead of conventional stormwater infrastructure netted a savings of more than $1.4 million in capital costs.

Combining several water-conservation strategies has reduced potable water demand by 73%. Native and drought-tolerant landscaping is irrigated with highly efficient smart irrigatic controllers using reclaimed graywater. Inside the building, dual-flush toilets and ultra-low-flow urinals use 100% recycled water from the agency's treatment facilities and use 27% less water than conventional toilets and urinals. Faucet aerators reduce limit flow to 0.5 gallons per minute.

Wastewater treated at the processing plant not only irrigates all landscaped areas, it will soon supply water to neighboring farms and industry where potable water is not needed. Water from the treatment process is also reclaimed and used for industry and for recharging regional aquifers.

Integrated groundwater program reduces Chino Basin's dependence on imported water

The Chino Basin Recycled Water Groundwater Project integrates stormwater management and water supply enhancement strategies to solve multiple problems. The project is part of the comprehensive Water Supply Enhancement Program sponsored by the Inland Empire Utilities Agency, Chino Basin Watermaster, Chino Basin Water Conservation District and the San Bernardino County Flood Control District.

It aims to reduce dependence on expensive imported water supplies and provide a local drought-proof supply of new water for the Chino Basin. The project will blend high-quality stormwater and recycled water to recharge the groundwater basin. It offsets the need for approximately 16,000 acre-feet of imported water, saving about $4 million per year in imported water purchases, and provides reliable water supplies to meet future growth without any significant increase in water and sewer rates. For more information: (909) 993-1600 or www.ieua.org/RecycledGroundwater.html.

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Implementation Principle 4 – Public involvement and stakeholder collaboration

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art to finish, projects ograms should involve blic, build relationships, crease the sharing of cess to information. rticipatory process should focus on ensuring that all residents have access to clean, reliable and affordable water for drinking and recreation.

Planning professionals, with their training and experience, are invaluable to the planning process. They cannot, however, be expected to foresee and understand every variable that may affect a project's outcome. On the other hand, residents may lack a thorough understanding of the principles and processes of planning, but they do bring valuable information and perspectives to the table.

The Public Policy Institute of California found that the quality of Urban Water Management Plans created by municipal water suppliers was significantly improved when the planning process included broad-based public participation and outreach. [50]

A proactive planning process, which includes a well-designed public involvement component, encourages individuals to consider the big-picture question of whether or not a proposed plan will enhance or damage the quality of life in the neighborhood and region in which it is built. It allows the community to make decisions based on shared goals and values.

Such a process allows participants to understand exactly what they are getting, assuring better public approval at build-out. Projects that develop strong public buy-in through participation are less likely to experience delays due to public opposition.

By involving residents in the planning process, a planning team can ensure that plans will have a long-lasting and stable constituency. Finally, a well-designed public process can renew the diminishing faith in government.

"Out of our effort in Pasadena to have thousands of residents in the community participate, came the seventh principle of the new general plan: Public participation will be a permanent part of achieving a greater city," according to Rick Cole, Pasadena's former mayor. "(Pasadena's) Seventh Principle has changed government, making it more open, responsive and effective. It has also raised the level of trust among residents – not trusting in City Hall, but trusting that they own City Hall."

New public participation tools

Many advances in technology are making it easier to involve the public in complex decisions, including computer simulation and geographic information systems.

Computer simulations allow the designer to produce a fairly accurate image of a proposed project. They help the public feel comfortable that they understand what they are going to get in the end.

Geographic Information Systems (GIS) allow complex spatial information to be displayed in the form of colored maps. They allow the users to envision various land use alternatives and understand their potential economic, social and environmental impacts. The result is a far more information decision-making process.

The Local Government Commission has also successfully employed a more low-tech approach called the Community Image Survey. This tool helps participants in a planning process understand their choices: Would they prefer a wide residential street or a narrow one? A mall or a town center? Contrasting photographs give participants the chance to choose what they would prefer. Results are tallied and the group's preferences are announced and incorporated in the proposed plan.

Implementation Principle 5 – Evaluate and adapt

Plans, programs and policies should be monitored and evaluated to determine if the expected results are achieved and to improve future practices.

Too often, plans end up on the shelf, programs are implemented and yet not completed, and policies don't achieve their intended outcomes. Monitoring and evaluation are important aspects of planning and implementation that ensure plans are effective, and that policies and programs are implemented and achieve results.

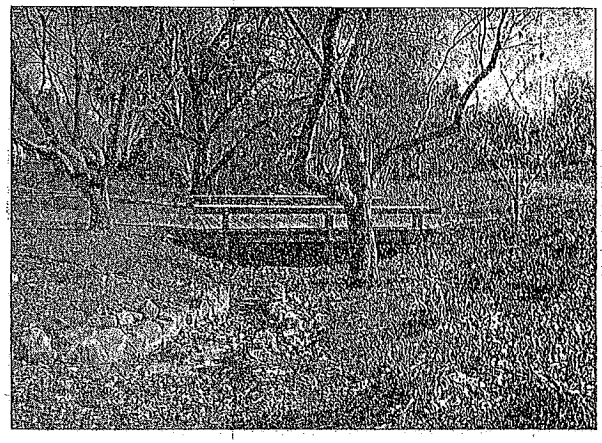
Because resources are required to evaluate the effects of public policy, this crucial task is not often undertaken. However, to assure that community policies are effective, evaluation is important. Evaluation also allows for adaptation so that policies and programs can evolve with the times.

Evaluation and monitoring should be based on good data and an open, ongoing dialogue between staff, elected leaders and the public. Natural resource managers call this "adaptive management," an approach that allows on-going refinement of policies so that decisions will reflect lessons learned and address current needs and issues.

Evaluation can take many forms. It can involve the collection of monitoring data, such as water quality indicators, to determine the effectiveness of a given program. It can also involve community surveys, public meetings and focus groups to gauge the public's view of a particular policy or program. The specific form and methodology depends on the situation, but it is always advisable to apply the resources needed to evaluate city or county programs.

A well-designed evaluation and monitoring program will:

- Establish measurable goals and objectives.
- Provide a framework for assessing project performance.



- Identify measures that can be used to monitor progress toward achieving project goals.
- Provide information to help improve current and future projects.
- Maximize the value of public expenditures to achieve environmental results.

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Levels of evaluation

A project can be evaluated on a number of levels, and a range of evaluation models have been developed for different needs. One key of all of these strategies is that evaluation needs to be conducted from start to finish in any project.

It is best to start evaluation before a project is developed or implemented. Often called a "needs assessment," this form of evaluation allows decision-makers to see what problems need to be addressed before they try to solve them. This

seems obvious, but assessing the needs that a given policy solution is meant to address is rarely done.

Once it is clear what needs to be done and a policy solution is developed, goals can be set. Setting goals and milestones for meeting those goals is a vital step in developing and implementing effective policies and programs. Goals clarify the intention of the program, policy or project being implemented, and help the community know what to expect.

The next level of evaluation should occur throughout the development of the policy or program being implemented. Identifying baseline data – whether it is quantitative or qualitative – provides a gauge for measurement. As the policy is implemented, progress can be checked against baseline information to see if it is working.

This level of evaluation is critical because it allows us to identify problems and adapt solutions to stay on course to reaching the intended goal.

Finally, evaluation should occur at the conclusion of a project. Once the project, program or policy has been implemented or built, it is important to measure its effectiveness. This helps to determine whether the desired outcome was met and what lessons were learned that could be applied to future decisions.

It also allows elected leaders to gauge the return on investment – whether the benefits are worth the costs. This is hard to determine if measurable goals have not been set.

Southern California studies demonstrate cost and water savings from weather-based irrigation controllers

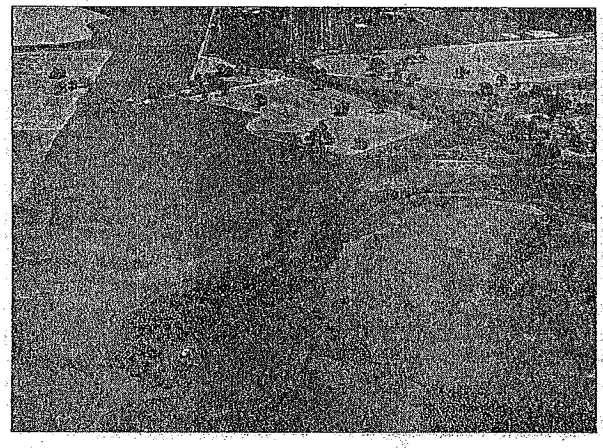
In 2001, the Irvine Ranch Water District, the Municipal Water District of Orange County and the Metropolitan Water District of Southern California completed a small-scale study of weather-based evapotranspiration (ET) irrigation controllers. Water demand and runoff from 40 controllers installed in Irvine's Westpark residential neighborhood were measured. Water savings averaged 37 gallons per day, or 7% of total household water use.

Based on these findings, the Irvine Ranch and Orange County districts partnered on another project, the Residential Runoff Reduction (R3) Study. The study had four primary purposes:

- Test the use of weather-based irrigation technology, also known as ET controllers, to manage irrigation water for residential homes and large landscape areas.
- Evaluate the effectiveness of a targeted education program on residential homeowners.
- Determine the correlation between proper water application in landscape irrigation and the quantity and quality of urban dry-season runoff.
- Gauge the acceptance of water management via the controller technology.

For more information: www.irwd.com/Conservation/water_conservation_research.php

Selected Resources





Principle 1: How we grow

The Local Government Commission (www.lgc.org) has developed several resources to help communities encourage compact growth through redevelopment, infill and other design strategies:

- Building Livable Communities: A Policymaker's Guide
- Street Design Guidelines for Healthy Neighborhoods
- Smart Growth Zoning Codes: A Resource Guide
- Compact Development Compact Disc: A Toolkit to Build Support for Higher Density
- Creating Great Neighborhoods: Density in Your Community

The Greenbelt Alliance, "Smarter Infill" (www.greenbelt.org)

U.S. EPA guides for using smart growth as a water management strategy (www.epa.gov/smartgrowth):

- Protecting Water Resources with Smart Growth
- Using Smart Growth Techniques as Stormwater Best Management Practices
- Protecting Water Resources with Higher Density Development
- National Management Measures to Control Nonpoint Source Pollution from Urban Areas
- Growing toward More Efficient Water Use: Linking Development, Infrastructure, and Drinking Water Policies

The EPA's model Phase II stormwater permit with language for smart growth strategies as stormwater best management practices: www.epa.gov/npdes/pubs/modpermit.pdf

Principle 2: Where we grow

The Center for Watershed Protection (www.cwp.org) hosts many articles and online tools.

The EPA's many resources on watershed protection practices include build-out tools (www.epa.gov/greenkit/2tools.htm) and source water protection plans (www.epa.gov/safewater/protect.html).

The Trust for Public Land published "Protecting the Source" on regional source water protection efforts: www.tpl.org/tier3_cd.cfm?content_item_id=1337&folder_id=195

Nonpoint Education for Municipal Officials (NEMO) has developed resources on "Natural Resource Based Planning:" www.nemonet.uconn.edu

Stormwater management

The EPA's National Menu of Stormwater Best Management Practices provides guidance for all six minimum control measures required for municipal (MS4) NPDES permits: http://cfpub.epa.gov/npdes/stormwater/menuofbmps

California's State Water Board (www.swrcb.ca.gov) is an important resource for current regulatory information and links to regional board web sites. Its stormwater program's Post Construction Runoff Control web page has links to low-impact development documents: www.swrcb.ca.gov/stormwtr/post_construction.html

The State Water Board's Nonpoint Source Pollution Control Program (www.swrcb.ca.gov/nps) has produced the California Nonpoint Source Encyclopedia: www.swrcb.ca.gov/nps/encyclopedia.html

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Principles 3-4-5: Low-impact development

The California Stormwater Quality Association (www.casqa.org) assists the State Water Board and communities to implement the National Pollutant Discharge Elimination System (NPDES) stormwater mandates.

The LID Center has information and technical tools on the selection and use of low impact development best management practices: www.lowimpactdevelopment.org/epa03/biospec.htm

The Bay Area Stormwater Management Agencies Association developed "Start at the Source – Design Guidance Manual for Stormwater Quality Protection." For this and other documents: www.basmaa.org/documents/index.cfm?fuseaction=documents&doctypeID=3

Principle 4: Water-wise landscaping

...e.Org has a good example of a guide – "Bay Friendly ...e Guidelines" – that cities and counties can develop ... water suppliers to educate the public about ... efficient landscaping.

The California Urban Water Conservation Council works to integrate water conservation's best management practices into the planning and management of California's water resources. Its web site (www.cuwcc.org) contains technical resources and a standard set of best management practices that the Council regularly updates as new practices evolve.

The Department of Water Resources' Landscape Water Use web site includes California's Model Water Efficient Landscape Ordinance and the "Water Use Classifications of Landscape Species" guide for selecting plants and planting materials, and developing irrigation schedules for existing landscapes: www.owue.water.ca.gov/landscape/faq/faq.cfm

Principle 4: Trees and urban forestry

Many resources on tree selection and benefits are available:

- The Local Government Commission's fact sheet on "Livable Communities and Urban Forests" highlights the economic, public health and environmental benefits provided by trees: www.lgc.org/environment/trees.html
- American Forests' City GREEN software is a useful tool for analyzing cost savings: www.americanforests.org
- The U.S. Forest Service's Center for Urban Forest Research (CUFR) at UC Davis hosts a web site with up-to-date research and technical guidance: www.fs.fed.us/psw/programs/cufr
- The LGC and CUFR have developed tree guidelines for California's San Joaquin Valley, Southern Coast and the Inland Empire regions: www2.lgc.org/bookstore/list.cfm?categoryId=2

Principle 5: Minimize impervious surface cover

The Congress for New Urbanism and the Institute of Transportation Engineers have produced an arterial-street design guide to accommodate pedestrians: www.cnu.org

U.S. EPA's Parking Spaces/Community Spaces: www.epa.gov/smartgrowth

Portland's Metro developed a regional street design manual, specifying stream treatments, street width and associated water quality benefits: www.metro-region.org



Many of the resources listed in the low impact development section offer solutions for minimizing paved surfaces and using permeable alternatives.

The Local Government Commission (www.lgc.org/freepub) has developed several useful resources, including two related to reducing impervious surfaces through street design:

- Emergency Response and Narrow Streets
- New Thinking for a New Transportation Age

Principle 6: Graywater

Graywater Central web site (hosted by Oasis Designs): www.graywater.net

California's graywater standards: www.owue.water.ca.gov/docs/Revised_Graywater_Standards.pdf

City of Santa Monica's Graywater Guidelines: santa-monica.org/epd/residents/Water/graywater.htm

City of Malibu's Graywater Handbook: www.ci.malibu.ca.us/index.cfm?fuseaction=detailgroup&navid=274&cid=2949

WateReuse Association: www.watereuse.org/ca/index.html

Principle 7: Recycled Water

WateReuse Association model recycled water ordinance (California): www.watereuse.org/ca/modelwrord.htm

Department of Water Resources' 2005 Water Plan Update Sections 12–Matching Water Quality to Use and 16–Recycled Municipal Water: www.waterplan.water.ca.gov/cwpu2005/index.cfm#vol2

The State Water Board's Office of Water Recycling has important information about the use and development of recycled water as well as information on funding programs to help communities get recycling: www.swrcb.ca.gov/recycling

California Recycled Water Task Force documents and findings: www.owue.water.ca.gov/recycle/taskforce/taskforce.cfm

South Bay Water Recycling Rules and Regulations: www.sanjoseca.gov/sbwr/rulesandregulations.htmf

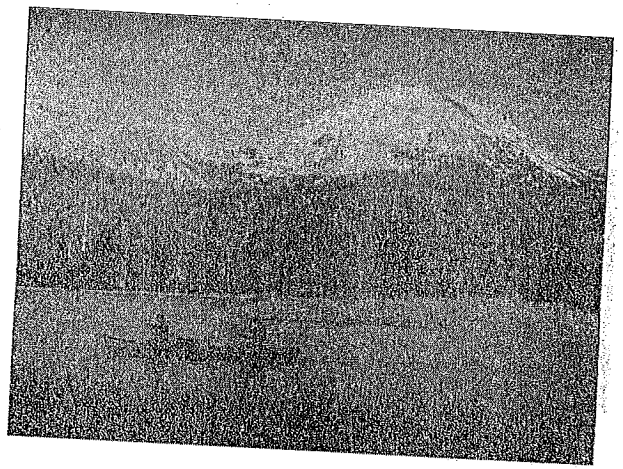
WateReuse.org: www.watereuse.org

WateReuse Technical Resources: www.watereuse.org/techres.htm

Department of Water Resources' Water Recycling and Desalination Program: www.owue.water.ca.gov/recycle/index.cfm

U.S. EPA Guidelines for Water Reuse: www.epa.gov/ORD/NRMRL/pubs/625r04108/625r04108.htm

West Basin Municipal Water District's Recycled Water User Manual: www.westbasin.org/pdf/Recycled_Water_User_Manual.pdf





Principle 8: Water conservation

The California Urban Water Conservation Council is a 350-plus member partnership of urban water agencies, public interest organizations and private entities working to increase efficient water use through integration of urban water efficiency Best Management Practices into the planning and management of California's water resources. These BMPS are regularly updated to reflect the most effective and current practices: www.cuwcc.org

Bewaterwise.com provides a range of water conservation information from the family of Southern California regional water agencies, including information on landscaping, native plant use and a watering index.

The Association of California Water Agencies has abundant information on current and pending legislation, and several resources on a range of water issues: www.acwa.com

The Department of Water Resources' Office of Water Use Efficiency provides support for the stewardship of Californ water resources and energy-efficient use of water: www.owue.water.ca.gov

www.h2ouse.org provides a virtual home tour of a model water-saving home.

The Pacific Institute has research publications on the use and potential of urban water conservation: www.pacinst.org

Principle 9: Cleaning up groundwater supplies

The Water Education Foundation has resources on groundwater and many other topics: www.water-ed.org

The Department of Water Resources (www.water.ca.gov) has information on desalination in the 2005 Water Plan Update: www.waterplan.water.ca.gov/cwpu2005/#vol2





End Notes

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9 Stein, Eric and Zaleski, Susan. 2005. "Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California." Southern California Coastal Water Research Project and USC Sea Grant.

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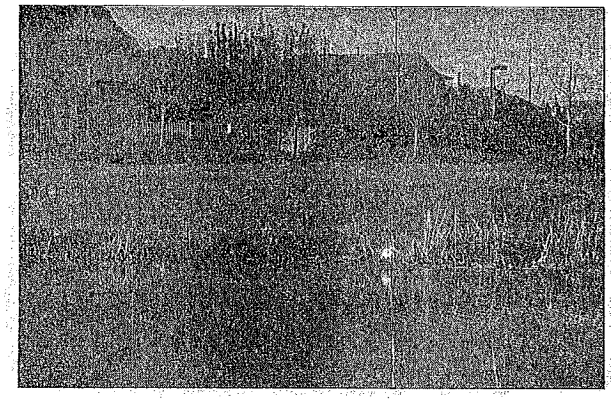



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Appendix A. The Model Water Element

Communities often have water-related policies interspersed throughout various elements of their General Plan because many aspects of the community's development and well-being are linked to water. Including a separate water element in the General Plan will help communities coordinate land use practices with the protection and management of water resources.

A stand-alone water element indicates a community's commitment to protecting local and regional water resources.

ng water-related policies and information in one
o allows for more integrated solutions and makes
rmation more accessible to the public. Once estab-
ater element policies can be interspersed through-
r General Plan elements and planning documents.

water information and policies in a single place can
amline compliance with requirements for National
t Discharge Elimination System (NPDES) permits,
SB 610 supply assessments and SB 221 supply verification.

This Model Water Element provides a policy framework to address the links between water and land use, and builds upon the watershed-based approach of the Ahwahnee Water Principles and the rest of this guidebook.

Watershed-based policy solutions provide the opportunity to build on the connectivity between the hydrological, ecological and social elements of watersheds. Surface water and groundwater are connected; water quality and supply are connected. Increasingly, our ability to grow as a community is a function of how the use and quality of water is managed. These policies, like the Ahwahnee Water Principles, strive to protect or restore the health and function of watersheds.

Sample Policy Language

The policy language provided in the Model Water Element has been taken from existing General Plans and other planning documents from around the state. Some local governments already have developed – or are developing – water elements for their General Plans. The State Office of Planning and Research also provides a chapter on developing a water element in its 2003 General Plan Guidelines (www.opr.ca.gov/publications/#pubs-G).

In addition to precise policy language, the Model Water Element provides "ideas for data and analysis" about integrating water into planning documents. It is also a helpful resource for communities that are not developing a stand-alone water element, but are looking to address water resource issues within their land use decision-making processes.

Each section of the Model Water Element also provides a set of policies and actions to support implementation. These are primarily program measures that address coordination and collaboration, public involvement, education and outreach, incentives, and monitoring and assessment.

These measures can make the difference between plans that are left on the shelf and those that are put into action. They build local and regional capacity to respond to needs with effective and adaptive policy solutions, and will help earn the trust and support of local residents and neighboring communities.

The following sample policies in the Model Water Element are arranged in three sections:

1. **Watershed protection and management**
2. **Protecting and improving water quality**
3. **Managing supply and demand of water resources**

While each section contains policies to address particular subjects, most water issues (and policies) are interrelated – and therefore difficult to limit to one category.

Watershed-based policy solutions take advantage of these linkages, and are especially effective when used in a coordinated manner to address several water quality, supply and flood management concerns. Similarly, policies intended to protect water quality can also augment water supplies, and help maintain essential watershed processes.

Watershed protection and management

These policies address how and where development occurs within a watershed. Many of them encourage community design that minimizes the impact and overall footprint of a community or a development project using smart growth techniques to create a compact, walkable design with mixed uses, a range of transportation options and a well-connected street network.

Other policies outlined in this appendix seek to protect natural areas and ecological systems to better maintain watershed processes. Taken together, these approaches are geared toward minimizing impacts from development and preserving watershed health to ensure sustainable water supplies, reduce flood risks and protect natural values.

Ideas for data and analysis

Compiling pertinent information about local natural resource conditions – such as floodplain maps, soils, local water bodies and important habitat or ecological areas – is typical in General Plans. This information is also useful for analyzing watershed conditions and can be supplemented with other data about local watersheds, including watershed boundaries, aquifer recharge areas, soil permeability and existing land uses related to the watershed(s).

In many places, local watershed councils or other groups have completed a watershed assessment that can provide a foundation for watershed-based policy solutions. These assessments typically include:

- A delineation of watershed boundaries.
- An inventory of important hydrologic features, such as rivers, lakes, groundwater basins, floodplains, riparian zones and estuaries.
- A discussion of the basic water resources and services that these features provide, including sufficient clean water, aquifer recharge, pollutant filtering and flood protection.
- A discussion of related resources such as fisheries, forestry, agriculture and recreation that are sustained by the watershed.

A water resource inventory should link water-related information to existing land uses and infrastructure. It should identify existing and projected water supply sources and analysis of projected demands. It may be possible to obtain this information from Urban Water Management Plans prepared by water suppliers. Local government can partner with water agencies and/or watershed groups to develop this information as part of a comprehensive watershed assessment that links data about water supply, demand, quality and land uses in the watershed.

Geographic Information Systems (GIS) is a very useful format for collecting and analyzing watershed data. GIS maps and data can be coordinated with other planning maps. Many communities already have many of the data layers needed, while others are available through state sources. A GIS's visual format allows planners, developers and the public to "see" the relationship between watershed features and functions, and zoned land uses. It also enables analysis of policy solutions using more sophisticated modeling techniques.

A. Compact development

These policies encourage compact development that mixes uses and supports multi-modal transportation options. Compact development can minimize the impact of new growth on water resources by reducing the community's footprint and allowing preservation of the watershed. Multi-modal transportation can reduce water pollution from cars, minimize the need for transportation-related impervious surfaces, and support compact development.

■ County of Los Angeles General Plan

Promote infill development to take full advantage of the existing capacities of public services and facilities.

Promote development of vacant infill sites at higher in recycle underutilized sites, and advocate the cleanup, redevelopment and reuse of brownfield (potentially p sites.

Promote compact, walkable, well-designed mixed-u opment in and adjacent to employment and transit and commercial corridors to provide convenient acce... jobs, shopping and services.

Promote ordinances that initiate transit-oriented development along bus and rail transit corridors.

Promote land use that encourages multi-modal transit nodes in unincorporated areas.

■ County of Riverside General Plan

Re-plan existing urban cores and specific plans for higher-density, compact development as appropriate to achieve the Riverside County Integrated Project Vision.

Concentrate th near community centers that provide a mixture of commercial, employment, entertainment, recreation, civic and cultural uses to the greatest extent possible.

Concentrate growth near or within existing urban and suburban areas to maintain Riverside County's rural and open space character to the greatest extent possible.

Site development to capitalize upon multi-modal transportation opportunities and promote compatible land use arrangements that reduce reliance on cars.

■ City of Livermore Land Use Element

Encourage the clustering of development to minimize its overall footprint in areas of ecological sensitivity, such as hillsides, alkali springs, creek corridors and watersheds.

ıta Monica Sustainable City Plan

nent land use and transportation planning and policies te compact, mixed-use projects, forming urban villages ed to maximize affordable housing and encourage , bicycling and the use of existing and future public ystems.

of Chico General Plan

Maintain and enhance a strong pedestrian scale and orientation within the downtown through the design of buildings and streets.

■ City of Windsor General Plan

Streets, paths and greenways connect the town and constitute the most basic civic open space. Their design should consider the needs of pedestrians and bicyclists, as well as cars, and contribute positively to the town's identity.

■ City of San Diego General Plan

Design an interconnected street network within and between communities, which includes pedestrian and bicycle access, while minimizing landform impacts.

B. Natural resource protection and watershed management

Protection of important natural areas, which is critical to watershed protection, is facilitated by compact land-use patterns that compact development policies create, but it also requires policies that ensure key areas are sufficiently protected and managed. This includes policies for wetland and stream protection, buffer and setback standards, and the acquisition and protection of open space to serve these purposes.

■ City of Thousand Oaks

Protect remaining floodplains to help retain stormwater runoff from tributary watersheds and reduce the potential for periodic flooding within downstream reaches of the Arroyo Conejo and Calleguas Creek.

■ City of Arcata General Plan

Ecological systems and natural processes are not to be disrupted by land use activities to a significant degree (e.g., a culvert or other drainage device that blocks fish passage).

An "adaptive management" approach shall be used to maintain ecological and biological integrity, including monitoring the status of ecological systems in the city and adjusting City implementation of the plan, to more closely approximate the conditions provided in the planning area's least-disturbed natural ecosystems.

Streamside Protection Areas (SPA) are established along both sides of the streams identified on the City Watercourse Map. These areas shall remain in a natural state to protect the streams' ecosystems and their associated riparian habitat areas. The SPA shall include:

1 In areas where existing development, as defined in the Land Use Code, is adjacent to the stream, the SPA shall be not less than 25 feet outward on both sides of the stream, measured from the top of bank.

2 In all other locations within the city, the SPA shall be not less than 100 feet outward on both sides of the stream, measured from the top of bank.

3 In locations within the city having significant areas of riparian vegetation exceeding 100 feet in width measured from the top of bank, the SPA shall be expanded to encompass all of the riparian vegetation, except in no case shall the SPA exceed 250 feet in width from the top of bank on either side of the stream.

Maintenance of streams as natural drainage systems: Arcata's creeks carry a significant amount of the city's stormwater. Drainage controls shall be enforced through implementation of the Drainage Master Plan, to protect water quality, and minimize erosion, sedimentation and flood impacts to city creeks. A comprehensive stream maintenance program shall be prepared to augment stormwater utility rehabilitation projects designed to improve flow capacity, minimize channel erosion, and enhance riparian habitat.

■ City of San Luis Obispo

Wetlands and associated wetland buffers are to be preserved as open space, and maintained in a natural state to protect the community's water quality, wildlife diversity, aesthetic values and recreation opportunities.

Wetlands are to be protected from development impacts by requiring a wetland buffer around these areas. The wetland buffer should: (1) be located between the wetland and proposed, existing or potential development; (2) be of a sufficient width and size to protect the species most sensitive to development disturbances and to compensate for project impacts as determined by a qualified biologist during the initial planning phase of development; and (3) be designed to complement the habitat value of the wetland resource.

■ County of Los Angeles General Plan

The goal is effective management of watersheds, which balances growth and development with resource conservation, flood hazard mitigation, habitat preservation and water quality protection.

Support the preparation and implementation of Watershed and River Master Plans to enhance aquatic habitats, promote recreational opportunities, and restore natural features.

Conserve, restore and monitor wetlands and other riparian habitats to preserve the natural hydrologic conditions and associated biotic habitats that support the wetland function.

Support the preservation, restoration and strategic acquisition of open space to preserve natural streams and drainage channels, which are necessary for the healthy function of watersheds.

■ City of San Diego General Plan

Apply the appropriate zoning and environmentally sensitive lands regulations to limit development of floodplains, wetlands, steep hillsides, canyons and coastal and waterfront lands.

■ City of Ventura General Plan

Require that sensitive wetland and coastal areas be preserved as undeveloped open space wherever feasible and that future developments result in no net loss of wetlands or "natural" coastal areas.

■ City of Livermore General Plan

Conserve the value and function of Livermore's open space as a biological resource.

Require appropriate setbacks, to be determined in coordination with resource agencies, LARPD, EBRPD and other responsible agencies, adjacent to natural streams to provide adequate buffer areas that ensure the protection of plant and animal communities.

■ City of Santa Cruz General Plan

Minimize the impact of development upon riparian and wetland areas through setback requirements of at least 100 feet from the center of a watercourse for riparian areas and 100 feet from a wetland. Include all riparian vegetation within the setback requirements, even if it extends more than 100 feet from the watercourse or if there is no defined watercourse present.

■ City of Fresno General Plan

The city will continue to support the concept of a regional river parkway system in the river bottom, in coordination with Fresno County, Madera County, public interest groups, property owners and the State of California.

■ City of Grass Valley General Plan

Establish open space easements along riparian corridors.

C. Vegetation protection and management

These policies address the use and protection of trees or natural vegetation for maintaining watershed processes, and the management of landscaping and urban forests in developed parts of the watershed. These policies overlap with those in other sections, including policies about construction practices and water quality.

■ City of Chico General Plan

Protect and enhance the urban forest that reinforces the image and identity of the community and its older neighborhoods.

■ City of San Luis Obispo Draft General Plan

Protect, preserve and create the conditions that will promote the preservation of significant trees and other vegetation, particularly native California species.

■ City of Livermore General Plan

Conserve Livermore's native trees and vegetation, which are important biological resources within the planning area.

Require new developments to incorporate native vegetation into their landscape plans, and prohibit the use of invasive non-native plant species. Propagules (seeds or plants) of native plants shall be from native sources.

■ City of Woodland General Plan

The City shall require that new development preserve natural woodlands to the maximum extent possible.

D. Sustainable site preparation practices

The site preparation phases of development can be among the most detrimental to water resources. It is also during these phases that on-site environmental features – soils, topography and vegetation – can either be protected for their value as "green infrastructure" or degraded. The dredging and filling of wetlands and streams, and intensive grading and vegetation removal, alters site hydrology and creates downstream impacts on water resources.

The following policies are designed to minimize the impacts of site preparation practices and promote the protection of on-site environmental features as natural water resource infrastructure for their benefit to the new development.

■ City of Livermore General Plan

Grading and excavation in woodland areas shall avoid disturbances to subsurface soil, water or rooting patterns for natural vegetation.

The use of "green construction" and land development techniques shall be encouraged as a means to reduce the environmental impacts of construction activity.

Encourage all additions and new development to follow green building practices for design, construction, and operation and to incorporate as many LEED prerequisites and credits as feasible.

■ City of Rohnert Park General Plan

Require new construction to utilize site preparation, grading, and foundation designs for erosion control to prevent sedimentation and contamination of streams.

■ City of Malibu Local Coastal Program Land Use Plan

New development shall protect the absorption, purifying and retentive functions of natural systems that exist on the site. Where feasible, drainage plans shall be designed to complement and utilize existing drainage patterns and systems, conveying drainage from the developed area of the site in a non-erosive manner. Disturbed or degraded natural drainage systems shall be restored, where feasible, except where there are geologic or public safety concerns.

■ City of Santa Cruz General Plan

Require site design and erosion control measures in areas subject to erosion hazards or adjacent to streams and wetland areas to minimize grading activities and vegetation removal.

E. Policies and programs to support implementation

■ County of Sonoma Draft General Plan – Water Resources Element

Correlate the quality and quantity of water captured, stored and contained within each unique watershed to the needs of beneficial water uses by all county residents, local industry, agriculture and the natural environment.

Encourage and support research on and monitoring of local groundwater conditions, aquifer recharge, watersheds and streams.

Where a problem has been identified, promote and seek funding to evaluate and remediate it through a watershed management approach.

Work with the Regional Water Quality Control Boards, watershed groups and stakeholders in the collection, evaluation and use of watershed-specific water resource information.

■ Riverside County General Plan

Allow techniques, such as incentives, transfer of development credit programs or other mechanisms, to achieve more efficient use of land.

Allow development clustering and/or density transfers in order to preserve open space, natural resources and/or biologically sensitive resources.

■ County of Los Angeles General Plan

Promote improved inter-jurisdictional coordination of land use and transportation policy matters between the county, cities, adjacent counties, special districts and regional and subregional agencies.

■ County of Inyo General Plan

Work with federal and state agencies, local districts, utilities (LADWP) and Native American tribes to ensure that the County and the public are involved early in any planning process and that routine feedback and public input is requested.

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Water quality

Land use development significantly impacts water quality. These water quality policies aim to mitigate development impacts and protect and improve the quality of water for domestic, environmental, agricultural and other uses.

The growing need for high-quality drinking water supplies, new water quality regulations, public health risks and environmental values are just a few of the reasons to institute local policies to ensure water quality.

Full-scale water quality protection is linked to the watershed protection policies in the preceding section as well as the water supply policies in the subsequent section.

Ideas for data and analysis

Any existing water-quality monitoring data from water purveyors, watershed councils or government agencies can be included and may be useful to provide baselines for evaluating the effectiveness of programs and policies.

Specific local water quality impairments (TMDLS) and threats, such as specific discharge points, should also be identified and related to the supply sources they might impact (for example, MTBE as a threat to groundwater supplies).

An increasing number of communities are analyzing development patterns to manage stormwater quality by mapping impervious surface areas and using modeling to project water-quality impacts likely to occur from different development decisions.

A. Stormwater management

Municipal stormwater permits under the National Pollutant Discharge Elimination System (NPDES) program require communities to address the impacts of development on stormwater quality.

The planning and design stages of development offer some of the best opportunities for incorporating effective stormwater best management practices. Regulated communities need to develop Stormwater Management Programs that include measures for addressing the post-development impacts of stormwater runoff.

Addressing stormwater in the General Plan and other planning documents also assures that land use planning and stormwater management efforts are coordinated and not contradictory.

Stormwater management requires regional and site-scale policies. The following policies are therefore linked to watershed protection policies as well as water-supply policies for treating stormwater as a local supply source.

■ Santa Monica Municipal Code

The following urban runoff reduction requirements shall apply to all persons submitting applications for new development within the city.

When an application is submitted for a new development project, the applicant shall be required to submit an Urban Runoff Mitigation Plan to the Department of Environmental and Public Works Management.

In developing an Urban Runoff Mitigation Plan, the applicant shall infiltrate or treat projected runoff for the new development by an amount equal to or greater than the volume of runoff produced from a storm event through the incorporation of design elements.

The design elements used by an applicant may, but are not required to, include the following:

1) Maximize permeable areas to allow more percolation of runoff into the ground through such means as:

   a) Biofilters;

   b) Green strips;

   c) Swales.

The use of permeable materials in lieu of or to replace hardscapes will increase the amount of runoff seepage into the ground.

2) Maximize the amount of runoff directed to permeable areas and/or maximize stormwater storage for reuse or infiltration by such means as:

   a) Orienting roof runoff towards permeable surfaces, drywells, French drains or other structural best management practices (BMPs) rather than directly to driveways or non-permeable surfaces so that runoff will penetrate into the ground instead of flowing off-site.

   b) Grading the site to divert flow to permeable areas.

   c) Using cisterns, retention structures or green rooftops to store precipitation or runoff for reuse.

   d) Removing or designing curbs, berms or the like so as to avoid isolation of permeable or landscaped areas.

3) Remove pollutants through the installation of treatment control BMPs.

4) For purposes of compliance with this [Santa Monica] Section, pools, hot tubs and spas shall be considered impermeable surfaces.

5) The Urban Runoff Mitigation Plan must also include the applicant's plan for the maintenance of all BMP's requiring ongoing maintenance.

6) All Urban Runoff Mitigation Plans must include the applicant's signed statement accepting responsibility for all structural and treatment control BMP maintenance. The transfer of property subject to an Urban Runoff Mitigation Plan must include as a written condition to the transfer that the transferee assumes full responsibility for maintenance of any structural, and/or source or treatment control BMPs.

■ City of San Luis Obispo General Plan

The City will employ the best available practices for pollution avoidance and control, and will encourage others to do so. "Best available practices" means behavior and technologies that result in the highest water quality, considering available equipment, life-cycle costs, social and environmental side effects, and the regulations of other agencies.

■ City of Ventura General Plan

Require new developments to incorporate stormwater treatment practices that allow percolation to the underlying aquifer and minimize offsite surface runoff using methods such as pervious paving material for parking and other paved areas to facilitate rainwater percolation and retention/detention basins that limit runoff to pre-development levels.

Require stormwater treatment measures within new development to reduce the amount of urban pollutant runoff in the Ventura and Santa Clara Rivers and other watercourses.

Use natural features such as bioswales, wildlife ponds and wetlands for flood control and water quality treatment when feasible.

■ City of Santa Clara General Plan

Maximize water retention and reduce the quantity of water runoff.

■ City of San Jose General Plan

To preserve and enhance the scenic and aesthetic qualities of rural areas located within the City's Sphere of Influence, the design and construction of public and private right-of-way improvements should conform to the following guidelines:

1) Streets should be designed in consideration of the natural topography and the landscape. Divided streets and grade separations may be used.

2) Concrete sidewalks, curbs and gutters should be constructed only when required by the topography. Crushed gravel walks and vegetation-lined swales are encouraged.

■ City of Santa Cruz General Plan

Design and site development to minimize lot coverage and impervious surfaces, limit post development runoff to pre-development volumes, and incorporate storm drainage facilities that reduce urban runoff pollutants to the maximum extent possible.

Where feasible, direct runoff from rooftops and other areas to drywells.

Require low-flow-velocity, vegetated open channels, area drains incorporating grease and sediment traps, groundwater recharge facilities and detention ponds directly connected to impervious areas.

■ City of Livermore General Plan

Revise the Subdivision Ordinance and other Municipal Code sections to reduce the creation of impermeable surfaces in new development. Examples of strategies to reach this goal might include requiring the use of vegetative swales (biofilters) and detention/infiltration basins.

Existing property owners shall be encouraged, or required as appropriate, to reduce stormwater runoff by reducing impermeable surfaces.

■ City of Palm Desert General Plan

For existing landscapes, runoff, low-head drainage, overspray or other similar conditions where water flows onto adjacent property, nonirrigated areas, walks, roadways or structures shall be prohibited.

■ City of Rohnert Park General Plan

All specific plans shall address hydrology and drainage for their respective areas, as well as practices to be incorporated as part of individual development projects.

As part of the building permit process, require all development projects to comply with hydrology and drainage policies incorporated in the applicable Specific Plans.

The City shall review and approve the proposed drainage system requirements prior to construction on the project site.

B. Groundwater quality

These policies are used to ensure the quality of groundwater resources. This can involve protection of groundwater recharge areas and wellheads from point and nonpoint sources of pollution, as well as the treatment of contaminated groundwater supplies.

These policies have clear links to groundwater policies in the following section on water supply and demand. They are also related to watershed protection policies that protect natural recharge areas and to water quality policies because of the connections between surface water and groundwater systems.

- City of Santa Cruz General Plan

Identify and protect groundwater recharge areas to maintain suitable groundwater levels and protect groundwater quality for existing and potential municipal water sources.

Ensure that new development or land uses near surface water and groundwater recharge areas do not degrade water quality.

- County of Shasta General Plan

Institute effective measures to protect groundwater quality from potential adverse effects of increased pumping or potential sources of contamination.

- Sonoma County Draft General Plan – Water Resources Element

Encourage pretreatment and waste load minimization of commercial and industrial wastes prior to their connection to sewer systems.

Consider on-site wastewater management districts in areas with septic problems.

Actively pursue the abatement of failing septic systems that have been demonstrated as causing a health/safety hazard.

C. Policies and programs to support implementation

- City of Livermore General Plan

Encourage coordination between land use planning, site design and stormwater pollution control.

- City of Santa Clara General Plan

Participate on a regional basis in a nonpoint source control program to reduce pollutants in stormwater runoff.

Managing supply and demand of water resources

These policies are intended to ensure the reliability and most-efficient use of water supplies. The amount and availability of water supplies is a function of how much there is (supply) and how it is used (demand).

Water management has long been focused on increasing the supply side of this equation, but our ability to develop new supply options to meet future needs will largely depend on shifting focus to reduce demand on existing supplies as well. Policies to increase efficiency through indoor and outdoor water conservation, recycling of municipal wastewater, reuse of household graywater, and capture and/or infiltration of stormwater are combined with those to manage water resources for maximum reliability. Reliability is achieved through policies that develop a portfolio of sustainable water supply options to meet local and regional needs.

Ideas for data and analysis

Analysis can build on information from any watershed assessment. Otherwise, collecting land-use based supply and demand data is recommended. Water supply and demand projections should cover wet, normal, dry and multiple-dry years.

Opportunities for demand reduction through conservation, recycling and reuse and other measures should be included.

Urban Water Management Plans provide an important reference and would ideally be cross-referenced in the General Plan to facilitate coordination with water suppliers and compliance with SB 610 water assessments and SB 221 water supply verification.

A. Water supply planning

These policies correspond to water supply and demand planning processes and actions. Some are directly related to the new "show me the water" laws.

- City of Cathedral City General Plan

One goal of the General Plan is a sustainable, long-term supply of clean and healthful domestic water available for existing residents and future growth.

- County of Los Angeles General Plan

Proposed large-scale development shall provide for a guaranteed supply of water to serve the project, consistent with state regulations.

■ Santa Clara County General Plan

Countywide land use and growth management planning should be coordinated with overall water supply planning in order to maximize dependability of long-term water supply resources.

■ City of Fresno General Plan

Maintain a comprehensive, long-range water resource management plan that provides for appropriate management of all sources of water available to the planning area and ensures that sufficient and sustainable water supplies of good quality will be economically available to accommodate existing and planned urban development.

■ City of San Diego General Plan

Prepare, implement and maintain long-term, comprehensive water supply plans and options in cooperation with the appropriate state and federal agencies, regional authorities, water utilities and local governments.

B. Water-use efficiency

These policies are intended to increase water-use efficiency through indoor and outdoor conservation measures. They support technologies and practices that minimize the day-to-day water use to decrease demand.

■ City of San Luis Obispo Draft General Plan

Maximize the implementation of water conservation measures as a cost-effective way to manage water demands and reduce the dependence on imported water.

In planning for urban water needs, the City will adopt and strive for the most efficient available practices. The City will encourage other agencies to follow this policy. "The most efficient available practices" means behavior and devices that use the least water for a desired outcome, considering available equipment, life-cycle costs, social and environmental side effects, and the regulations of other agencies.

■ County of Riverside General Plan

Incorporate water conservation techniques, such as groundwater recharge basins, use of porous pavement, drought-tolerant landscaping and water recycling, as appropriate.

Require that new development utilize drought-tolerant landscaping and incorporate adequate drought-conscious irrigation systems.

■ City of Santa Cruz General Plan

Promote water conservation to reduce future demand through the implementation of the Urban Water Management Plan.

■ City of Ventura General Plan

Require low-flow fixtures, leak repair and drought-tolerant landscaping (native species, if possible), plus emerging water conservation techniques, such as reclamation, as they become available.

Demonstrate low water-use techniques at community gardens and city-owned facilities.

■ City of Livermore General Plan

The City shall adopt a series of Best Management Practices for water conservation measures that will be mandatory in new development and strongly encouraged in existing developments.

Projects deemed appropriate for the use of recycled water shall be required to use recycled water, when available, for uses outlined in the State Water Code.

Require compliance with the State and City's mandatory water efficient landscape ordinance.

Develop and provide incentives for existing and future customers to reduce water consumption.

Develop and institute a City-sponsored program of mandatory water conservation measures for new development. Develop a program for existing developments based on a voluntary participation with incentives to achieve specific targets for water conservation, including such elements as:

- ➢ Ultra-low flush toilets;
- ➢ Plumbing retrofits;
- ➢ Leak detection;
- ➢ Efficiency standards for water-using appliances and irrigation devices, and industrial and commercial processes;
- ➢ Graywater use;
- ➢ Swimming pool and spa conservation measures such as covers to reduce evaporation;
- ➢ Xeriscape landscape design standards.

■ County of Sonoma Draft General Plan – Water Resources Element

Increase the role of conservation and safe, beneficial reuse in meeting water supply needs of both urban and rural users.

Use water effectively and reduce water demand by:

- ➢ Requiring water conserving design and equipment in new construction.

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- Encouraging water conserving landscaping and other conservation measures.
- Encouraging retrofitting with water-conserving devices.
- Designing wastewater systems to minimize inflow and infiltration to the extent economically feasible.
- Limiting impervious surfaces to minimize runoff.

■ City of Cathedral City General Plan

Require the use of water-conserving appliances and fixtures in all new development, as mandated by state law.

■ City of Santa Cruz General Plan

Develop and implement a systemwide program to convert existing toilets to Ultra Low Flush (ULF) models; analyze how best to apply the savings realized from this conversion; and investigate other options and incentives for retrofitting other old water-inefficient fixtures.

Enforce the New Construction/Ultra-Low-Flush-Toilet Water Conservation Ordinance and periodically review this ordinance to determine if additional fixtures should be added.

Efficient water use in landscaping:

1) Choose plants that are suitable for the climate and their intended function, with an emphasis on native and drought-tolerant plants.
2) Prepare soils for water penetration and retention.
3) Design and operate suitable and efficient irrigation systems.
4) The City will encourage drought-tolerant landscaping, vegetable gardens and fruit trees in lieu of large expanses of lawn or other more water-demanding plantings.

Landscape maintenance: Landscaped areas will be properly designed for efficient water use, and shall be properly installed and maintained, including the upkeep and replacement of low-flow irrigation fixtures and equipment.

■ City of Palm Desert General Plan

If a project's water bills indicate that the landscaped areas are using less than or equal to the maximum water allowance for those landscaped areas of one or more acres, an audit shall not be required by the water purveyor.

■ City of Palm Desert Landscape Program

Develop and adopt a landscape ordinance for new and rehabilitated landscaping with specific irrigation designs, planting and maintenance plans emphasizing unity, aesthetics, water efficiency and stressing the planting of a diversity of native, drought-resistant species.

- Compose a list of recommended landscaping species that are native, drought tolerant and have forage value for wildlife.
- Compose a list of noxious and invasive species and educate the public about their disadvantages.
- Make drought-resistant trees and native species apart of the Master Street Tree List.

Each landscape construction documentation package shall include a cover sheet, referred to as the water conservation concept statement, similar to the following example. It serves as a checklist to verify that the elements of the landscape documentation package have been completed and as a narrative summary of the project. This applies to:

a) All new and rehabilitated landscaping for public agency projects and private development projects including, but not limited to, industrial, commercial and recreational projects;
b) Developer-installed landscaping in single-family and multi-family projects.

C. Groundwater supplies

The following policies address the use and management of groundwater supplies. Groundwater systems are connected to surface waters and are vital components of watersheds. Overdraft of groundwater affects base-flow to local water bodies as well as the health of terrestrial and riparian ecosystems. Thus, these policies are closely related to watershed protection and water-quality policies about surface water and groundwater systems.

■ City of Santa Cruz General Plan

Identify and protect groundwater recharge areas to maintain suitable groundwater levels and to protect groundwater quality for existing and potential municipal water sources.

■ County of Shasta General Plan

Institute effective measures to protect groundwater quality from potential adverse effects of increased pumping or potential sources of contamination.

■ City of San Jose General Plan

The City should not permit urban development to occur in areas not served by a sanitary sewer system.

The City should protect groundwater recharge areas, particularly creeks and riparian corridors.

■ County of Sonoma Draft General Plan – Water Resources Element

Manage groundwater as a valuable and limited shared resource.

Encourage new groundwater recharge opportunities and protect existing groundwater recharge areas.

Work with public water suppliers to decrease reliance on groundwater and prevent diminishment of groundwater supplies.

Conserve, enhance and manage groundwater resources on a sustainable basis, which assures sufficient amounts of clean water required for future generations, the uses allowed by the General Plan, and the natural environment.

Revise procedures for proving adequate groundwater for discretionary projects by adding criteria for study boundaries, review procedures and required findings that the area's groundwater supplies and surface water flows will not be adversely impacted by the project and the cumulative amount of development allowed in the area and will not cause or exacerbate groundwater overdraft, land subsidence or saltwater intrusion.

Procedures for proving adequate groundwater for discretionary projects should be flexible enough to consider the expense of such study in relation to the size of the discretionary project.

Require that discretionary projects, to the maximum extent practicable, maintain or increase the site's pre-development absorption of runoff to recharge groundwater. Implementation would include standards which could regulate impervious surfaces, vary by project type, land use, soils and area characteristics, and provide for water impoundments, protecting and planting vegetation, cisterns and other measures to increase runoff retention and groundwater recharge.

Monitor groundwater conditions, require descriptive information for well permits, and analyze, map and publicize the data gathered.

■ County of Los Angeles General Plan

Protect natural groundwater recharge areas and artificial spreading grounds and increase the storage of water underground for future use.

■ City of Woodland General Plan

The City shall cooperate with other jurisdictions in jointly studying the potential for using surface water sources to balance the groundwater supply so as to protect against aquifer overdrafts and water quality degradation.

D. Recycling and reuse of water supplies

These policies support the reuse of recycled wastewater and household graywater. Plan language can advance the use of recycled water by supporting the development or expansion of water recycling facilities, by ensuring policies are in place so that proposed projects are outfitted with purple pipe, and by requiring the use of recycled water for appropriate applications wherever feasible.

Graywater policies should support the inclusion of graywater systems in new development and simplify local permitting for installation and use of those systems.

■ City of Chino General Plan

It is the policy of the City that recycled water be used for any purposes approved for recycled water use, when it is economically, technically and institutionally feasible. Recycled water shall be the primary source of supply for commercial and industrial uses, whenever available and/or feasible. Use of potable water for commercial and industrial uses shall be contrary to city policy; shall not be considered the most beneficial use of a natural resource; and shall be avoided to the maximum extent possible.

■ City of Santa Clara General Plan

Maximize the use of reclaimed water for construction, maintenance and irrigation, and encourage its use elsewhere, as appropriate.

■ City of Livermore General Plan

Require all new industrial, commercial and office development within pressure Zone 1 to use reclaimed water for landscape irrigation, where available.

■ City of Palm Desert General Plan

Coordinate with the Coachella Valley Water District on the continued use and future expansion of tertiary-treated wastewater treatment and distribution facilities to serve existing and new development projects in the city.

■ County of Sonoma Draft General Plan – Water Resources Element

Encourage graywater systems, roof catchment of rainwater and other methods of reusing water and minimizing the need to use groundwater.

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■ County of Los Angeles General Plan

Encourage the production and use of reclaimed water and stormwater runoff to provide water for irrigation, groundwater recharge, saltwater intrusion barriers or other beneficial uses.

■ City of San Luis Obispo General Plan

Facilitate use of tertiary-treated water and seek to legalize use of graywater for non-potable household purposes.

E. Stormwater supplies

New practices are allowing communities to treat stormwater as a resource rather than a nuisance. Practices that allow the capture and reuse of stormwater on-site for landscaping, as well as those that encourage stormwater infiltration to recharge groundwater systems can help comply with water quality regulations for stormwater management – and also enhance local supplies. General Plans can advance the development of stormwater as a water supply through policies that encourage or require the capture and/or infiltration of stormwater.

■ County of Sonoma Draft General Plan – Water Resources Element

Conserve and recognize stormwater as a valuable resource.

■ City of Santa Cruz General Plan

Investigate the feasibility of using stormwater runoff, if all water quality measures are in place, for irrigation and groundwater recharge.

■ Santa Monica Municipal Code

Maximize the amount of runoff directed to permeable areas and/or maximize stormwater storage for reuse or infiltration by such means as:

- ➢ Using cisterns, retention structures or green rooftops to store precipitation or runoff for reuse.
- ➢ Grading the site to divert flow to permeable areas.
- ➢ Orienting roof runoff towards permeable surfaces, drywells, French drains or other structural BMPs rather than directly to driveways or non-permeable surfaces so that runoff will penetrate into the ground instead of flowing off-site.

F. Policies and programs to support implementation

■ County of Inyo General Plan

Goal: To ensure planning decisions are reached in a collaborative environment and to provide opportunities of early and consistent input by Inyo County and its citizens into the planning processes of other agencies, districts and utilities.

■ County of Sonoma Draft General Plan – Water Resources Element

Work with public water suppliers in assessments of the sustainable yield of surface water, groundwater, recycled water and conserved water. This work should include the exploration of potentially feasible alternative water supplies. Surface and groundwater supplies must remain sustainable and not exceed safe yields.

Support inter-regional planning efforts by the public water suppliers, their contractors and involved stakeholders in Sonoma County to determine the preferred combination of sources to meet projected demand.

Initiate an educational program to inform residents, agriculture, businesses and other groundwater users of best management practices in the areas of efficient water use, water conservation and increasing groundwater recharge. Implementation would include preparation and distribution of educational materials and public workshops.

■ City of Fresno General Plan

Maintain and expand cooperative multi-agency planning and programs for water conservation.

■ City of San Diego General Plan 2005

Implement conservation incentive programs that increase water-use efficiency and reduce urban runoff:

- ➢ Develop a response plan to assist citizens in reducing water use during periods of water shortages and emergencies.
- ➢ Encourage local water agencies to use state-mandated powers to enforce conservation measures that eliminate or penalize wasteful uses of water.
- ➢ Explore alternative conservation measures and technology as they become available.
- ➢ Develop and expand water-efficient landscaping to include urban forestry, urban vegetation, and demonstration projects.

The Ahwahnee Principles

for Resource-Efficient Communities



The Ahwahnee Principles for Resource-Efficient Communities, written in 1991 by the Local Government Commission, paved the way for the Smart Growth movement and New Urbanism.

These principles provide a blueprint for elected officials to create compact, mixed-use, walkable transit-oriented developments in their local communities. Cities and counties across the nation have adopted them to break the cycle of sprawl.

If you like the newly emerging downtowns across the nation – full of people, activities and great public spaces – that's the Ahwahnee Principles in action.

Since then, the Ahwahnee Principles for Economic Development in 1997 and the Ahwahnee Water Principles in 2005 have been developed to complement this pioneering vision.

- *The authors of the Ahwahnee Principles include: Peter Calthorpe, Michael Corbett, Andres Duany, Elizabeth Moule, Elizabeth Plater-Zyberk and Stefanos Polyzoides, with editors: Peter Katz, Judy Corbett and Steve Weissman.*

- **www.lgc.org/ahwahnee/principles.html**

Local Government Commission

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The Ahwahnee Principles

Preamble

Existing patterns of urban and suburban development seriously impair our quality of life.

The symptoms are: more congestion and air pollution resulting from our increased dependence on automobiles, the loss of precious open space, the need for costly improvements to roads and public services, the inequitable distribution of economic resources, and the loss of a sense of community.

By drawing upon the best from the past and the present, we can plan communities that will more successfully serve the needs of those who live and work within them. Such planning should adhere to certain fundamental principles.



Community Principles

1 All planning should be in the form of complete and integrated communities containing housing, shops, work places, schools, parks and civic facilities essential to the daily life of the residents.

2 Community size should be designed so that housing, jobs, daily needs and other activities are within easy walking distance of each other.

3 As many activities as possible should be located within easy walking distance of transit stops.

4 A community should contain a diversity of housing types to enable citizens from a wide range of economic levels and age groups to live within its boundaries.

5 Businesses within the community should provide a range of job types for the community's residents.

6 The location and character of the community should be consistent with a larger transit network.

7 The community should have a center focus that combines commercial, civic, cultural and recreational uses.

Regional Principles

1 The regional land use planning structure should be integrated within a larger transportation network built around transit rather than freeways.

2 Regions should be bounded by and provide a continuous system of greenbelt/wildlife corridors to be determined by natural conditions.

3 Regional institutions and services (government, stadiums, museums, etc.) should be located in the urban core.

4 Materials and methods of construction should be specific to the region, exhibiting continuity of history and culture and compatibility with the climate to encourage the development of local character and community identity.

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for Resource-Efficient Communities



8 The community should contain an ample supply of specialized open space in the form of squares, greens and parks whose frequent use is encouraged through placement and design.

9 Public spaces should be designed to encourage the attention and presence of people at all hours of the day and night.

10 Each community or cluster of communities should have a well defined edge, such as agricultural greenbelts or wildlife corridors, permanently protected from development.

11 Streets, pedestrian paths and bike paths should contribute to a system of fully connected and interesting routes to all destinations. Their design should encourage pedestrian and bicycle use by being small and spatially defined by buildings, trees and lighting; and by discouraging high-speed traffic.

12 Wherever possible, the natural terrain, drainage, and vegetation of the community should be preserved with superior examples contained within parks or greenbelts.

13 The community design should help conserve resources and minimize waste.

14 Communities should provide for the efficient use of water through the use of natural drainage, drought tolerant landscaping and recycling.

15 The street orientation, the placement of buildings and the use of shading should contribute to the energy efficiency of the community.







Implementation Strategy

1 The general plan should be updated to incorporate the above principles.

2 Rather than allowing developer-initiated, piecemeal development, local governments should take charge of the planning process. General plans should designate where new growth, infill or redevelopment will be allowed to occur.

3 Prior to any development, a specific plan should be prepared based on the planning principles. With the adoption of specific plans, complying projects could proceed with minimal delay.

4 Plans should be developed through an open process and participants in the process should be provided visual models of all planning proposals.

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Ahwahnee Principles for Resource-Efficient Communities

Preamble:

Existing patterns of urban and suburban development seriously impair our quality of life. The symptoms are: more congestion and air pollution resulting from our increased dependence on automobiles, the loss of precious open space, the need for costly improvements to roads and public services, the inequitable distribution of economic resources, and the loss of a sense of community. By drawing upon the best from the past and the present, we can plan communities that will more successfully serve the needs of those who live and work within them. Such planning should adhere to certain fundamental principles.

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4. A community should contain a diversity of housing types to enable citizens from a wide range of economic levels and age groups to live within its boundaries.
5. Businesses within the community should provide a range of job types for the community's residents.
6. The location and character of the community should be consistent with a larger transit network.
7. The community should have a center focus that combines commercial, civic, cultural and recreational uses.
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Authors: Peter Calthorpe, Michael Corbett, Andres Duany, Elizabeth Moule, Elizabeth Plater-Zyberk, and Stefanos Polyzoides

Editor: Peter Katz, Judy Corbett, and Steve Weissman

(Adopted in 1991)

If you would like more background information on the Ahwahnee Principles (including where the name came from), please read the **article reprinted from Western Cities Magazine.**

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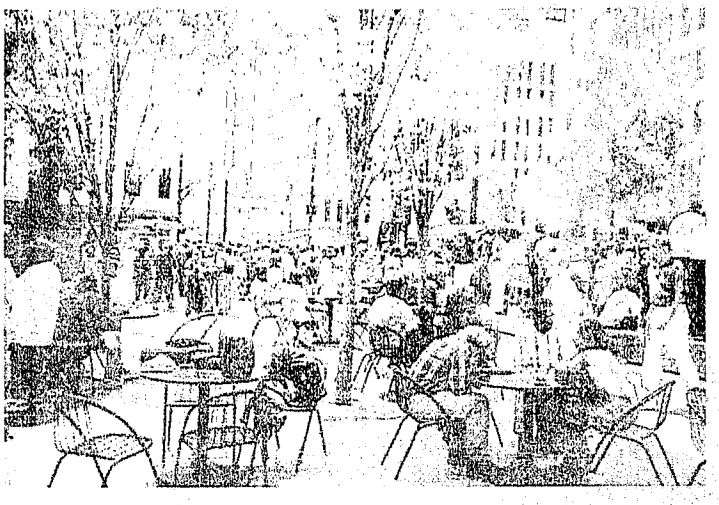
The Ahwahnee Principles for Economic Development

As the smart-growth approaches to development began taking root in the early 1990s, it became clear that a companion set of principles addressing the economic development aspects of creating more livable communities was also needed. The Ahwahnee Principles for Economic Development were adopted in 1997, a half-dozen years following the establishment of the precepts for resource-efficient land use.

Prosperity in the 21st century will be based on creating and maintaining a sustainable standard of living and a high quality of life for all. To meet this challenge, a new comprehensive model is emerging which embraces economic, social and environmental responsibility and recognizes the economic value of natural and human capital.



www.lgc.org/ahwahnee/econ_principles.html

The Ahwahnee Water Principles

Water – how we capture it, treat it, use it, control it, manage it and release it – is vital to the 36 million people who live in California and has a tremendous impact on our quality of life, local budgets and day-to-day policy-making. And as California adds another 12 million residents by 2030, water-resource challenges will be increasingly serious.

Unless we locate new growth in the right places and develop it properly, the streams, rivers and lakes that receive runoff water will become increasingly more polluted and the natural functions of watersheds that collect and cleanse our water supplies will diminish.

Adopted in 2005, the 14 Ahwahnee Water Principles – identified by water experts at the federal, state and local levels as the most effective and politically and economically viable least-cost options to help guide communities concerned about their future water supplies – can be grouped into four different categories:

1. Growing in a water-wise manner.
2. Water-friendly neighborhood/site-scale planning and design strategies.
3. Water conservation approaches to make the most efficient use of our existing water supplies.
4. A set of corollary guidelines that can help put these nine community principles into action through strategies for implementing practical steps to make the physical changes necessary to ensure water sustainability.

The California State Water Resources Control Board now promotes the principles and is using them as a way of prioritizing grants and loans to local government. The number of cities and counties adopting these principles as policy is growing every day.

www.lgc.org/ahwahnee/h2o_principles.html

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Ahwahnee Principles for Economic Development

Smart Growth: Economic Development for the 21st Century
A Set of Principles for Building Prosperous and Livable Communities

Preamble

Prosperity in the 21st Century will be based on creating and maintaining a sustainable standard of living and a high quality of life for all. To meet this challenge, a comprehensive new model is emerging which recognizes the economic value of natural and human capital. Embracing economic, social, and environmental responsibility, this approach focuses on the most critical building blocks for success, the community and the region. It emphasizes community-wide and regional collaboration for building prosperous and livable places. While each community and region has unique challenges and opportunities, the following common principles should guide an integrated approach by all sectors to promoting economic vitality within their communities, and in partnership with their neighbors in the larger region.

1. Integrated Approach

Government, business, education, and the community should work together to create a vibrant local economy, through a long-term investment strategy that:

- encourages local enterprise
- serves the needs of local residents, workers, and businesses
- promotes stable employment and revenues by building on local competitive advantages
- protects the natural environment
- increases social equity
- is capable of succeeding in the global marketplace.

2. Vision and Inclusion

Communities and regions need a vision and strategy for economic development according to these principles. Visioning, planning and implementation efforts should continually involve all sectors, including the voluntary civic sector and those traditionally left out of the public planning process.

3. Poverty Reduction

Both local and regional economic development efforts should be targeted to reducing poverty, by promoting jobs that match the skills of existing residents, improving the

skills of low-income individuals, addressing the needs of families moving off welfare, and insuring the availability in all communities of quality affordable child care, transportation, and housing.

4. Local Focus

Because each community's most valuable assets are the ones they already have, and existing businesses are already contributing to their home communities, economic development efforts should give first priority to supporting existing enterprises as the best source of business expansion and local job growth. Luring businesses away from neighboring communities is a zero-sum game that doesn't create new wealth in the regional economy. Community economic development should focus instead on promoting local entrepreneurship to build locally based industries and businesses that can succeed among national and international competitors.

5. Industry Clusters

Communities and regions should identify specific gaps and niches their economies can fill, and promote a diversified range of specialized industry clusters drawing on local advantages to serve local and international markets.

6. Wired Communities

Communities should use and invest in technology that supports the ability of local enterprises to succeed, improves civic life, and provides open access to information and resources.

7. Long-Term Investment

Publicly supported economic development programs, investments, and subsidies should be evaluated on their long-term benefits and impacts on the whole community, not on short-term job or revenue increases. Public investments and subsidies should be equitable and targeted, support environmental and social goals, and prioritize infrastructure and supportive services that promote the vitality of all local enterprises, instead of individual firms.

8. Human Investment

Because human resources are so valuable in the information age, communities should provide life-long skills and learning opportunities by investing in excellent schools, post-secondary institutions, and opportunities for continuous education and training available to all.

9. Environmental Responsibility

Communities should support and pursue economic development that maintains or improves, not harms, the environmental and public health.

10. Corporate Responsibility

Enterprises should work as civic partners, contributing to the communities and regions where they operate, protecting the natural environment, and providing workers with good pay, benefits, opportunities for upward mobility, and a healthful work

environment.

11. Compact Development

To minimize economic, social, and environmental costs and efficiently use resources and infrastructure, new development should take place in existing urban, suburban, and rural areas before using more agricultural land or open space. Local and regional plans and policies should contain these physical and economic development planning principles to focus development activities in desired existing areas.

12. Livable Communities

To protect the natural environment and increase quality of life, neighborhoods, communities and regions should have compact, multi-dimensional land use patterns that ensure a mix of uses, minimize the impact of cars, and promote walking, bicycling, and transit access to employment, education, recreation, entertainment, shopping, and services. Economic development and transportation investments should reinforce these land use patterns, and the ability to move people and goods by non-automobile alternatives wherever possible.

13. Center Focus

Communities should have an appropriately scaled and economically healthy center focus. At the community level, a wide range of commercial, residential, cultural, civic, and recreational uses should be located in the town center or downtown. At the neighborhood level, neighborhood centers should contain local businesses that serve the daily needs of nearby residents. At the regional level, regional facilities should be located in urban centers that are accessible by transit throughout the metropolitan area.

14. Distinctive Communities

Having a distinctive identity will help communities create a quality of life that is attractive for business retention and future residents and private investment. Community economic development efforts should help to create and preserve each community's sense of uniqueness, attractiveness, history, and cultural and social diversity, and include public gathering places and a strong local sense of place.

15. Regional Collaboration

Since industries, transportation, land uses, natural resources, and other key elements of a healthy economy are regional in scope, communities and the private sector should cooperate to create regional structures that promote a coherent metropolitan whole that respects local character and identity.

(Adopted in 1997)

More information and case studies of each principle are available in our guidebook "**The Ahwahnee Principles for Smart Economic Development: An Implementation Guidebook**".

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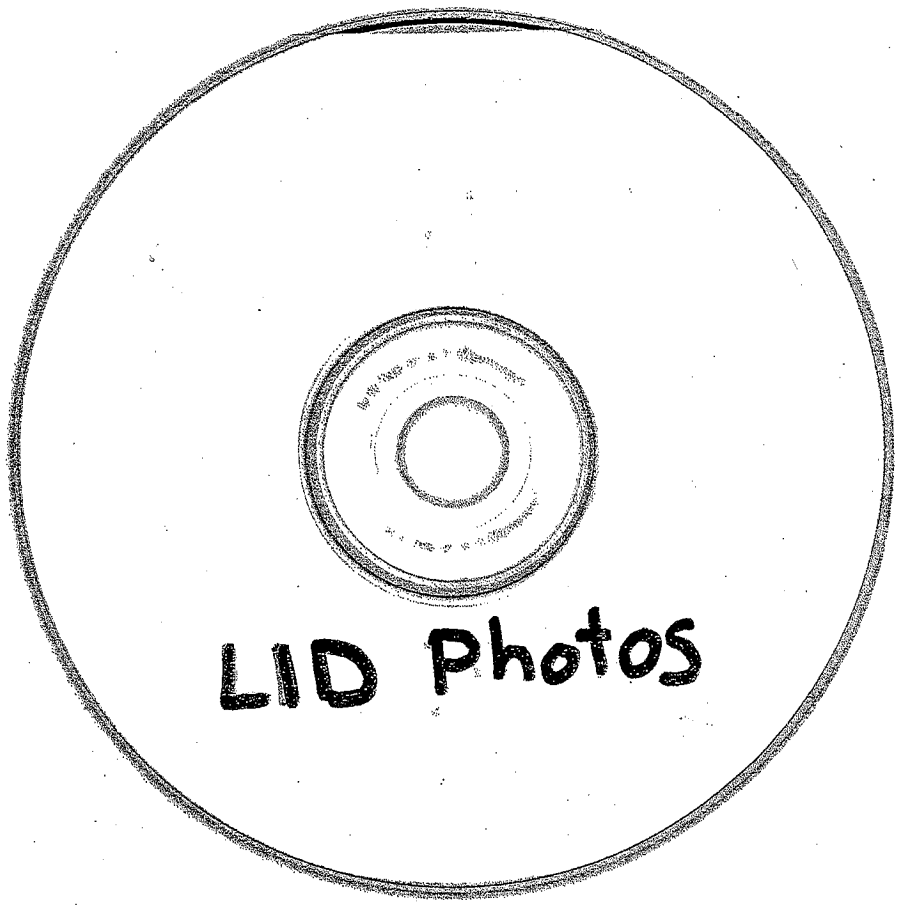
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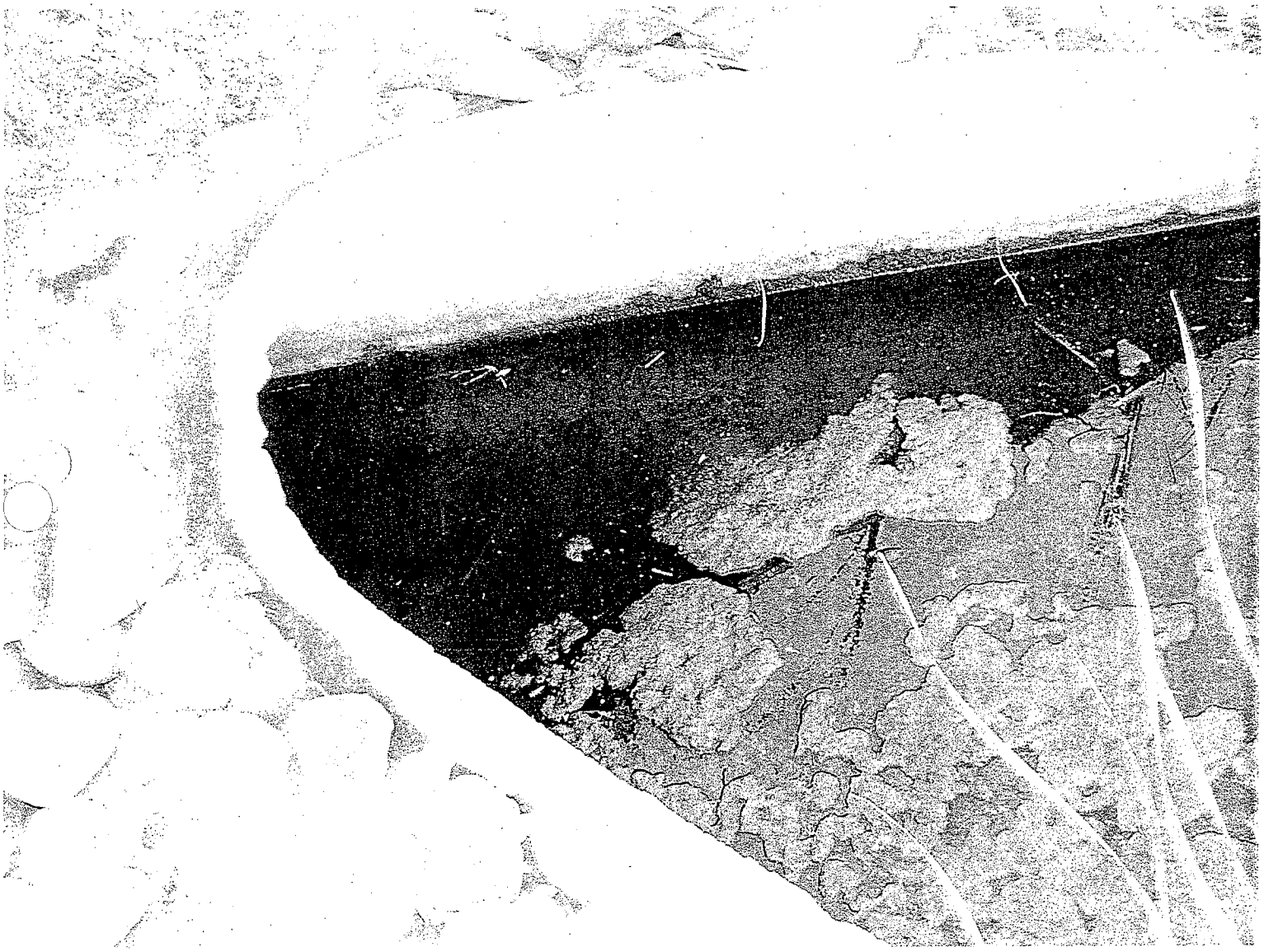



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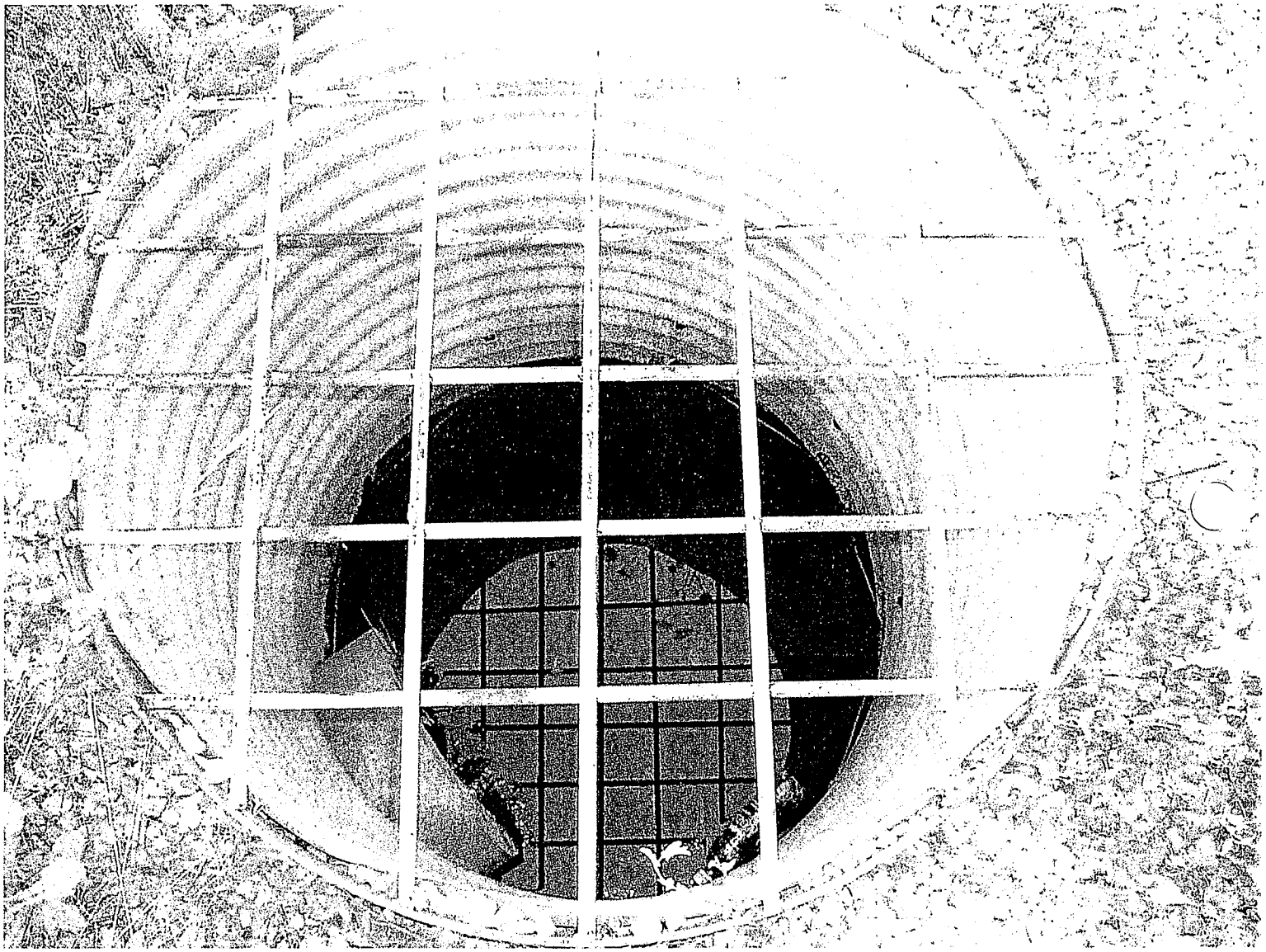

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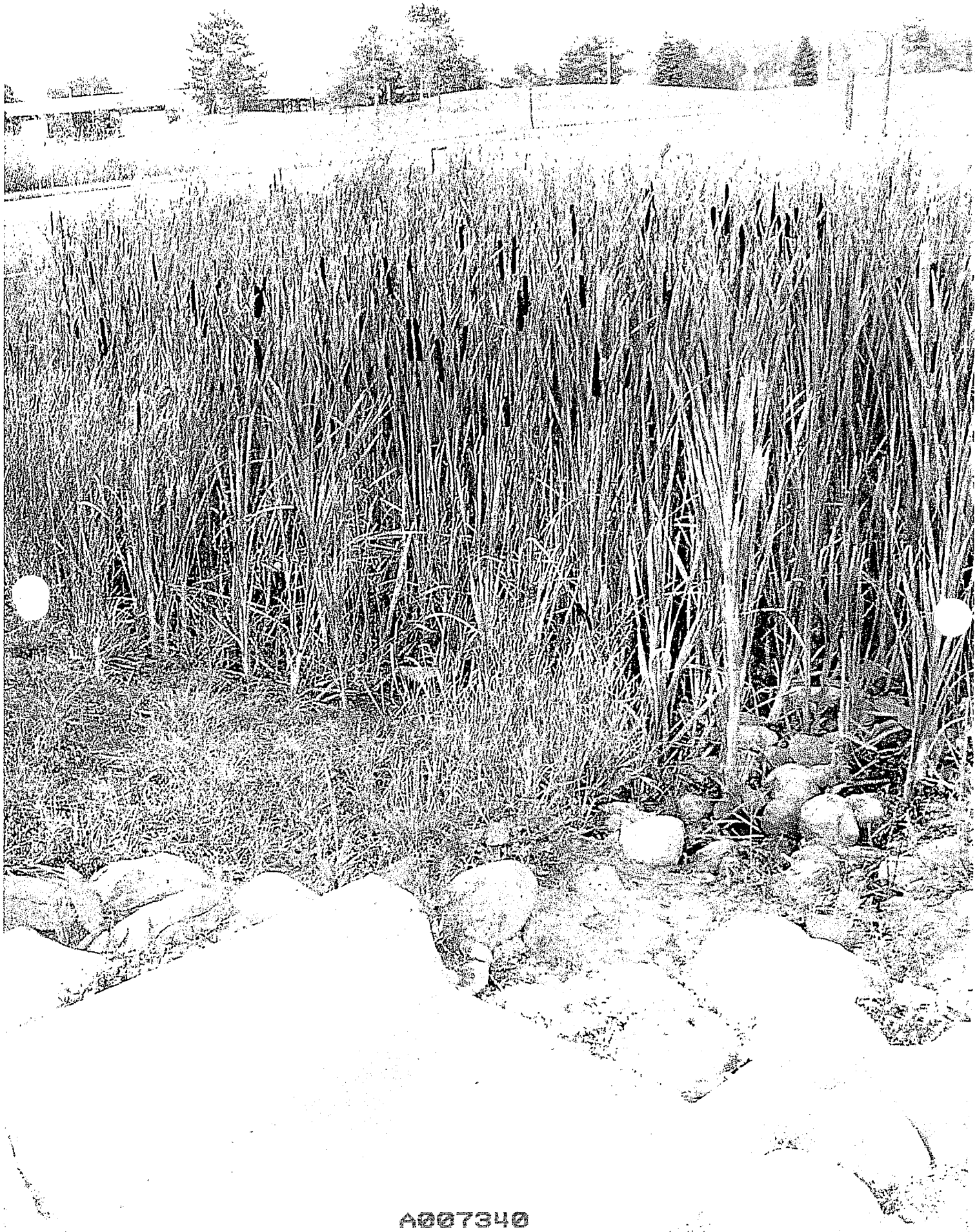

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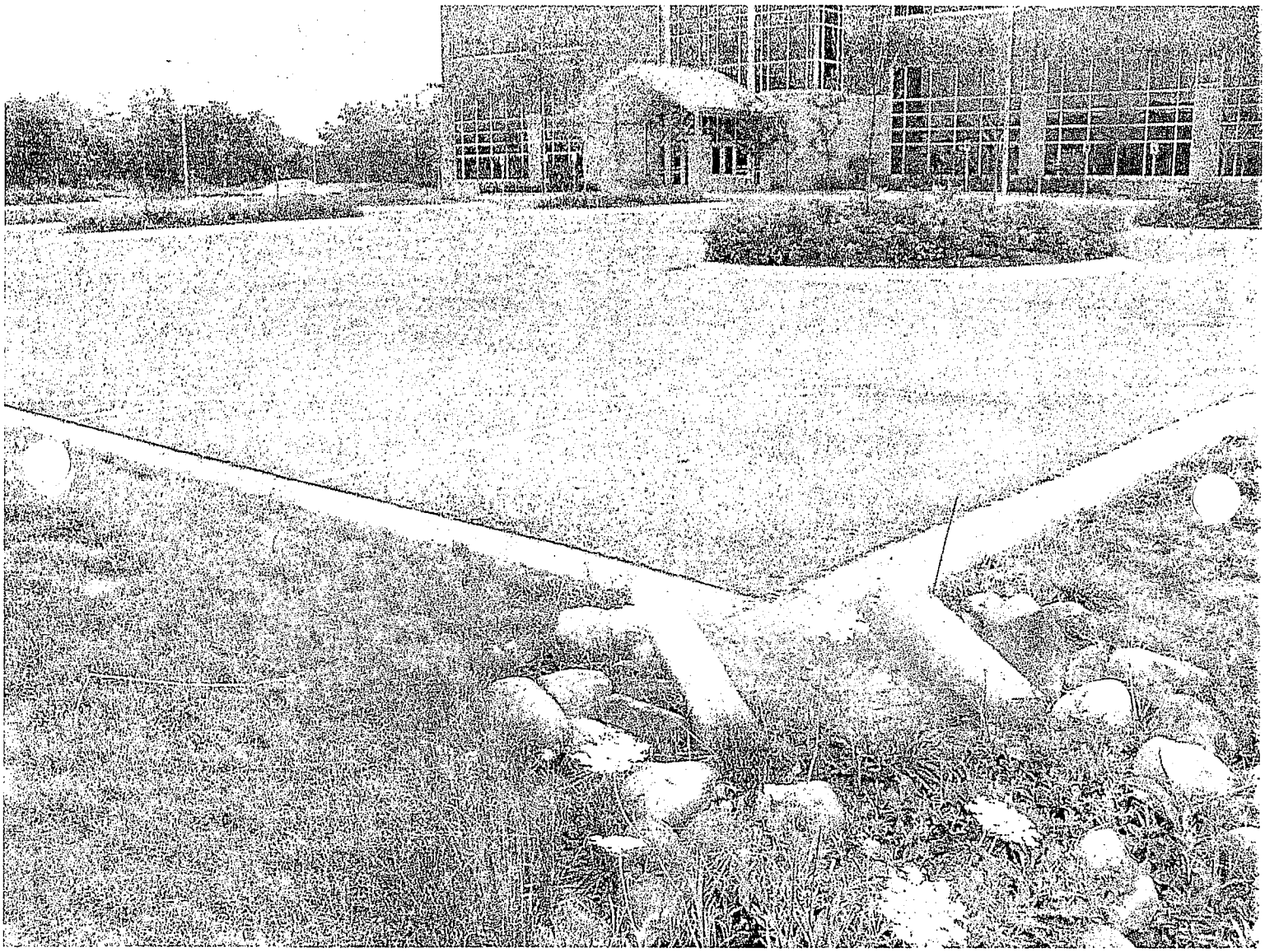





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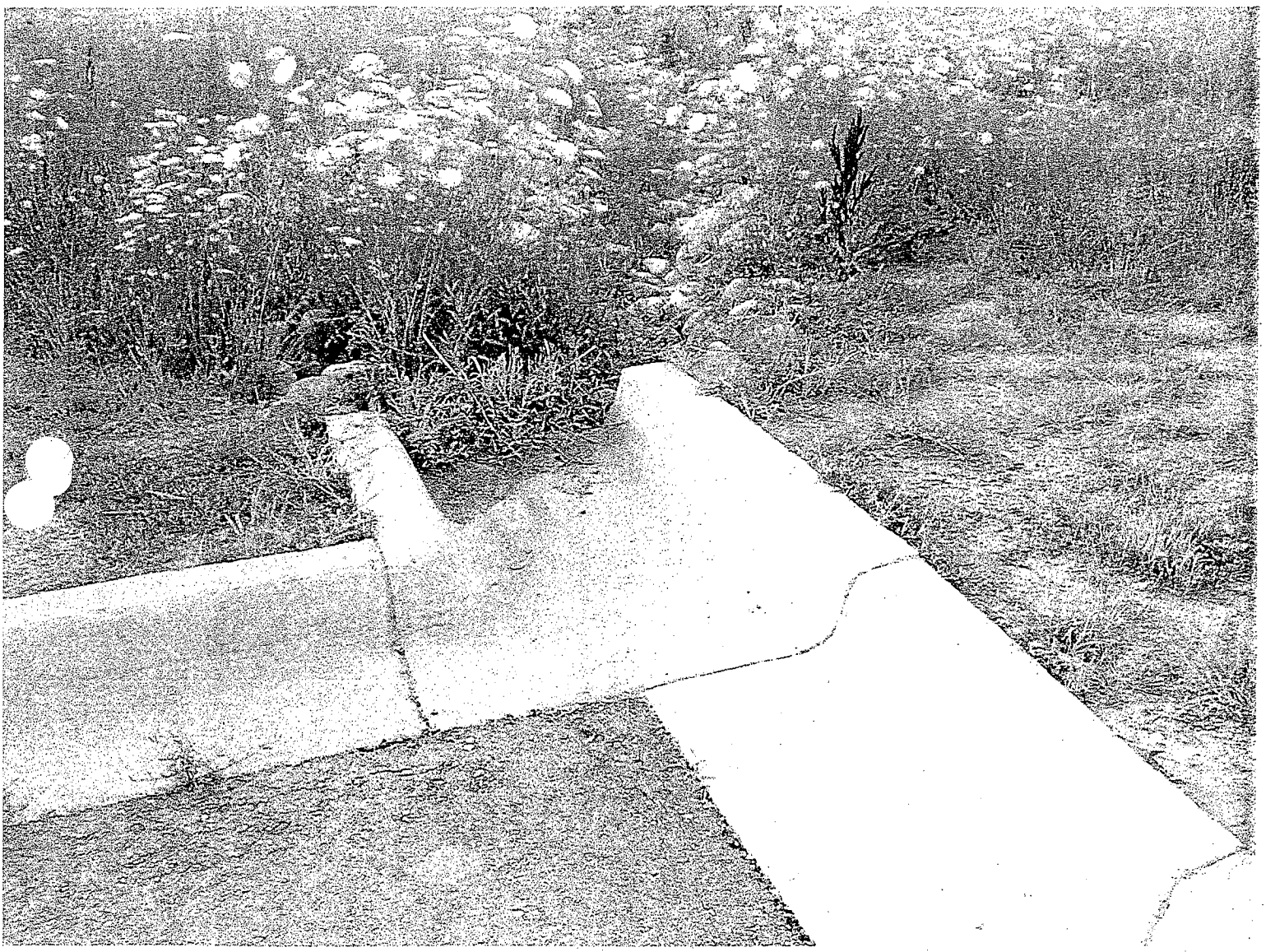

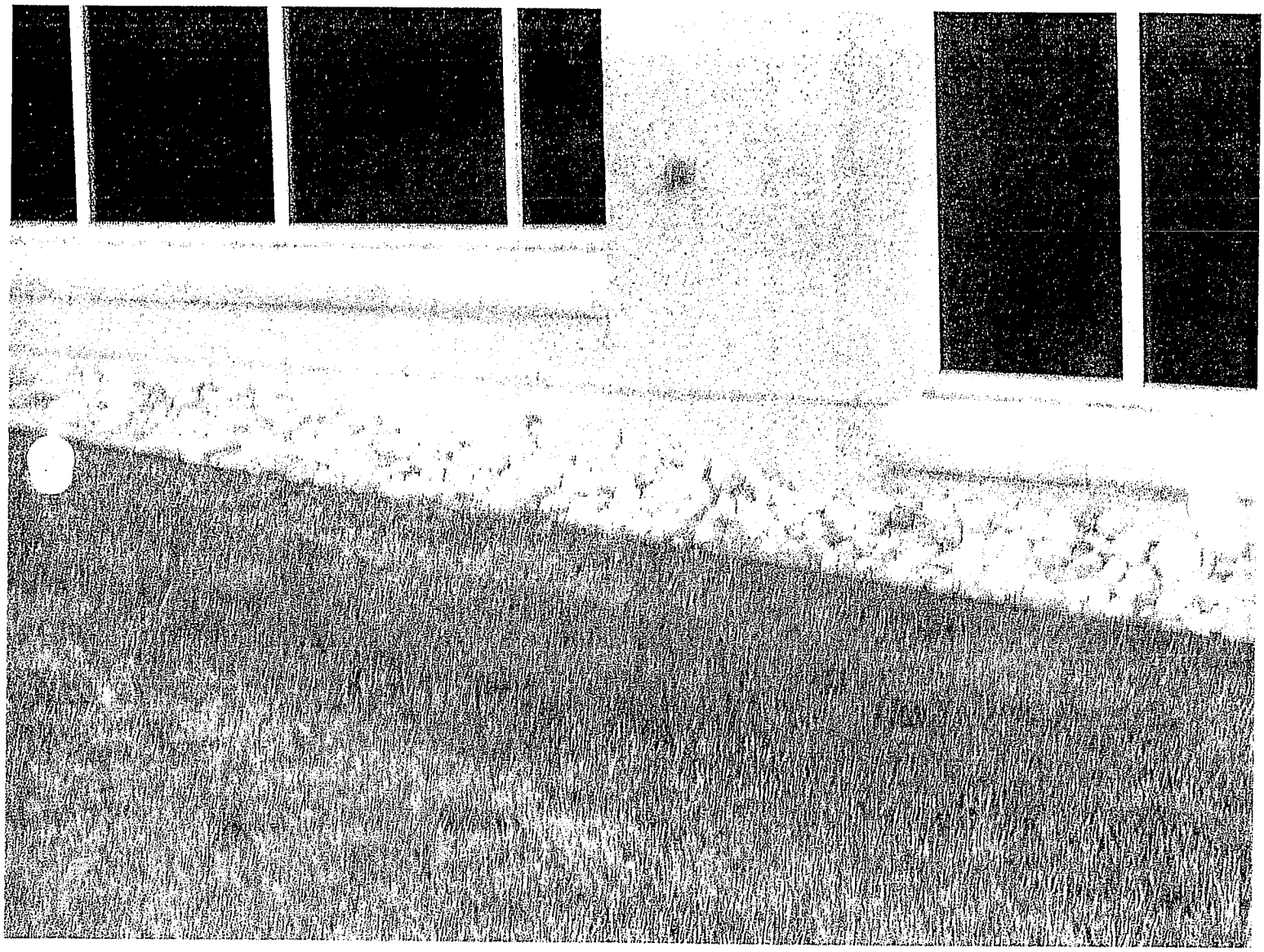

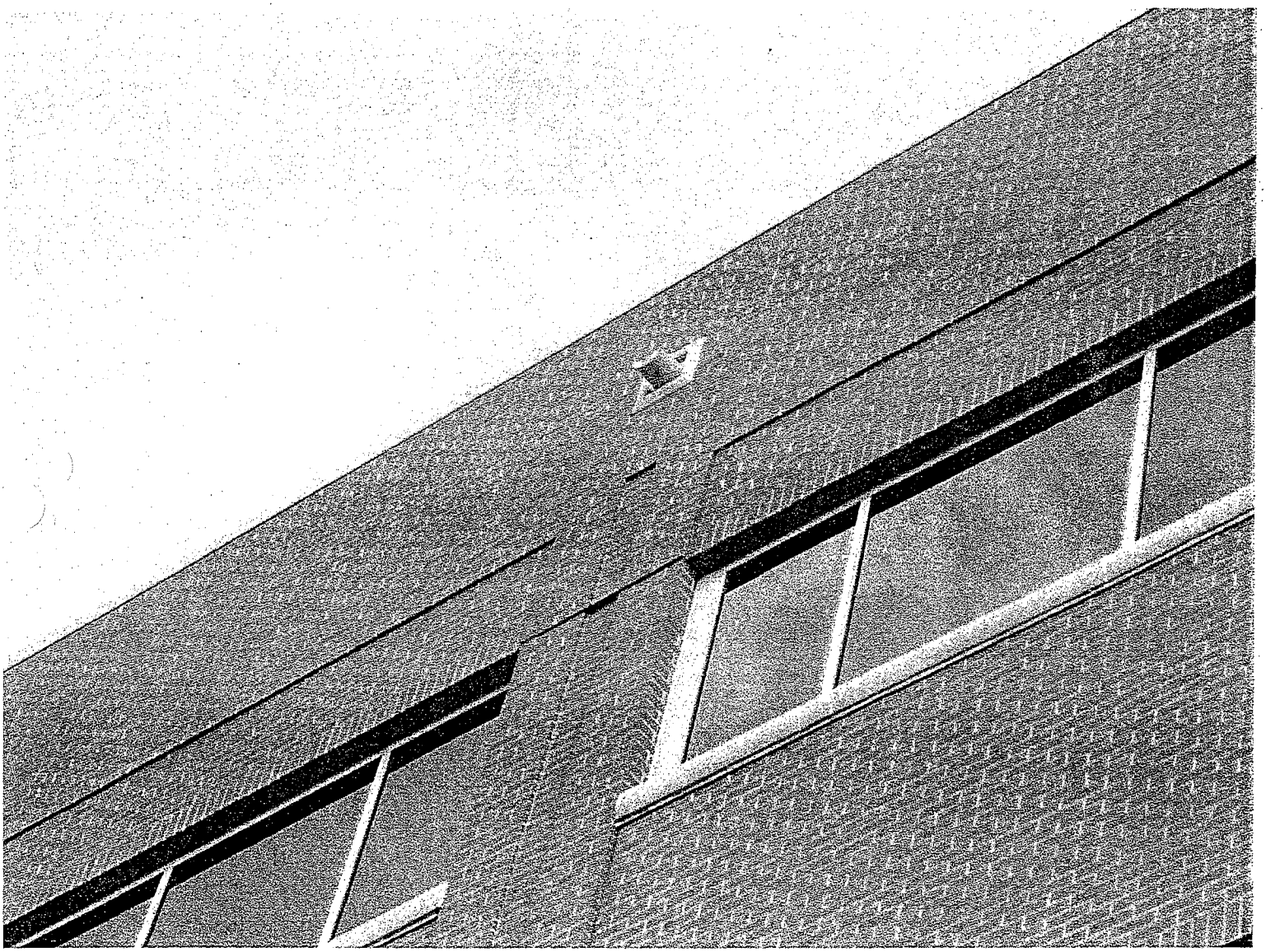

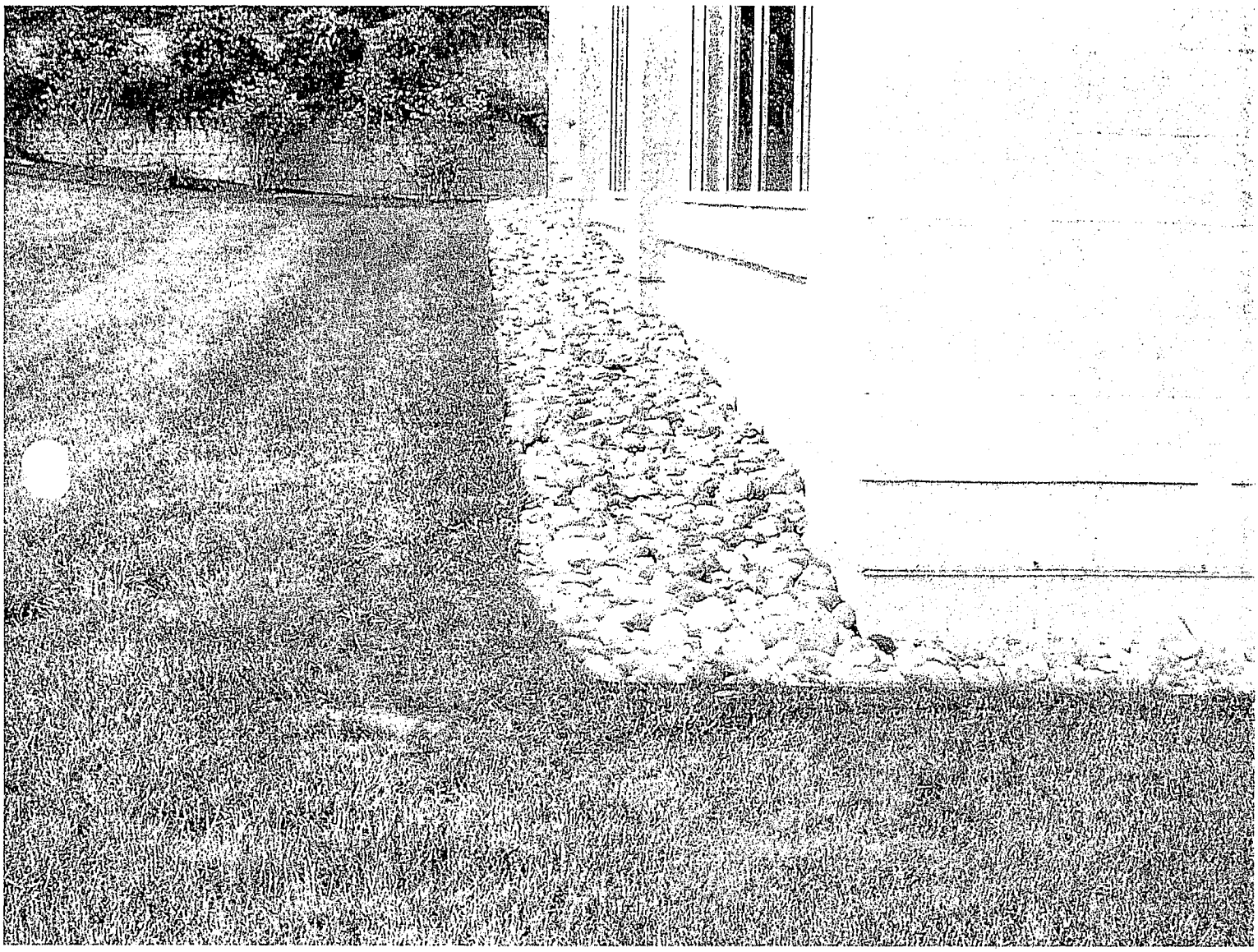





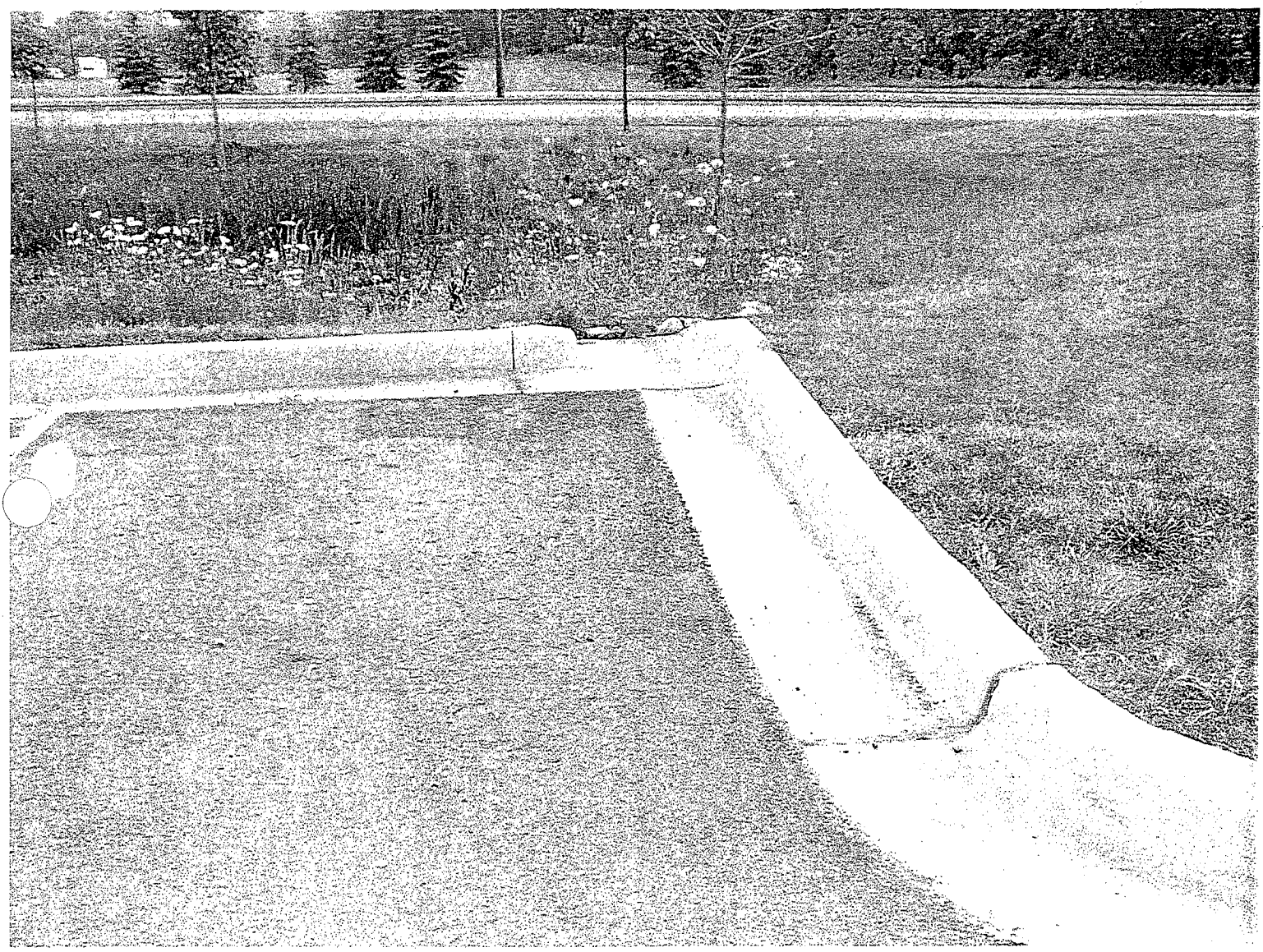

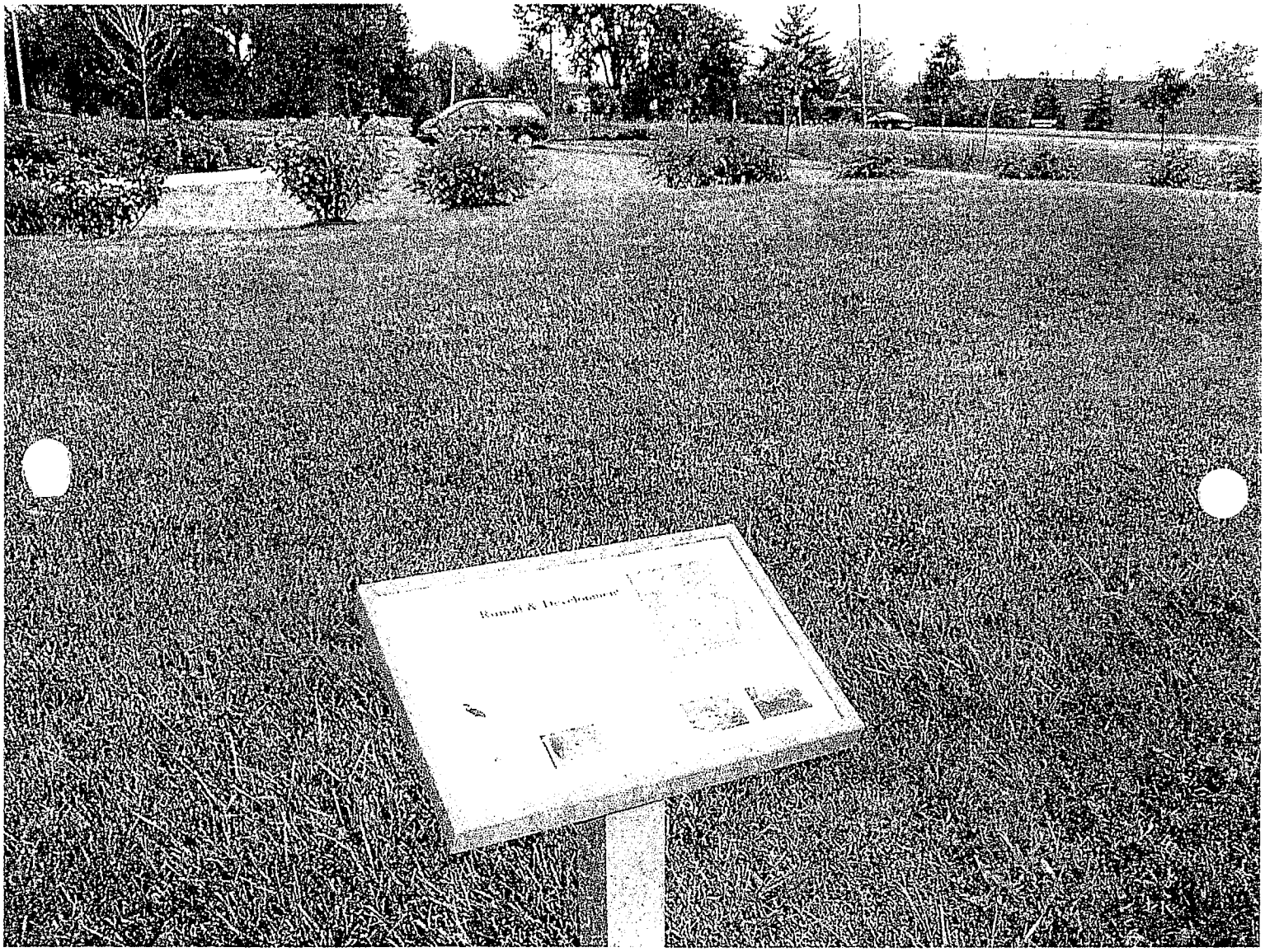

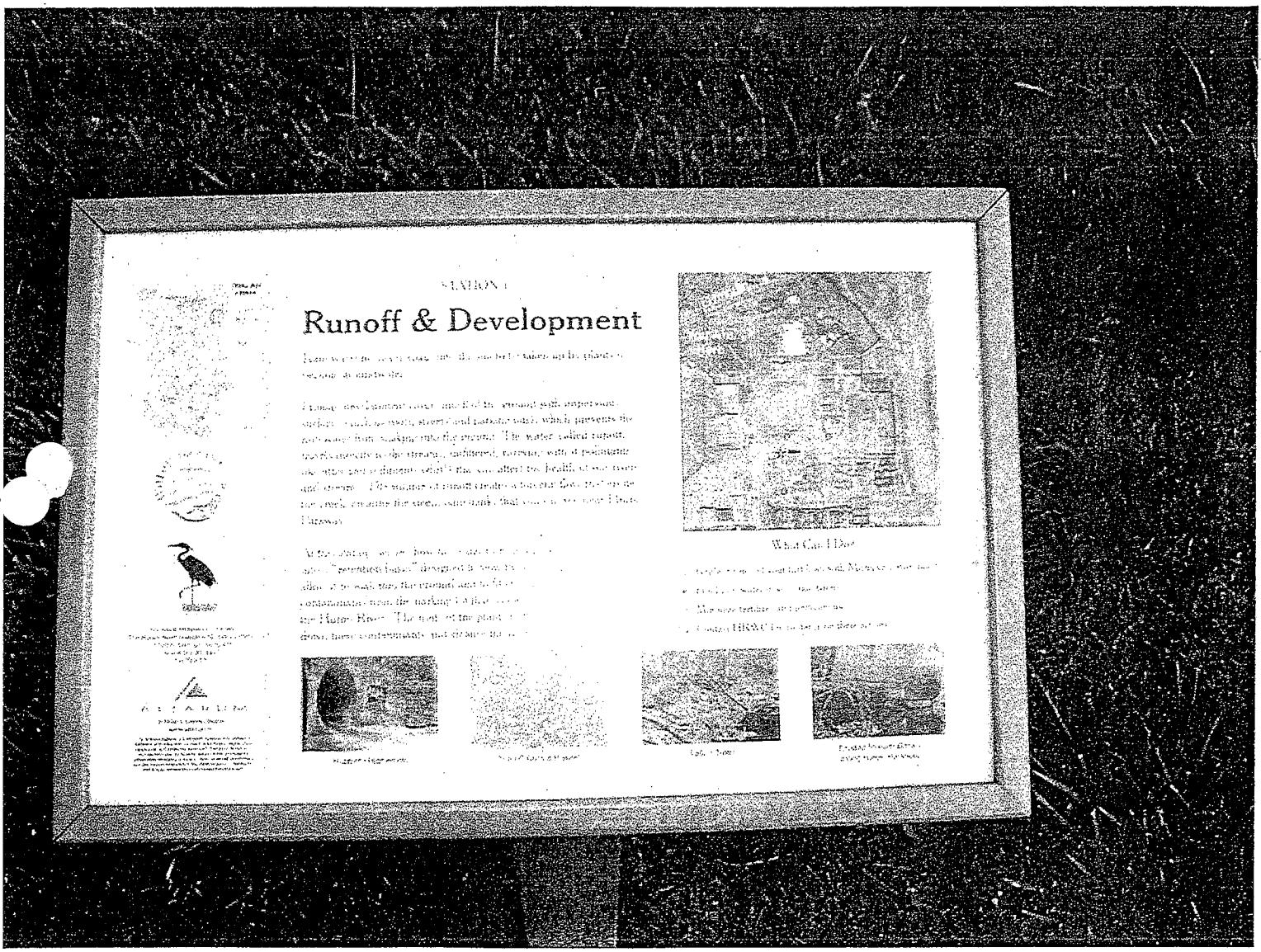

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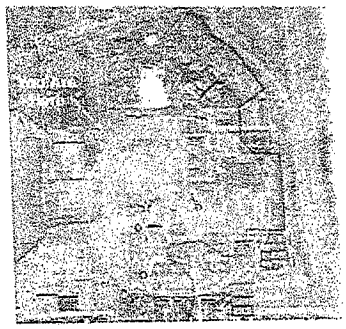
STATION 2

Native Environment

One of the strategies in restoring Miller Creek is the use of Marin's native plants. Trees, shrubs, wildflowers and grasses enhance the area into low-maintenance landscapes that provide habitat for many birds, butterflies, and other animal life. Their root systems hold rain and survive drought much better, than non-native plants and turf grass.

To accompany the native plants and to help control invasive species, each year usually in the spring/summer, a prescribed ecological burn is done. As practiced by our Native American ancestors, the controlled burn discourages the growth of exotic species (eucalyptus saplings, such as Smooth Brome and Kentucky bluegrass), suppresses the establishment of woody plants, and stimulates the growth and regeneration of native plants and seed.

Some of the native species that can be seen here at Station 2 around the restoration basin are: Little Bluestem Grass, Butterfly Milkweed, Sweetgrass, New England Aster, Wild Bergamot, Yellow Coneflower, Black-Eyed Susan and Showy Goldenrod.



What Can I Do?

- Prepare [illegible] with native plants [illegible]
- Help [illegible] you in your [illegible]
- Maintain walkways and pathways [illegible]
- Contact HRWC for assistance on these actions







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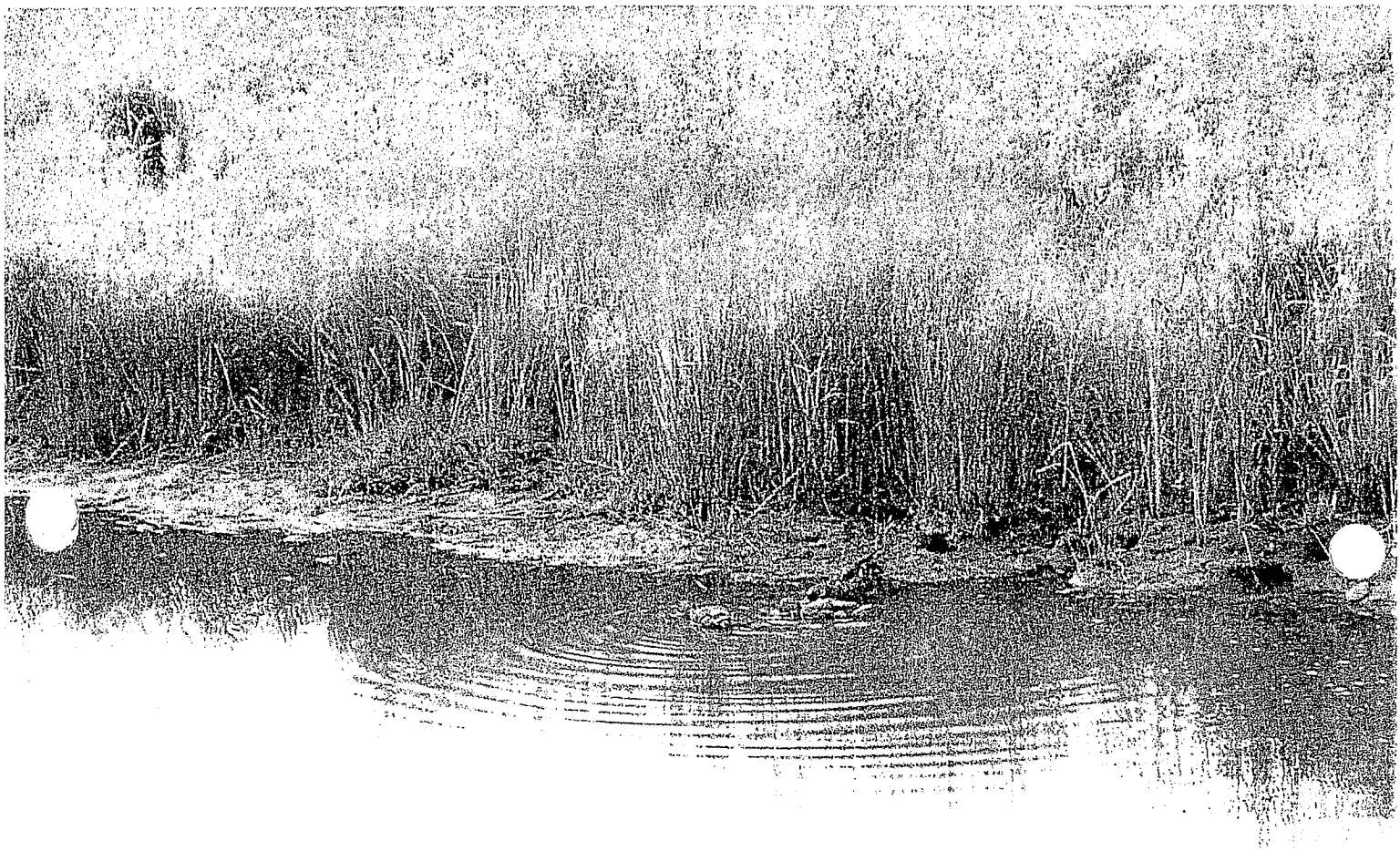

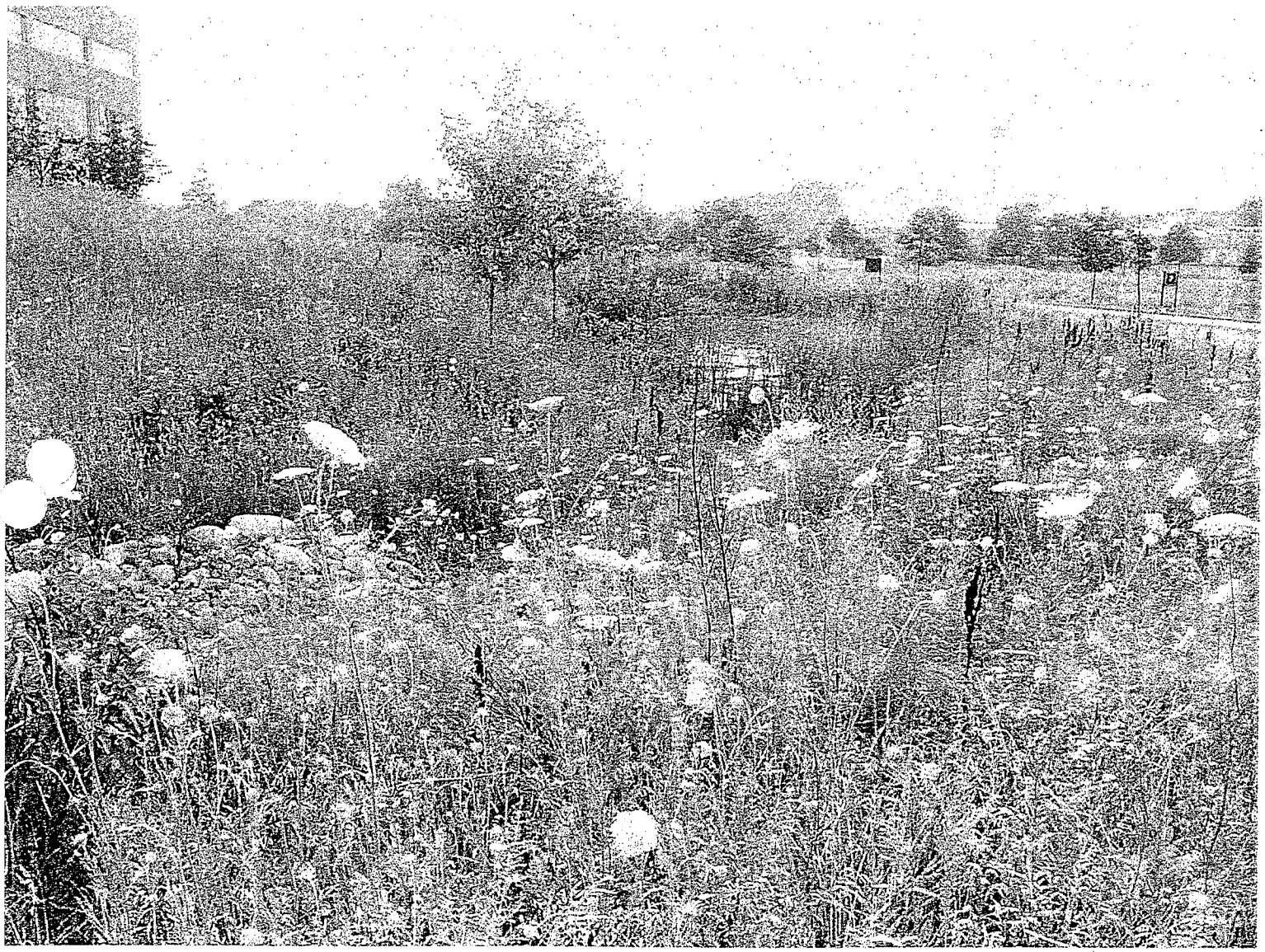



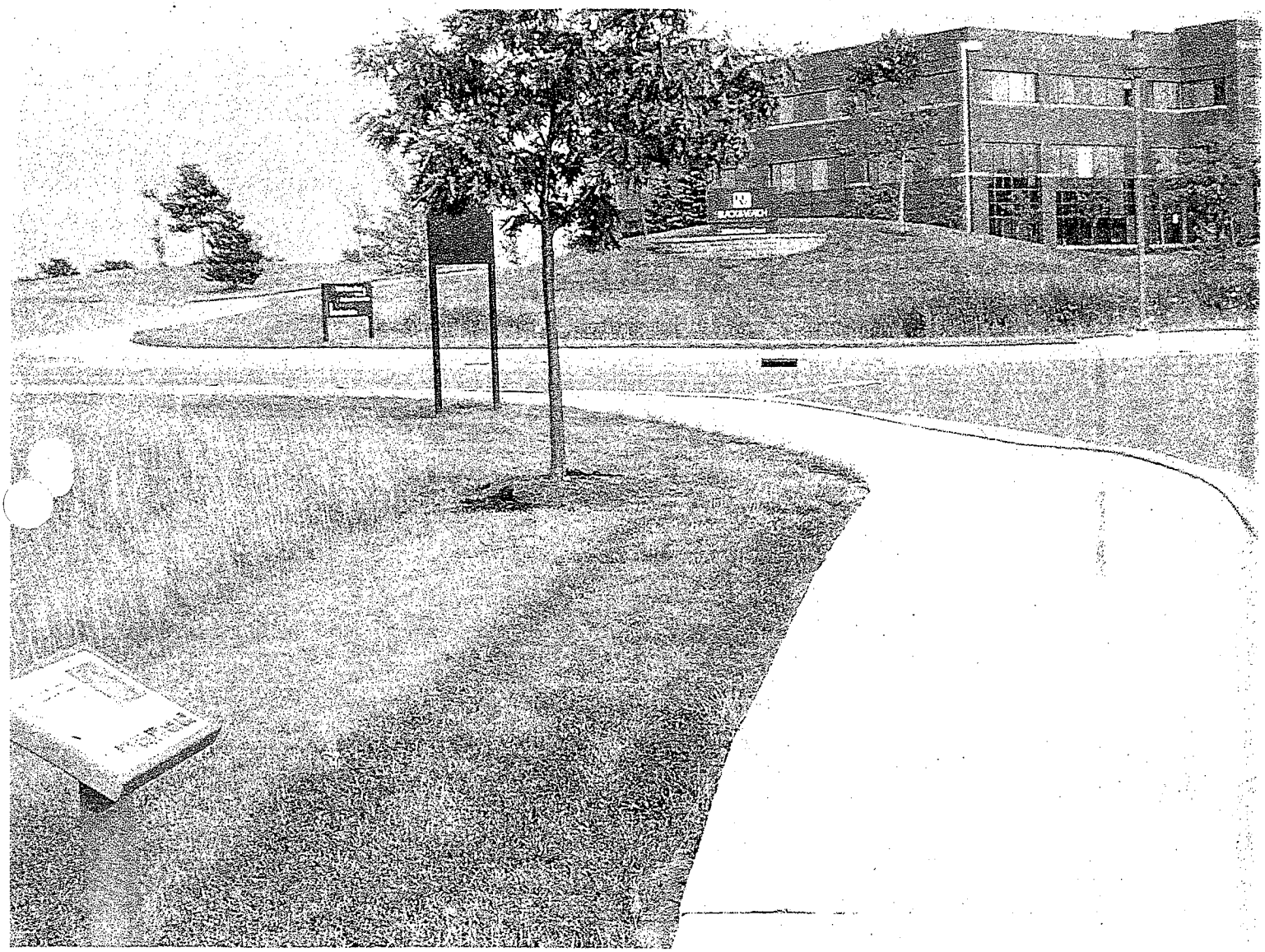





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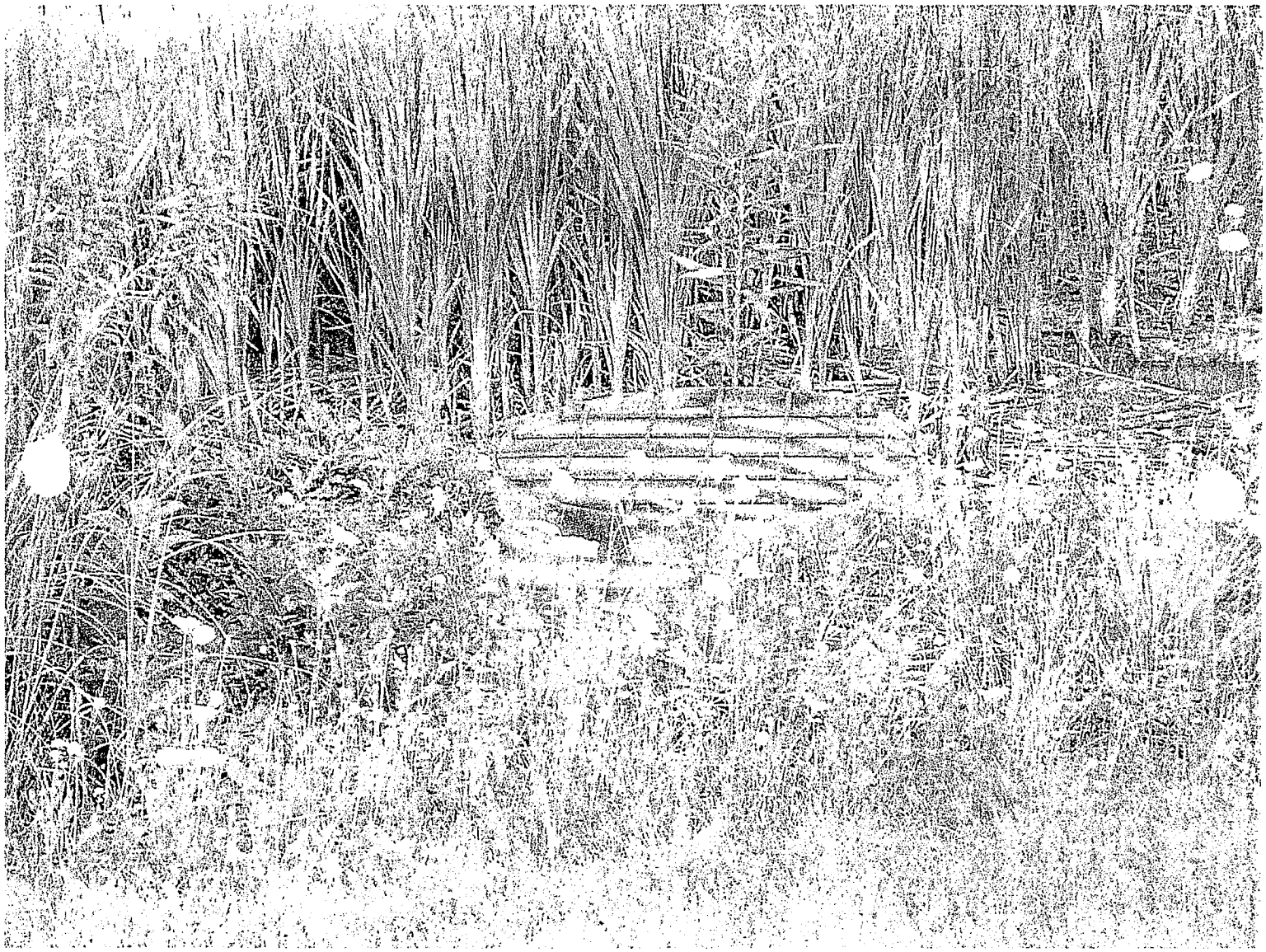





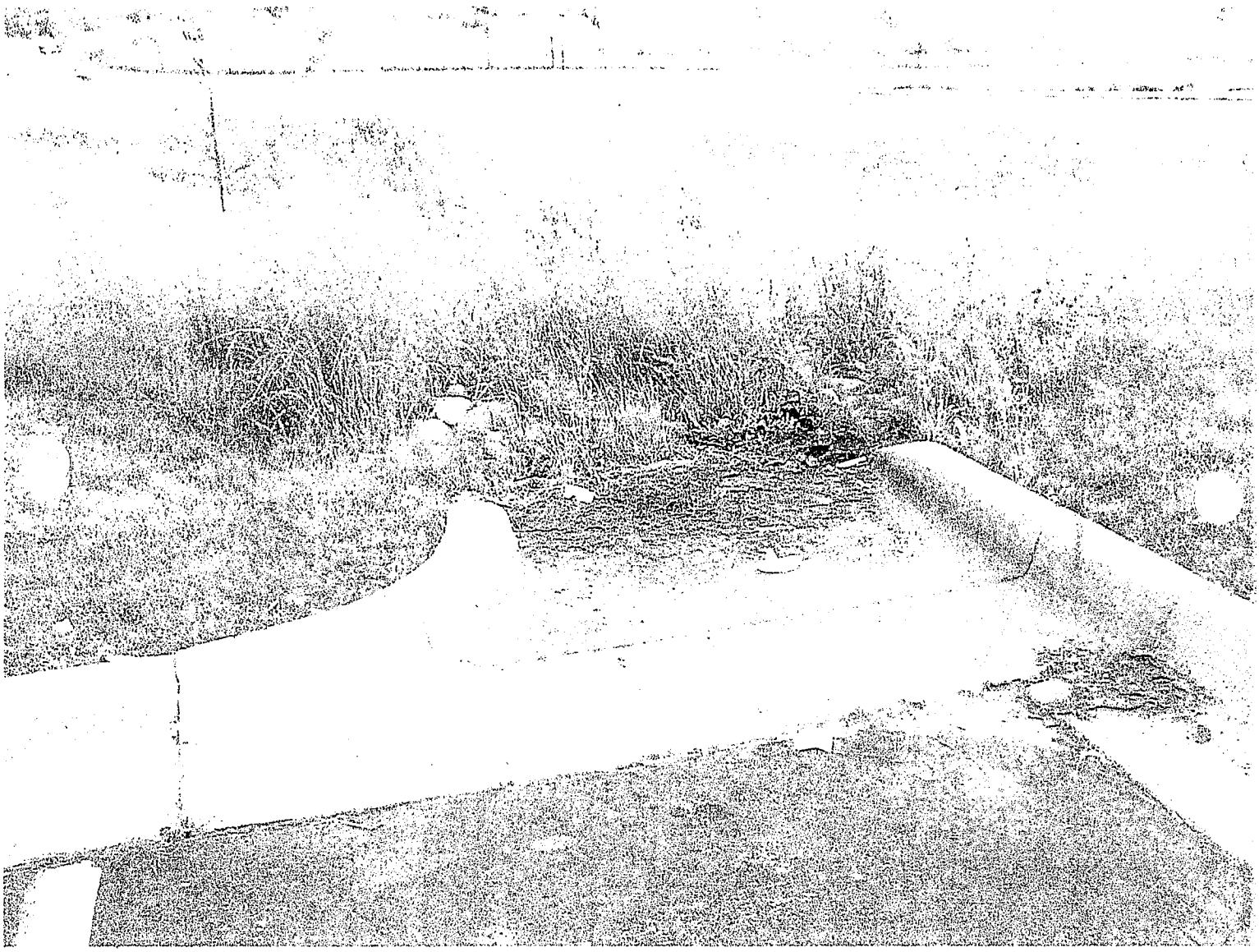

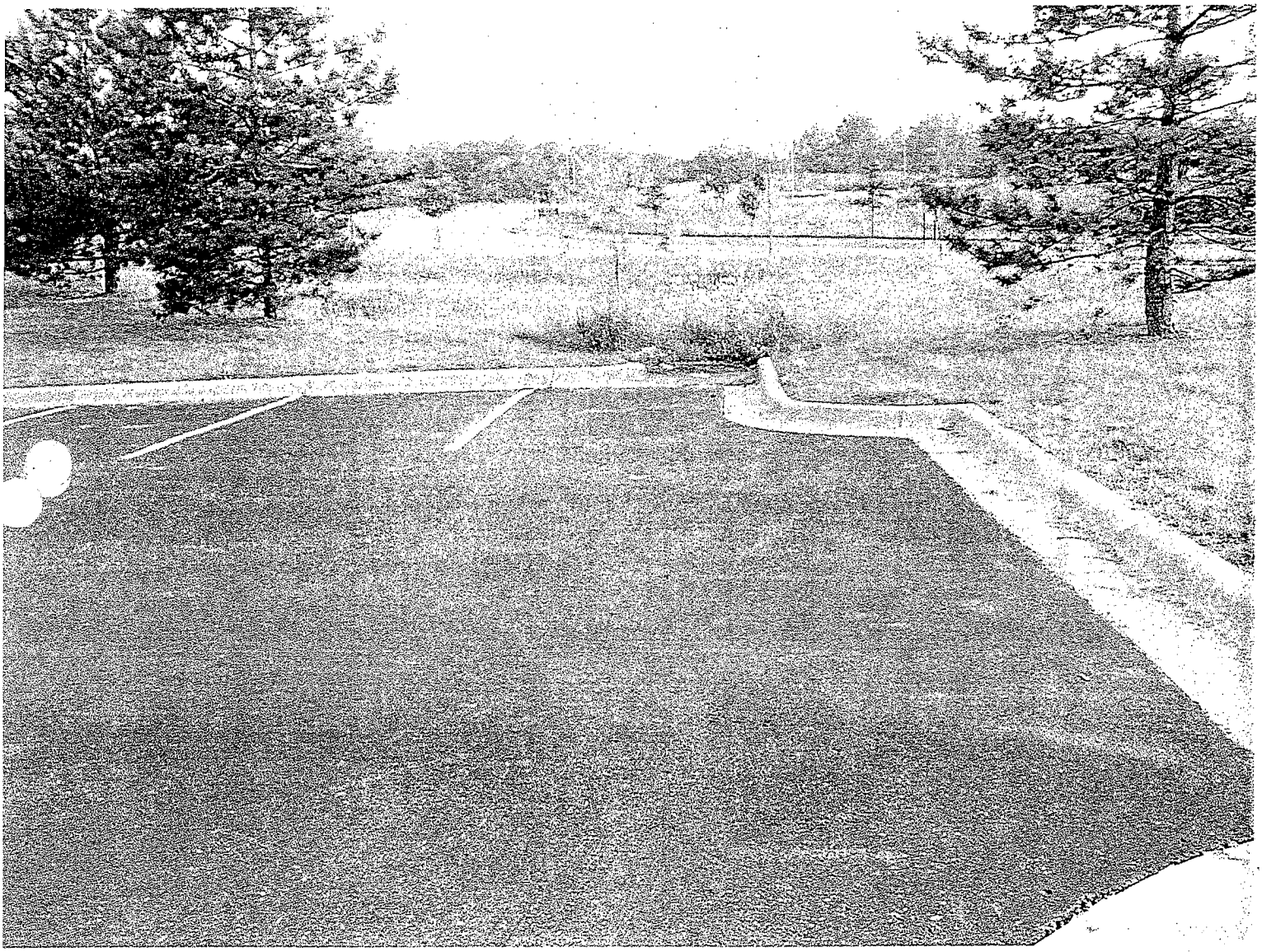



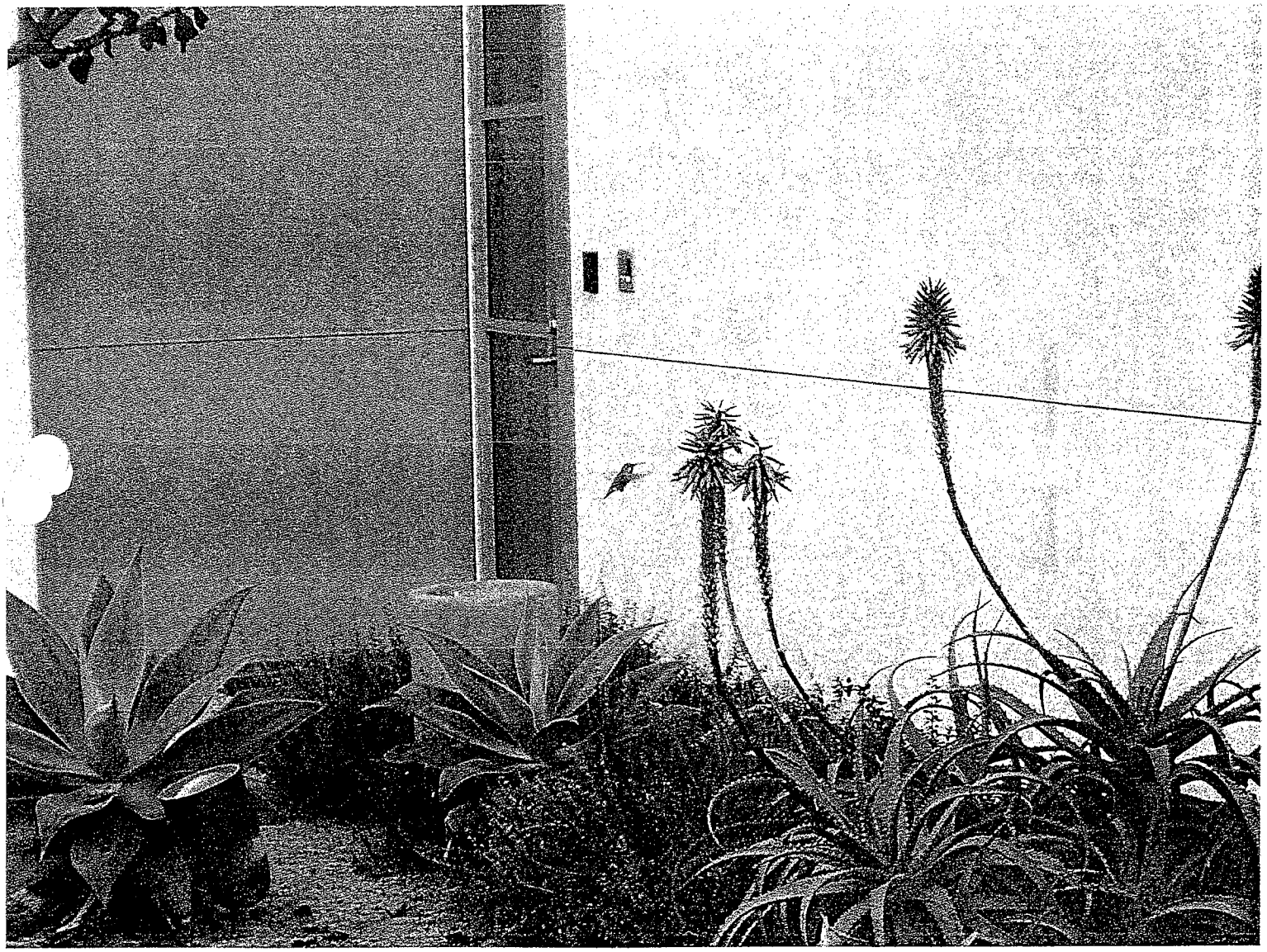

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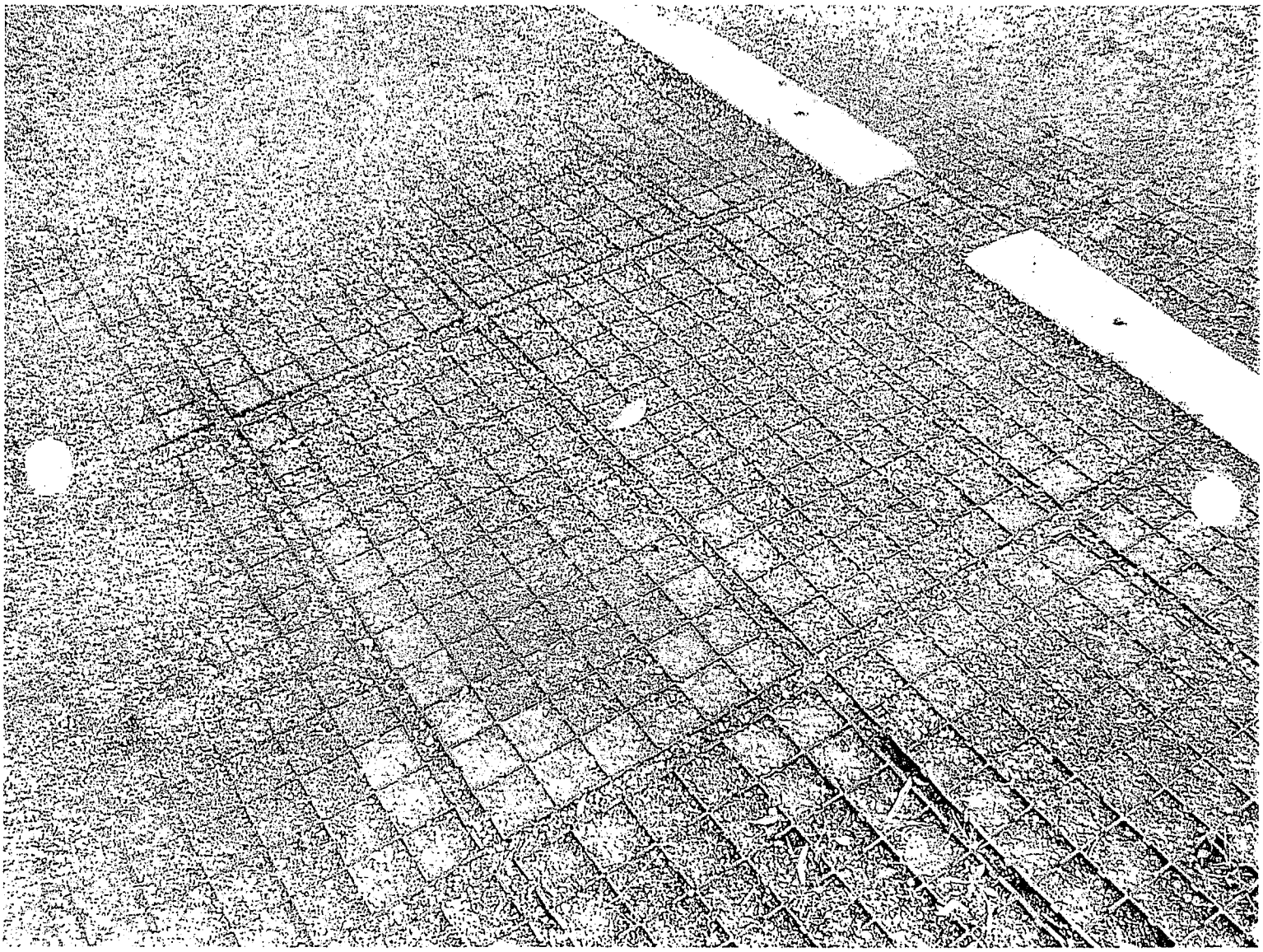

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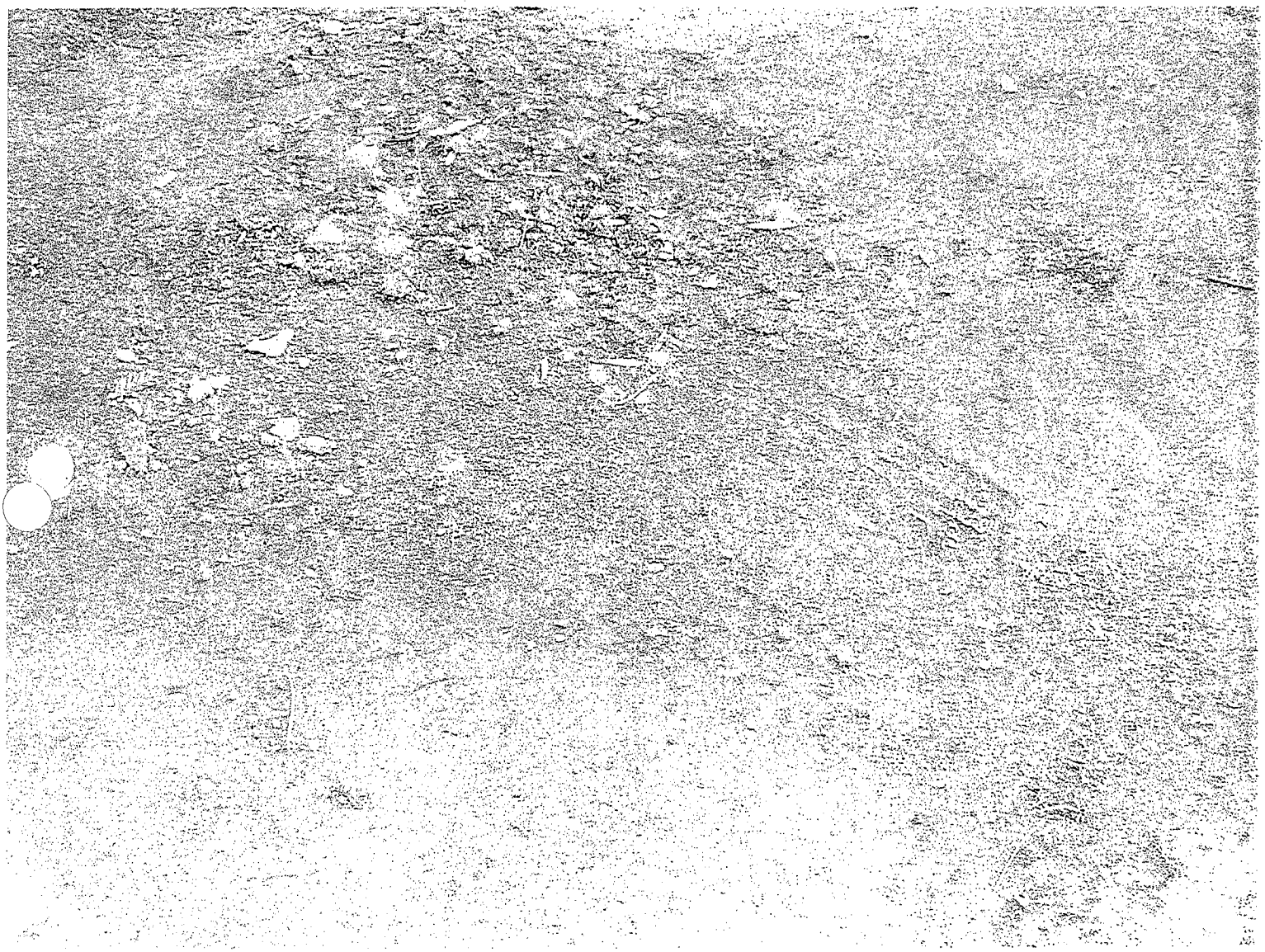



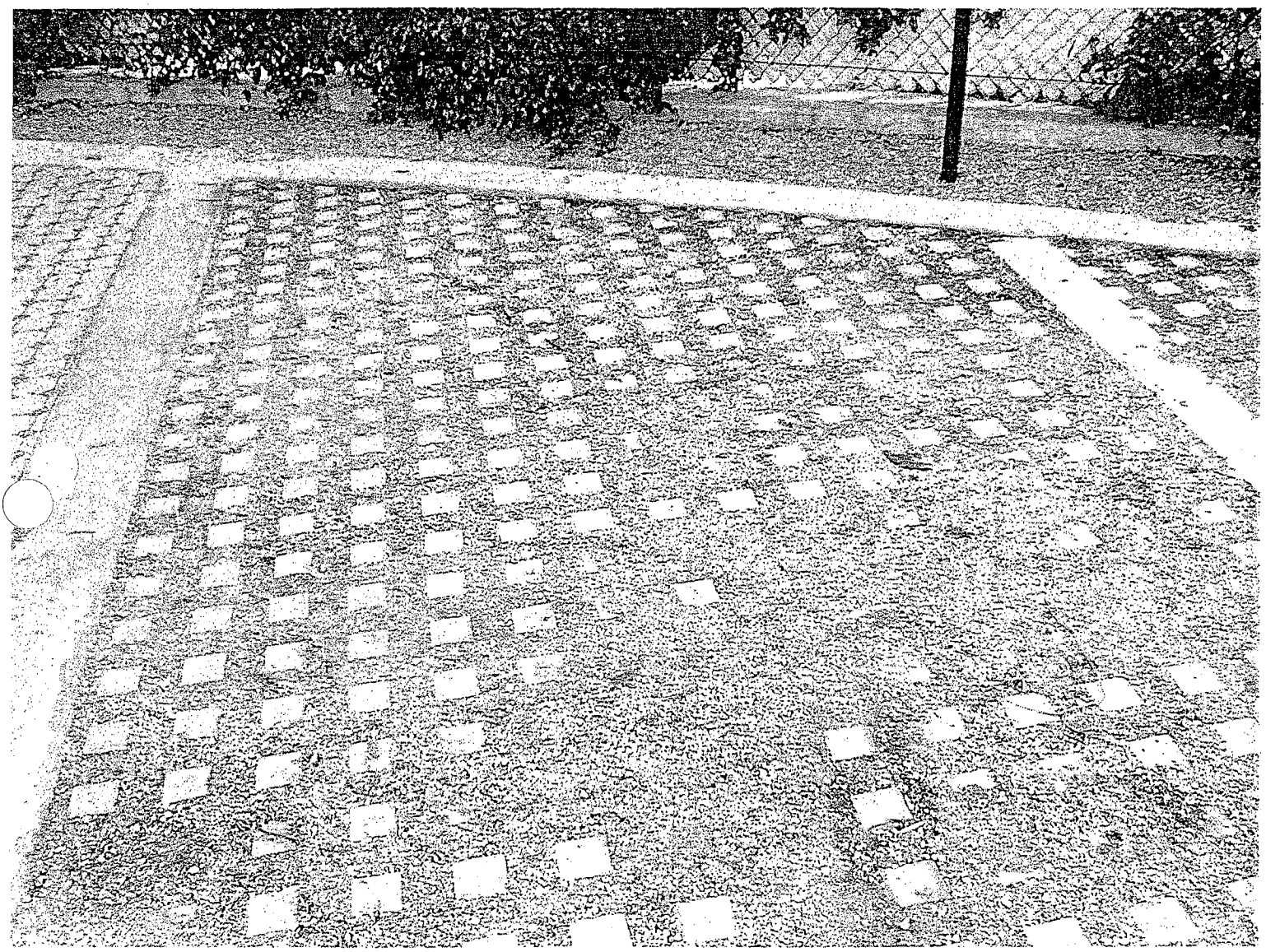

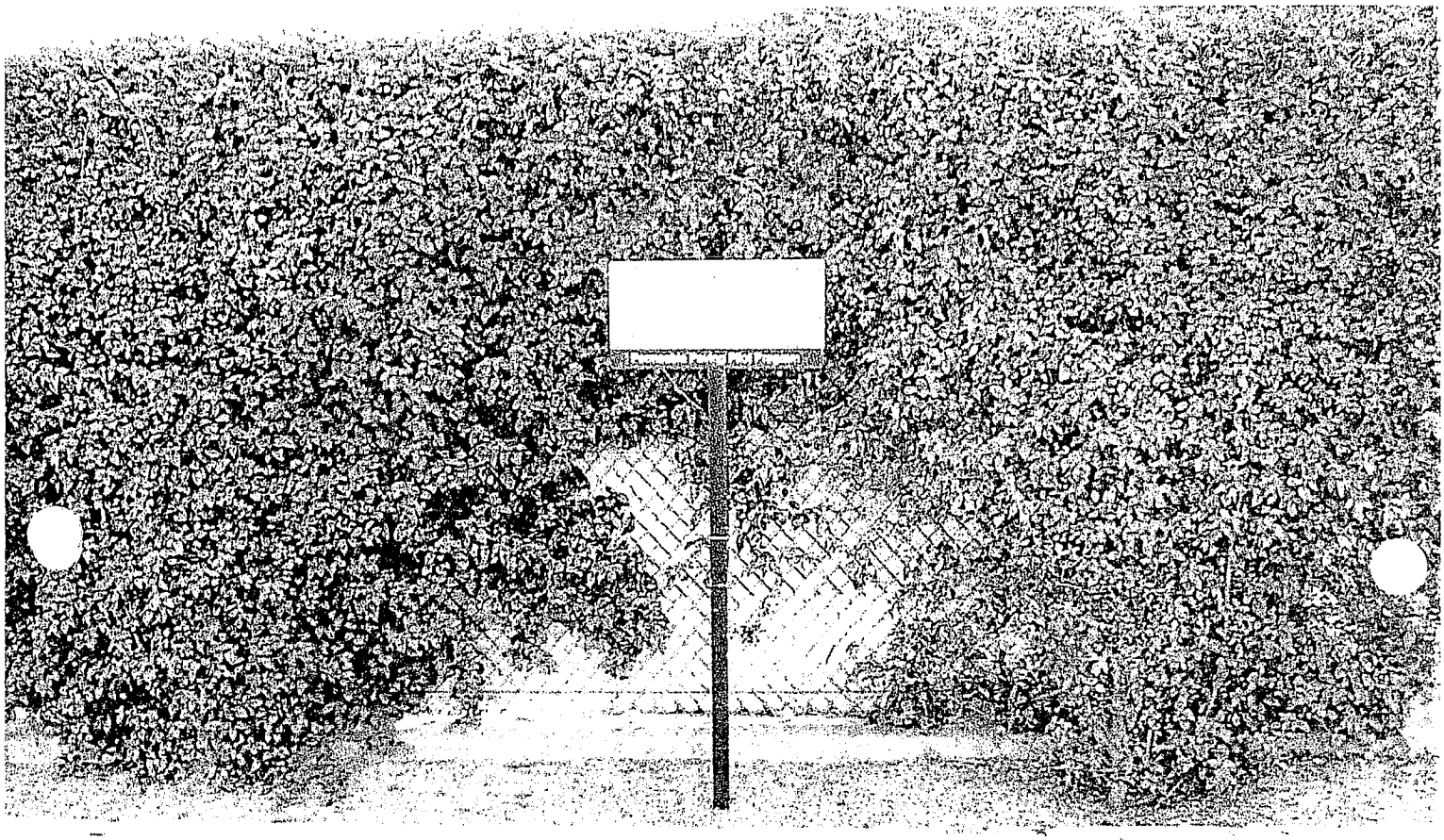

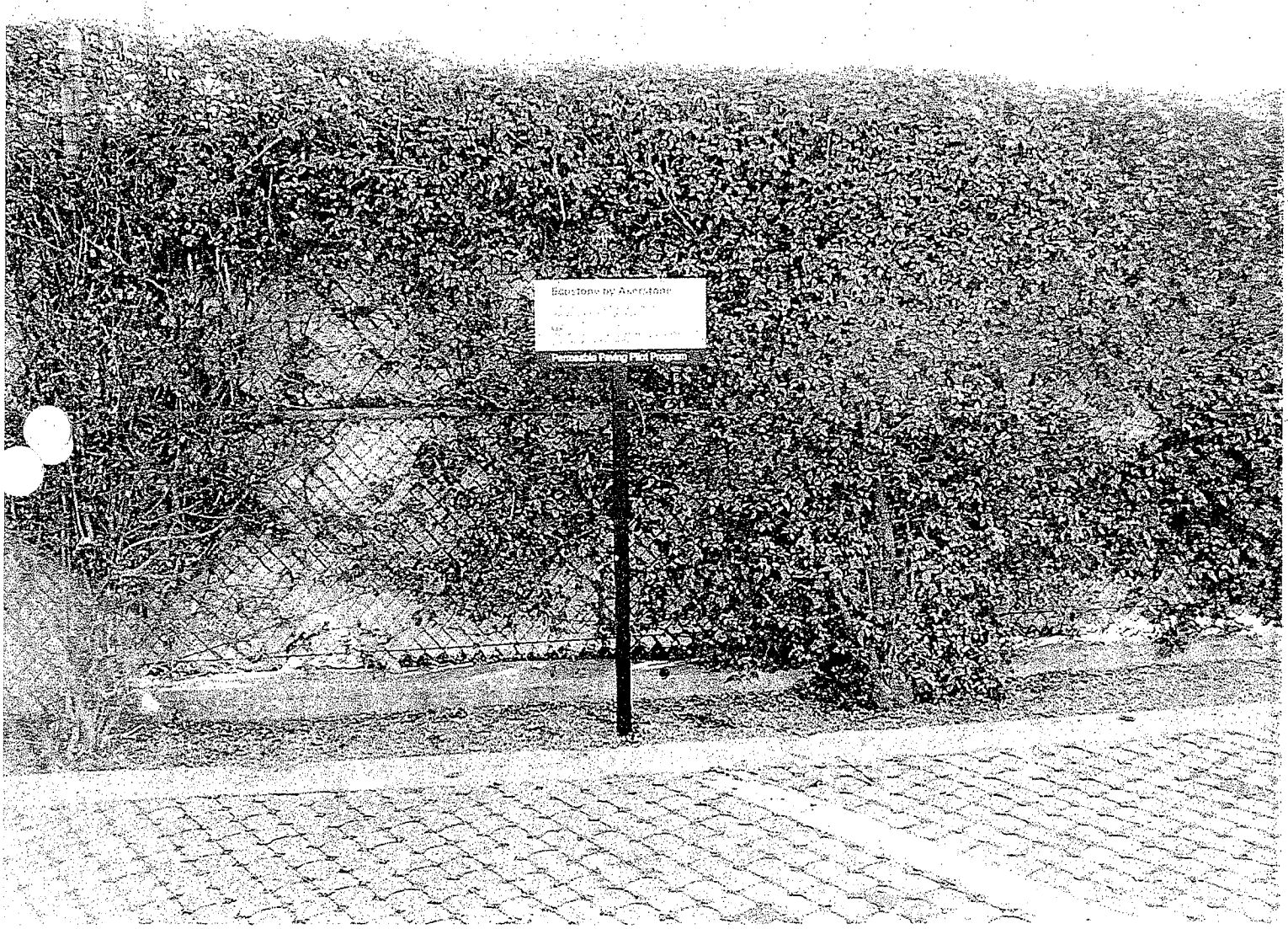

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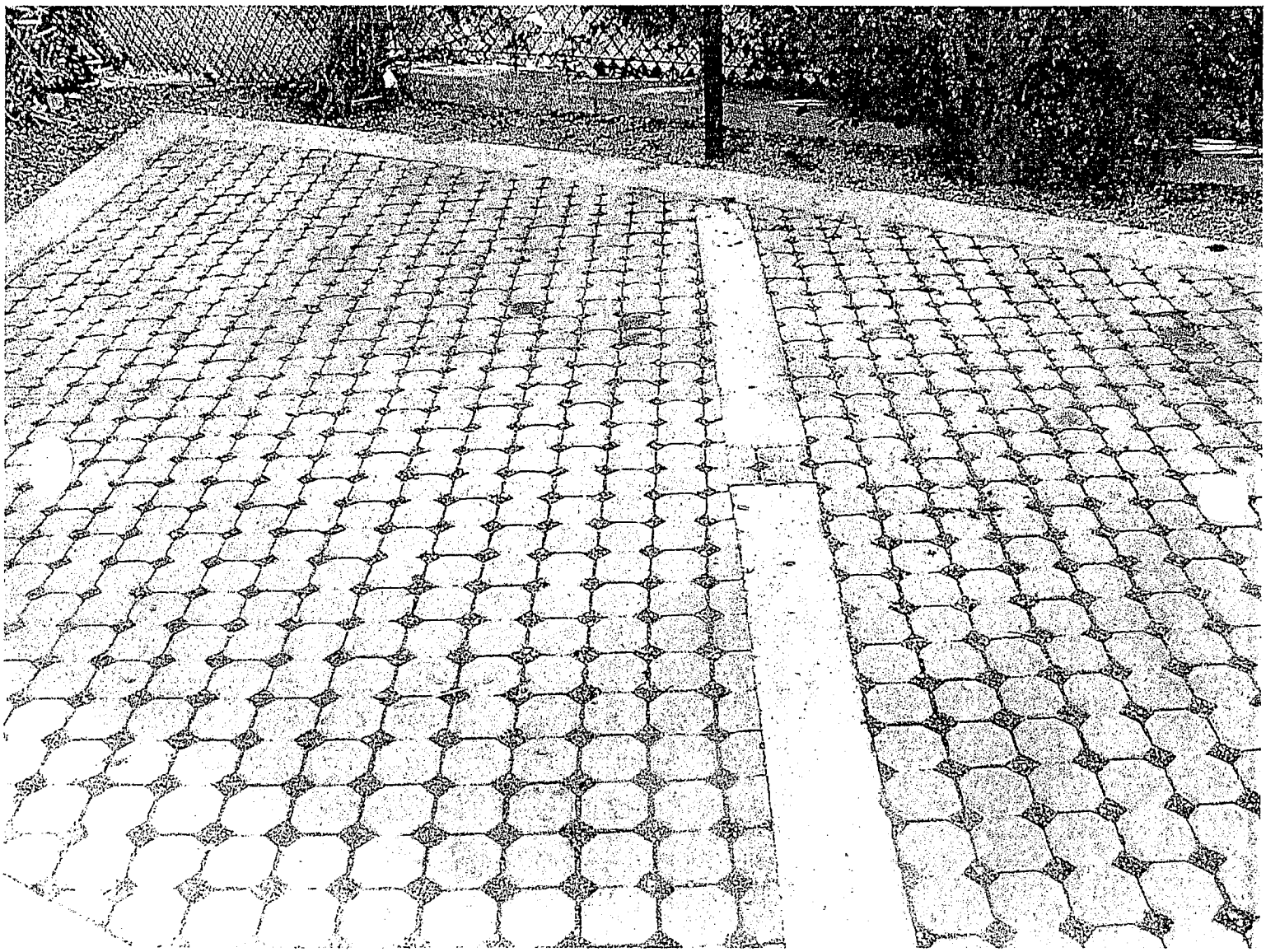

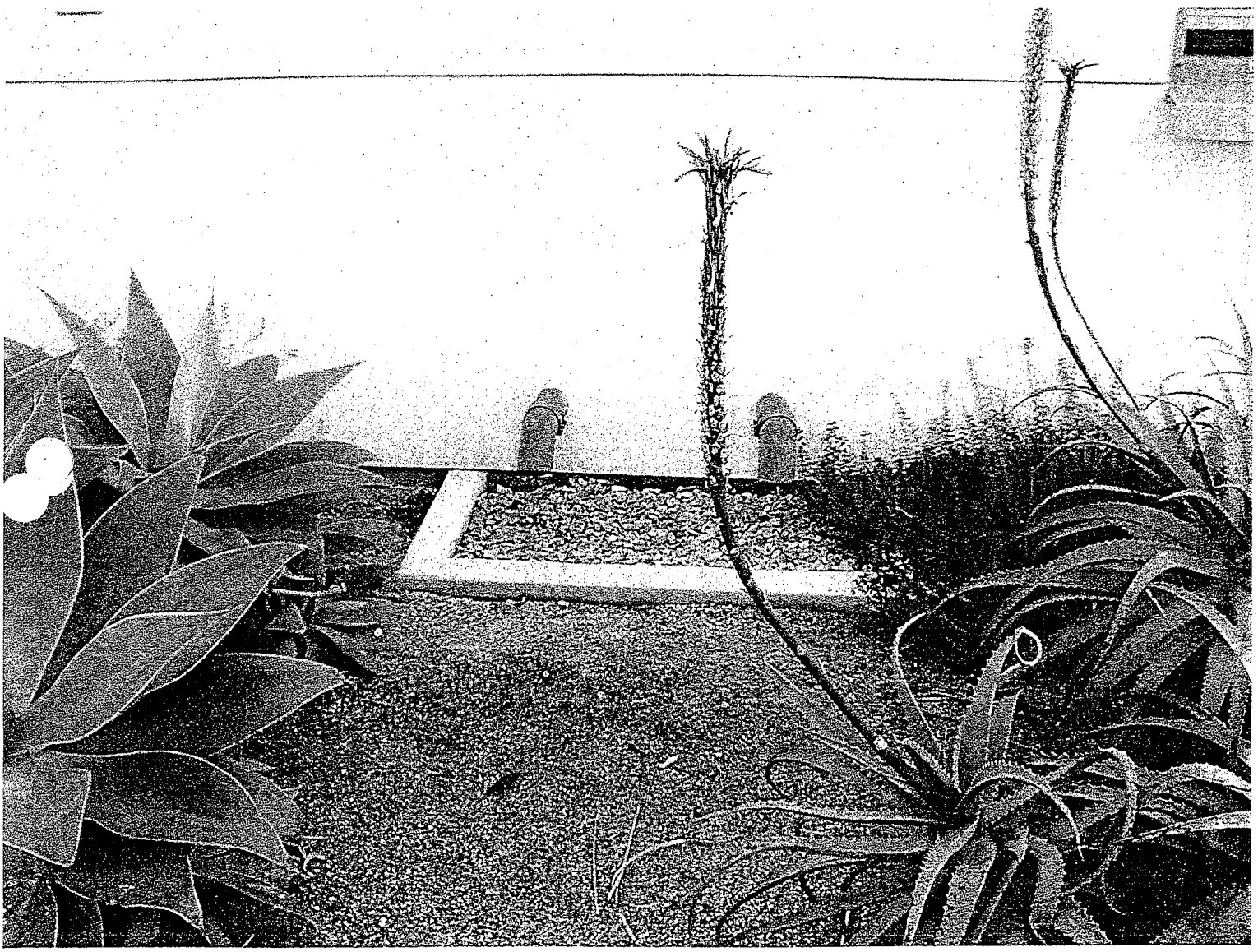







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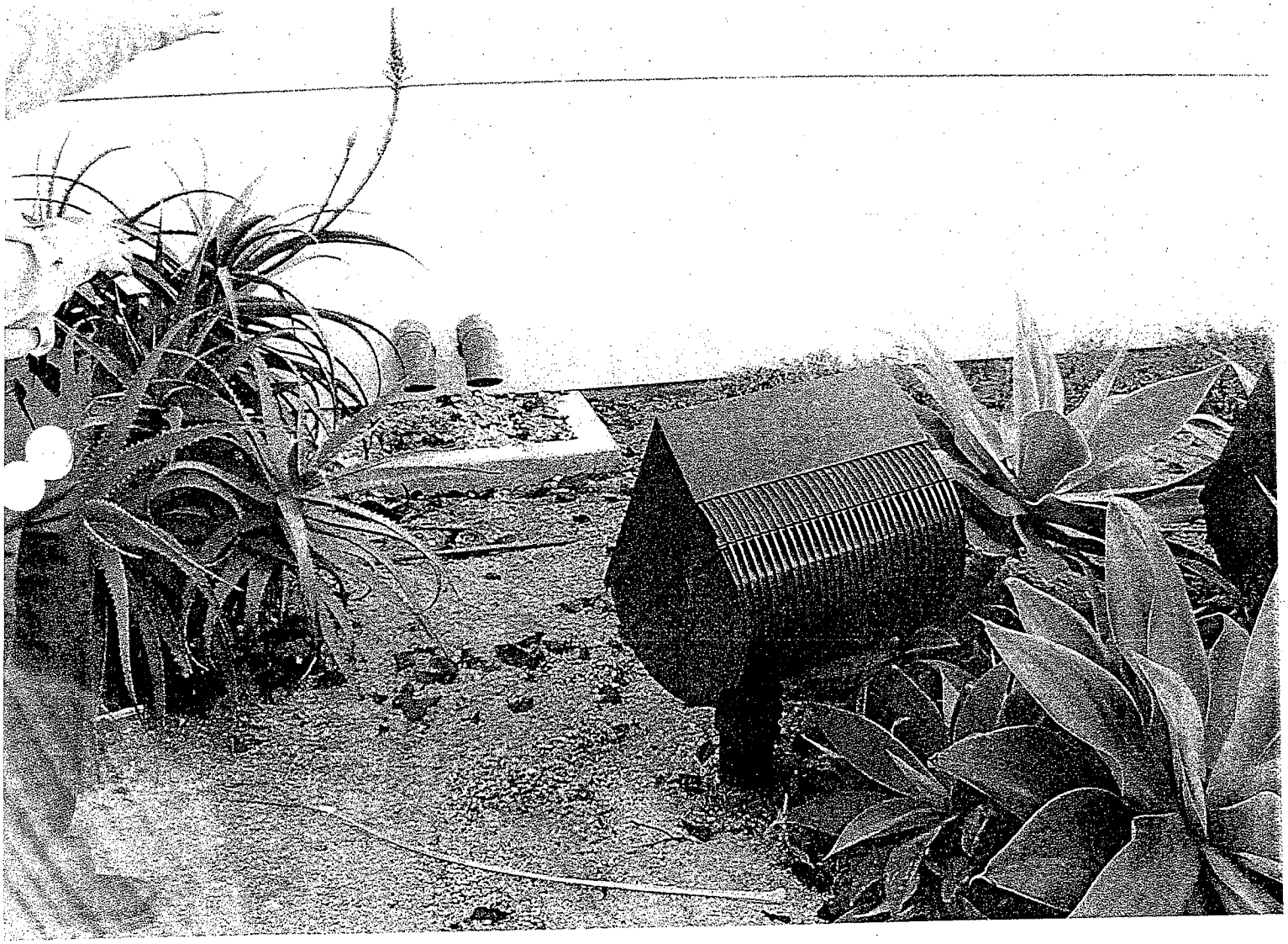
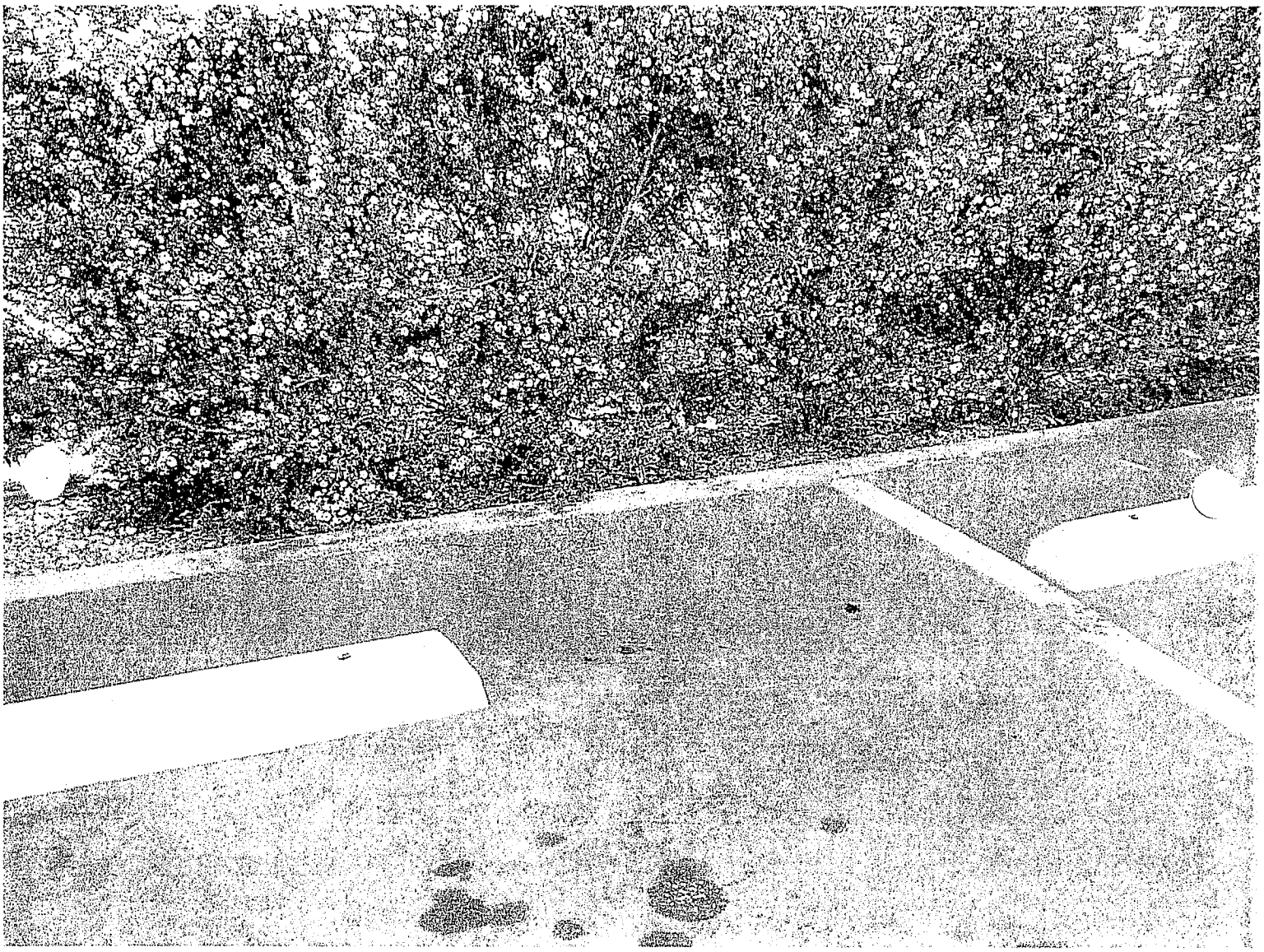
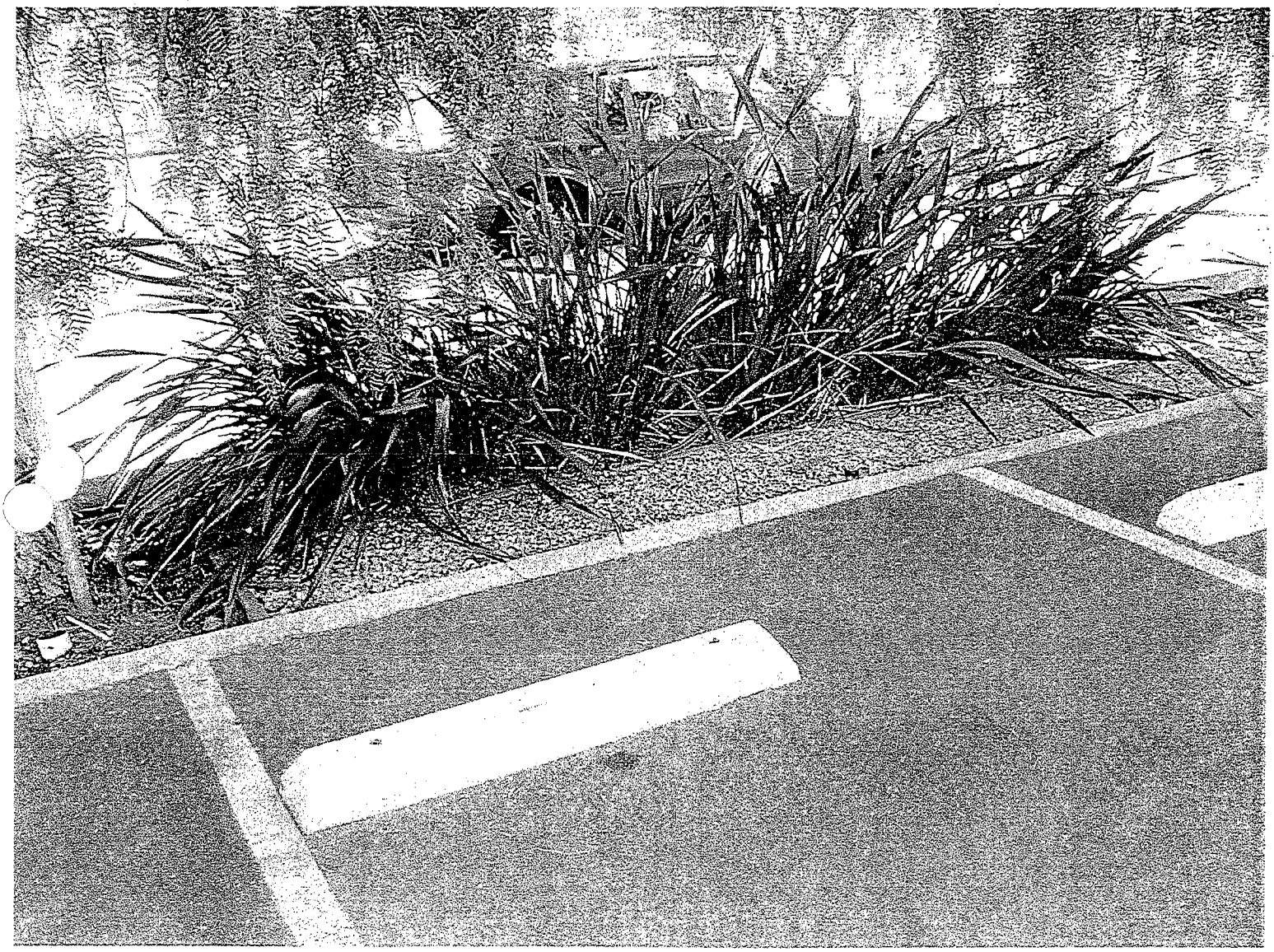
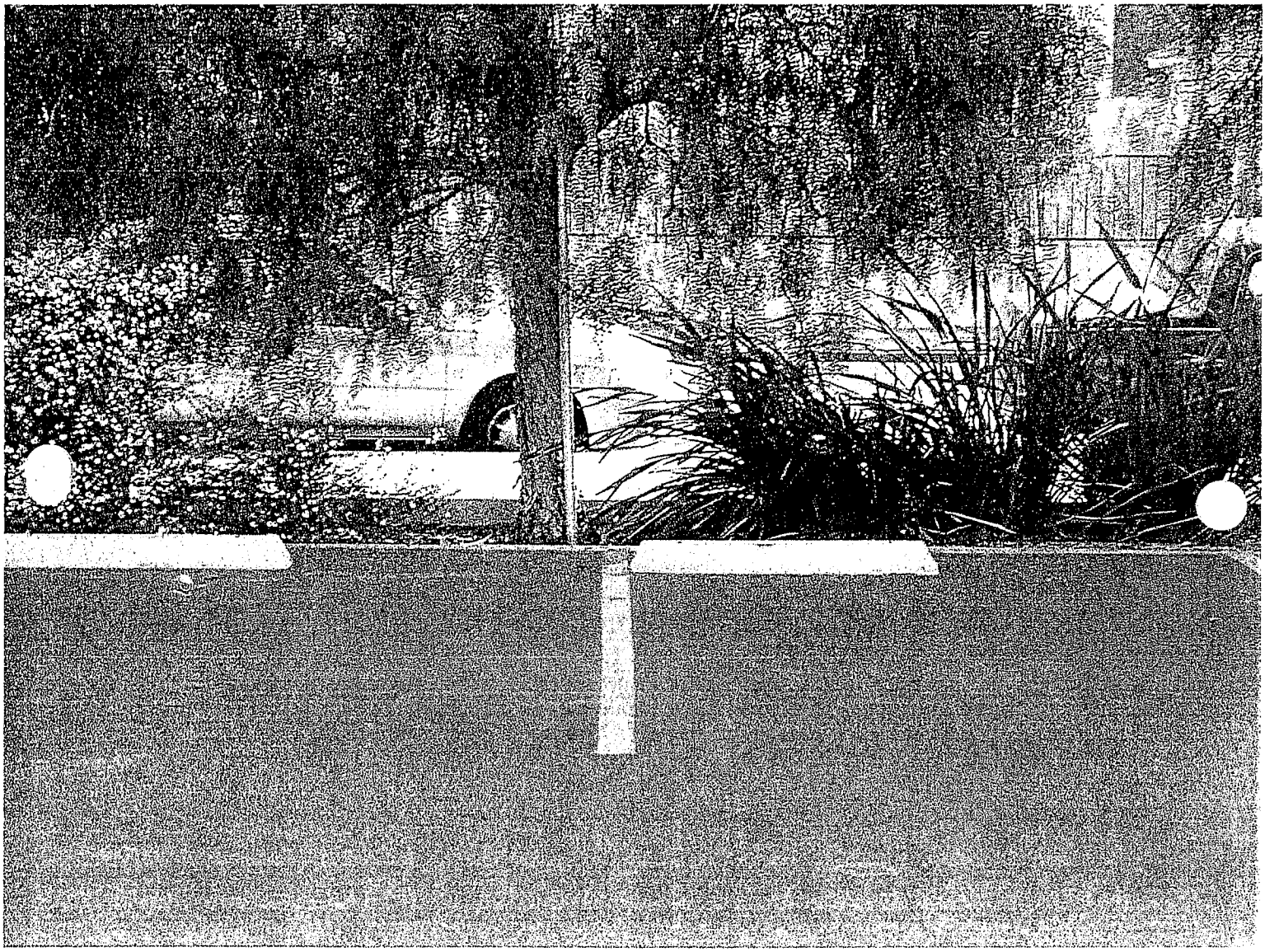
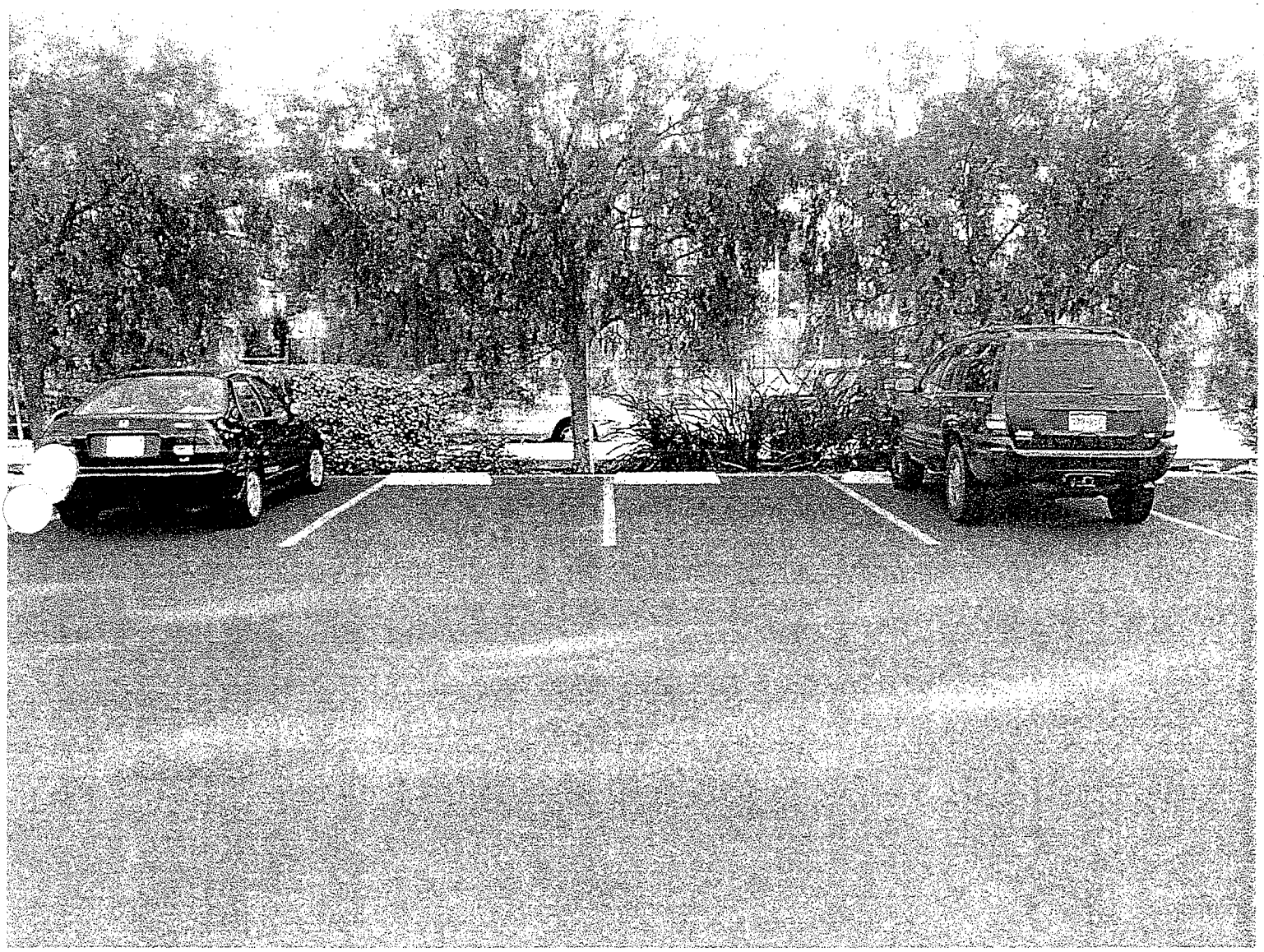










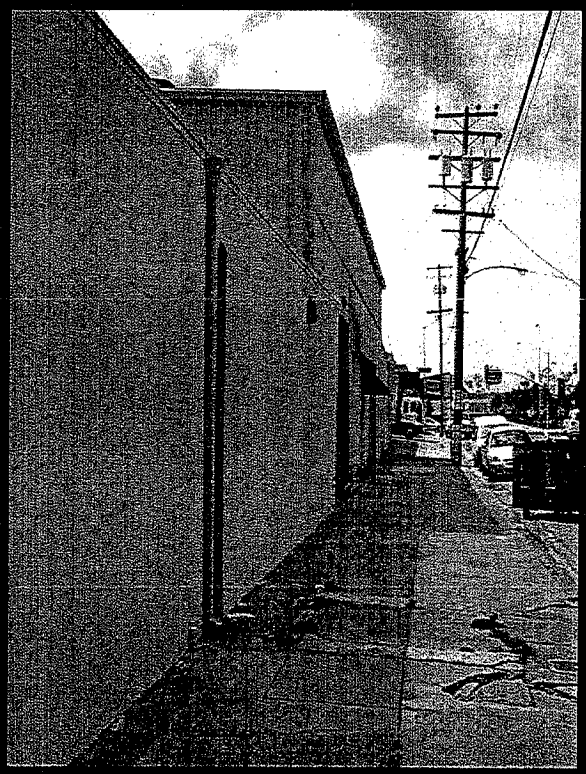
Emeryville Green Dense Development

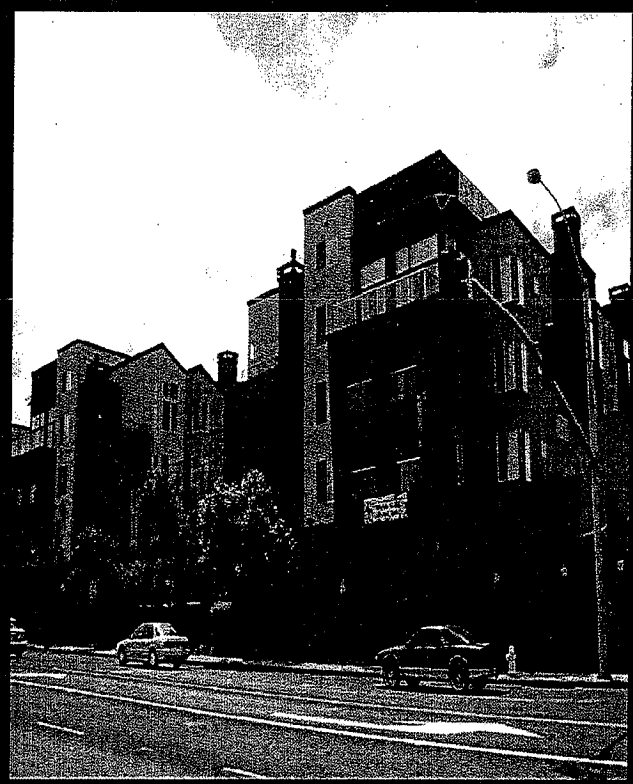
Diana Keena, City of Emeryville
January 27, 2005



Community Design + Architecture • Nelson\Nygaard • Philip Williams Associates

Emeryville is Converting from Industrial to Commercial and Residential





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Alameda Countywide Clean Water Program

County and cities with joint NPDES permit

Permit Requirement:

- New development and redevelopment projects

Treat 85% of average annual runoff

(22.4"/year)

(treat all of the runoff in a 2-year storm)

Challenges in Emeryville

Mostly built and paved

Redevelopment is dense

Most soils are clayey

Many sites are contaminated

High water table - near the Bay

Kinds of Stormwater Treatment

Detention

Store water until after the storm

Tree canopies

Cisterns & irrigation

Retention

Collect & filter water as it soaks into ground

Bio-Retention -
- dripline planter
- tree wells
- rain garden

Infiltration

Allow water to soak in while slowly flowing

Bio-filtration -
- swale
- green roof

Infiltration without plants
- trench
- basin
- permeable paving

Stormwater Treatment Methods for Urban Settings

Emeryville Handbook Recommends:

- Trees
- Green Roofs
- Cisterns & Irrigation
- Bio-Retention
- Bio-Filtration
- Infiltration over capped contaminants

Trees



53rd Street

- Stormwater Functions
  - Intercept and hold large quantities of rainwater on the leaf surfaces
  - Absorb and transpire large quantities of ground water
  - Remove pollutants from stormwater and stabilize them
  - Canopies shade and cool paved areas, reduce heat pollution

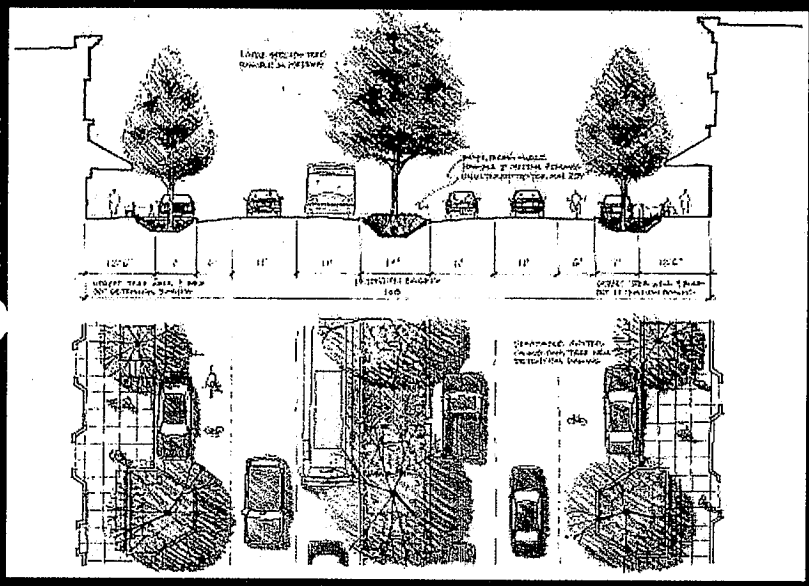
Trees

- Preservation + Planting Strategies
  - Preserve existing trees in new and retrofit projects
  - Plant large species where possible
  - Plant long-lived species
  - Plant evergreens where it rains in winter
  - Require parking lots to have 50 percent canopy cover



Temescal Creek Park

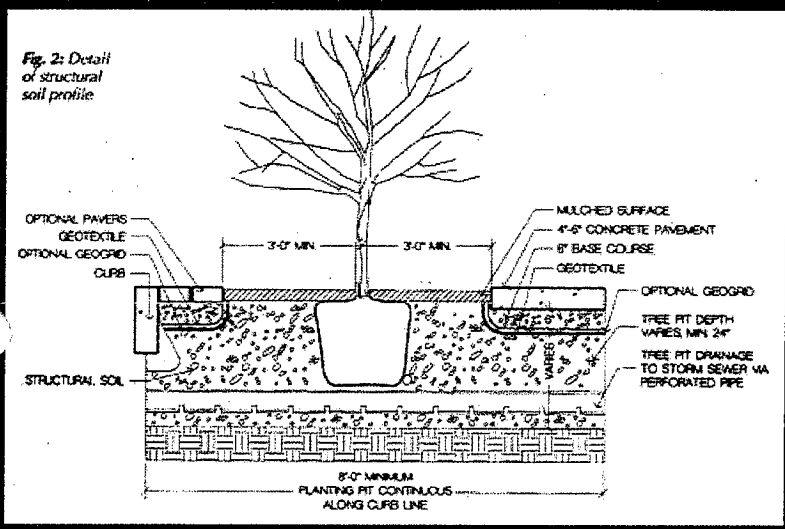
Trees



Green Streets, Metro, Portland, OR

- Include More Trees in Streets Design
  - Sidewalks
  - Parking Lanes
  - Medians

Trees



Structural Soils, Cross Section

Structural Soils

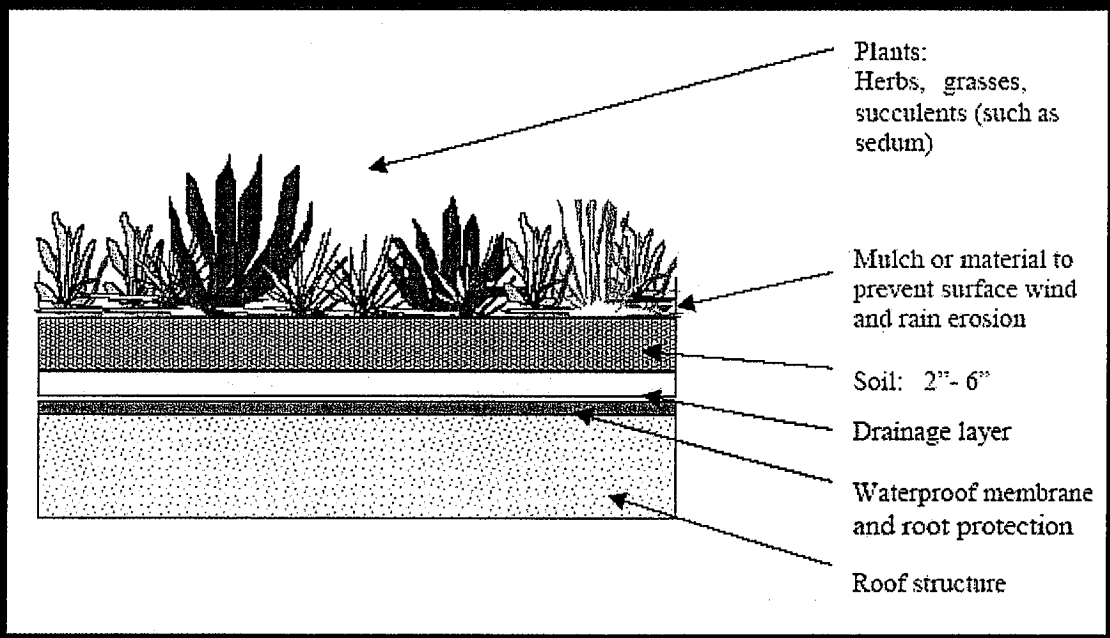
- Artificial growing medium encourages root growth and satisfies pavement requirements
- Gap graded gravels: crushed stone, clay loam, and a hydrogel stabilizing agent
- Work well on remediated sites that require new fill
- Ideal for trees in parking lots, sidewalks, and other constrained spaces

Green Roofs

- **Extensive Green Roofs**

  ? Light, thin layer of planting medium and vegetation

  •Bio-Filtration, evapotranspiration - can intercept 10 to 100% of the rain

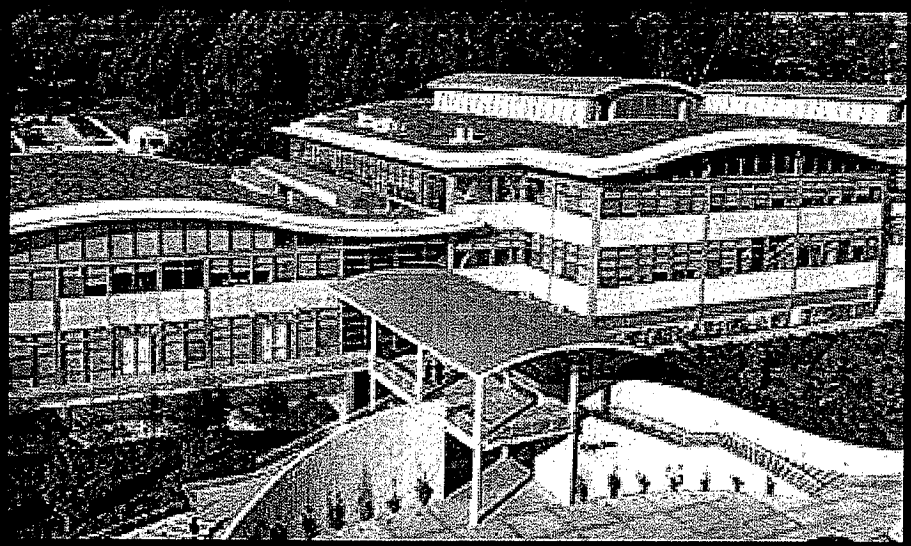


Source: City of Portland

Extensive Green Roof Cross Section

Green Roofs

- Extensive Green Roofs
  - Maintenance is minimal but key - especially during plant establishment
  - Not intended for frequent access



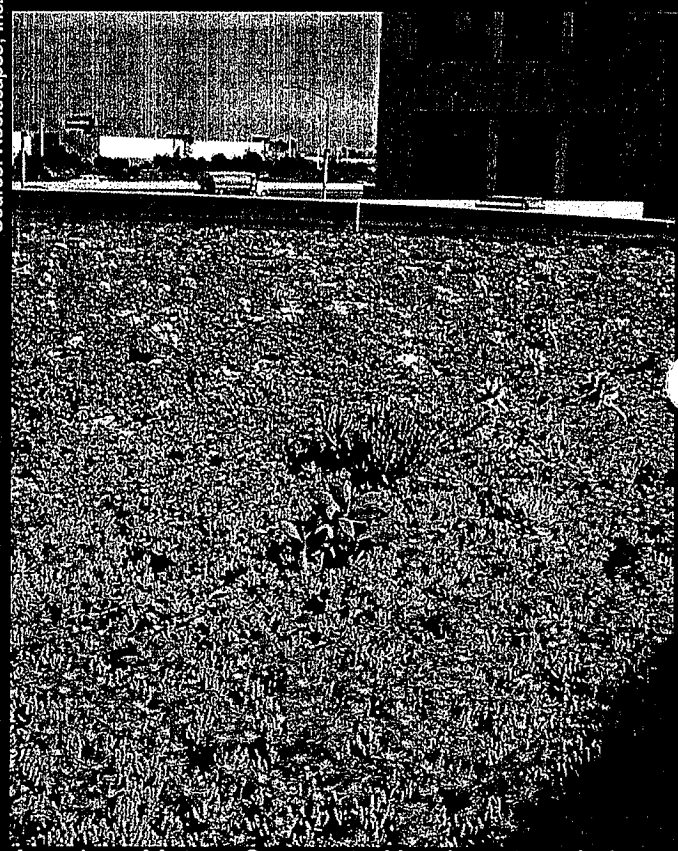
Source: American Hydrotech

Gap Corporate headquarters, San Bruno, CA

Green Roofs

- Extensive Green Roofs
  - Create savings through reduced energy demand
  - Provide bird and insect habitat
  - Provide aesthetic value
  - Feasible on contaminated sites
  - Potentially feasible for retrofit projects

Source: Roofscapes, Inc.

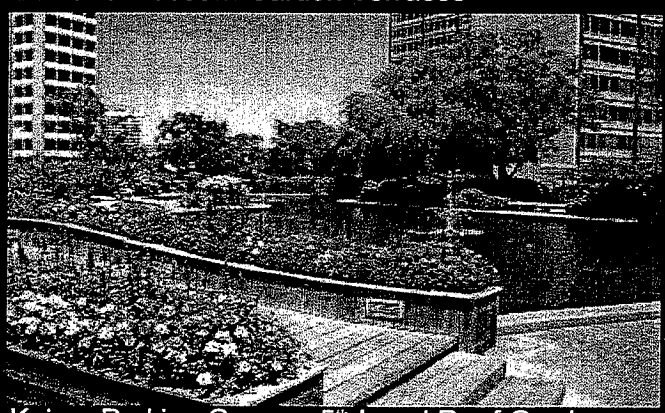


American Motors Corporate Headquarters, Irvine

Green Roofs



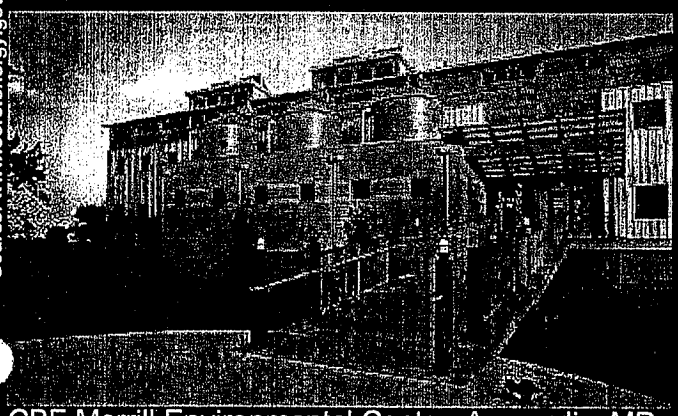
Oakland Museum Garden Terraces



Kaiser Parking Garage, 5th Level Roof Garden, Oakland, CA

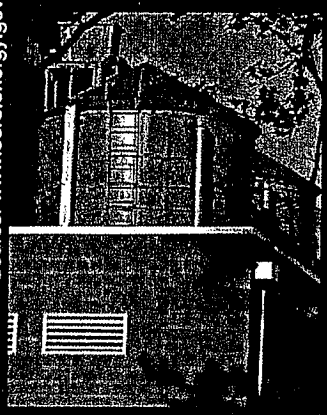
- Intensive Green Roofs
  - Bio-filtration, evapotranspiration of runoff
  - Public or private access to gardens, open space or recreation facilities
  - Feasible on contaminated sites
  - Higher economic/structural demands- less suitable for retrofit projects

Cisterns and Irrigation

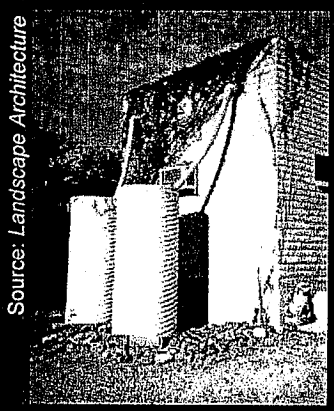


Source: www.eere.energy.gov

CBF Merrill Environmental Center, Annapolis, MD



Source: www.eere.energy.gov



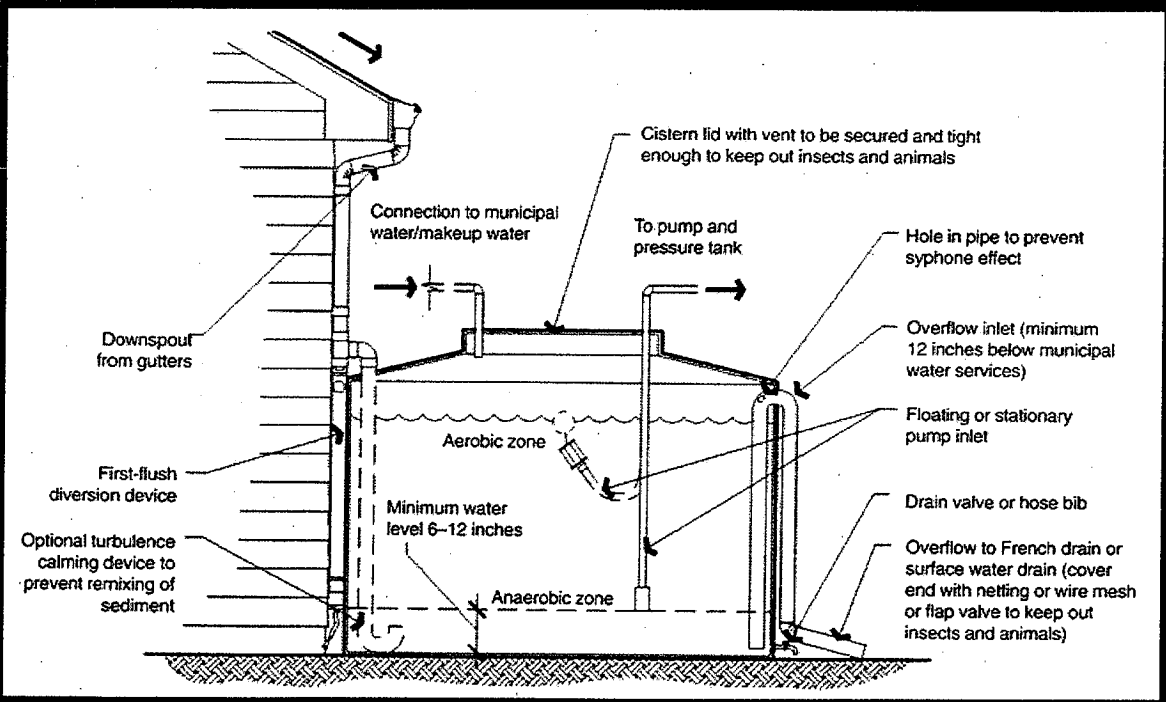
Source: *Landscape Architecture*

Residential Cisterns, AZ

- Collect rainwater from roof and store it for irrigation and other non-potable uses
- Attenuate peak runoff flows
- Conserve potable water resources

Cisterns and Irrigation

- Connections to gutters and downspouts convey water to cisterns
- Cisterns can be located above or below ground

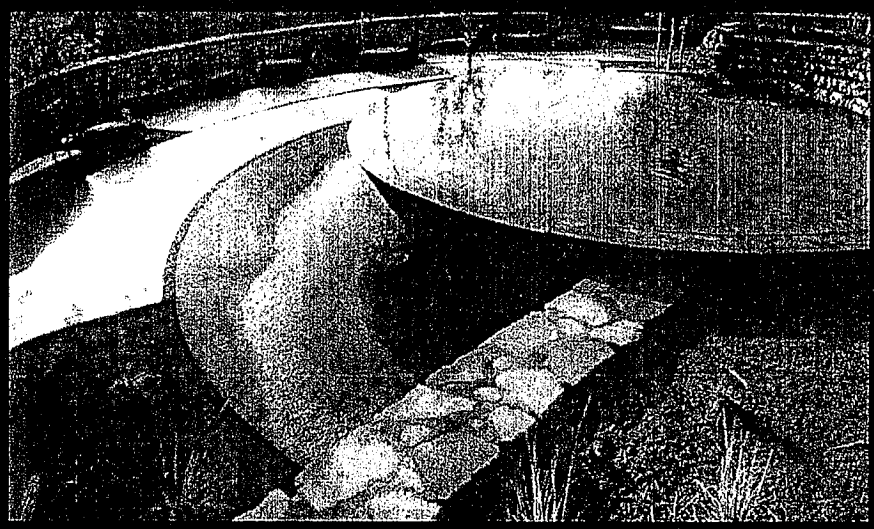


Source: *Landscape Architecture*

Cistern Detail

Cisterns and Irrigation

- Most roofing materials are compatible
- System should include a "roof washer" or "first flush" device

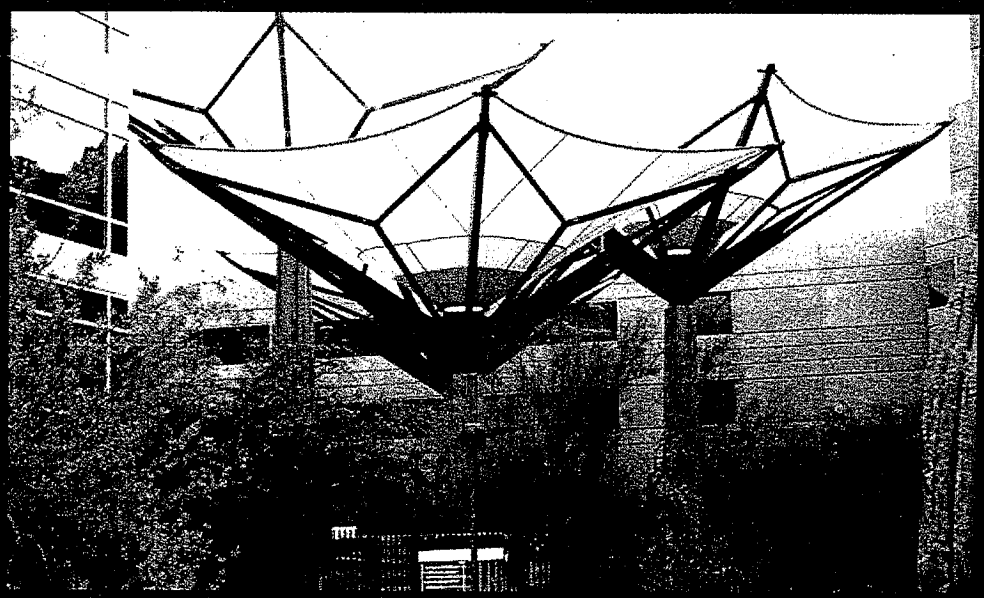


Source: *Landscape Architecture*

Steele Indian School Park, Phoenix, AZ

Cisterns and Irrigation

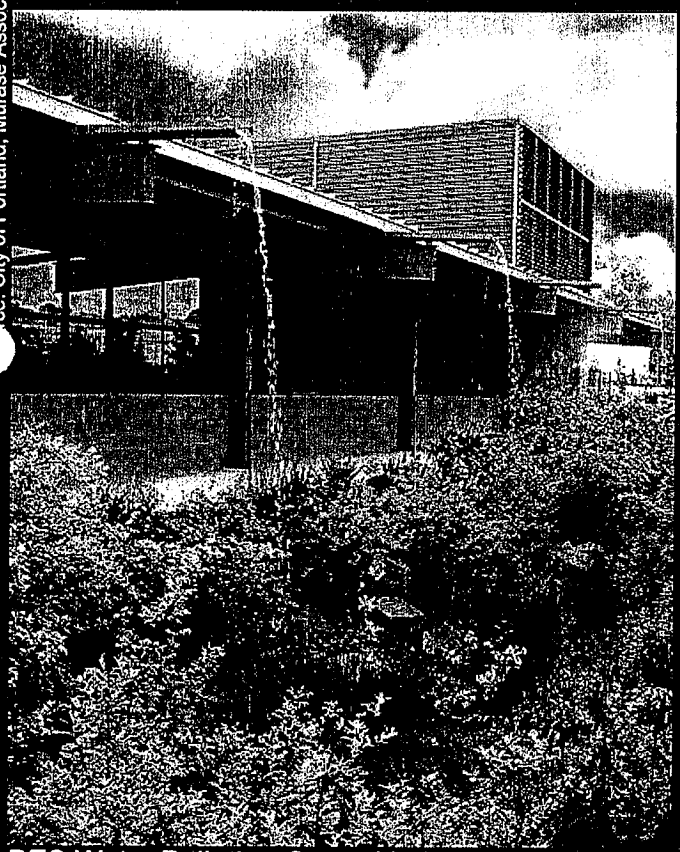
- Rain Catchers
  - Intercept rainfall for storage and harvesting
  - Unique urban design elements-- lend visual character and identity



Source: *Landscape Architecture*

Phoenix Office Complex with Rain Catchers

Bio-Retention



ce: City of Portland; Murase Assoc.

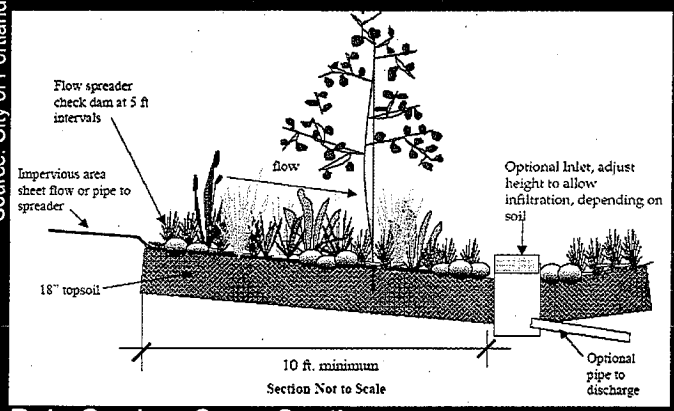
BES Water Pollution Control Lab, Portland, OR

- Rain Gardens
  - Use soil, plants, trees, and hardscape to enhance infiltration and bioremediation
  - A broad range of plant types can be used
  - Can provide habitat and aesthetic value

Bio-Retention

- **Rain Gardens**
  - Consist of a grasssy buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants.
  - Require stable soils
  - Water table should be more than 6 feet below the ground surface
  - Stormwater should not infiltrate or leach through contaminated soils.

Source: City of Portland

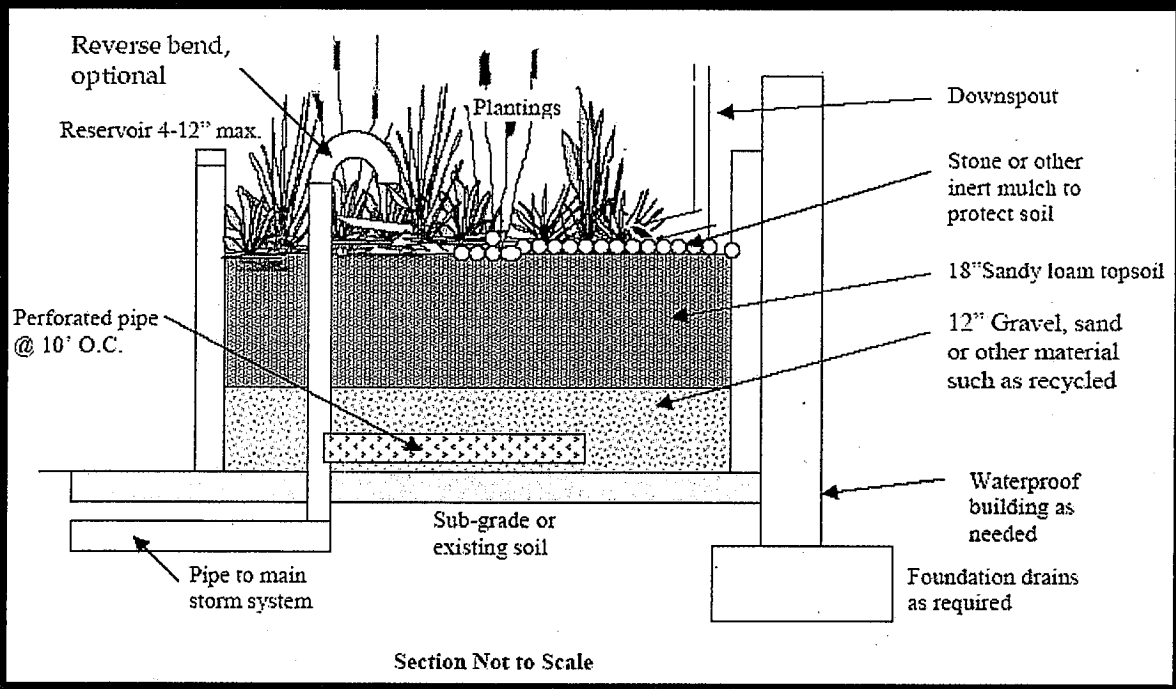


Rain Garden, Cross Section



Bio-Retention

- **Drip-Line Planters**
  - Suitable for contaminated sites- planter prevents exfiltration to underlying soils
  - Should include a "roof washer" or "first flush" device



Source: City of Portland

Drip-line Planter, Cross Section

Bio-Retention

- **Drip-Line Planters**
  - Feasible for sites with space constraints
  - Feasible for retrofit projects

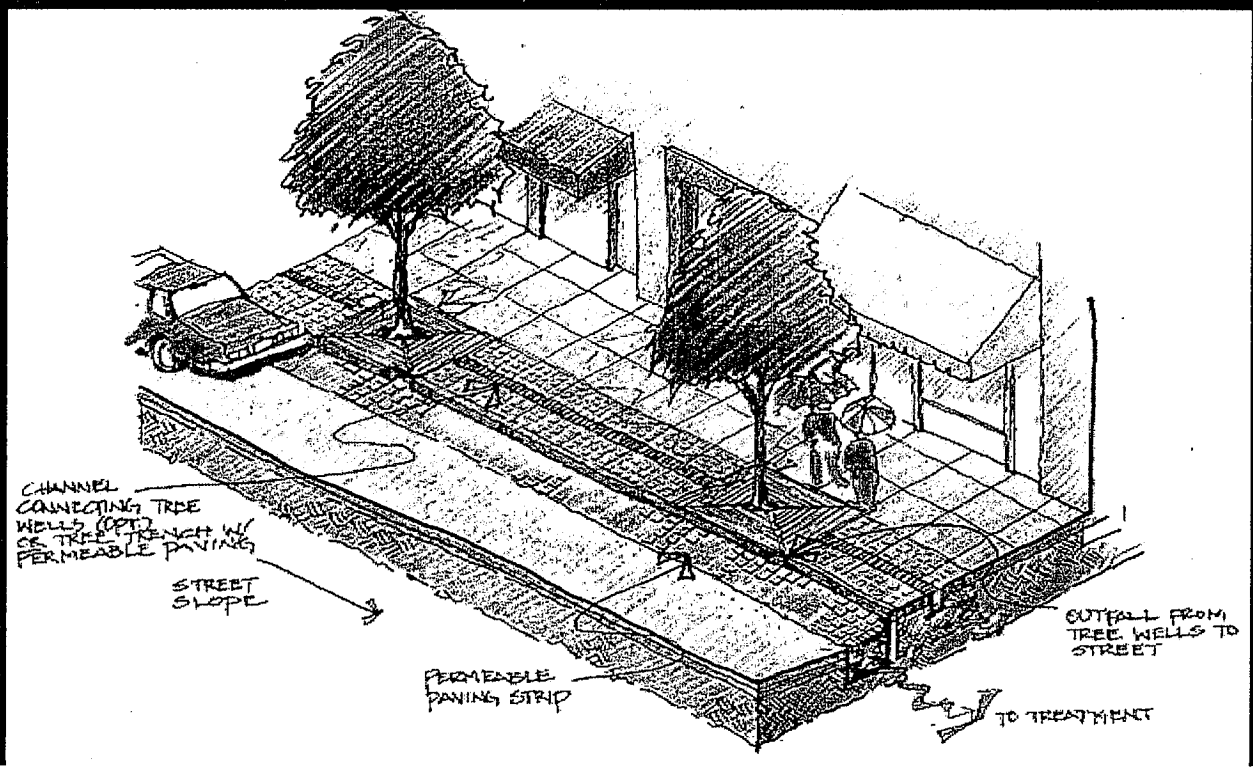


Source: City of Portland

Buckman Heights Apartments, Portland, OR

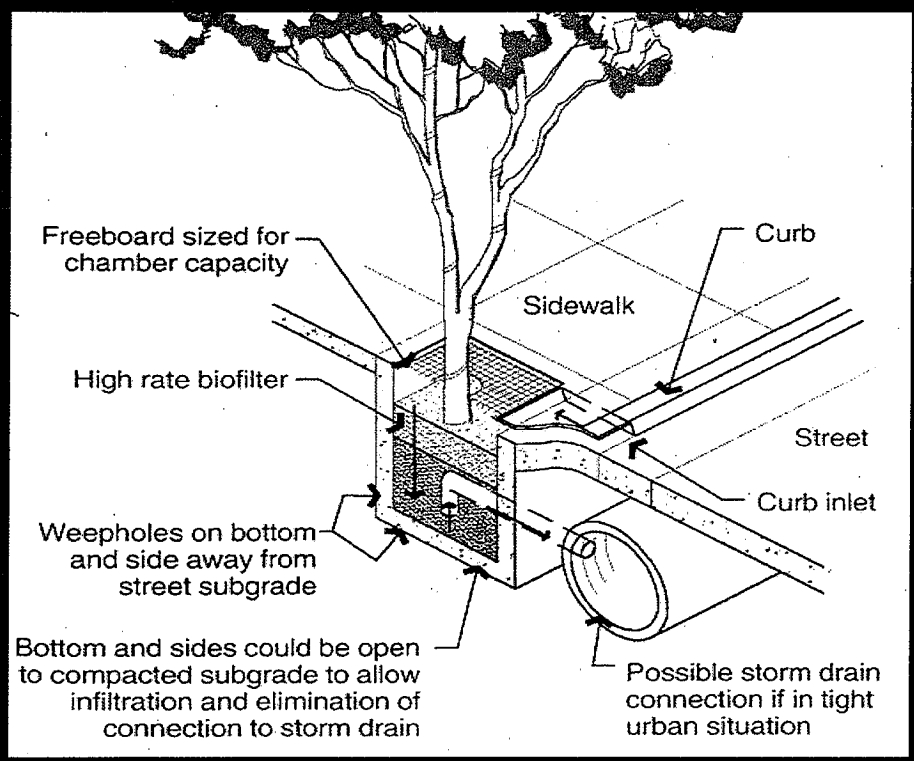
Bio-Retention

- Street Tree Wells
  - Appropriate for urban streetscapes



Bio-Retention

- Street Tree Wells
  - Proper drainage provides better environment for street trees



Source: *Landscape Architecture*

Bio-Filtration

- Swales
  - May include trees, check dams in sloped areas
  - Broad range of plant types can be used

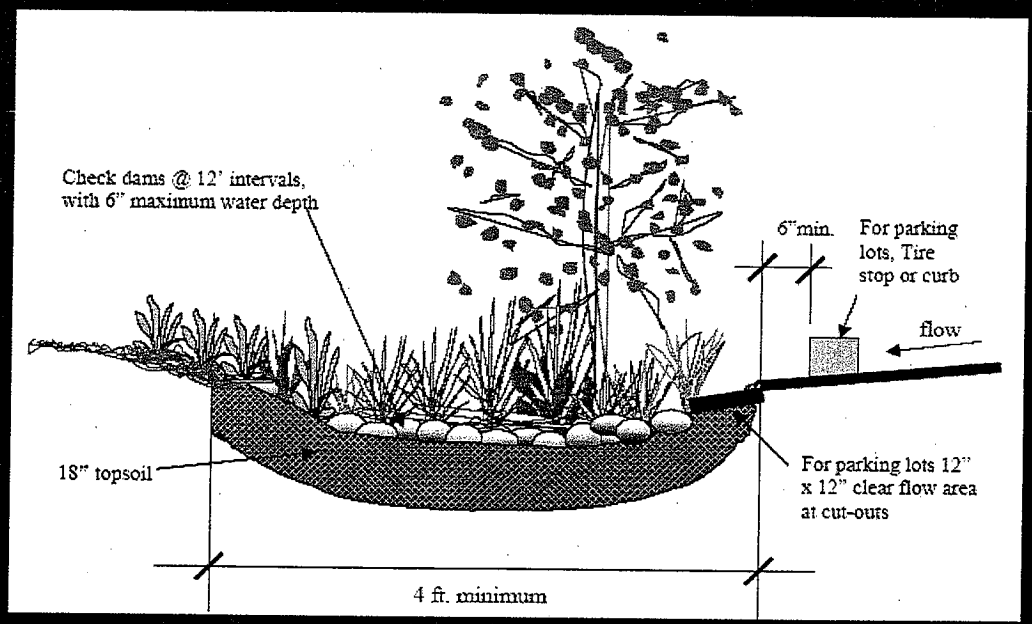


School Parking Lot, Portland OR

Source: SEWNET

Bio-Filtration

- Swales
  - Curb treatments can be flexible
  - Allow appropriate "residence time" for water to be in contact with vegetation



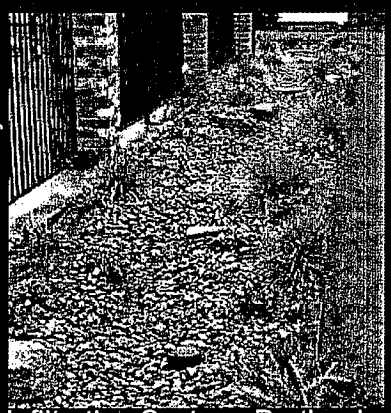
Source: City of Portland

Swale, Cross Section

Infiltration

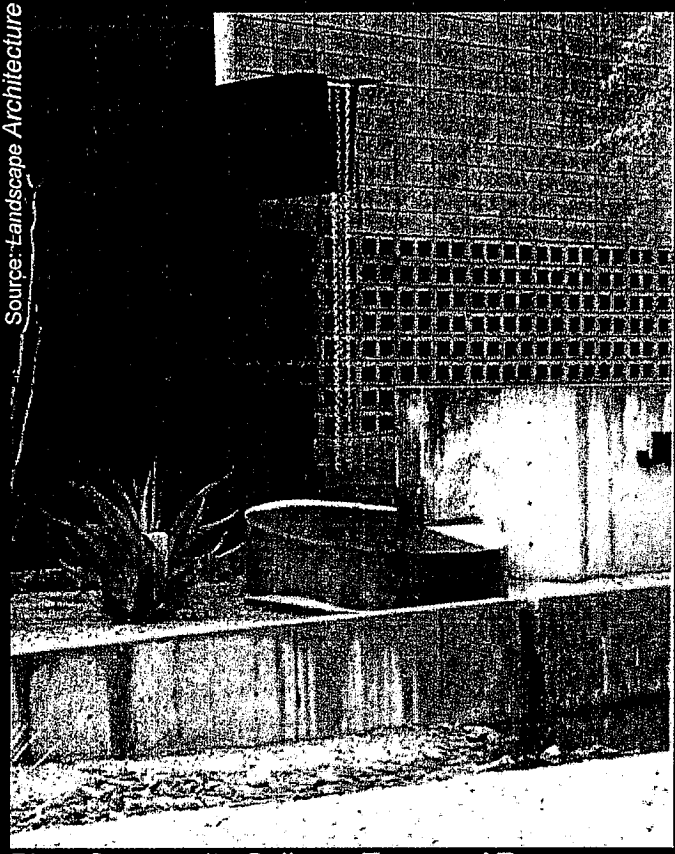
- Infiltration Trenches
  - Collect storm water and slowly infiltrate
  - Can employ filtering devices
  - Can connect to existing storm sewer system

Source: City of Portland



Infiltration System, Portland, OR

Source: *Landscape Architecture*



Pima Community College, Tucson, AZ

Infiltration

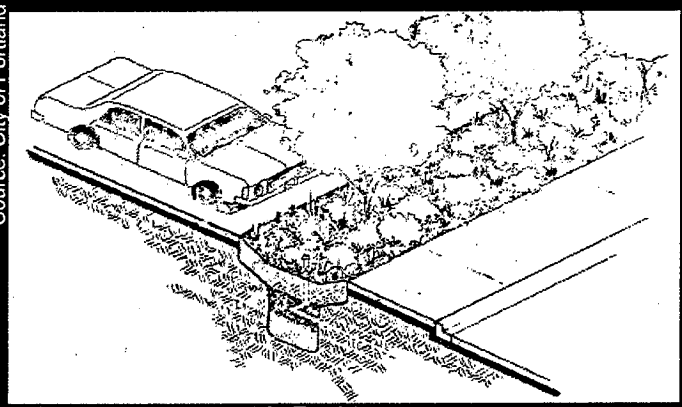
- Infiltration Basins
  - Water infiltrates slowly while flowing through

Infiltration Basin Plan



Source: City of Portland

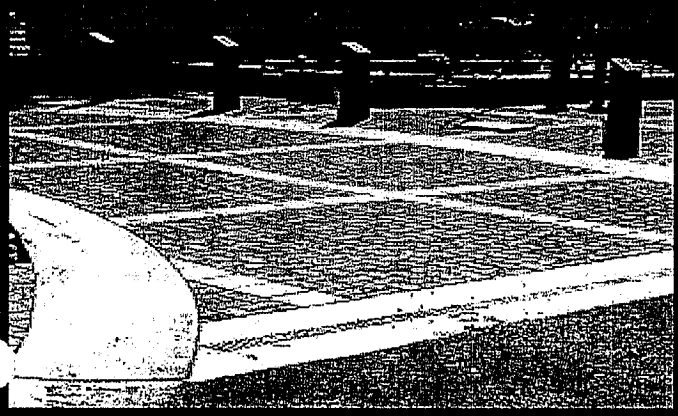
Infiltration Basin with Parking



Source: City of Portland

Infiltration Basin with Parking

Infiltration



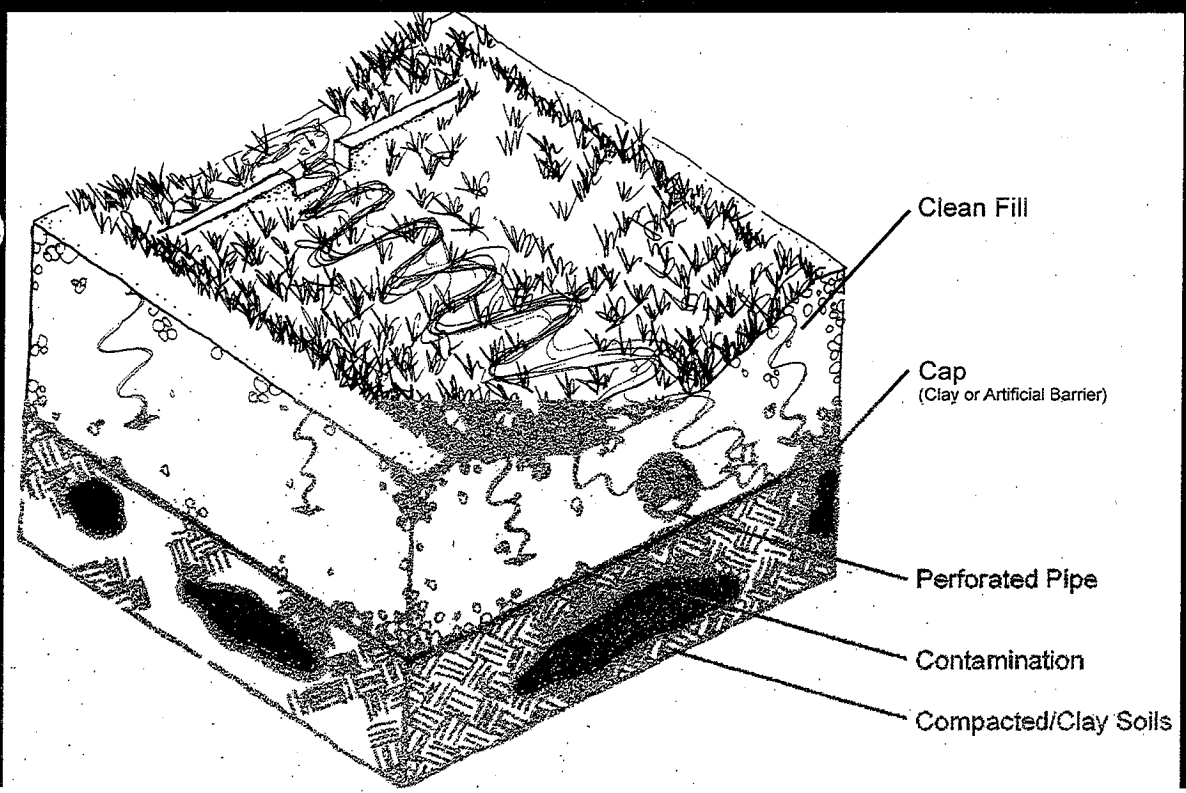


Grass Pavers, Havana, Cuba

- Permeable Paving
  - Reduces amount of impervious surface
  - Appropriate for low-speed locations
  - ADA issues
  - In brownfield conditions requires underground cap

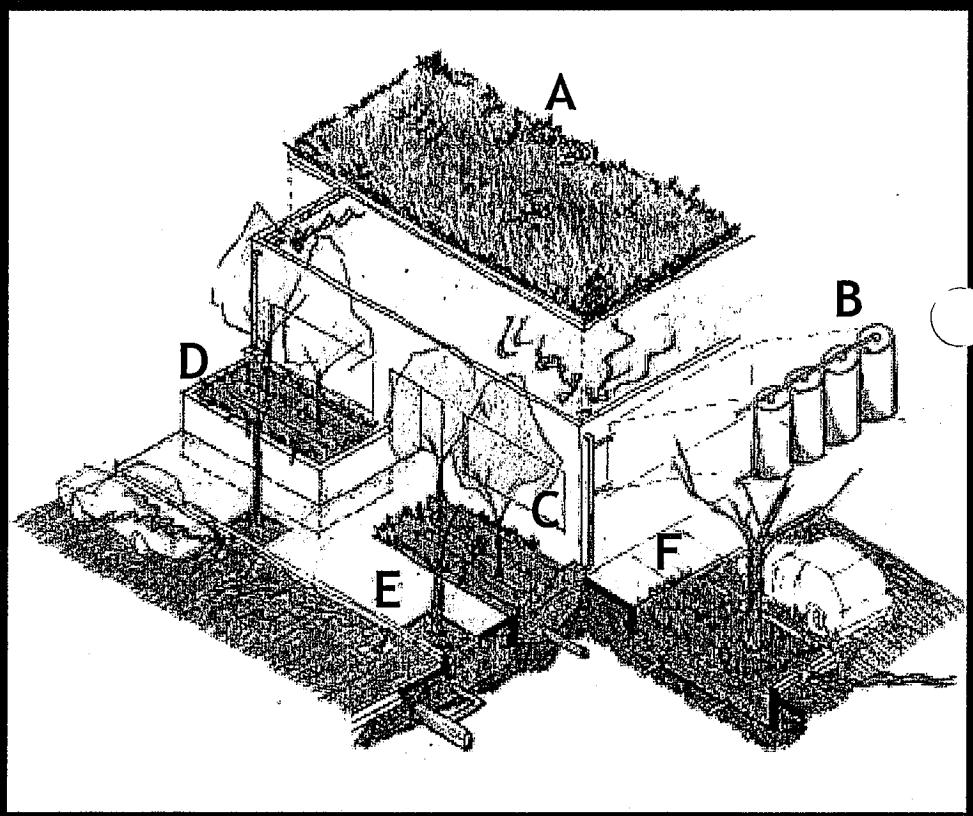
Infiltration Above Contamination

Infiltration Above a Cap Prevents Flow into Contaminated Soil and Ground Water



Combining Solutions

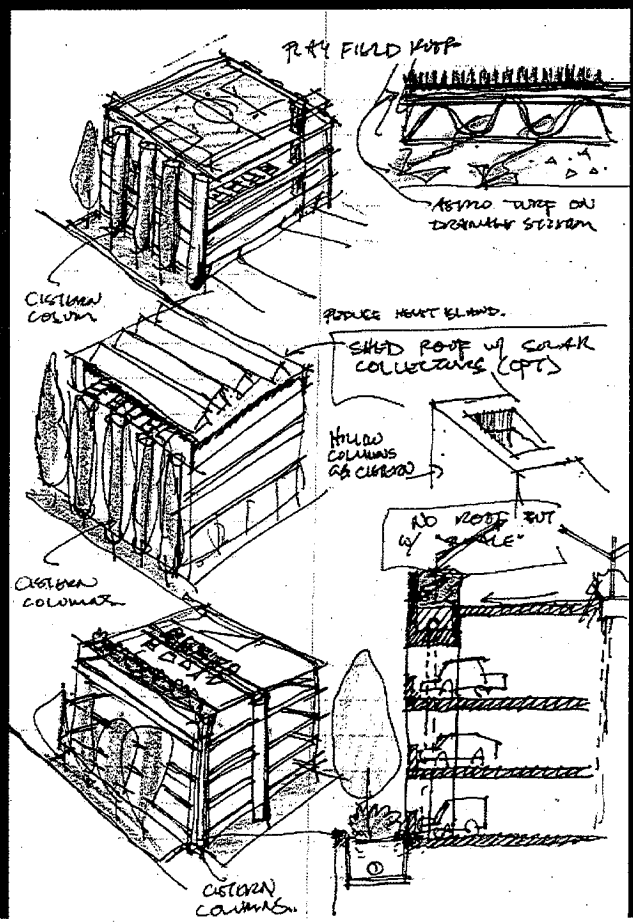
A. Green Roof
B. Cisterns
C. Rain garden at drip line
D. Drip-line planter
E. Bio-retention tree well
F. Infiltration basin



Combining Solutions

Parking Garage Example:

Cistern Columns
With Drainage from
- Playfield,
- Solar Collectors or
- Bioswales



Combining Solutions

Sizing Worksheet

TABLE 1

Calculate Water Quality Volume

Designed to Capture 85% of runoff, based on Hydrological Data for Oakland WSO Airport (6335) - Alameda County, California

Roof

ID#	Description	Impervious Area (sq. ft)	Garden Area (sq. ft)	Total Area (sq. ft)	Roof "C"	Water Quality Volume (feet^3)	Water Quality Volume (gallons)	TREATMENT OPTIONS (gallons) Closed Cistern	TREATMENT OPTIONS (gallons) Irrigation/ Retention
	C=	0.85	0.15						
R1	Rooftop	2,000	500	2,500	0.71	115	859	0	859
R2	Rooftop	2,500	0	2,500	0.85	136	1,016	500	516
	TOTAL ROOF AREA	5,000			TOTAL	251	1,875	TOTAL 500	1,375

Site

ID#	Description	Impervious Area (feet^2)	Pervious Area[1] Flat	Pervious Area[1] Average (feet^2)	Pervious Area[1] Steep	Total (feet^2)	Parcel "C"	Water Quality Volume (feet^3)	Water Quality Volume (gallons)	TREATMENT OPTIONS Irrigation/Retention	TREATMENT OPTIONS Swale (sq.feet)	TREATMENT OPTIONS Bioretention	TREATMENT OPTIONS Other
	C=	0.85	0.15	0.2	0.3								
A1		8,000	100		500	8,600	0.81	444	3,324	8,600			
A2		1,000				1,000	0.85	54	406	1,000			
A3		150,000				150,000	0.85	8,150	60,966		150,000		
A4		3,000				3,000	0.85	163	1,219	3,000			
A5		25,000				25,000	0.85	1,358	10,161			25,000	
A6		76,150	100			76,250	0.85	4,143	30,991		76,250		
	TOTAL SITE/ROOF AREA					268,850	sq.feet						
	TOTAL SITE/ROOF WQ VOLUME							(feet^3) 14,564	(gallons) 108,943				
	TOTAL BMP TREATMENT AREA												268,850
	ALL AREA ACCOUNTED FOR												

NOTES

[1]

Pervious Area	Ground Slope
Flat	2% or Less
Average	2%-7%
Steep	Greater than 7%





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Low Impact Development

Definition

Low Impact Development (LID) is a design strategy with the goal of maintaining or replicating the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic site design. Hydrologic functions of storage, infiltration and ground water recharge, as well as the volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of runoff flow paths and flow time. Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands, and highly permeable soils.

Purpose

LID design strategies, including ***structural**** and/or ***non-structural stormwater practices****, can be applied to land development projects, where practicable, to meet certain technical requirements of federal, state, and local government stormwater management (SWM) regulations, as well as natural resource protection and restoration goals.

The Federal Clean Water Act, the Virginia SWM Regulations, the Virginia Erosion and Sediment Control (ESC) Regulations, the Virginia Chesapeake Bay Preservation Area Designation and Management Regulations, and the Virginia Water Protection Permit Regulations establish criteria for protecting sensitive natural resources and adjacent properties and waterways from the impacts of land development. Maintaining or replicating the pre-development surface and sub-surface hydrologic regime on a development site is generally considered to meet some of those criteria. Therefore, the design techniques intended to create a functionally equivalent hydrologic landscape must be quantified or measured in order to document compliance with regulatory principles and technical requirements. The following provides a brief description of some of the current regulatory requirements that may be met in part or in full by LID practices.

* ***Bold italics*** indicate that a definition is provided in the glossary.

Stream Channel Erosion

SWM Regulations (4VAC3-20-81 et seq.)
ESC Regulations (4VAC50-30-40.19 et seq.)

LID structural and non-structural practices can be used to protect downstream natural channels and waterways by maintaining the pre-developed stormwater runoff volume, duration, frequency, peak rate of discharge, groundwater recharge, and surface and groundwater drainage patterns. LID may be used as a stand-alone design approach or in conjunction with other stormwater structural practices and/or channel improvements to meet channel protection requirements.

It should be noted that the ESC and SWM regulatory requirements for protecting stream channels are based on the capacity of the downstream natural and/or manmade channel or conveyance system. When a downstream channel or conveyance system is determined to be inadequate, the designer must either provide for downstream channel or system improvements, develop a site design that will not cause the pre-developed peak rate of runoff to increase, or provide a combination of channel improvements, stormwater detention, or other measures satisfactory to the plan approving authority to prevent downstream erosion[1].

The most common practice for protecting inadequate downstream channels has been to detain the runoff from the 2-year 24-hour design storm and release it at the pre-developed rate. An alternative criterion that has been accepted by the state and some local plan approving authorities is the extended detention of the runoff from the 1-year 24-hour design storm[2]. Currently available LID design guidance[3] includes simplified computational procedures for sizing LID ***Integrated Management Practices*** (IMP's) to maintain the pre-developed runoff volume and/or rate of discharge for a specified rainfall amount. In addition, other more rigorous analytical methods can be used to quantify the hydrologic response of LID strategies in order to calculate compliance with any regulatory criteria. However, the extent to which these methods can show LID practices to satisfy regulatory requirements for stream channel protection may be site-specific and require a detailed hydrologic analysis. In order to accommodate LID designs, localities may choose to simplify this process by developing their own regulatory criteria (consistent with the VA SWM Regulations) for applying LID design strategies and techniques based on local conditions and practices. (Refer to Computational Methods section of this Technical Bulletin for additional information on these methods.)

[1] Virginia Erosion and Sediment Control Regulations Minimum Standard 19 (4VAC50-30-40.19 et seq.)
[2] Department of Conservation and Recreation Technical Bulletin #1, Stream Channel Erosion Control.
[3] Low Impact Development Hydrologic Analysis, Prince George's County, Maryland; July 1999.

Stormwater Runoff Quality

SWM Regulations (4 VAC 3-20-71 et seq.)
Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et seq.)

LID structural and non-structural practices can protect downstream waterways by reducing the post-developed pollutant loading through stormwater runoff volume reduction and/or the filtering and settling of pollutants. Stormwater volume reduction and the corresponding reduction in the peak rate of discharge can also serve to reduce water quality impacts associated with channel erosion.

Permits and Certifications

Virginia Water Protection Permit Regulation (9 VAC 25-210 et seq.)
§401 and §404 Permits

LID structural and non-structural practices may reduce the direct impacts of development on wetlands and water bodies by reducing or eliminating the need for structural stormwater facilities that would otherwise be located in wetlands or other protected lands. (In some cases, however, LID practices may not provide adequate quantity control of large storms so as to eliminate the need of structural facilities designed for flood or large storm control.) LID structural and non-structural practices may also serve to reduce indirect impacts on these lands by satisfying the stream channel erosion and water quality requirements of the land development activity as described above.

Total Maximum Daily Load (TMDL) Requirements

To the extent that water quality impairments are a result of stormwater runoff inputs, LID structural and non-structural practices and strategies implemented on a development site can assist in reducing the pollutant loadings that contribute to the TMDL of the receiving water body.

Applicability

SWM must be considered early in the land development planning process in order to fully realize the benefit of the natural hydrologic features of the landscape. While the use of LID practices may be limited by the physical characteristics of a development site, those same characteristics help to identify and prioritize the best locations for utilizing IMP's, non-structural stormwater practices, or ***conventional*** or ***centralized Best Management Practices*** (BMP's). Introducing LID concepts during the preliminary planning and concept phase of site design will serve to maximize the extent and effectiveness of LID practices. In contrast, once the site and development infrastructure

design has been established, the proposed site features, and not the existing natural physical characteristics, will dictate the location and extent of LID implementation.

The applicability and effectiveness of LID practices on development projects will be influenced by physical site characteristics such as:

- Soil suitability
- Depth to water table
- Tidal effects
- Topography
- Karst topography
- Drainage area size
- Maintenance Considerations
- Expansiveness of impervious cover
- Density of on-site structures
- Overall spatial constraints
- Downstream drainage and runoff conveyance infrastructure

Refer to Appendix A for additional information on design considerations.

It should also be noted that local land use ordinances might also influence the implementation of certain LID practices. These include:

- Zoning
- Local subdivision ordinances
- State and local building codes
- Open space requirements

In general, when introduced early in the development process, LID planning strategies and techniques, such as reducing impervious cover, conserving natural areas, and diffusing and disconnecting stormwater runoff, can conform to most local ordinances and still be both hydrologically and economically effective.

The applicability and effectiveness of LID site design strategies should be progressively evaluated at the zoning, preliminary planning, conceptual drainage and SWM design, and final site design phases of project development. At each successive step in the process, as more detailed site evaluations reveal more information regarding the site's physical characteristics, the designer can evaluate and continually modify the design to better mimic the pre-developed hydrology, meet stormwater regulatory requirements, and achieve aquatic resource protection goals.

When the use of LID practices on a particular site is limited by physical constraints or other factors, or the stormwater regulatory requirements cannot be satisfied solely with the use of LID design techniques, then a ***"hybrid" design*** may be employed. A hybrid design employs both LID and conventional BMP's or detention practices (e.g., ***centralized BMP's***) to meet stormwater requirements. Such a design might conserve specific natural features and provide open space to the greatest extent possible, while detention measures or centralized BMP's are also implemented to provide peak rate or quantity control beyond the site-specific capabilities of the LID strategy. Another example of a hybrid design is one that incorporates LID for both the attenuation and infiltration of small storm events, and centralized BMP's to provide storage for larger storm events. (Control of runoff from larger storm events may be necessary to protect

downstream manmade or natural conveyance systems in accordance with MS-19, or other watershed specific criteria.)

Once LID site design strategies and practices have been evaluated and employed to the greatest extent practicable, and, where needed, additional SWM controls have been added, the designer must measure and document the target performance of the design in satisfying any regulatory requirements. While the calculation procedures for documenting compliance using traditional detention, extended detention, or other types of BMP's have been in use for many years (refer to the Virginia SWM Handbook), the use of LID type strategies for regulatory compliance is relatively new. (Some of the currently accepted computational methods for calculating regulatory compliance are provided in this Technical Bulletin.) In addition, there may be a desire to quantify the extent to which LID practices are implemented in order to establish that the development is indeed an "LID design". This can be accomplished by calculating the percentage of the total site area or total site impervious area being treated by appropriate LID strategies, or calculating the ratio of the estimated depth of rainfall or volume of runoff being treated by the LID strategy to the total depth or volume respectively. (At this time there is no established standard for a design to be qualified as an LID design.)

LID Design Components

The LID strategy of replicating the pre-development surface and sub-surface hydrologic regime is accomplished through the combination of design principles: *Conservation, Minimization of Impacts, Maintaining Site Runoff Rate and Patterns, the use of IMP's, and Pollution Prevention (P2).* These design principles incorporate structural and non-structural stormwater practices into a site design, and will each have either a ***direct*** or ***indirect effect*** on the measurable hydrologic characteristics of the site. Structural practices, when considered in the context of LID design strategies, imply small-scale stormwater BMP's distributed throughout a site or drainage area, and are often referred to as IMP's and can include, but are not limited to, engineered and natural temporary surface storage for runoff attenuation, and infiltration for groundwater recharge and runoff volume reduction.

Non-structural practices can include, but are not limited to, preservation of natural areas and functions such as permeable soils and existing flow paths, the disconnection of impervious surfaces, and P2 activities. (A list of accepted structural and non-structural practices will be provided by the Virginia Department of Conservation and Recreation or the local plan approving authority.)

The following provides a brief description of these design principles and how they may be incorporated into the site development design to replicate the pre-developed hydrology. Design principles 1 through 4 are listed in the order of expected consideration and evaluation during the development planning and design process in

order to utilize the natural hydrologic processes in the final development stormwater design. Design principle 5, P2, should be an integral part of the site design process from beginning to end in order to facilitate the post-construction site function and management in addition to any construction related requirements of the ***Stormwater Pollution Prevention Plan*** (SWPPP).

1.) ***Conservation.*** Conservation of any natural lands within a development site may have the direct effect on the site hydrology of minimizing impervious cover that would otherwise generate higher rates and volume of runoff. Indirect benefits of conservation can be derived by locating and protecting certain hydrologic features such as drainage paths, permeable soils, steep slopes, etc.; and, in accordance with appropriate zoning and subdivision requirements, strategically locating setbacks, easements, woodland conservation zones, buffers, utility corridors, and other permanent site features to enhance the overall goals of maintaining the pre-developed hydrology.

   The Center for Watershed Protection offers 22 "Better Site Design"[4] principals aimed at reducing the impacts of development on sensitive lands and aquatic resources. Conserving specific sensitive lands on a site is a crucial first step. The implementation of a SWPPP and/or ***Erosion and Sediment Control Plan*** further minimizes the impact of construction and development activities on these sensitive lands.

2.) ***Minimization of Impacts.*** Minimization of impacts refers to reducing the extent of construction and development practices that adversely impact the hydrologic conditions of the site. This includes limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure, as well as locating the land disturbances so as to avoid impacting hydrologically sensitive areas. The designer must conduct a thorough analysis of the existing topography and site geometry when locating fixed improvements such as roads, houses or buildings, sanitary and storm sewer utility corridors, etc., in order to minimize unnecessary grading and/or compaction of the natural soil horizon, clearing of trees, and creating of impervious surfaces.

   The minimization of impacts can have both direct and indirect beneficial effects on the hydrologic characteristics of the site. The extent of these benefits is dependent on the ability of the selected hydrologic analysis method to accurately depict impervious cover, land slope, soils, types of vegetation, and other factors that affect surface and subsurface hydrology.

3.) ***Preserve Pre-development Runoff Rate and Patterns.*** Preserving the site pre-developed runoff rate and patterns are two of the overall objectives in replicating the pre-developed hydrology (other objectives include maintaining the pre-developed volume, frequency, and duration of runoff). Effectively implementing

[4] Better Site Design – An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act; The Center for Watershed Protection. http://www.cwp.org/better_site_design.htm

conservation practices and minimizing impacts, as described above, represent the first steps in achieving these objectives. Further steps involve evaluating how certain design choices can influence the post-developed hydrologic processes to reduce the rate and volume of runoff. These design choices include disconnecting impervious cover in order to maintain sheet flow conditions, lengthening the developed condition time of concentration (Tc), etc. Ideally the post-development drainage divides should replicate those of the pre-developed condition

Stormwater detention practices can be effective in maintaining the pre-developed rate of runoff, however detention practices alone are not able to achieve the objectives of maintaining the pre-development volume, frequency, and duration of runoff. LID design strategies, on the other hand, focus on using site design techniques to influence the hydrology before (or instead of) conveyance of the runoff to a centralized detention practice.

4.) ***Integrated Management Practices*** **(IMP's).** IMP's refer to decentralized small-scale (source control) stormwater retention and detention structural BMP's integrated uniformly throughout the site or drainage area. These practices can be integrated into the landscape, buildings, and overall development infrastructure to reduce the volume and rate of stormwater runoff. These systems are designed to emulate the natural processes of detention, retention, interception, evaporation, transpiration, and groundwater recharge, in order to replicate the pre-developed hydrology. Common examples of IMP's include: bioretention cells (or rain gardens), water quality swales, green roofs, and other small scale runoff attenuation practices.

5.) ***Pollution Prevention (P2).*** P2 is a non-structural practice aimed towards reducing pollutant loads at the source by eliminating the behavior or practices within the urban and suburban landscape that have been shown to generate a non-point source pollutant load. P2 is applicable both during the active construction phase of development and during the life of the facility. This includes the implementation of soil conservation and erosion control measures employed during construction, long-term management of post-construction BMP's, and proper onsite storage, use, and disposal of chemicals or potential pollutants.

Pollution prevention can also include community-wide education efforts and specific training and education programs directed toward the owners/operators of properties designed and constructed in accordance with these principles. Common examples of P2 techniques include storm drain stenciling, public outreach and education on the appropriate use of fertilizers and pesticides, street sweeping, etc.

Computational Methods

The level of effectiveness to which LID techniques and practices satisfy the technical regulatory requirements can be measured using conventional hydrologic parameters. These parameters or values are used in several different computational methods to calculate the pre- and post-developed hydrologic response of the land. These methods include relatively simple calculations using charts calibrated for the rainfall distributions of Virginia, as well as detailed routing of stormwater through individual IMP's and any other structural practices within a given subwatershed, or some combination of these methods.

Much of the basis for these computational methods have been developed and detailed in numerous references. The selection of a specific computational method will often be a function of the stormwater component being measured: stormwater quality, quantity, or both. LID practices applied to a development site with the goal of improving runoff quality may also achieve some level of quantity or peak rate control. Likewise, practices that are designed with the goal of rate or volume control may also derive a water quality benefit.

This section will provide an overview of some of the existing methods available with which to measure the effectiveness of an LID design strategy. The scope of this section will in no way serve as a design manual or otherwise replace the available documentation for each of the methods listed, nor are the available options limited to those presented here. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) National Engineering Handbook Section 4: Hydrology (NEH 4), and Section 5: Hydraulics (NEH 5), and the Virginia SWM Handbook (VSWMH) provide detailed information on the accepted analytical methods described in this Bulletin, as well as other methods that may be determined to be acceptable by the designer or plan approving authority.

This Technical Bulletin will not establish one acceptable method, rather it will give designers and plan reviewers the information needed to hopefully design and evaluate an LID strategy for a development project using the best suited method. However, the compatibility or translation of the chosen analytical techniques to NRCS methods may serve to facilitate the acceptance of the analysis in those jurisdictions where NRCS methods are utilized.

Water Quality Control

Compliance with the Virginia water quality criteria (4VAC3-20-71 et seq.) may be achieved by applying the *Performance-based* criteria or the *Technology-based* criteria to the site as outlined in the VSWMH.

The Performance-based criteria utilize the percent impervious cover of the site to calculate the post-developed pollutant load, and then apply the target pollutant removal efficiency of the stormwater BMP's to determine compliance. Each stormwater BMP, including accepted non-structural practices, must therefore have an assigned target pollutant removal efficiency associated with the accepted design standard.

The Technology-based criteria require that the runoff from the impervious cover of the site be captured by an appropriately designed BMP (considered to be the best available technology for the specific site characteristics).

Strategically locating IMP's through out the development site or as part of a hybrid design, can serve to meet either the Performance or Technology-based criteria. The VSWMH provides a list of currently accepted stormwater BMP's, including design criteria and corresponding target pollutant removal efficiencies. The Virginia SWM Regulations also allow for innovative or alternate BMP's not included in the VSWMH to be approved at the discretion of the plan approving authority. Additional design and performance guidance may be necessary to expand this list to include certain IMP's, site design techniques, and non-structural practices, in order to effectively document compliance with either criterion.

Water Quantity Control

Quantity (or rate) controls are implemented to reduce the peak rate of stormwater discharge from the developed site in order to prevent stream channel erosion and/or localized flooding. These controls are generally volume-based practices and utilize recognized hydrologic and hydraulic analytical methods in order to make comparisons between the pre- and post-developed conditions. The VSWMH specifically refers to NRCS TR-55 and the modified rational methodologies for such computations. These analytical methods vary in terms of flexibility and complexity. It is the responsibility of the designer to be familiar with these methods and determine the appropriate method, or combination of methods, that will demonstrate the effectiveness and verify compliance with applicable Federal, state, or local codes and ordinances.

This section provides four methods or categories of procedures that can be used to analyze and evaluate the effectiveness of LID designs. They are: Hydrologic and Hydraulic Models, Hydrograph Modification, LID Hydrologic Analysis (PGDER, 1999) and a Credit or Point System. The first three methods utilize recognized hydrologic and hydraulic analytical methods in order to make comparisons between the pre-and post-development conditions. A Credit or Point System can be developed and implemented by localities to place an emphasis on design and protection strategies that protect or enhance critical watershed natural resource areas.

1. Hydrologic and Hydraulic Models

   The following provides a general description of the procedures associated with accepted hydrologic and hydraulic models used to determine the effectiveness of an LID design.

   Hydrology – The first step in evaluating an LID design or any SWM strategy is to characterize the runoff from the site or drainage area. The methods for characterizing the hydrology or runoff range from the Rational Method to

single event distribution methods, such as widely used NRCS models that develop a rainfall and runoff relationship with respect to time (i.e., a runoff hydrograph), to continuous simulation models that develop runoff hydrographs from multiple storm events.

The evaluation or measure of the performance of LID techniques must consider runoff volume, frequency, duration, and peak rate of discharge. Therefore, the method employed to calculate the site hydrology must be capable of generating a runoff hydrograph. The designer must establish the runoff characteristics with respect to time at each proposed IMP location or other critical locations throughout the drainage area as input parameters for the model. The model then must evaluate these characteristics for each area all on the same time scale and then sum the hydrographs at the selected study point. Critical locations include any areas where an engineered or natural control is proposed.

Hydraulics – Once the rainfall-runoff hydrographs are developed for specific locations, the engineer can apply standard hydraulic calculations to account for groundwater abstraction, storage attenuation, and surface runoff velocity at each location. The calculations should reflect the individual hydraulic characteristics of each IMP or critical area, and be physically based on the measurable unit processes being considered.

For simplicity, many SWM software packages generalize interactions with groundwater and other losses rather than perform a detailed routing. Most, however, allow the user to export the hydrograph in order for it to be modified to reflect specific infiltration rates, retention storage volume, or other losses as appropriate. The modified hydrograph can then be imported back into the model. (The designer must determine the analytical values for these losses through field investigations or acceptable documented sources and should coordinate those values with the plan approving authority.)

Detailed modeling of LID designs, therefore, can be accomplished in much the same manner as hydrologic and hydraulic analyses used for traditional SWM designs. The key differences are: (1) the designer must identify and model a potentially large number of structures or control points, and (2) a greater emphasis is placed on quantifying the volume reduction associated with infiltration, retention storage volume, *evaporation, transpiration*, rainwater harvesting, etc. at each control point. The benefit of detailed modeling is a more direct prediction of the decrease in the peak rate and volume of runoff attributed to the measurable LID design features in order to verify compliance with regulatory requirements. However, complex modeling may not necessarily result in greater accuracy in predicting the developed condition hydrology. The selection of the most appropriate analytical method will vary depending on the site conditions and design values.

2. Hydrograph Modification

Routing hydrographs through IMP's and other LID site features as discussed above may require a significant amount of time and effort to quantify all of the site characteristics in enough detail to meet the requirements of the various models. The following theoretical methods provide more simplistic approaches for modifying the runoff hydrograph in order to reflect the site conditions represented by a comprehensive LID design. Some of these methods have been accepted in other jurisdictions; however, further evaluation and modification may be required before they are accepted for use by the local plan approving authority.

- *Truncated Hydrograph Method,* (MDE, 1983). This approach analyzes distributed retention storage by assuming that the sum of the retention storage is available for filling at the beginning of the runoff event (like an empty pond), and that there is no resultant runoff until all available retention storage has been filled. This method does not take into account the spatial distribution of the retention storage (small pockets throughout the watershed) and the timing of outflows from these facilities. Additional work is needed to verify the accuracy of this method and/or calibrate the relationships between the distributed storage, drainage area size, and overall hydrologic benefits as reflected in the final hydrograph at the study point. However, the value of this method is its simplicity and may be effective in assessing the LID potential of a development site during the early stages of development.

- *Change in Curve Number Method,* (MDE, 1983). This method reduces the post-developed curve number to reflect the runoff volume stored by the IMP's. This assumes that all of the storage volume is infiltrated, evaporated, or otherwise available for the next storm event. As with any method that assumes infiltration, care must be taken in the proper location and design of the infiltration IMP's to ensure long-term function.

- *Scalar Multiplication,* (LID Center, 2004). This method estimates the effects of IMP storage by reducing the ordinates of the runoff hydrograph by the ratio of total retention storage to total runoff generated. This approach assumes that volume of retention storage provided will proportionally reduce the runoff volume and rate uniformly at all points along the runoff hydrograph.

- *Subtract Retention from Rainfall,* (LID Center, 2004). Subtraction of IMP storage volume from the rainfall depth by modifying the NRCS equation for the relationship between rainfall and runoff.

- *Subtract Retention from Runoff,* (LID Center, 2004). Subtraction of IMP storage volume from the runoff depth by modifying the NRCS equation for the relationship between rainfall and runoff.

- *Adjust CN for 24-hour Storm Depth,* (LID Center, 2004). Subtraction of the IMP storage volume from the runoff depth at the end of the storm event.

3. Low Impact Development Hydrologic Analysis, Prince George's County, Maryland.

This approach is described in detail in the "Low Impact Development Hydrologic Analysis" (PGDER 1999) and can be used to determine the storage volume required to maintain the frequency of pre-development runoff volume and/or peak runoff rate that is generated from the post-development condition for a range of 24-hour Type II storm events.

The method can be used to analyze a variety of storm frequencies or recurrence intervals, and is most useful for analyzing volume replication and peak attenuation goals for specified storm events. The design storm can be selected in accordance with local requirements, although the stated goal is to replicate the pre-developed hydrology. Therefore, the design storm is calculated as that which generates initial runoff from the pre-developed site condition (assumed to be woods in good hydrologic condition, and the actual hydrologic soil group classification of the site), or the 1-year event, whichever is greater. Using design charts aimed at simplifying the computational procedures, the designer determines the total storage volume required on the site. The designer must then determine if the resulting volume requirement meets the regulatory requirements for channel protection, flooding, or other criteria.

There is no standardized method within the manual to correlate the resulting distributed storage with the 1-year extended detention channel protection or larger storm requirements. However, the designer may use various acceptable hydrologic parameters to compare the LID design with the peak rate or extended detention requirements and make up any shortfall through a hybrid design. Any method chosen to document compliance may be subject to local review and approval.

This method is based on the NRCS computational procedures found in Urban Hydrology for Small Watersheds Technical Release 55 (TR-55), and therefore has similar limitations to TR-55 in that it cannot be used for complex storage routing or when a high degree of accuracy in the storage/discharge relationship of any BMP is required. Also, the design charts generally require that the pre- and post-development drainage areas are the same, and that the designer is able to maintain the pre-development Tc. Further, the method assumes that the volume of the required structural controls are decentralized or distributed evenly throughout the site. The reader is encouraged to review this methodology further in the referenced manual.

4. Credit or Point System Approach

A credit or point system can be developed by a locality in order to encourage the use of certain design strategies, protection methods, or IMP's to address local water quality goals, natural resource protection objectives, or regulatory requirements. Such a system may function as a stand-alone compliance assessment tool or may be used in conjunction with other analytical (hydrologic and hydraulic) methods. If stand-alone, the results are "presumptive," i.e., compliance is based on a project receiving a certain number of credits or points based on the proposed management practices that are presumed to meet the relevant requirements (e.g., biofilters or open space protection is presumed to meet certain water quality goals).

Alternately, a credit or point system can be used to enhance the use of other analytical methods to influence the design towards certain LID measures. For instance, hydrologic and hydraulic computations may be used to verify design criteria, and the credit/point system added to promote the protection of open space or critical areas, or other practices aimed at preserving the pre-developed hydrologic condition.

A stand-alone credit or point system may be appropriate for those developments where a highly analytical approach to ensure compliance for LID features may act as a disincentive for LID implementation. These developments may include relatively simple projects, redevelopment projects, or projects with relatively low impervious cover (such as a typical rural subdivision) or where downstream drainage and flooding are not a concern. In these cases, the program authority may elect to develop a simplified compliance system in order to encourage LID design strategies.

The premise of this approach is that LID practices are presumed to achieve certain water quantity and/or quality requirements if certain performance standards are met. Although such a methodology is not specified in the VSWMH, it can be viewed as an enhancement to the technology-based criteria for water quality compliance, where certain LID practices are included in the allowable technology list. A credit or point system can also be adapted into the performance-based criteria if LID practices can be assigned target pollutant removal credits or proportional pollutant removal efficiencies. In either case, guidance on specific design criteria and target pollutant removal efficiencies must be provided in order to ensure consistent application.

As stated above, a credit or point system can also be used in conjunction with other computational methods. The hydrologic and hydraulic model chosen can be used to verify partial compliance with water quality/quantity requirements, with the gap being filled by other LID measures (e.g., open space protection) that are not easily modeled, but should still receive points or credits towards the overall compliance objective.

Several examples of a credit or point system can be found throughout the Chesapeake Bay watershed. In one Virginia county, a BMP point system is used as a technology-based approach to ensure that development sites are adequately covered by preferred BMP's. The proportion of the site served by the BMP weights the pre-set points assigned to each BMP. In addition, points assigned to specific site development practices such as preservation or minimization of impacts are weighted by the value of the practice, e.g.: open space is positioned in a way that accepts and treats stormwater or is adjacent to a wetland, mature forest, or Resource Protection Area.

Another example includes a water quality credit system for non-structural measures such as adding additional stream buffer area to the minimum requirement, re-vegetating existing buffers, protecting buffers with permanent easements, and disconnecting impervious cover. While some of these practices provide both direct and indirect benefits to the site hydrology and can therefore be measured by accepted analytical tools, the credit system serves to create an incentive by simplifying the required design calculations and associated plan review requirements. Additional credits can be assigned to the modification or use of certain structural practices, such as using open space as stormwater treatment areas (if certain design parameters can be met) and using individual lot practices, such as rain gardens.

Specific design standards and performance criteria must be developed if a local program authority elects to use a credit or point system. Design standards can include relationships between the required water quality volume based on impervious cover and the individual BMP or cumulative distributed storage volume or surface area coverage associated with IMP's, as well as any variable design criteria that may allow for additional points or credits based on certain performance goals. At a minimum, design and performance standards should provide for the long-term maintenance and proper function of the BMP's, IMP's, and/or other LID site features, as well as be consistent with accepted statewide design standards.

The credit or point system is a very flexible concept; the program authority can adapt it to meet local needs and conditions or to promote particular practices. One main caution to using this approach is that it may require interpretation on the part of the reviewer and may be viewed as more of a negotiated approach to compliance than other, more quantitative methods. The positive side is that it can be simple for both plan preparers and reviewers and can lead to designs that more fully incorporate LID and encourage use of natural open space. The program authority should strive for review procedures that are equitable while allowing for a certain amount of case-by-case interpretation.

Construction and Maintenance

The first steps in ensuring the long-term effectiveness of any LID practice are the proper selection, location, and design of the practice. Equally important are the construction and long-term maintenance practices and techniques. Ideally, the designer will not only have all the site information necessary for the design related activities, but also an understanding of the construction requirements and the ultimate land use and management (or ownership with regard to maintenance). It should be noted that while these elements are critical to the effectiveness of any stormwater practice, the distributed and small-scale nature of LID practices and techniques make them especially vulnerable to impacts from mass grading and construction operations, as well as long-term neglect.

The location and design of LID practices must include a sequence of construction. The sequence of construction is important because some LID practices cannot be built until the contributing drainage area has been stabilized. Similarly, if certain areas of the site are to be preserved for post-construction LID practices, the site design must account for adequate access to the proposed construction areas without impacting those protected areas. Impacts to protected areas, even if only temporary, can cause compaction of the natural soil horizon or contamination with silt, thus reducing the effectiveness and long-term function of the practice. If impacting a select area is unavoidable, the plans should include provisions for restoration and preparation of the area for the post-construction use.

Therefore, the construction drawings must reflect areas to be preserved and include adequate ESC measures to protect those areas (especially since those areas may serve as natural drainage paths). The sequence of construction should be prominently displayed on the plans as a critical element to the site design, and reflect the multiple phases of the construction as related to the implementation of the designed LID practices within the overall construction activity. Local officials are encouraged to incorporate intermediate inspections to ensure proper soils, materials, and construction practices related to the stormwater features.

The design and construction of any structural LID practice (or stormwater BMP) should be in accordance with the accepted standards of the local jurisdiction or state regulations. The references provided at the end of this Technical Bulletin provide an array of guidance documents, including the VSWMH, as well as guidance documents from other states. Local plan approving authorities may adopt plan design and construction inspection criteria that exceed the current state minimum in order to ensure the long-term effectiveness of LID designs.

Post-construction inspections and maintenance of LID structural and non-structural practices are equally important to ensure effectiveness. Annual inspections are recommended at a minimum, with more frequent inspections during the first year or

growing season for vegetated practices, or as required by any permit conditions. Some LID practices may require more frequent inspections, (e.g. after significant rain events, quarterly, during property transfers, etc.). Inspection and maintenance of structural LID practices such as cisterns, vegetated roofs, permeable pavements, infiltration structures, and manufactured proprietary devices should follow local heath department, state or local stormwater minimum standards, as well as manufacturer's recommendations for maintenance or repair. Any under-drains or outfall structures should be inspected on a regular basis and cleaned out or repaired as necessary.

The primary maintenance requirement for vegetative LID structural and non-structural practices is inspection and periodic repair or replacement of the treatment area's components. This often includes the upkeeping of the vegetative cover (pruning), replacing mulch, removing weeds, and possibly removing sediment to preserve the practice's hydraulic properties. For many LID practices, this generally involves little more than the routine periodic landscape type maintenance.

To ensure continued long term maintenance, all affected landowners should be made aware of their individual or collective maintenance responsibilities through legal instruments such as maintenance agreements and maintenance easements that convey with the property. Outreach materials, such as LID brochures or facts sheets that explain the function of practices and the anticipated maintenance responsibilities for homeowners, should be included in settlement or home owner association documents.

Glossary

Best Management Practices (BMP's) are activities, procedures, and structural and non-structural devices or features that are specifically identified or designed to prevent or reduce the impact of development on surface and groundwater systems.

Conventional (centralized) Best Management Practices (BMP's) are structural BMP's designed to capture and treat stormwater runoff from a large drainage area. SWM ponds and basins located at the bottom of a developed drainage area or watershed are generally considered to be conventional (centralized) BMP's.

Direct effects are those that are measured or quantified with analytical methods to identify the hydrologic or hydraulic response of the site to the post-development condition or the SWM strategy or technique. For example, the direct effect of providing on-site storage is that the rate of peak discharge.

Erosion and Sediment Control (ESC) Plan means a document that is prepared in accordance with good engineering practices and containing details and instructions for the conservation of soil and water resources of a unit or group of units of land during land disturbing activities.

Evaporation is the process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces.

"Hybrid" design means a design that employs both LID and conventional BMP's or detention practices to meet stormwater requirements. Such a design might include LID practices or strategies such as the conservation of specific natural features and open space to the greatest extent possible, while detention measures or centralized BMP's are also implemented to provide peak rate or quantity control beyond the site-specific capabilities of the LID strategy. Another example of a hybrid design is one that incorporates LID for both the attenuation and infiltration of small storm events, and centralized BMP's to provide storage for larger storm events.

Indirect effects are those where the hydrologic or hydraulic response may not be quantifiable by established analytical methods, yet they have inherent effects on the hydrologic and hydraulic response of the site to the post-development condition, including water quality. For example, the preservation and/or enhancement of the natural stream buffer, or the strategic location of utility corridors may preserve and protect certain hydrologic components of the pre-developed site, without the benefit of being quantified in the hydrologic analysis.

Integrated Management Practices (IMP's) are small-scale structural stormwater practices distributed through out a site or drainage area for the purpose of managing or influencing the site hydrology.

Non-structural practices are natural features or directed activities specifically utilized for the purpose of managing or influencing the site hydrology and/or improving water quality. Non-structural practices can include pollution prevention, preservation of open space and natural flow paths, street sweeping, etc.

Stormwater Pollution Prevention Plan (SWPPP) means a document that is prepared in accordance with good engineering practices and that identifies potential sources of Pollution that may reasonably be expected to affect the quality of stormwater discharges from a construction site or its associated land disturbing activities. In addition the document shall describe and ensure the implementation of best management practices, and shall include, but not be limited to the inclusion of, or the incorporation by reference of, an erosion and sediment control plan, a post construction stormwater management plan, a spill prevention control and countermeasure (SPCC) plan, and other practices which will be used to reduce pollutants in stormwater discharges from land disturbing activities.

Structural practices include any man made stormwater practice or feature that requires maintenance in order to function or provide the hydrologic benefit as designed. Structural practices include, but are not limited to, rain gardens, stormwater bioretention basins, stormwater infiltration facilities, stormwater retention and detention facilities, engineered vegetated filter strips, and any other features that are designed, constructed

and maintained in order to managing or influencing the site hydrology and/or improve runoff water quality.

Transpiration is the process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

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Appendix A

Design Considerations

Soil Permeability

The soil permeability, or infiltration rate, is critical to the proper function of IMP's that incorporate infiltration as part of their control mechanism. The best location for these practices is in areas that have characteristics of Hydrologic Soils Groups A and B, which have high infiltration rates during saturated conditions. These are typically sandy soils. Hydrologic Soil Groups C and D have low to very low infiltration rates when thoroughly wetted. These are typically silts and clays or compacted soils. Due to these characteristics, soil groups C and D are not conducive to exfiltration and may impact the proper functioning of IMP's, such as grass swales, bioretention basins, and permeable pavements. Underdrains can be used in these facilities to control the rate of flow and to ensure that the facility will not become inundated with runoff over a long period of time.

High Water Table

A high water table may reduce the storage capacity of the below ground portion of the IMP and may also impede the ability of the media in the IMP to filter out pollutants before they enter the groundwater.

Topography (Steep Slopes)

A slope stability analysis should be conducted in areas with high potential for slope failure or fill slopes to ensure that any proposed infiltration IMP will not affect the stability of the area

Karst Topography

Infiltration IMP's placed in karst topography may cause subsurface collapse and sink hole formation. A subsurface analysis and the depth of the table should be determined at the beginning stages of design to determine the capacity of the soils for saturation when LID infiltration practices are considered.

Septic Systems

An adequate buffer between any infiltration practice and a septic system should be provided to ensure that the septic field will not be inundated, the infiltration rate of the field will not be affected, or any roots from the practices will enter the reserve area.

Water Supply Wells

Infiltration IMP's should be located in areas where there is the potential for contamination. Particular attention should be paid in areas where there are high pollutant loads (e.g. industrial areas) or shallow wells.

Structures and Foundations
A sufficient buffer should be provided between IMP's and basements building structural areas that must not become saturated. Impermeable liners and underdrains are appropriate for use in these areas.

Expansive Impervious Areas
The amount of drainage to each individual IMP in large impervious areas such as parking lots or compacted areas with high runoff potential should be minimized due to the high frequency and potentially large volumes of water that these areas will receive. Adequate underdrains and overflow paths, such as a secondary storm drain system, should be included for high flow events.

High Sediment Loads
Areas that drain to filtering or infiltration IMP's that are not adequately stabilized and have high erosive potential or soils with high "K" values will require additional control measures to filter the sediment or more frequent maintenance to reduce the potential for clogging of the facility.

Flood Control
Site constraints, such as limited downstream storm drain infrastructure, inadequate channel capacity, and flooding considerations, may necessitate additional volume storage by employing traditional end-of-pipe detention and retention basins in addition to LID practices at the discharge points.

Spatial Constraints
A high density of infrastructure or building areas on a site may limit the use of IMP's.

Appendix C

Example Checklists

Low Impact Development

Definition

Low Impact Development (LID) is a design strategy with the goal of maintaining or replicating the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic site design. Hydrologic functions of storage, infiltration and ground water recharge, as well as the volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of runoff flow paths and flow time. Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands, and highly permeable soils.

Purpose

LID design strategies, including ***structural**** and/or ***non-structural stormwater practices****, can be applied to land development projects, where practicable, to meet certain technical requirements of federal, state, and local government stormwater management (SWM) regulations, as well as natural resource protection and restoration goals.

The Federal Clean Water Act, the Virginia SWM Regulations, the Virginia Erosion and Sediment Control (ESC) Regulations, the Virginia Chesapeake Bay Preservation Area Designation and Management Regulations, and the Virginia Water Protection Permit Regulations establish criteria for protecting sensitive natural resources and adjacent properties and waterways from the impacts of land development. Maintaining or replicating the pre-development surface and sub-surface hydrologic regime on a development site is generally considered to meet some of those criteria. Therefore, the design techniques intended to create a functionally equivalent hydrologic landscape must be quantified or measured in order to document compliance with regulatory principles and technical requirements. The following provides a brief description of some of the current regulatory requirements that may be met in part or in full by LID practices.

* ***Bold italics*** indicate that a definition is provided in the glossary.

Stream Channel Erosion

SWM Regulations (4VAC3-20-81 et seq.)
ESC Regulations (4VAC50-30-40.19 et seq.)

LID structural and non-structural practices can be used to protect downstream natural channels and waterways by maintaining the pre-developed stormwater runoff volume, duration, frequency, peak rate of discharge, groundwater recharge, and surface and groundwater drainage patterns. LID may be used as a stand-alone design approach or in conjunction with other stormwater structural practices and/or channel improvements to meet channel protection requirements.

It should be noted that the ESC and SWM regulatory requirements for protecting stream channels are based on the capacity of the downstream natural and/or manmade channel or conveyance system. When a downstream channel or conveyance system is determined to be inadequate, the designer must either provide for downstream channel or system improvements, develop a site design that will not cause the pre-developed peak rate of runoff to increase, or provide a combination of channel improvements, stormwater detention, or other measures satisfactory to the plan approving authority to prevent downstream erosion[1].

The most common practice for protecting inadequate downstream channels has been to detain the runoff from the 2-year 24-hour design storm and release it at the pre-developed rate. An alternative criterion that has been accepted by the state and some local plan approving authorities is the extended detention of the runoff from the 1-year 24-hour design storm[2]. Currently available LID design guidance[3] includes simplified computational procedures for sizing LID ***Integrated Management Practices*** (IMP's) to maintain the pre-developed runoff volume and/or rate of discharge for a specified rainfall amount. In addition, other more rigorous analytical methods can be used to quantify the hydrologic response of LID strategies in order to calculate compliance with any regulatory criteria. However, the extent to which these methods can show LID practices to satisfy regulatory requirements for stream channel protection may be site-specific and require a detailed hydrologic analysis. In order to accommodate LID designs, localities may choose to simplify this process by developing their own regulatory criteria (consistent with the VA SWM Regulations) for applying LID design strategies and techniques based on local conditions and practices. (Refer to Computational Methods section of this Technical Bulletin for additional information on these methods.)

[1] Virginia Erosion and Sediment Control Regulations Minimum Standard 19 (4VAC50-30-40.19 et seq.)
[2] Department of Conservation and Recreation Technical Bulletin #1, Stream Channel Erosion Control.
[3] Low Impact Development Hydrologic Analysis, Prince George's County, Maryland; July 1999.

Stormwater Runoff Quality

SWM Regulations (4 VAC 3-20-71 et seq.)
Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et seq.)

LID structural and non-structural practices can protect downstream waterways by reducing the post-developed pollutant loading through stormwater runoff volume reduction and/or the filtering and settling of pollutants. Stormwater volume reduction and the corresponding reduction in the peak rate of discharge can also serve to reduce water quality impacts associated with channel erosion.

Permits and Certifications

Virginia Water Protection Permit Regulation (9 VAC 25-210 et seq.)
§401 and §404 Permits

LID structural and non-structural practices may reduce the direct impacts of development on wetlands and water bodies by reducing or eliminating the need for structural stormwater facilities that would otherwise be located in wetlands or other protected lands. (In some cases, however, LID practices may not provide adequate quantity control of large storms so as to eliminate the need of structural facilities designed for flood or large storm control.) LID structural and non-structural practices may also serve to reduce indirect impacts on these lands by satisfying the stream channel erosion and water quality requirements of the land development activity as described above.

Total Maximum Daily Load (TMDL) Requirements

To the extent that water quality impairments are a result of stormwater runoff inputs, LID structural and non-structural practices and strategies implemented on a development site can assist in reducing the pollutant loadings that contribute to the TMDL of the receiving water body.

Applicability

SWM must be considered early in the land development planning process in order to fully realize the benefit of the natural hydrologic features of the landscape. While the use of LID practices may be limited by the physical characteristics of a development site, those same characteristics help to identify and prioritize the best locations for utilizing IMP's, non-structural stormwater practices, or ***conventional*** or ***centralized Best Management Practices*** (BMP's). Introducing LID concepts during the preliminary planning and concept phase of site design will serve to maximize the extent and effectiveness of LID practices. In contrast, once the site and development infrastructure

design has been established, the proposed site features, and not the existing natural physical characteristics, will dictate the location and extent of LID implementation.

The applicability and effectiveness of LID practices on development projects will be influenced by physical site characteristics such as:

- Soil suitability
- Depth to water table
- Tidal effects
- Topography
- Karst topography
- Drainage area size
- Maintenance Considerations
- Expansiveness of impervious cover
- Density of on-site structures
- Overall spatial constraints
- Downstream drainage and runoff conveyance infrastructure

Refer to Appendix A for additional information on design considerations.

It should also be noted that local land use ordinances might also influence the implementation of certain LID practices. These include:

- Zoning
- Local subdivision ordinances
- State and local building codes
- Open space requirements

In general, when introduced early in the development process, LID planning strategies and techniques, such as reducing impervious cover, conserving natural areas, and diffusing and disconnecting stormwater runoff, can conform to most local ordinances and still be both hydrologically and economically effective.

The applicability and effectiveness of LID site design strategies should be progressively evaluated at the zoning, preliminary planning, conceptual drainage and SWM design, and final site design phases of project development. At each successive step in the process, as more detailed site evaluations reveal more information regarding the site's physical characteristics, the designer can evaluate and continually modify the design to better mimic the pre-developed hydrology, meet stormwater regulatory requirements, and achieve aquatic resource protection goals.

When the use of LID practices on a particular site is limited by physical constraints or other factors, or the stormwater regulatory requirements cannot be satisfied solely with the use of LID design techniques, then a ***"hybrid" design*** may be employed. A hybrid design employs both LID and conventional BMP's or detention practices (e.g., ***centralized BMP's***) to meet stormwater requirements. Such a design might conserve specific natural features and provide open space to the greatest extent possible, while detention measures or centralized BMP's are also implemented to provide peak rate or quantity control beyond the site-specific capabilities of the LID strategy. Another example of a hybrid design is one that incorporates LID for both the attenuation and infiltration of small storm events, and centralized BMP's to provide storage for larger storm events. (Control of runoff from larger storm events may be necessary to protect

downstream manmade or natural conveyance systems in accordance with MS-19, or other watershed specific criteria.)

Once LID site design strategies and practices have been evaluated and employed to the greatest extent practicable, and, where needed, additional SWM controls have been added, the designer must measure and document the target performance of the design in satisfying any regulatory requirements. While the calculation procedures for documenting compliance using traditional detention, extended detention, or other types of BMP's have been in use for many years (refer to the Virginia SWM Handbook), the use of LID type strategies for regulatory compliance is relatively new. (Some of the currently accepted computational methods for calculating regulatory compliance are provided in this Technical Bulletin.) In addition, there may be a desire to quantify the extent to which LID practices are implemented in order to establish that the development is indeed an "LID design". This can be accomplished by calculating the percentage of the total site area or total site impervious area being treated by appropriate LID strategies, or calculating the ratio of the estimated depth of rainfall or volume of runoff being treated by the LID strategy to the total depth or volume respectively. (At this time there is no established standard for a design to be qualified as an LID design.)

LID Design Components

The LID strategy of replicating the pre-development surface and sub-surface hydrologic regime is accomplished through the combination of design principles: *Conservation, Minimization of Impacts, Maintaining Site Runoff Rate and Patterns, the use of IMP's, and Pollution Prevention (P2).* These design principles incorporate structural and non-structural stormwater practices into a site design, and will each have either a ***direct*** or ***indirect effect*** on the measurable hydrologic characteristics of the site. Structural practices, when considered in the context of LID design strategies, imply small-scale stormwater BMP's distributed throughout a site or drainage area, and are often referred to as IMP's and can include, but are not limited to, engineered and natural temporary surface storage for runoff attenuation, and infiltration for groundwater recharge and runoff volume reduction.

Non-structural practices can include, but are not limited to, preservation of natural areas and functions such as permeable soils and existing flow paths, the disconnection of impervious surfaces, and P2 activities. (A list of accepted structural and non-structural practices will be provided by the Virginia Department of Conservation and Recreation or the local plan approving authority.)

The following provides a brief description of these design principles and how they may be incorporated into the site development design to replicate the pre-developed hydrology. Design principles 1 through 4 are listed in the order of expected consideration and evaluation during the development planning and design process in

order to utilize the natural hydrologic processes in the final development stormwater design. Design principle 5, P2, should be an integral part of the site design process from beginning to end in order to facilitate the post-construction site function and management in addition to any construction related requirements of the ***Stormwater Pollution Prevention Plan*** (SWPPP).

1.) ***Conservation.*** Conservation of any natural lands within a development site may have the direct effect on the site hydrology of minimizing impervious cover that would otherwise generate higher rates and volume of runoff. Indirect benefits of conservation can be derived by locating and protecting certain hydrologic features such as drainage paths, permeable soils, steep slopes, etc.; and, in accordance with appropriate zoning and subdivision requirements, strategically locating setbacks, easements, woodland conservation zones, buffers, utility corridors, and other permanent site features to enhance the overall goals of maintaining the pre-developed hydrology.

   The Center for Watershed Protection offers 22 "Better Site Design"[4] principals aimed at reducing the impacts of development on sensitive lands and aquatic resources. Conserving specific sensitive lands on a site is a crucial first step. The implementation of a SWPPP and/or ***Erosion and Sediment Control Plan*** further minimizes the impact of construction and development activities on these sensitive lands.

2.) ***Minimization of Impacts.*** Minimization of impacts refers to reducing the extent of construction and development practices that adversely impact the hydrologic conditions of the site. This includes limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure, as well as locating the land disturbances so as to avoid impacting hydrologically sensitive areas. The designer must conduct a thorough analysis of the existing topography and site geometry when locating fixed improvements such as roads, houses or buildings, sanitary and storm sewer utility corridors, etc., in order to minimize unnecessary grading and/or compaction of the natural soil horizon, clearing of trees, and creating of impervious surfaces.

   The minimization of impacts can have both direct and indirect beneficial effects on the hydrologic characteristics of the site. The extent of these benefits is dependent on the ability of the selected hydrologic analysis method to accurately depict impervious cover, land slope, soils, types of vegetation, and other factors that affect surface and subsurface hydrology.

3.) ***Preserve Pre-development Runoff Rate and Patterns.*** Preserving the site pre-developed runoff rate and patterns are two of the overall objectives in replicating the pre-developed hydrology (other objectives include maintaining the pre-developed volume, frequency, and duration of runoff). Effectively implementing

[4] Better Site Design – An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act; The Center for Watershed Protection. http://www.cwp.org/better_site_design.htm

conservation practices and minimizing impacts, as described above, represent the first steps in achieving these objectives. Further steps involve evaluating how certain design choices can influence the post-developed hydrologic processes to reduce the rate and volume of runoff. These design choices include disconnecting impervious cover in order to maintain sheet flow conditions, lengthening the developed condition time of concentration (Tc), etc. Ideally the post-development drainage divides should replicate those of the pre-developed condition

Stormwater detention practices can be effective in maintaining the pre-developed rate of runoff, however detention practices alone are not able to achieve the objectives of maintaining the pre-development volume, frequency, and duration of runoff. LID design strategies, on the other hand, focus on using site design techniques to influence the hydrology before (or instead of) conveyance of the runoff to a centralized detention practice.

4.) ***Integrated Management Practices*** **(IMP's).** IMP's refer to decentralized small-scale (source control) stormwater retention and detention structural BMP's integrated uniformly throughout the site or drainage area. These practices can be integrated into the landscape, buildings, and overall development infrastructure to reduce the volume and rate of stormwater runoff. These systems are designed to emulate the natural processes of detention, retention, interception, evaporation, transpiration, and groundwater recharge, in order to replicate the pre-developed hydrology. Common examples of IMP's include: bioretention cells (or rain gardens), water quality swales, green roofs, and other small scale runoff attenuation practices.

5.) ***Pollution Prevention (P2).*** P2 is a non-structural practice aimed towards reducing pollutant loads at the source by eliminating the behavior or practices within the urban and suburban landscape that have been shown to generate a non-point source pollutant load. P2 is applicable both during the active construction phase of development and during the life of the facility. This includes the implementation of soil conservation and erosion control measures employed during construction, long-term management of post-construction BMP's, and proper onsite storage, use, and disposal of chemicals or potential pollutants.

Pollution prevention can also include community-wide education efforts and specific training and education programs directed toward the owners/operators of properties designed and constructed in accordance with these principles. Common examples of P2 techniques include storm drain stenciling, public outreach and education on the appropriate use of fertilizers and pesticides, street sweeping, etc.

Computational Methods

The level of effectiveness to which LID techniques and practices satisfy the technical regulatory requirements can be measured using conventional hydrologic parameters. These parameters or values are used in several different computational methods to calculate the pre- and post-developed hydrologic response of the land. These methods include relatively simple calculations using charts calibrated for the rainfall distributions of Virginia, as well as detailed routing of stormwater through individual IMP's and any other structural practices within a given subwatershed, or some combination of these methods.

Much of the basis for these computational methods have been developed and detailed in numerous references. The selection of a specific computational method will often be a function of the stormwater component being measured: stormwater quality, quantity, or both. LID practices applied to a development site with the goal of improving runoff quality may also achieve some level of quantity or peak rate control. Likewise, practices that are designed with the goal of rate or volume control may also derive a water quality benefit.

This section will provide an overview of some of the existing methods available with which to measure the effectiveness of an LID design strategy. The scope of this section will in no way serve as a design manual or otherwise replace the available documentation for each of the methods listed, nor are the available options limited to those presented here. The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) National Engineering Handbook Section 4: Hydrology (NEH 4), and Section 5: Hydraulics (NEH 5), and the Virginia SWM Handbook (VSWMH) provide detailed information on the accepted analytical methods described in this Bulletin, as well as other methods that may be determined to be acceptable by the designer or plan approving authority.

This Technical Bulletin will not establish one acceptable method, rather it will give designers and plan reviewers the information needed to hopefully design and evaluate an LID strategy for a development project using the best suited method. However, the compatibility or translation of the chosen analytical techniques to NRCS methods may serve to facilitate the acceptance of the analysis in those jurisdictions where NRCS methods are utilized.

Water Quality Control

Compliance with the Virginia water quality criteria (4VAC3-20-71 et seq.) may be achieved by applying the *Performance-based* criteria or the *Technology-based* criteria to the site as outlined in the VSWMH.

The Performance-based criteria utilize the percent impervious cover of the site to calculate the post-developed pollutant load, and then apply the target pollutant removal efficiency of the stormwater BMP's to determine compliance. Each stormwater BMP, including accepted non-structural practices, must therefore have an assigned target pollutant removal efficiency associated with the accepted design standard.

The Technology-based criteria require that the runoff from the impervious cover of the site be captured by an appropriately designed BMP (considered to be the best available technology for the specific site characteristics).

Strategically locating IMP's through out the development site or as part of a hybrid design, can serve to meet either the Performance or Technology-based criteria. The VSWMH provides a list of currently accepted stormwater BMP's, including design criteria and corresponding target pollutant removal efficiencies. The Virginia SWM Regulations also allow for innovative or alternate BMP's not included in the VSWMH to be approved at the discretion of the plan approving authority. Additional design and performance guidance may be necessary to expand this list to include certain IMP's, site design techniques, and non-structural practices, in order to effectively document compliance with either criterion.

Water Quantity Control

Quantity (or rate) controls are implemented to reduce the peak rate of stormwater discharge from the developed site in order to prevent stream channel erosion and/or localized flooding. These controls are generally volume-based practices and utilize recognized hydrologic and hydraulic analytical methods in order to make comparisons between the pre- and post-developed conditions. The VSWMH specifically refers to NRCS TR-55 and the modified rational methodologies for such computations. These analytical methods vary in terms of flexibility and complexity. It is the responsibility of the designer to be familiar with these methods and determine the appropriate method, or combination of methods, that will demonstrate the effectiveness and verify compliance with applicable Federal, state, or local codes and ordinances.

This section provides four methods or categories of procedures that can be used to analyze and evaluate the effectiveness of LID designs. They are: Hydrologic and Hydraulic Models, Hydrograph Modification, LID Hydrologic Analysis (PGDER, 1999) and a Credit or Point System. The first three methods utilize recognized hydrologic and hydraulic analytical methods in order to make comparisons between the pre-and post-development conditions. A Credit or Point System can be developed and implemented by localities to place an emphasis on design and protection strategies that protect or enhance critical watershed natural resource areas.

1. Hydrologic and Hydraulic Models

   The following provides a general description of the procedures associated with accepted hydrologic and hydraulic models used to determine the effectiveness of an LID design.

   Hydrology – The first step in evaluating an LID design or any SWM strategy is to characterize the runoff from the site or drainage area. The methods for characterizing the hydrology or runoff range from the Rational Method to

single event distribution methods, such as widely used NRCS models that develop a rainfall and runoff relationship with respect to time (i.e., a runoff hydrograph), to continuous simulation models that develop runoff hydrographs from multiple storm events.

The evaluation or measure of the performance of LID techniques must consider runoff volume, frequency, duration, and peak rate of discharge. Therefore, the method employed to calculate the site hydrology must be capable of generating a runoff hydrograph. The designer must establish the runoff characteristics with respect to time at each proposed IMP location or other critical locations throughout the drainage area as input parameters for the model. The model then must evaluate these characteristics for each area all on the same time scale and then sum the hydrographs at the selected study point. Critical locations include any areas where an engineered or natural control is proposed.

Hydraulics – Once the rainfall-runoff hydrographs are developed for specific locations, the engineer can apply standard hydraulic calculations to account for groundwater abstraction, storage attenuation, and surface runoff velocity at each location. The calculations should reflect the individual hydraulic characteristics of each IMP or critical area, and be physically based on the measurable unit processes being considered.

For simplicity, many SWM software packages generalize interactions with groundwater and other losses rather than perform a detailed routing. Most, however, allow the user to export the hydrograph in order for it to be modified to reflect specific infiltration rates, retention storage volume, or other losses as appropriate. The modified hydrograph can then be imported back into the model. (The designer must determine the analytical values for these losses through field investigations or acceptable documented sources and should coordinate those values with the plan approving authority.)

Detailed modeling of LID designs, therefore, can be accomplished in much the same manner as hydrologic and hydraulic analyses used for traditional SWM designs. The key differences are: (1) the designer must identify and model a potentially large number of structures or control points, and (2) a greater emphasis is placed on quantifying the volume reduction associated with infiltration, retention storage volume, ***evaporation***, ***transpiration***, rainwater harvesting, etc. at each control point. The benefit of detailed modeling is a more direct prediction of the decrease in the peak rate and volume of runoff attributed to the measurable LID design features in order to verify compliance with regulatory requirements. However, complex modeling may not necessarily result in greater accuracy in predicting the developed condition hydrology. The selection of the most appropriate analytical method will vary depending on the site conditions and design values.

2. Hydrograph Modification

Routing hydrographs through IMP's and other LID site features as discussed above may require a significant amount of time and effort to quantify all of the site characteristics in enough detail to meet the requirements of the various models. The following theoretical methods provide more simplistic approaches for modifying the runoff hydrograph in order to reflect the site conditions represented by a comprehensive LID design. Some of these methods have been accepted in other jurisdictions; however, further evaluation and modification may be required before they are accepted for use by the local plan approving authority.

- *Truncated Hydrograph Method,* (MDE, 1983). This approach analyzes distributed retention storage by assuming that the sum of the retention storage is available for filling at the beginning of the runoff event (like an empty pond), and that there is no resultant runoff until all available retention storage has been filled. This method does not take into account the spatial distribution of the retention storage (small pockets throughout the watershed) and the timing of outflows from these facilities. Additional work is needed to verify the accuracy of this method and/or calibrate the relationships between the distributed storage, drainage area size, and overall hydrologic benefits as reflected in the final hydrograph at the study point. However, the value of this method is its simplicity and may be effective in assessing the LID potential of a development site during the early stages of development.

- *Change in Curve Number Method,* (MDE, 1983). This method reduces the post-developed curve number to reflect the runoff volume stored by the IMP's. This assumes that all of the storage volume is infiltrated, evaporated, or otherwise available for the next storm event. As with any method that assumes infiltration, care must be taken in the proper location and design of the infiltration IMP's to ensure long-term function.

- *Scalar Multiplication,* (LID Center, 2004). This method estimates the effects of IMP storage by reducing the ordinates of the runoff hydrograph by the ratio of total retention storage to total runoff generated. This approach assumes that volume of retention storage provided will proportionally reduce the runoff volume and rate uniformly at all points along the runoff hydrograph.

- *Subtract Retention from Rainfall,* (LID Center, 2004). Subtraction of IMP storage volume from the rainfall depth by modifying the NRCS equation for the relationship between rainfall and runoff.

- *Subtract Retention from Runoff,* (LID Center, 2004). Subtraction of IMP storage volume from the runoff depth by modifying the NRCS equation for the relationship between rainfall and runoff.

- *Adjust CN for 24-hour Storm Depth,* (LID Center, 2004). Subtraction of the IMP storage volume from the runoff depth at the end of the storm event.

3. Low Impact Development Hydrologic Analysis, Prince George's County, Maryland.

   This approach is described in detail in the "Low Impact Development Hydrologic Analysis" (PGDER 1999) and can be used to determine the storage volume required to maintain the frequency of pre-development runoff volume and/or peak runoff rate that is generated from the post-development condition for a range of 24-hour Type II storm events.

   The method can be used to analyze a variety of storm frequencies or recurrence intervals, and is most useful for analyzing volume replication and peak attenuation goals for specified storm events. The design storm can be selected in accordance with local requirements, although the stated goal is to replicate the pre-developed hydrology. Therefore, the design storm is calculated as that which generates initial runoff from the pre-developed site condition (assumed to be woods in good hydrologic condition, and the actual hydrologic soil group classification of the site), or the 1-year event, whichever is greater. Using design charts aimed at simplifying the computational procedures, the designer determines the total storage volume required on the site. The designer must then determine if the resulting volume requirement meets the regulatory requirements for channel protection, flooding, or other criteria.

   There is no standardized method within the manual to correlate the resulting distributed storage with the 1-year extended detention channel protection or larger storm requirements. However, the designer may use various acceptable hydrologic parameters to compare the LID design with the peak rate or extended detention requirements and make up any shortfall through a hybrid design. Any method chosen to document compliance may be subject to local review and approval.

   This method is based on the NRCS computational procedures found in Urban Hydrology for Small Watersheds Technical Release 55 (TR-55), and therefore has similar limitations to TR-55 in that it cannot be used for complex storage routing or when a high degree of accuracy in the storage/discharge relationship of any BMP is required. Also, the design charts generally require that the pre- and post-development drainage areas are the same, and that the designer is able to maintain the pre-development Tc. Further, the method assumes that the volume of the required structural controls are decentralized or distributed evenly throughout the site. The reader is encouraged to review this methodology further in the referenced manual.

4. Credit or Point System Approach

A credit or point system can be developed by a locality in order to encourage the use of certain design strategies, protection methods, or IMP's to address local water quality goals, natural resource protection objectives, or regulatory requirements. Such a system may function as a stand-alone compliance assessment tool or may be used in conjunction with other analytical (hydrologic and hydraulic) methods. If stand-alone, the results are "presumptive," i.e., compliance is based on a project receiving a certain number of credits or points based on the proposed management practices that are presumed to meet the relevant requirements (e.g., biofilters or open space protection is presumed to meet certain water quality goals).

Alternately, a credit or point system can be used to enhance the use of other analytical methods to influence the design towards certain LID measures. For instance, hydrologic and hydraulic computations may be used to verify design criteria, and the credit/point system added to promote the protection of open space or critical areas, or other practices aimed at preserving the pre-developed hydrologic condition.

A stand-alone credit or point system may be appropriate for those developments where a highly analytical approach to ensure compliance for LID features may act as a disincentive for LID implementation. These developments may include relatively simple projects, redevelopment projects, or projects with relatively low impervious cover (such as a typical rural subdivision) or where downstream drainage and flooding are not a concern. In these cases, the program authority may elect to develop a simplified compliance system in order to encourage LID design strategies.

The premise of this approach is that LID practices are presumed to achieve certain water quantity and/or quality requirements if certain performance standards are met. Although such a methodology is not specified in the VSWMH, it can be viewed as an enhancement to the technology-based criteria for water quality compliance, where certain LID practices are included in the allowable technology list. A credit or point system can also be adapted into the performance-based criteria if LID practices can be assigned target pollutant removal credits or proportional pollutant removal efficiencies. In either case, guidance on specific design criteria and target pollutant removal efficiencies must be provided in order to ensure consistent application.

As stated above, a credit or point system can also be used in conjunction with other computational methods. The hydrologic and hydraulic model chosen can be used to verify partial compliance with water quality/quantity requirements, with the gap being filled by other LID measures (e.g., open space protection) that are not easily modeled, but should still receive points or credits towards the overall compliance objective.

Several examples of a credit or point system can be found throughout the Chesapeake Bay watershed. In one Virginia county, a BMP point system is used as a technology-based approach to ensure that development sites are adequately covered by preferred BMP's. The proportion of the site served by the BMP weights the pre-set points assigned to each BMP. In addition, points assigned to specific site development practices such as preservation or minimization of impacts are weighted by the value of the practice, e.g.: open space is positioned in a way that accepts and treats stormwater or is adjacent to a wetland, mature forest, or Resource Protection Area.

Another example includes a water quality credit system for non-structural measures such as adding additional stream buffer area to the minimum requirement, re-vegetating existing buffers, protecting buffers with permanent easements, and disconnecting impervious cover. While some of these practices provide both direct and indirect benefits to the site hydrology and can therefore be measured by accepted analytical tools, the credit system serves to create an incentive by simplifying the required design calculations and associated plan review requirements. Additional credits can be assigned to the modification or use of certain structural practices, such as using open space as stormwater treatment areas (if certain design parameters can be met) and using individual lot practices, such as rain gardens.

Specific design standards and performance criteria must be developed if a local program authority elects to use a credit or point system. Design standards can include relationships between the required water quality volume based on impervious cover and the individual BMP or cumulative distributed storage volume or surface area coverage associated with IMP's, as well as any variable design criteria that may allow for additional points or credits based on certain performance goals. At a minimum, design and performance standards should provide for the long-term maintenance and proper function of the BMP's, IMP's, and/or other LID site features, as well as be consistent with accepted statewide design standards.

The credit or point system is a very flexible concept; the program authority can adapt it to meet local needs and conditions or to promote particular practices. One main caution to using this approach is that it may require interpretation on the part of the reviewer and may be viewed as more of a negotiated approach to compliance than other, more quantitative methods. The positive side is that it can be simple for both plan preparers and reviewers and can lead to designs that more fully incorporate LID and encourage use of natural open space. The program authority should strive for review procedures that are equitable while allowing for a certain amount of case-by-case interpretation.

Construction and Maintenance

The first steps in ensuring the long-term effectiveness of any LID practice are the proper selection, location, and design of the practice. Equally important are the construction and long-term maintenance practices and techniques. Ideally, the designer will not only have all the site information necessary for the design related activities, but also an understanding of the construction requirements and the ultimate land use and management (or ownership, with regard to maintenance). It should be noted that while these elements are critical to the effectiveness of any stormwater practice, the distributed and small-scale nature of LID practices and techniques make them especially vulnerable to impacts from mass grading and construction operations, as well as long-term neglect.

The location and design of LID practices must include a sequence of construction. The sequence of construction is important because some LID practices cannot be built until the contributing drainage area has been stabilized. Similarly, if certain areas of the site are to be preserved for post-construction LID practices, the site design must account for adequate access to the proposed construction areas without impacting those protected areas. Impacts to protected areas, even if only temporary, can cause compaction of the natural soil horizon or contamination with silt, thus reducing the effectiveness and long-term function of the practice. If impacting a select area is unavoidable, the plans should include provisions for restoration and preparation of the area for the post-construction use.

Therefore, the construction drawings must reflect areas to be preserved and include adequate ESC measures to protect those areas (especially since those areas may serve as natural drainage paths). The sequence of construction should be prominently displayed on the plans as a critical element to the site design, and reflect the multiple phases of the construction as related to the implementation of the designed LID practices within the overall construction activity. Local officials are encouraged to incorporate intermediate inspections to ensure proper soils, materials, and construction practices related to the stormwater features.

The design and construction of any structural LID practice (or stormwater BMP) should be in accordance with the accepted standards of the local jurisdiction or state regulations. The references provided at the end of this Technical Bulletin provide an array of guidance documents, including the VSWMH, as well as guidance documents from other states. Local plan approving authorities may adopt plan design and construction inspection criteria that exceed the current state minimum in order to ensure the long-term effectiveness of LID designs.

Post-construction inspections and maintenance of LID structural and non-structural practices are equally important to ensure effectiveness. Annual inspections are recommended at a minimum, with more frequent inspections during the first year or

growing season for vegetated practices, or as required by any permit conditions. Some LID practices may require more frequent inspections, (e.g. after significant rain events, quarterly, during property transfers, etc.). Inspection and maintenance of structural LID practices such as cisterns, vegetated roofs, permeable pavements, infiltration structures, and manufactured proprietary devices should follow local heath department, state or local stormwater minimum standards, as well as manufacturer's recommendations for maintenance or repair. Any under-drains or outfall structures should be inspected on a regular basis and cleaned out or repaired as necessary.

The primary maintenance requirement for vegetative LID structural and non-structural practices is inspection and periodic repair or replacement of the treatment area's components. This often includes the upkeeping of the vegetative cover (pruning), replacing mulch, removing weeds, and possibly removing sediment to preserve the practice's hydraulic properties. For many LID practices, this generally involves little more than the routine periodic landscape type maintenance.

To ensure continued long term maintenance, all affected landowners should be made aware of their individual or collective maintenance responsibilities through legal instruments such as maintenance agreements and maintenance easements that convey with the property. Outreach materials, such as LID brochures or facts sheets that explain the function of practices and the anticipated maintenance responsibilities for homeowners, should be included in settlement or home owner association documents.

Glossary

Best Management Practices (BMP's) are activities, procedures, and structural and non-structural devices or features that are specifically identified or designed to prevent or reduce the impact of development on surface and groundwater systems.

Conventional (centralized) Best Management Practices (BMP's) are structural BMP's designed to capture and treat stormwater runoff from a large drainage area. SWM ponds and basins located at the bottom of a developed drainage area or watershed are generally considered to be conventional (centralized) BMP's.

Direct effects are those that are measured or quantified with analytical methods to identify the hydrologic or hydraulic response of the site to the post-development condition or the SWM strategy or technique. For example, the direct effect of providing on-site storage is that the rate of peak discharge.

Erosion and Sediment Control (ESC) Plan means a document that is prepared in accordance with good engineering practices and containing details and instructions for the conservation of soil and water resources of a unit or group of units of land during land disturbing activities.

Evaporation is the process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces.

"Hybrid" design means a design that employs both LID and conventional BMP's or detention practices to meet stormwater requirements. Such a design might include LID practices or strategies such as the conservation of specific natural features and open space to the greatest extent possible, while detention measures or centralized BMP's are also implemented to provide peak rate or quantity control beyond the site-specific capabilities of the LID strategy. Another example of a hybrid design is one that incorporates LID for both the attenuation and infiltration of small storm events, and centralized BMP's to provide storage for larger storm events.

Indirect effects are those where the hydrologic or hydraulic response may not be quantifiable by established analytical methods, yet they have inherent effects on the hydrologic and hydraulic response of the site to the post-development condition, including water quality. For example, the preservation and/or enhancement of the natural stream buffer, or the strategic location of utility corridors may preserve and protect certain hydrologic components of the pre-developed site, without the benefit of being quantified in the hydrologic analysis.

Integrated Management Practices (IMP's) are small-scale structural stormwater practices distributed through out a site or drainage area for the purpose of managing or influencing the site hydrology.

Non-structural practices are natural features or directed activities specifically utilized for the purpose of managing or influencing the site hydrology and/or improving water quality. Non-structural practices can include pollution prevention, preservation of open space and natural flow paths, street sweeping, etc.

Stormwater Pollution Prevention Plan (SWPPP) means a document that is prepared in accordance with good engineering practices and that identifies potential sources of Pollution that may reasonably be expected to affect the quality of stormwater discharges from a construction site or its associated land disturbing activities. In addition the document shall describe and ensure the implementation of best management practices, and shall include, but not be limited to the inclusion of, or the incorporation by reference of, an erosion and sediment control plan, a post construction stormwater management plan, a spill prevention control and countermeasure (SPCC) plan, and other practices which will be used to reduce pollutants in stormwater discharges from land disturbing activities.

Structural practices include any man made stormwater practice or feature that requires maintenance in order to function or provide the hydrologic benefit as designed. Structural practices include, but are not limited to, rain gardens, stormwater bioretention basins, stormwater infiltration facilities, stormwater retention and detention facilities, engineered vegetated filter strips, and any other features that are designed, constructed

and maintained in order to managing or influencing the site hydrology and/or improve runoff water quality.

Transpiration is the process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

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Appendix A

Design Considerations

Soil Permeability
The soil permeability, or infiltration rate, is critical to the proper function of IMP's that incorporate infiltration as part of their control mechanism. The best location for these practices is in areas that have characteristics of Hydrologic Soils Groups A and B, which have high infiltration rates during saturated conditions. These are typically sandy soils. Hydrologic Soil Groups C and D have low to very low infiltration rates when thoroughly wetted. These are typically silts and clays or compacted soils. Due to these characteristics, soil groups C and D are not conducive to exfiltration and may impact the proper functioning of IMP's, such as grass swales, bioretention basins, and permeable pavements. Underdrains can be used in these facilities to control the rate of flow and to ensure that the facility will not become inundated with runoff over a long period of time.

High Water Table
A high water table may reduce the storage capacity of the below ground portion of the IMP and may also impede the ability of the media in the IMP to filter out pollutants before they enter the groundwater.

Topography (Steep Slopes)
A slope stability analysis should be conducted in areas with high potential for slope failure or fill slopes to ensure that any proposed infiltration IMP will not affect the stability of the area

Karst Topography
Infiltration IMP's placed in karst topography may cause subsurface collapse and sink hole formation. A subsurface analysis and the depth of the table should be determined at the beginning stages of design to determine the capacity of the soils for saturation when LID infiltration practices are considered.

Septic Systems
An adequate buffer between any infiltration practice and a septic system should be provided to ensure that the septic field will not be inundated, the infiltration rate of the field will not be affected, or any roots from the practices will enter the reserve area.

Water Supply Wells
Infiltration IMP's should be located in areas where there is the potential for contamination. Particular attention should be paid in areas where there are high pollutant loads (e.g. industrial areas) or shallow wells.

Structures and Foundations
A sufficient buffer should be provided between IMP's and basements building structural areas that must not become saturated. Impermeable liners and underdrains are appropriate for use in these areas.

Expansive Impervious Areas
The amount of drainage to each individual IMP in large impervious areas such as parking lots or compacted areas with high runoff potential should be minimized due to the high frequency and potentially large volumes of water that these areas will receive. Adequate underdrains and overflow paths, such as a secondary storm drain system, should be included for high flow events.

High Sediment Loads
Areas that drain to filtering or infiltration IMP's that are not adequately stabilized and have high erosive potential or soils with high "K" values will require additional control measures to filter the sediment or more frequent maintenance to reduce the potential for clogging of the facility.

Flood Control
Site constraints, such as limited downstream storm drain infrastructure, inadequate channel capacity, and flooding considerations, may necessitate additional volume storage by employing traditional end-of-pipe detention and retention basins in addition to LID practices at the discharge points.

Spatial Constraints
A high density of infrastructure or building areas on a site may limit the use of IMP's.

Appendix C

Example Checklists



RECOMMENDED MODEL DEVELOPMENT PRINCIPLES

for Baltimore County, Maryland Consensus of the Builders for the Bay Site Planning Roundtable

FUNDED IN PART BY:
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Center for Watershed Protection
Alliance for the Chesapeake Bay
Home Builders Association of Maryland
Baltimore County, MD

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BALTIMORE COUNTY

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- Baltimore County, MD
- Chesapeake Bay Trust
- Constellation Energy
- National Association of Home Builders
- National Fish and Wildlife Foundation
- Rauch Foundation
- US EPA Chesapeake Bay Program

We would also like to thank the individuals who served as subcommittee spokespersons:

- Jay Doyle: Residential Streets, Parking Lots and Infrastructure Subcommittee
- Russ Dickens and Pat Keller: Lot Development Subcommittee
- Ernie Shepp: Stormwater Management Subcommittee
- Bruce Seeley: Review and Approval Process Subcommittee

In addition, we would like to extend a special thanks to the staff of Baltimore County and Home Builders Association of Maryland who assisted in completing the Codes and Ordinances Worksheet (COW) and the Codes Analysis. We also want to thank the following organizations for the use of their facilities:

- Baltimore County Department of Environmental Protection and Resource Management
- Baltimore County Department of Recreation and Parks
- Baltimore County Department of Planning
- GW Stephens & Associates
- Morris Ritchie and Associates
- Ruxton-Riderwood Lake Roland Area Improvement Association

Team members included Rebecca Winer, Hye Yeong Kwon, Ted Brown, Pam Rowe, Tiffany Wright, and Chris Swann from the Center for Watershed Protection and Lou Etgen of the Alliance for the Chesapeake Bay. Sarah Weammert from the Chesapeake Research Consortium also provided assistance to this effort.

Copies of this document are available from: Baltimore County Department of Environmental Protection and Resource Management (**www.co.ba.md.us/Agencies/environment/**), Home Builders Association of Maryland (**www.homebuilders.org**), or the Center for Watershed Protection (**www.cwp.org**).

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Just over a year ago, a partnership of the Baltimore County Government, Alliance for the Chesapeake Bay, Home Builders Association of Maryland, and the Center for Watershed Protection initiated a process known as the Local Site Planning Roundtable to systematically examine local codes and ordinances with an eye to promoting more environmentally-sensitive and economically-viable development. This process, known as Builders for the Bay, is a collaborative consensus initiative designed to pull together local government agencies, the development community, neighborhood organizations, engineering and planning firms, and groups interested in environmental and conservation issues.

Throughout the past year, participants have reviewed current development practices involving five major categories: 1) Residential Streets and Parking Lots, 2) Lot Development, 3) Natural Areas, 4) Stormwater Management, and 5) the Review and Approval Process. From this review, the participants have prepared a consensus document, which contains a variety of recommendations and action items. These range from very specific changes in policy to ongoing review and updating of the County's development review process. These actions will require an ongoing commitment of all the partners to work together to see that the recommendations of the consensus document are implemented. There is also a commitment to continue to identify improvements to the development process and environmental protection of Baltimore County's natural resources and quality of life.

The Builders for the Bay has been embraced by the County Executive and partners, acknowledging a long history of progressive management of our natural resources. The consensus process also positions this county to look forward to continuing our quality of life, supporting economic growth, and ensuring that we have strong communities. On behalf of the Builders for the Bay partners, we are pleased to convey this document to the citizens of Baltimore County and to seek their support in our stewardship challenges for our environmental resources.

Very truly yours,

James T. Smith, Jr.
County Executive, Baltimore County

David Altfeld
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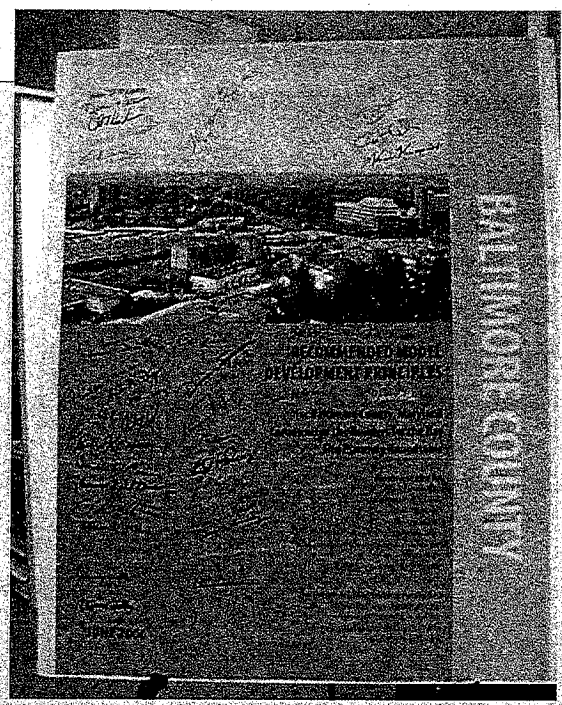
Executive Summary

This document is a product of the Baltimore County Site Planning Roundtable (Roundtable), a consensus process initiated by the Builders for the Bay Program. The Baltimore County Site Planning Roundtable is the sixth of 12 Builders for the Bay roundtables planned for the Chesapeake Bay region. The purpose of the Builders for the Bay program is to comprehensively evaluate existing development practices with the goal of more effectively protecting natural resources by utilizing innovative and cost effective site design and land planning techniques.



Participants signed this representative cover of the Consensus Document at the final Roundtable meeting.

Membership of the Roundtable consisted of a multi-stakeholder group of local government, civic, non-profit, environmental, homebuilding, development and other community professionals. Through a consensus process, members of the Roundtable provided the expertise needed to adapt the national Model Development Principles to specific local conditions including greenfield, infill and redevelopment settings. Roundtable membership recommendations include general and specific code and ordinance revisions that would increase flexibility for site design standards and promote the use of open space and flexible design development in Baltimore County.

The national Model Development Principles refined by the Roundtable are designed to collectively meet the objectives of Better Site Design, which are to: (1) reduce overall site impervious cover, (2) preserve and enhance existing natural areas, (3) integrate stormwater management, and (4) retain a marketable product. Code modifications and other targeted recommendations of the Roundtable were crafted to remove regulatory hurdles and provide incentives, flexibility, and guidance for developers in implementing Better Site Design. This process is focused on Model Development Principles at the site level and does not include discussions on zoning designations or land use.

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Purpose

This document presents specific recommendations on how to foster more environmentally-sensitive greenfield, infill and redevelopment site design in Baltimore County. The recommendations were crafted by a diverse cross-section of local government, civic, non-profit, environmental, homebuilding, and other community professionals that participated in the Baltimore County Site Planning Roundtable initiated by the Builders for the Bay program.

Introduction and Background

Every year, over two million acres of land are altered as a part of the development process of the United States. Development has historically led to degradation in water quality and biological integrity (NRCS, 2001). The impacts of watershed urbanization on the water quality, biology, and physical conditions of aquatic systems have been well documented (CWP, 2003). As such, local codes and ordinances that promote reduced impact of development on local water resources are critical to future sustainability.

Protecting water resources and the character of the local landscape while allowing growth and promoting redevelopment, requires local governments, developers, and site designers to fundamentally change current development practices. Deciding where to allow or encourage development, promote redevelopment, and protect natural resources are difficult issues that jurisdictions have to balance. While effective zoning and comprehensive planning are critical, communities should also explore measures to minimize the impact of impervious cover, maintain natural hydrology, and preserve contiguous open space on sites where development is to occur.

Toward this end, the Center for Watershed Protection, in concert with the Alliance for the Chesapeake Bay, the Home Builders Association of Maryland, and the Baltimore County Department of Environmental Protection and Resource Management, convened a local Site Planning Roundtable in Baltimore County.

The local Roundtable process in Baltimore County was modeled after the National Site Planning Roundtable (CWP, 1998a), the 22 Model Development Principles (CWP, 1998b), the Smart Site Practices for Redevelopment and Infill (CWP, 2001) and four basic objectives:

1. Reduce overall site impervious cover.
2. Preserve and enhance existing natural resources.
3. Integrate stormwater management.
4. Retain a marketable product.

The Model Development Principles act as benchmarks upon which more specific code and ordinance recommendations were adapted for Baltimore County. The benefits of applying these Model Development Principles are summarized in the table on the following page.

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Benefits of Applying the Model Development Principles

Local Government:
- Increase local property tax revenues
- Facilitate compliance with wetlands and other regulations
- Assist with stormwater regulation compliance

Homeowners:
- Increase property values
- Create more pedestrian friendly neighborhoods
- Provide open space for recreation
- Result in a more attractive landscape
- Reduce car speed on residential streets
- Promote neighborhood designs that provide a sense of community

Developers:
- Provides flexibility in design options
- Reduce development costs
- Allow for more sensible locations for stormwater facilities
- Facilitate compliance with wetlands and other regulations

Environment:
- Protect sensitive forests, wetlands, and habitats from clearing
- Preserve urban wildlife habitat
- Protect the quality of local streams, lakes, and estuaries
- Generate smaller loads of stormwater pollutants
- Help to reduce soil erosion during construction

Why Baltimore County?

The Baltimore County Site Planning Roundtable is the sixth of 12 Builders for the Bay roundtables planned for the entire Chesapeake Bay watershed. The purpose of the project is to adapt the principles developed at the national level for local application and to identify local codes and ordinances that act to prohibit or impede Better Site Design through a consensus building process. Baltimore County was selected as a location for a roundtable for several reasons:

- Baltimore County is within the Chesapeake Bay Watershed.
- Baltimore County has experienced a moderate amount of growth within the past few years. From 1990 to 2000, the number of housing units increased by 11.4%.
- Moderate growth is expected to continue and households are expected to increase by 10.3% by 2030.
- As the amount of developable land continues to shrink in Baltimore County, new and innovative techniques will be necessary to encourage and promote efficient and environmentally-sensitive infill and redevelopment within these remaining areas.
- The County government expressed an interest and was willing to commit staff and resources to the process.
- The County has a 40-year track record of progressive growth and natural resource management.
- The Home Builders Association of Maryland generated support for the project among its members.

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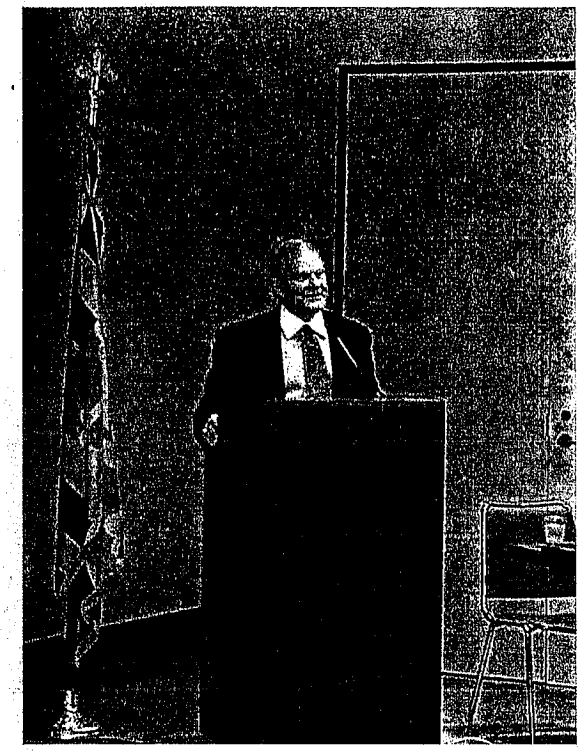
Baltimore County's Green Renaissance Program

On January 20, 2005, Baltimore County Executive Jim Smith announced the Green Renaissance Initiative before the Baltimore County Planning Board. Baltimore County's Green Renaissance represents a comprehensive approach to the protection of the County's natural resources. It also seeks to move the County away from old-school adversarial relationships to an inclusive decision-making process that is open to ongoing improvements. Green Renaissance seeks to establish a holistic and sustainable approach to maintaining the County's forests, preserving land heritage, protecting watersheds and incorporating an environmental stewardship ethic in all its citizens. Green Renaissance incorporates a full range of programs, initiatives and projects designed to enhance existing neighborhoods, create the setting to encourage more creative design for new communities and to protect, restore and enhance Baltimore County's unique natural heritage.



Baltimore County Executive Jim Smith announcing the Baltimore County Builders for the Bay Roundtable as part of the County's Green Renaissance initiative.

The Baltimore County Roundtable Process

Baltimore County Roundtable members convened many times over a 12-month period to become familiar with the Model Development Principles, review existing codes and regulations, work in subcommittees, and reach group consensus on a final set of recommendations. The Roundtable consisted of over 60 dedicated members representing a wide range of professional backgrounds and experience related to local development issues. The process included the following steps:

Kick-off Meeting: June 2005

Approximately 60 stakeholders from Baltimore County participated in the meeting. Almost every major stakeholder group was represented including those from the development community, local government, environmental groups, community associations and local utilities. The kickoff meeting introduced stakeholders to the Better Site Design principles (greenfields), Smart Sites practices (infill and redevelopment) and the Roundtable process.

Detailed Codes Analysis: September 2005

The results of the codes analysis were presented to the Roundtable membership at the September 2005 meeting. The results were based on output from the Baltimore County Codes and Ordinances Worksheet (COW)[1]; feedback from the June kickoff meeting; in-depth review of existing codes; ordinances, policies and regulations; and interviews conducted with

[1] Codes and Ordinances Worksheet (COW): Worksheet that quantitatively scores local development rules against the model development principles. The COW can be downloaded from www.buildersforthebay.net.

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developers, engineers and County staff. This analysis, completed by the Roundtable facilitators, provided a concise summary of the regulatory barriers to implementing environmentally-sensitive site design in Baltimore County and served as the foundation for subcommittee discussions. This analysis was presented to the Roundtable membership at a meeting held in September 2005.

More than 30 documents were reviewed as part of the codes analysis, with a primary focus on the following County documents:

- Bureau of Development Plans Review Policy Manual
- Citizen's Guide to Zoning in Baltimore County
- Code of Ordinances
- Comprehensive Manual of Development Policies
- Department of Public Works Design Manual
- Development Management Policy Manual
- Forest Conservation Technical Manual
- Local Open Space Manual
- Manual of Landscaping Standards
- Master Plan 2010
- Stormwater Management Regulations
- Zoning Regulations

Subcommittee Meetings and Consensus Building: October 2005 – May 2006

The full Roundtable divided into five subcommittees with the diversity of interests and expertise represented in each. Each subcommittee was responsible for reaching consensus on a subset of the Model Development Principles:

1. Residential Streets, Parking Lots and Infrastructure
2. Lot Development
3. Natural Areas
4. Stormwater Management
5. Review and Approval Process

All five subcommittees met multiple times between October 2005 and May 2006. The full Roundtable membership met again in January 2006 and April 2006 to complete the full membership consensus-building process.



Baltimore County Roundtable participants at the Kick-off Meeting

Consensus on Final Recommendations: June 2006

The Roundtable came to consensus on the full set of recommendations.

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Membership Statement of Support

This document of Model Development Principles and associated recommendations for implementation was crafted in conjunction with the diverse cross-section of development, local government, non-profit, environmental, and other community professionals who participated in the Builders for the Bay Baltimore County Site Planning Roundtable.

The Model Development Principles set forth in this document are recommended guidelines for development that, when used in combination, will help reduce the impacts of development on receiving waters. The recommendations provided for the Model Development Principles identify specific actions that should be taken to allow for full implementation and application of the Model Development Principles in Baltimore County.

Members of the Roundtable provided the technical experience and input needed to craft and refine the Model Development Principles for Baltimore County. These Model Development Principles and associated recommendations reflect the Roundtable members' professional and personal experiences with land development and do not necessarily carry the endorsement of the organizations, agencies, and companies represented by their members. Endorsement implies support of the principles and recommendations as a package and does not necessarily imply an equal level of support among individual recommendations by all Roundtable members.

The members of the Baltimore County Site Planning Roundtable endorse the Model Development Principles presented in the document: Recommended Model Development Principles for Baltimore County, Maryland.

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Model Development Principles

Recommended by the Baltimore County Site Planning Roundtable

Throughout this section the icon shown to the left is used to denote principles that address infill and redevelopment.

Residential Streets, Parking Lots and Infrastructure Recommendations

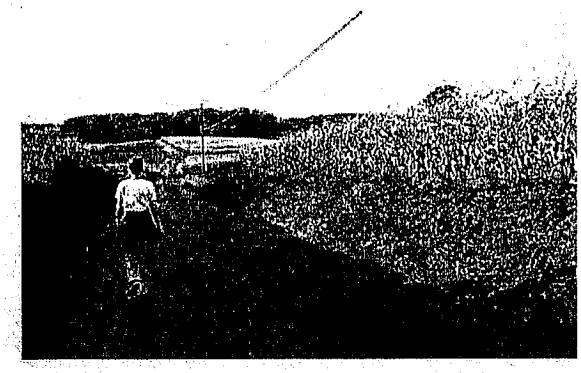
PRINCIPLE S1. STREET WIDTH

Design Residential Streets for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume and surrounding land use.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- This principle should be addressed through ongoing discussions regarding the development of rural road standards.



Source: Valleys Planning Council

Pedestrian on a rural road

The following recommendations apply to projects inside the urban-rural demarcation line (URDL):

- Utilize bump-outs creatively for possible natural landscaping and/or stormwater conveyance off the street.
- Section 8, Part B of the Bureau of Development Plans Review Policy Manual (February 27, 2002) regarding Public Facilities should incorporate the language as stated in the principle above.

Rationale

The County scored well for maintaining minimum pavement widths within the suggested parameters. The Department of Public Works (DPW) is not comfortable with queuing streets at this time due to concerns about parked cars. Utilizing bump-outs to control speeds and convey stormwater is encouraged.

PRINCIPLE S2. STREET LENGTH

Support a more efficient layout and connectivity of streets that encourage neighborhood designs and facilitate walking and biking.

Recommendation

The Roundtable supports this principle and recommends the inclusion of the principle in the Bureau of Development Plans Review Policy Manual and in the preliminary considerations of the Baltimore County Design Manual Section on Roads and Streets (page R1, paragraph IIA).

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Rationale

Rather than focusing on street length, the subcommittee believes that promoting efficient street layout as a whole and encouraging walking and biking meets several objectives including reducing overall impervious cover, promoting alternative transportation options, and promoting better site layout.

PRINCIPLE S3. RIGHT-OF-WAY WIDTH

Wherever possible, residential street right-of-way widths should reflect the Master Plan designation and the minimum needed to accommodate the travel-way, sidewalk, and stormwater infrastructure. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The specific language of the principle to be included in the Bureau of Development Plans Review Policy Manual.
- Revisions should also reflect recommendations made in Principle L2 of the Lots Subcommittee.
- This principle should be addressed through ongoing discussions regarding the development of rural road standards.

Rationale

The County scored well on its right-of-way standards. For example, the Better Site Design Handbook (CWP, 1996) recommends minimum right-of-way widths of 45' or less, Baltimore County recommends minimum right-of-way widths of 40' in its codes for local roads. The principle can be strengthened by encouraging reduced right-of-way widths in general so that impervious cover is minimized. To this end, the principle recommends inclusion of the specific language in the Bureau of Development Plans Review Policy Manual and practicing these widths.

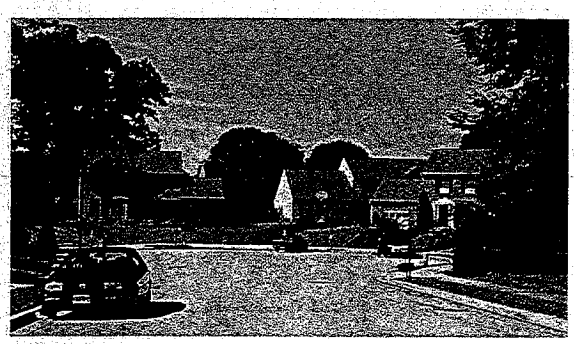
PRINCIPLE S4. CUL-DE-SACS

Consider other alternatives to cul-de-sacs to increase connectivity and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.

Recommendation

The Roundtable supports this principle and makes the following recommendation:

Add "or design alternatives such as eyebrows and loop roads" along with the term "cul-de-sacs" throughout the Baltimore County Design Manual for Water Mains, Sanitary Sewers, Storm Drains, Roads and Streets, Bridges and Culverts, and Structural and Land Acquisition.



Source: Baltimore County Office of Planning

Missed opportunity: A cul-de-sac that could have incorporated a landscaped island

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Rationale

The current codes in the Baltimore County Design Manual for Water Mains, Sanitary Sewers, Storm Drains, Roads and Streets, Bridges and Culverts, and Structural and Land Acquisition state that the number of cul-de-sacs utilized on a site should be minimized, but does not mention other cul-de-sac alternatives. Other cul-de-sac alternatives such as eyebrows, loop roads, and t-turnarounds can reduce the amount of impervious cover and pavement costs providing both environmental and economic benefits. This principle does not eliminate the use of cul-de-sacs, but simply states that other alternatives exist that may reduce impervious cover.

PRINCIPLE S5. PARKING RATIOS

Existing parking ratios should be reviewed for conformance taking into account local and national experience to see if lower ratios are warranted and feasible. The required parking ratio governing a particular land use or activity should be minimized when possible.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The County should conduct annual research into parking ratios and update code accordingly.
- The County should allow for reduced parking ratios if a developer can substantiate claims for the reduction.
- This principle language should be stated in section 409.6 and 307.1 of the Baltimore County Zoning Regulations.



Well utilized parking lot

Rationale

Current code numbers do not reflect trends in parking space usage. Opportunities to reduce parking may be found by updating actual parking ratios. To this end, this principle recommends addition of the above language in the Baltimore County Zoning Regulations Manual.

PRINCIPLE S6. PARKING CODES

Provide incentives for shared parking and a model shared parking agreement. Shared parking arrangements for smaller businesses should be encouraged by changing the minimum square footage requirements.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The County should maintain a model agreement on the Baltimore County Bureau of Development Plans Review website.
- Section 409.6 of the Baltimore County Zoning Regulations should include a model agreement and cite the above mentioned website where an electronic copy can be obtained.

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RATIONALE

The County code currently reduces minimum requirements where mass transit is available and where shared parking arrangements are in place. Additional measures can be taken to further encourage these practices, thereby reducing impervious cover and providing environmental benefits. Therefore, this principle recommends a more visible presentation of these alternatives in the codes and on the Baltimore County websites.

PRINCIPLE S7. PARKING LOTS

Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating safe, efficient parking and travel lanes, and using pervious materials in spill-over parking areas.

RECOMMENDATION

The Roundtable supports this principle and makes the following recommendations:

The County should:

- Maintain a current list of approved alternative, pervious parking surfaces. This list should be referenced in section 409.8 of the Baltimore County Zoning Regulations.
- Utilize parking islands creatively for possible conservation landscaping and/or stormwater management in parking lots.
- Revise existing County stormwater regulations to allow stormwater credits for approved alternative, pervious parking surfaces.

RATIONALE

The County requires a durable and dustless surface for all parking areas, but does not define what durable or dustless means. Some alternative paving materials can be both durable and dustless, and by adding a list of approved surfaces, the use of permeable alternatives can be encouraged.

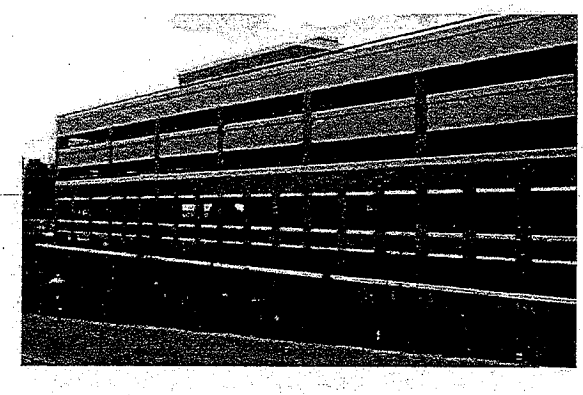
PRINCIPLE S8. STRUCTURED PARKING

Where appropriate and when public benefit is demonstrated, provide meaningful incentives to encourage structured parking to make it more economically viable.

RECOMMENDATION

The Roundtable supports this principle and makes the following recommendations:

- "Public benefits" and "incentives" should be defined.
- The County should authorize a cost effectiveness study of structured parking that considers life cycle costs such as maintenance, savings from snow removal, and landscaping savings.
- The County should promote greenroofs on top level parking structures.



Structured parking lot

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- The above principle, in conjunction with the recommendations, should be applied in the front of section 409 of the Baltimore County Zoning Regulations with its own subsection using the words "Structured Parking" as the lead.

Rationale

Structured parking can provide a method for reducing the total amount of land acreage used for parking. Currently, structured parking is not necessarily encouraged, and most often economics alone dictate whether or not it will be built. This principle provides additional ways to encourage structured parking where appropriate.

PRINCIPLE S9. MAXIMIZE TRANSPORTATION CHOICES

Design sites to maximize transportation choices in order to reduce pollution and improve air and water quality.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The County should convene a task force to address this principle on a regional scale[2].
- The County should include an addendum in the Baltimore County Master Plan, 2010 stating that the Roundtable supports the following policies of the Master Plan and encourages its adoption:
  1. Improve bicycle and pedestrian linkages within and between residential and commercial areas and transit and;
  2. The County will develop a plan for a comprehensive bicycle network with on-road and off-road facilities and;
  3. Adopt a coordinated county policy for pedestrian facilities.

Rationale

This principle recognizes that Smart Growth and environmental benefits go beyond impervious cover. Issues like air pollution, livability, and community benefits are also important to consider and help improve overall environmental benefit.

[2] Task Force should reflect the diversity of interests represented in the Roundtable membership.

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Lot Development Recommendations

PRINCIPLE L1. OPEN SPACE DESIGN

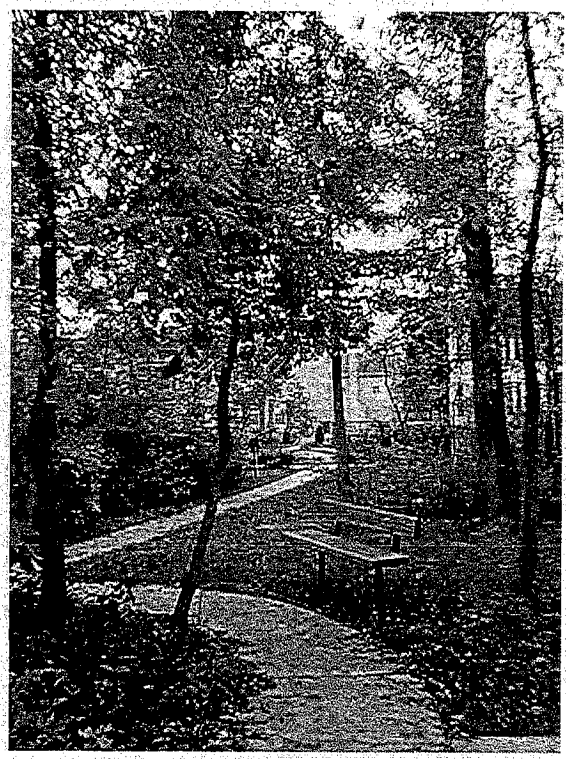
Advocate environmentally-sensitive development that incorporates certain practices to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection. These practices may include:

- Smaller lot sizes and/or reduced setback and frontage requirements
- Reduced length and/or width of driveways
- Trails and other passive recreational amenities along stream corridors in designated recreational greenways, County parks or where the County believes they facilitate valuable connections between other recreational amenities
- Development with ecological/environmental focus

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Revise the Local Open Space Manual (LOSM) to address the following issues:
  - o Clarify and differentiate how the LOSM is applied in rural versus urban areas, including addressing the following issues:
    - > Outside the URDL (Rural areas):
      - Allow open space within subdivisions outside of the urban-rural demarcation line (URDL) to be waived for fee-in-lieu.
      - Developers may pay into a fund to meet open space needs on a multi-district or other regional basis, rather than creating small, poorly utilized and inaccessible open space areas in neighborhoods.
      - Provide staff with more flexibility in determining how open space needs will be met through the development review process in rural areas.
    - > Inside the URDL:
      - Revise the LOSM to specify performance standards, rather than prescriptive requirements, that identify ratios and locations of passive and active open space. Develop standards for paths, benches, etc. to be provided in greenway or forest buffer areas and allow these areas to count for part of the open space element, rather than clearing and grading desirable natural areas to meet open space requirements.
      - Allow a more flexible development process that gives the developer an option to set aside the necessary land area and designate it as active open space and provide escrow funds to be used by the homeowners' association (or similar entity) to develop desired facilities, but not develop specific active recreational facilities until later in the land development process.



Source: Baltimore County Office of Planning

Path through natural open space

A007491

- Develop standards for urban parks/pocket parks that can be used in redevelopment and infill scenarios:
  - Allow flexibility to exchange quality of space or additional amenities for dimensional requirements.
  - Conduct strategic neighborhood planning to identify options for creating contiguous (larger) open space areas in redevelopment.
  - Develop design standards and guidance on credit for using urban open space areas for multiple purposes including stormwater management facilities (e.g., bioretention, infiltration practices, grass channels, rain gardens, etc.).
- As an incentive, where Better Site Design principles are used, allow more options for unit type in the lower density Density Residential (DR) zones in order to provide flexibility for clustering and open space preservation.

Rationale

Although "cluster" design subdivisions are allowed in certain zones, the land area in the County that remains to be developed in these zones is very small. Adding cluster provisions to the Resource Conservation Rural-residential Zone (RC-5), which currently does not allow it, was not considered a good option due to the potential for extensive community opposition, and the limited benefit due to the relatively small land area that remains undeveloped. The options remaining for improving environmental site design include addressing how active versus environmental open space is provided, and improving the provision and design of urban parks. The current open space requirements are fairly prescriptive and lack flexibility to respond to specific site conditions, resulting in frequent variances or waivers. As an example, currently it is possible that desirable natural areas would be graded and cleared to meet "active" open space requirements, rather than leaving them in a natural condition and allowing for more passive recreation. The flexibility to meet requirements with more environmental open space, along with developing better standards for urban parks and pocket parks, are priority issues. Providing incentives for more options of unit types in several of the DR zones could provide more options to cluster development and preserve open space. Developers also find that addressing impervious cover in site planning is difficult to do without baselines or targets that can help to guide the design process. Establishing some goals, either by zone or subwatershed, would provide a basis for design and other decision-making.

PRINCIPLE L2. REDUCE SETBACKS

Relax setbacks to reduce driveway length and overall site imperviousness. Utilize this practice in combination with a narrower street width, to provide more flexibility in the right-of-way for viable tree plantings.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

Outside the URDL (rural areas):

- Revert to 50' front setbacks in the rural areas, reserving the 100' to 150' front setback requirements for specifically designated scenic roads.
- Better define scenic vistas and provide more flexibility in the site plan review process to establish appropriate setbacks.



Source: Baltimore County Office of Planning

Development with shortened front setbacks

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Inside the URDL:
In order to provide more width for tree planting within the Neighborhood Street and Neighborhood Collector right-of-way (ROW), locate the sidewalk within the ROW to abut the outside edge of the ROW (closest to the house), and locate the 2' Public Utilities Easement (PUE) outside of the ROW, inside the lot line.

Rationale

In rural areas of the County, very wide setbacks result in long driveways that add impervious cover to lots, and result in the need for donut turnarounds on private driveways in order to allow emergency fire and rescue vehicles to avoid backing long distances. Narrower front setbacks will provide more flexibility in lot layout, provide opportunities to preserve more unfragmented open space, and reduce impervious cover.

In urban areas of the county, the DR zones provide a good level of flexibility in establishing setbacks. The need is for more space within the ROW to provide for viable tree plantings. The recommended ROW configuration that locates the 2' PUE outside of the ROW is actually the standard in the Comprehensive Manual of Development Policies (CMDP); however, it is not always done this way in practice – placing the PUE within the ROW puts too much constraint on tree planting areas.

PRINCIPLE L3. MORE FLEXIBLE SIDEWALK STANDARDS

Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- This principle applies only applies inside the URDL.
- Revise the CMDP and public works standards to create performance standards that identify types of development where single-sided sidewalks will be allowed without a variance.

Rationale

Providing sidewalks on only one side of the street is considered a viable way of reducing impervious cover, however, this needs to be balanced with pedestrian safety and pedestrian movement concerns, particularly in higher density areas and around transit. Clear standards should be developed that reduce the need to request a variance in all instances to do single-sided sidewalks.

PRINCIPLE L4. DRIVEWAY ALTERNATIVES

Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

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Outside the URDL (rural areas):

- Reduce front setbacks as recommended under Principle L2, and eliminate use of donut turnarounds on private driveways.

Inside the URDL:

- In the urban areas, in certain circumstances, allow paved on-street parking to count for some or all of the required on-site parking spaces, thereby allowing a reduction in the parking pad width.
- Develop policies and regulations to better address shared driveways, particularly for minor subdivisions.



Source: Baltimore County Office of Planning

Example of a shared driveway

Rationale

In rural areas, the front setback typically determines driveway length. The very wide setbacks currently required in many rural zones contribute to increased impervious cover. The expansion of driveways in urban areas is deemed to be problematic but difficult to control. The use of shared driveways, particularly in an infill setting, needs to be carefully addressed, because it involves two-fold issues: shared driveways are desirable for reducing impervious cover, but their inappropriate use may result in providing access to otherwise unbuildable lots, thereby increasing overall neighborhood impervious cover.

PRINCIPLE L5. ADDRESS IMPERVIOUS COVER CREEP

Establish impervious cover performance goals to provide a baseline and allow the development of meaningful design guidelines.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Address impervious cover creep from driveway expansions, new auxiliary structures, modified ingress and egress points, etc., by ensuring appropriate measures are taken to provide adequate public facilities and meet applicable stormwater management requirements.
- Form a technical advisory committee, including all stakeholders, to consider impervious cover caps/limits for each zoning category[3].
- Intersect this effort with the small watershed action plan process.

Rationale

Impervious cover creep commonly occurs in older existing neighborhoods where homeowners are looking to make improvements to their lots. Individually, the modifications are often small and do not require permits or thorough reviews from the County. Cumulatively, these changes can have a negative impact on existing conditions because inadequate infrastructure exists to reasonably accommodate the modifications.

[3] Technical advisory committee should reflect the diversity of interests represented in the Roundtable membership.

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PRINCIPLE L6. LONG-TERM MANAGEMENT OF OPEN SPACE

Clearly specify how community open space will be managed and designate a sustainable legal entity or other designated party responsible for managing both natural and recreational open space.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Provide assistance to developers and/or real estate agents to develop and transfer information to homebuyers and homeowners' associations concerning maintenance of on-site water quality practices, the purpose of stormwater management facilities, proper management of conservation areas, etc.
- Work creatively with existing communities to identify and monument existing stream buffer and forest conservation areas.

Rationale

The majority of concerns over open space management in subdivisions revolve around managing encroachment into conservation areas in existing neighborhoods, particularly in the DR zones, and in RC-5. Better tools for educating residents are needed along with better ways of identifying the most severe encroachments that should be addressed on a prioritized basis.

PRINCIPLE L7. EFFICIENT USE OF IMPERVIOUS COVER

Sites should be designed to utilize impervious cover efficiently and to minimize stormwater runoff. Where possible impervious cover should be reduced in accordance with State of Maryland redevelopment stormwater requirements, i.e. a 20% reduction in impervious cover. In situations where impervious cover stays the same or increases, sites should be designed to improve the quality of stormwater runoff at the site in accordance with State redevelopment requirements, at a minimum.

Recommendation

The Roundtable supports this principle and makes the following recommendation:

- As an incentive, allow clustering and additional unit types in DR 1, 2, and 3.5 zones where it is shown to result in reduced impervious cover.

Rationale

This recommendation effectively reinforces existing state stormwater requirements for redevelopment sites. The County currently follows these state regulations.

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PRINCIPLE L8. BETTER SITE DESIGN TECHNIQUES FOR INFILL AND REDEVELOPMENT

Utilize a combination of Better Site Design techniques with redevelopment and infill projects to minimize stormwater runoff and maximize vegetated areas.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Define infill development in a manner that will help differentiate it from new development so that stormwater management and related site design features are treated in a uniform and consistent manner.
- Examine four case studies to determine how existing Better Site Design practices for infill and redevelopment, such as redevelopment stormwater requirements, parking lot and perimeter landscaping, the provision of open space, etc., are done in practice.



Source: Baltimore County Office of Planning

Infill residential development

Rationale

The County has a number of Better Site Design requirements for infill and redevelopment; however, there is concern that what is on paper looks better than what really occurs in practice. A detailed comparison of "paper" versus "practice" will allow the County to determine where to focus Better Site Design improvements.

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Natural Areas Recommendations

PRINCIPLE N1. STREAM BUFFER SYSTEMS

Create a variable width, naturally vegetated buffer system along all perennial/intermittent streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands on all development sites outside of the Chesapeake Bay Critical Area. Minor subdivisions, lot line adjustments, building permits, and similar limited exemptions on agricultural land are excluded from this buffer system requirement, except for non-agricultural lots resulting from agricultural minor subdivisions.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Baltimore County should continue to require the establishment of a science-based variable width buffer that protects water quality; streams; wetlands; water bodies; steep slopes; erodible soils; riverine floodplains; and significant fish, plant and wildlife habitats. However, the current requirements should be modified as follows:
  - A. The steep slope and erodible soils evaluation regulations should be updated to include current scientific literature, and additional diagrams and figures for clarification purposes.
  - B. A definition for "adjacent" wetlands and wetland regulatory authority should be added to the Forest Buffer and Critical Area laws for clarification purposes.
  - C. The process and requirements for the establishment of, and reductions to, the 300-foot buffer adjacent to streams, tidal wetlands and tidal waters in certain portions of the Critical Area should be updated for clarification purposes. These updates should take into consideration:
    1. Goals of the State-mandated Critical Area law
    2. Goals of both Baltimore County and the Critical Area Commission to protect existing riparian forests
    3. Existing land uses within the buffer at the time of development
    4. Adequacy of mitigative measures proposed by an applicant to offset impacts to water quality, forests, and significant fish, plant and wildlife habitats
    5. Provision of clear and consistent definitions for terms
  - D. In order to streamline the review process and to enhance water quality functions of disturbed buffers, a provision should be added to the steep slope and erodible soils evaluation regulations to require an applicant to establish "good" vegetative cover in buffers where "poor" or "moderate" cover exists (these terms are to be defined through a collaborative process). Evaluation approval is conditional based on one of the following scenarios:
    1. The applicant must establish "good" vegetative cover in predetermined areas of the buffer prior to grading/sediment control plan approval by the Baltimore County Department of Environmental Protection and Resource Management (DEPRM). A planting plan for the buffer areas must be approved by DEPRM prior to planting. This scenario would not require posting of a security or installation of additional sediment control measures within the Limit of Disturbance for the project; OR
    2. The applicant must establish "good" vegetative cover in predetermined areas of the buffer within one year of grading permit or building permit issuance by the County, as determined by the Environmental Impact Review Section of DEPRM. This scenario would require posting of a security via an Environmental Agreement with DEPRM. The security would be released once "good" vegetative cover has been established. This scenario would also require installation of additional sediment control measures, as prescribed by DEPRM, within the Limit of Disturbance for the project to alleviate the potential for sediment runoff into a stream or other resource areas during construction; OR

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3. The applicant must phase grading and building to avoid disturbance in areas of the development site that drain to buffers proposed to be established in "good" vegetative cover. Under this scenario, DEPRM would "hold" grading or building permits for certain areas of a site until "good" cover has been established. A planting plan for the buffer areas must be approved by DEPRM prior to planting. DEPRM would reserve the right to set planting timeframes, and prescribe installation of additional sediment control measures within the Limit of Disturbance to alleviate the potential for sediment runoff into a stream or other resource areas during construction.

- There are extensive geographic areas of Baltimore County where protection of productive agricultural land is essential to maintaining the overall long-term viability of farming in the County. However, on proposed development sites in these areas, the full application of laws pertaining to protection of forests and stream buffers may potentially result in loss of productive agricultural land. DEPRM should reevaluate existing forest conservation and forest buffer regulations and procedures to ensure that they include provisions for continued farming on properties with productive agricultural lands, while ensuring adequate protection of priority forests and water quality and implementation of best management practices.
- DEPRM should update the regulations entitled "environmental guidelines for agricultural minor subdivisions" to address the item above.

Rationale

Vegetated systems along shorelines, wetlands and streams can protect water quality, reduce flooding impacts, provide wildlife habitat, serve as a recreational resource and offer many economic benefits to the local community. Baltimore County has had buffer requirements for a number of years, with a minimum width of 75 feet or greater that is adjusted to include contiguous, sensitive areas, such as steep slopes or erodible soils. Current County buffer requirements can be improved through adjustments to the existing policies to account for changes in knowledge and procedures. The County can also implement policies and regulations that resolve potential conflicts between the goals of preserving agriculture and protecting environmental resources.



Overly manicured stream buffer

PRINCIPLE N2. BUFFER MANAGEMENT

The riparian stream buffer should be preserved and managed to encourage native vegetation that can be maintained throughout the plan review, delineation, construction, and occupancy stages of development.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The following standard note should be added to right-of-way plats for minor subdivisions, and other development plans where recordation is required and record plats are not required, to provide for conveyance of environmental easements to Baltimore County by successive property owners:

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"Highways and highway widenings, slope easements, drainage and utility easements, access easements, forest buffer areas in fee or easement, forest conservation areas in fee or easement, Critical Area protected areas in fee or easement, and stormwater management areas, no matter how entitled, shown hereon are reserved unto the owner and except for those indicated as private are hereby offered for dedication to Baltimore County, Maryland. The owner, his personal representatives and assigns will convey said areas by deed to Baltimore County, Maryland at no cost. Until such time as said conveyance is accepted by Baltimore County, the owner authorizes Baltimore County, its agents and assigns the right to enter upon the property for the purpose of installing, constructing, maintaining and repairing roads, utility lines and facilities and stormwater ponds and facilities."

- DEPRM should prepare colorful "fact sheets" to educate homeowners about the values of natural resources within environmental easements, and about protective covenants governing allowable uses within the easements.
- DEPRM should determine a legal mechanism for requiring a seller to notify prospective buyers about the presence of environmental easements and associated declarations of protective covenants.
- DEPRM should prepare procedures for allowing property owners to control invasive plant species within environmental easements. These procedures should encourage planting of these areas with native woody and herbaceous species.
- Surveyed limits of environmental easements near or on lots, or in other areas of potential human impact, should be clearly marked in the field at predetermined intervals with a permanent below-grade marker to facilitate identification of easement limits by both homeowners and County staff. Easement "Do Not Disturb" signs should be installed as "witness" posts near each permanent below grade marker location. Additionally, the locations of the permanent below-grade markers, and the outer easement limits, should be submitted digitally to DEPRM in a format that could be incorporated into a GIS layer for future County use.
- Baltimore County should pursue the adoption of environmental enforcement laws, regulations and procedures similar to those currently contained in Article 3, Title 6 of the Baltimore County Code that are implemented by the Department of Permits and Development Management.
- DEPRM should promulgate regulations and procedures regarding in-kind and out-of-kind mitigation standards for forest buffers, Critical Area buffers and wetlands.
- A provision should be added to the Forest Buffer law to allow a development project applicant to pay a fee to the County in-lieu of performing mitigation, when onsite and offsite mitigation opportunities are unavailable. However, an applicant should not be allowed to pay a fee-in-lieu of mitigation to avoid mitigation requirements or to justify impacts to the Forest Buffer or resources contained therein.

Rationale

Buffer requirements should be more than a line drawn on a map, which is virtually invisible to contractors and landowners. The key to effective preservation and management is development and active enforcement of a strong buffer ordinance that outlines the legal rights and responsibilities for the long-term management of the buffer. Education of land owners is vital to preventing encroachment within the buffer, as well as real penalties for violation of buffer requirements to emphasize the importance of maintaining buffer integrity.

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PRINCIPLE N3. CLEARING AND GRADING

Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to accommodate improvements, allow access and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.

Recommendation

The Roundtable supports this principle with no further recommendations.

Rationale

Conservation of natural areas within a site can reduce erosion and sediment and clearing and grading costs while maintaining natural features of the site. Common tools to limit clearing are: erosion and sediment control ordinances, grading ordinances, forest conservation or tree protection ordinances, and open space development.



New construction

PRINCIPLE N4. TREE CONSERVATION

Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Where appropriate, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote low maintenance or sustainable, native, and naturalized vegetation.

The Roundtable supports this principle and makes the following recommendations:

- Large contiguous conservation easements have been demonstrated to provide better habitat and water quality functions than small isolated easements. Therefore, in order to ensure the long-term viability of natural resources within Baltimore County, and to minimize fragmentation of these resources, existing environmental laws and regulations should be modified to encourage consolidation of environmental easements on development sites. Baltimore County should explore ways to achieve this goal without impacting site density.
- Implementation projects that involve vegetation planting should adopt the definitions and guidance being created by the Baltimore County Advisory Commission on Environmental Quality (CEQ) with regards to the use of the following terms: Native plants, Invasive plants, Naturalized plants, Natural vegetation, Conservation Landscaping.
- Baltimore County should adopt the coordinated, multi-departmental plan being developed by the CEQ for implementing conservation landscaping (i.e., "bayscaping") practices on property owned or maintained by the County.
- County planting guidance should denote vegetation that is resistant to browsing by wildlife in some way (e.g., with an asterisk).

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Rationale

Native trees, shrubs, and grasses are important contributors to the overall quality and viability of the environment. In addition, they can provide noticeable economic benefits to developers and homeowners. Baltimore County has several initiatives and regulations that demonstrate their continuing long-term commitment to tree conservation, and should continue to pursue policies that increase natural areas in the County.

PRINCIPLE N5. LAND CONSERVATION INCENTIVES

Incentives and flexibility in the form of density compensation, property tax reduction, stormwater credits, and by-right cluster development should be encouraged to promote the conservation of stream buffers, forests, meadows, rare species or unique habitat, and other areas of environmental value. In addition, off-site mitigation consistent with locally adopted watershed plans should be encouraged.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- DEPRM should incorporate forest retention, forest planting, and wetland mitigation "banks" into existing regulatory programs to encourage long-term protection and establishment of large contiguous forests and wetlands in stream buffers and other sensitive environmental areas.
- Baltimore County should encourage redevelopment of commercial and industrial waterfront sites containing historically impacted buffers by incorporating redevelopment measures for these areas into the County's Chesapeake Bay Critical Area Buffer Management Plan. These measures should ensure water quality protection.
- Baltimore County should waive Forest Conservation requirements under certain circumstances to encourage redevelopment of properties containing a predominance of impervious surfaces.

Rationale

Conservation and protection measures that require excessive administrative requirements, such as lengthy plan reviews, additional upfront costs to developers and unclear appeal procedures can create a major barrier to implementation. Incentives and flexibility are an effective way to promote adoption of conservation and protection measures.

PRINCIPLE N6. PRESERVE NATURAL AREAS, REVEGETATE

Plan and design sites to preserve naturally vegetated areas and to encourage revegetation, soil restoration and the utilization of CEQ recommended conservation landscaping vegetation where feasible.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

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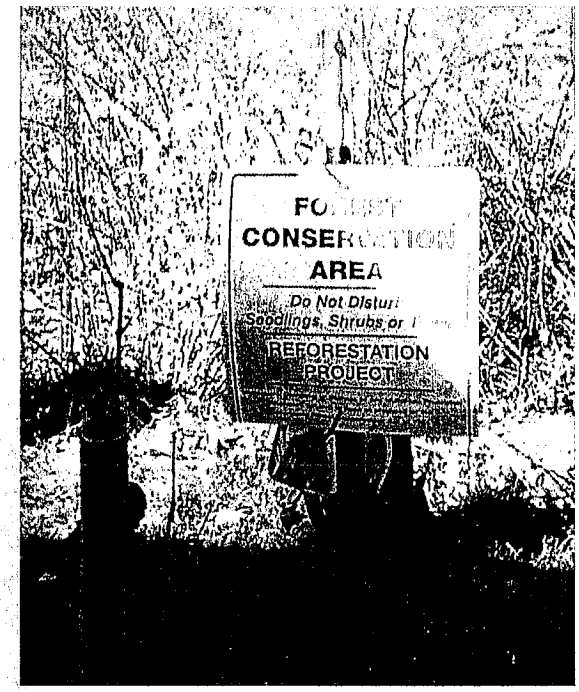
- Baltimore County should promote conservation landscaping throughout the County by:
  1. Updating existing development-related regulations and manuals, as necessary, to include conservation landscaping provisions.
  2. Encouraging public participation in conservation landscaping efforts.
  3. Educating the public about the benefits of conservation landscaping.
  4. Promoting existing County programs that involve conservation landscaping practices.
- County planting guidance should denote vegetation that is resistant to browsing by wildlife in some way (e.g., with an asterisk).
- The County should look for opportunities to promote conservation landscaping guidance in state and private party landscaping lists.



Reforestation area

Rationale

The urban environment often contains remnants of what were once large tracts of natural areas, which may be good candidates for restoration. The potential benefits of natural areas restoration and preservation can be aesthetic, environmental and economic. Designed properly, benefits can include increased land values, reduced small drainage complaints, creation of habitat for urban wildlife, better stormwater management, reduced air conditioning costs, lower ambient temperature, reduced incidents of violence in public housing, and provision of passive recreational space.

PRINCIPLE N7. LONG-TERM MAINTENANCE OF VEGETATED AREAS

Establish mechanisms to guarantee long term management and maintenance of all vegetated areas.

Recommendation

The Roundtable supports this principle with no recommendations.

Rationale

The benefits of continuing maintenance of vegetated areas are abundant. For the local community, benefits include increased property values for land adjacent to vegetated spaces, and community participation and buy-in for further redevelopment due to increased private investment. Guaranteed long-term management and maintenance of vegetated areas can also ensure continuous enjoyment and function of the area as planned. Responsible land owner upkeep through innovative partnerships, conservation easements, or donations to land trusts can help ensure that vegetated areas on urban lands are actively maintained.

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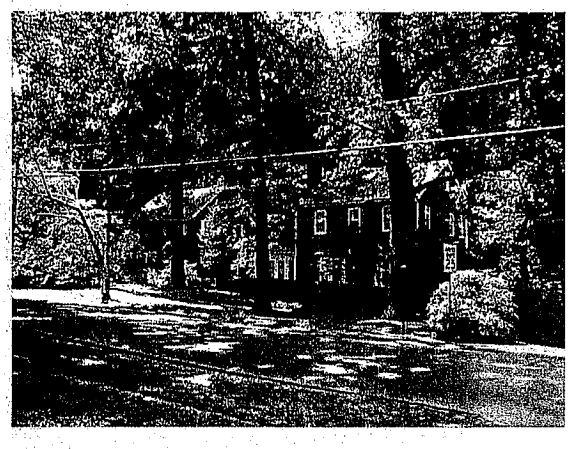
PRINCIPLE N8. INCREASE TREE CANOPY

Assess the physical condition and health of urban tree cover and take appropriate action to increase canopy coverage and vitality.

Recommendation

The Roundtable supports this principle with the following recommendation:

- Baltimore County should explore options and funding opportunities for increasing urban tree canopy cover in the county, including street tree planting in existing neighborhoods.



Source: Baltimore County Office of Planning

Good tree canopy in existing neighborhoods

Rationale

Today there is greater recognition of the value of urban trees and forests and their benefits to air and water quality, reduction of storm water runoff, energy conservation, and public health. The loss of trees and forests in developing watersheds and the deterioration of urban tree canopy in inner cities through removal or lack of replacement has become a major concern. Baltimore County has begun to address this concern through its Green Renaissance Initiatives and programs such as Growing Home Campaign and Neighborspace of Baltimore County. Continued emphasis should be placed on programs that evaluate the health and economic vigor of the county's urban tree resources and support efforts to increase tree coverage and health.

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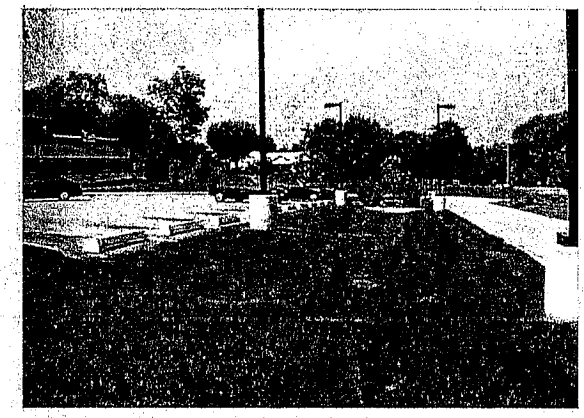
Stormwater Management Recommendations

PRINCIPLE SW1. VEGETATED OPEN CHANNELS

Where density, topography, soils, and slope permit, vegetated open channels should be used in, or adjacent to, the street right-of-way to convey and treat stormwater runoff. In particular, open section roads should be encouraged in non-residential areas such as industrial/business parks, boulevards, and other collector roads where appropriate site conditions exist.

Recommendation

The Roundtable supports this principle and makes the following recommendations:



Vegetated open channel

- More flexibility in design criteria to accommodate use of open section roads. Specifically, modifying language associated with the Environmentally Sensitive Design stormwater credit as presented in the Maryland Stormwater Design Manual (MDE, 2000). Replace the bullet discussing average lot size with a bullet that says the credit can apply to development projects using clustering techniques in the RC zone criteria. Also replace the bullet discussing grass channels with the following language: the use of open section roads with slopes up to 6% and designed so as to be non-erosive in the 10-year storm in accordance with Appendix D.12 criteria in the Maryland Stormwater Design Manual.
- The grass channel credit in the Maryland Stormwater Design Manual should be revised to allow steeper slopes and greater velocities, but with a smaller credit. Specifically, the recommended modification is to give 50% of the water quality credit for channels in excess of 4% but up to 6% slope and to allow maximum flow velocity for runoff from the 1-inch rainfall to be less than or equal to 2 feet per second.

Rationale

Streets contribute higher loads of pollutants to urban stormwater than any other source area in residential developments. The use of vegetated open channels to convey stormwater runoff can remove some of these pollutants and decrease the volume of stormwater generated from a site.

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PRINCIPLE SW2. PARKING LOT RUNOFF

Encourage use of parking lot landscaped areas as stormwater receiving areas (i.e., depression islands in parking lots for stormwater management that act as bioretention areas). Perimeter landscape areas of parking lots should also be encouraged to receive stormwater where possible.

RECOMMENDATION

The Roundtable supports this principle and makes the following recommendations:

- The County Landscape Manual guidance should be modified so that landscape islands are not required to be mounded or curbed. Stormwater regulations should also be modified to allow bioretention in parking areas with adjusted criteria for side slopes (maximum allowed of 2H:1V) and no fencing requirement. Adequate provisions and guidelines need to be provided to ensure that the interface between pavement and vegetated area is protected from impacts such as vehicle encroachment and snow plows. Potential design options include use of curb cuts, curb stops, and bollards.



Source: Ray Bahr

Recently planted raingarden treating residential rooftop runoff

- Issue impervious cover reduction credits for alternative pavers (e.g., interlocking grid pavers, porous asphalt and concrete, and other similar surfaces) for light use parking areas such as churches and overflow parking areas associated with retail, commercial and institutional land uses.

RATIONALE

Parking lots generate high volumes of stormwater runoff, and high levels of runoff contamination from pollutants deposited on the lot surface. Additionally, internal landscaping requirements already exist. Therefore, there is an opportunity to achieve two site objectives/requirements within a single location of a parking lot.

PRINCIPLE SW3. ROOFTOP RUNOFF

Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and/or use rain barrels, cisterns, or greenroofs. Avoid routing rooftop runoff directly to the roadway and hardlined stormwater conveyance system.

RECOMMENDATION

The Roundtable supports this principle with no further recommendations.

RATIONALE

Directing rooftop runoff over a pervious surface before it reaches an impervious surface can decrease annual runoff volume from developed sites and also provide water quality benefits through filtering of runoff.

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PRINCIPLE SW4. STORMWATER MANAGEMENT FOR INFILL PROJECTS

Develop stormwater criteria and standards that are applied in a uniform and consistent manner for infill development.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- For sites defined as infill development, water quality and recharge requirements should be fulfilled on site, but fee-in-lieu for water quantity (i.e., channel protection and larger storms) is an acceptable alternative, provided that the downstream watershed can handle the resulting flows and volumes (i.e., the infill project doesn't flood or cause undue harm to downstream neighbors for specified design storms). The burden of demonstrating no undue harm on downstream property is that of the applicant.

Rationale

There is a perception that variances or waivers are arbitrarily granted by County reviewers for certain stormwater criteria in what are considered to be infill development cases. Defining infill development in a manner that will help differentiate it from new development will reduce the occurrence of variances associated with infill projects and should reduce the administrative burden on County reviewers while at the same time satisfying the public that infill development is being treated in a uniform and consistent manner from a stormwater perspective.

PRINCIPLE SW5. WATERSHED-BASED STORMWATER CRITERIA

Establish watershed overlay districts or Small Watershed Action Plans (SWAPs) for targeted County water resource areas such as drinking water supplies, watersheds with known flooding issues, cold water fisheries, Tier II waters, and Total Maximum Daily Load (TMDL) waters. At a minimum, these overlay districts or SWAPs should be identified in County stormwater regulations and regional planning documents. Special stormwater management provisions should be developed for each overlay district, which will apply to both new development and redevelopment. The provisions should specifically address the targeted watershed issue.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The County should pursue a process whereby it initiates dialogue between Baltimore County Department of Environmental Protection and Resource Management (DEPRM), Maryland Department of Natural Resources, and Maryland Department of the Environment to identify specific subwatershed areas where modified stormwater management requirements are put in place based on known biological conditions and associated watershed data primarily related to presence or absence of cold water fisheries.
- The County should convene a technical advisory team comprised of different stakeholder groups to develop appropriate stormwater provisions in priority overlay areas[4]. Where feasible, a regional approach that extends to adjacent counties and shared watersheds should be pursued.

[4] Technical advisory team should reflect the diversity of interests represented in the Roundtable membership.

A007508

Rationale

Special stormwater and water quality criteria developed using a watershed overlay approach provide flexibility to specifically address targeted watershed issues. Considering stormwater management with a watershed perspective in addition to a site perspective can provide better receiving water protection and be more cost effective.

PRINCIPLE SW6. STORMWATER MANAGEMENT FOR OPEN SPACE DESIGN

Open space regulations should contain the flexibility necessary to incorporate appropriate stormwater management features and limit the total amount of site disturbance.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The Open Space Regulations should be revisited by County staff and revised to remove inflexible barriers to Better Site Design and associated stormwater management inside the urban/rural demarcation line (URDL).
- The intent of open space requirements should not be compromised in order to accommodate a stormwater best management practice (BMP). Rather, this recommendation is looking for opportunities to incorporate stormwater BMPs within or adjacent to open space areas in ways that improve the overall aesthetics and use of the open space while at the same time minimizing site environmental impacts.

Rationale

Existing open space regulations contain multiple constraints that are counter productive to environmentally-sensitive site design, particularly with respect to meeting stormwater management requirements.

PRINCIPLE SW7. STORMWATER INFRASTRUCTURE MAINTENANCE

A dedicated and reliable funding source is necessary to properly and effectively keep up with long-term maintenance requirements of the County's stormwater infrastructure (conveyance and BMPs).

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The County should establish a technical advisory team to investigate stormwater utility fees and other options (which may include future homeowners' association (HOA) agreements) for long-term maintenance of facilities[5].
- The County should encourage but not require HOAs and other willing community groups to do routine maintenance (mowing, fence maintenance, trash pick up) of stormwater facilities. Appropriate education and training on how to conduct the routine maintenance activities should also be provided by the County.

[5] Technical advisory team should reflect the diversity of interests represented in the Roundtable membership.

A007509

RATIONALE

A dedicated source of funding is needed to keep up with increasing amount of infrastructure as well as increasing maintenance burden due to infrastructure aging.

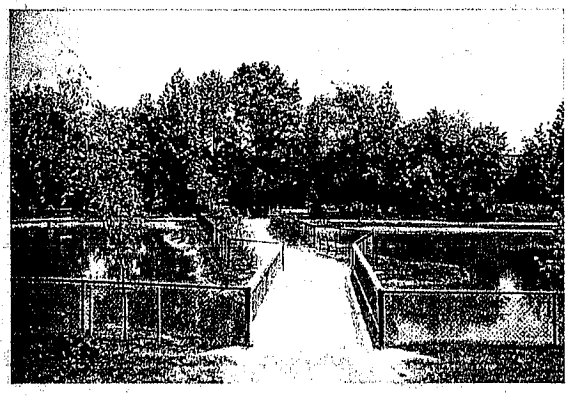
PRINCIPLE SW8. FEE-IN-LIEU FOR REDEVELOPMENT

DEPRM should regularly assess and adjust as necessary the fee-in-lieu rate schedules to fairly and accurately reflect the actual cost of designing, constructing and maintaining a stormwater practice that would be required at a site requesting the fee-in-lieu option.

RECOMMENDATION

The Roundtable supports this principle and makes the following recommendations:

- Applicants must demonstrate that on-site treatment is not possible before requesting the fee-in-lieu option.
- When fee-in-lieu is approved and received, funds will be applied (as a first priority when feasible) toward projects within the same community or watershed that the proposed development site is located in.
- DEPRM should continue to consider and approve alternative treatment technologies that have demonstrated capabilities to meet certain stormwater criteria. In addition, DEPRM should make efforts to inform applicants about these technologies. Examples include, but are not limited to, greenroofs, cisterns, stormwater planters and porous pavement.



Source: Morris & Ritchie Associates, Inc.

Stormwater pond retrofit in a redevelopment setting

RATIONALE

The current fee-in-lieu payment structure is inadequate with respect to being representative of the true cost of construction and long-term maintenance of new BMPs that are installed. A reasonable increase to the fee-in-lieu cost structure would be fair and would provide adequate and needed funds for "equivalent" implementation and maintenance of stormwater management facilities, retrofits, and other regional BMP projects. The current costs incurred under fee-in-lieu may also be stifling innovative practices.

[6] Technical advisory team should reflect the diversity of interests represented in the Roundtable membership.

A007510

PRINCIPLE SW9. POLLUTION PREVENTION

Utilize proper storage, handling and site design techniques to avoid the contact of pollutants with stormwater runoff.

Recommendation

The Roundtable supports this principle and makes the following recommendation:

- A technical advisory team should be formed to develop specific pollution prevention measures and criteria and associated stormwater credits for redevelopment sites[6]. These measures and credits may also apply to new development located in special watershed overlay areas.

Rationale

During the design of redevelopment and infill projects, opportunities exist to reduce and improve water quality by reducing the level of polluted runoff leaving a site. Controlling pollutants at the site (source control) is often the simplest and most cost-effective way to limit stormwater runoff contamination, especially for commercial sites. Source control can be characterized as 1) handling and storage practices and 2) site design practices. Handling and storage practices focus on vehicle and material storage in outdoor areas, while site design practices include improved design of loading docks, coverings for materials stored outdoors, and containment of dumpsters and fueling areas. Other opportunities to reduce pollutants can be found in fleet parking areas, outdoor maintenance areas, and above ground storage tanks.

PRINCIPLE SW10. ROOFTOP RUNOFF FOR INFILL AND REDEVELOPMENT

Manage rooftop runoff through storage, reuse, and/or redirection to pervious surfaces for stormwater management and other environmental benefits.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Encourage the use of greenroofs where feasible as a means to meet the 20% impervious cover reduction target for redevelopment.

Rationale

Directing rooftop runoff over a pervious surface before it reaches an impervious surface can decrease annual runoff volume from developed sites and also provide water quality benefits through filtering of runoff.



Source: Baltimore County Office of Planning

Missed opportunity for treating rooftop runoff

A007511

PRINCIPLE SW11. COURTYARDS AND PLAZAS FOR INFILL AND REDEVELOPMENT

Design courtyards, plazas, and amenity open space areas to store, filter, or treat rainfall.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Site layouts will effectively dictate where and how this dual use approach can be used.

Rationale

Much of the open space in redevelopment and infill projects consists of hard surfaces that generate runoff. With creative site planning and consideration, courtyards, plazas, and open spaces can be designed to store, filter and treat rainfall.

PRINCIPLE SW12. PARKING AND STREETSCAPES FOR INFILL AND REDEVELOPMENT

Parking lots, especially surface lots, should be minimized and designed to reduce, store and treat stormwater runoff. Where site limitations or other considerations prevent full parking lot runoff management, designs should target high use areas first. Then, priority should be placed on using alternative paving materials on low use areas, including parking stalls. Similarly, where possible with redevelopment streetscapes, provide planting spaces that promote the growth of healthy street trees so that they can capture and treat stormwater runoff.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Water quality and/or impervious cover reduction credits should be issued for alternative pavers (e.g., interlocking grid pavers, porous asphalt and concrete, and other similar surfaces) for light use parking areas such as churches and overflow parking areas associated with retail, commercial and institutional land uses.



Source: City of Portland, OR

Street bumpouts both act as a traffic calming measure and provide stormwater treatment

Rationale

Parking lots generate high volumes of stormwater runoff, and high levels of runoff contamination from pollutants deposited on the lot surface. Additionally, internal landscaping requirements already exist. Therefore, there is an opportunity to achieve two site objectives/requirements within a single location of a parking lot. With proper design and consideration, the streetscape (or interface between the street, sidewalk and other structures) of a site plan can also provide opportunities to manage stormwater runoff while providing numerous other environmental and aesthetic benefits.

A007512

Review and Approval Process Recommendations

PRINCIPLE P1. LAND DEVELOPMENT REVIEW PERMITTING SYSTEM UPDATE

Baltimore County should prioritize the funding and implementation of the replacement of the current land development review information permitting system to a Windows-based format accessible to all County agencies and made available on-line.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Aim for a three- to five-year timeline for the process to occur.
- Implementation should address, but not be limited to, personnel training and adequate staffing.

Rationale

Despite the large cost of this conversion, updating the database would vastly improve coordination and communication of the application and permit approval process on a project by project basis both internally and to the general public.



Treed right-of-way in Baltimore County, MD

A007513

PRINCIPLE P2. PERMIT AND DEVELOPMENT MANAGEMENT HEARINGS – GEOGRAPHIC REFERENCE

The Baltimore County Department of Permits and Development Management (PDM) currently publishes a weekly calendar of development related hearings and meetings on its website. The Department of Permits and Development Management should add a geographic reference to these postings such as a tax map reference, address or nearest intersection.

Recommendation

The Roundtable supports this principle with no further recommendations.

Rationale

The geographic reference could better facilitate the communication of development proposals to community associations and other interested parties.

PRINCIPLE P3. MINOR SUBDIVISION OR LIMITED EXEMPTION COMMUNITY NOTIFICATION

An applicant who submits a minor subdivision or limited exemption package should be required to send one copy, with contact information, to the primary community association wherein the property is located or nearest to.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- An up-to-date list of community associations and contacts should be created and maintained by the Department of Planning.
- If multiple community associations exist in the vicinity of the proposed development, the plan will be submitted to the primary community organization. Plans will not be sent out to multiple community associations.
- It is strongly recommended that the applicant offer to meet with the primary community organization prior to the Development Review Committee (DRC) meeting.
- Timeframe: The minor subdivision or limited exemption package should be submitted simultaneously to the County and the community association. The community association submission and optional meeting will not lengthen or change the current limited exemption process timeframe and must occur at the time of the DRC meeting.

A007514

Rationale

Many of the development proposals coming into Baltimore County fall into the Minor Subdivision or Limited Exemption approval processes. Providing the opportunity for community input at an early stage could assist in identifying drainage issues and other similar community concerns that can be addressed in the plan and improve project acceptance.

PRINCIPLE P4. OPTIONAL EARLY ENVIRONMENTAL SUBMITTALS

In the interest of providing adequate review time, all required and complete environmental submittals may be submitted to the Baltimore County Department of Environmental Protection and Resource Management (DEPRM) as early as possible or at least 30 days prior to the filing of the development plan. This early submittal would guarantee that DEPRM have a review of the plan by the development plan conference, but does not necessarily guarantee an approval. The review will be delivered at time of review completion, but no later than the development plan conference. This submittal will not increase or delay the current review process timeline.

Recommendation

The Roundtable supports this principle and makes the following recommendation:

- This recommendation applies to the full development review process and should be implemented as DEPRM policy. Depending on the site, environmental submittals may include:
  - An Alternatives Analysis: to document the need for impacts by roads, utilities and/or grading to the Forest Buffer and/or Forest Conservation Easements
  - A Forest Buffer Variance and/or Special Variance to the Forest Conservation regulations: for impacts by houses, buildings and yard space in the easements
  - Stormwater Management: Hydrology, Outfall Suitability Analysis, and a Breach Analysis
  - Groundwater Management (private wells and/or septic systems) documents: Revised plans - especially if additional perc tests are needed, and a Water Balance Assessment for Commercial Sites
  - Chesapeake Bay Critical Areas Requirements

Rationale

This recommendation would provide DEPRM staff with additional review time to ensure adequate protection of natural resources and appropriate application of stormwater management.

PRINCIPLE P5. INFILL DEFINITION

There are unique issues and characteristics associated with infill development that are beyond the scope of this Roundtable. A separate technical group[7] should be charged with defining and examining infill in the context of:

- Planned open space
- Traffic
- Schools
- Smart Growth
- Environmental constraints
- Infrastructure (roads, drainage, etc.)
- Stormwater
- Economics
- Density
- Neighborhood

[7] Technical advisory group should reflect the diversity of interests represented in the Roundtable membership.

A007515

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- The group studying this issue should be comprised of a diverse group of stakeholders including community associations, local government and the development community.
- This group should also identify the mechanism for implementation.



Source: Baltimore County Office of Planning

Infill development in Baltimore County, MD

Rationale

Currently infill development is reviewed on a case-by-case basis and is not examined at a larger scale to judge potential impacts. Since much of the development occurring within the urban-rural demarcation line (URDL) is infill development, the Process subcommittee recommends that a technical group be set up to proactively look at the impact of developing infill lots.

PRINCIPLE P6. GREEN BUILDING TAX INCENTIVE

The County should work with a diverse group of stakeholders[7] to develop residential and commercial green building incentives. These incentives should be tied to an established certification such as Leadership in Energy and Environmental Design (LEED), Green Globe or other similar established standards.

Recommendation

The Roundtable supports this principle with no further recommendations.

Rationale

Additional incentives should be examined in order to encourage and make innovative development more cost-efficient and appealing.

A007516

PRINCIPLE P7. DEVELOPMENT PROCESS EDUCATION

The Baltimore County Development Review Agencies should reach out to residents beyond Roundtable members to foster better understanding between parties regarding the current development processes and community concerns.

Recommendation

The Roundtable supports this principle and makes the following recommendations:

- Representatives from the development community should also be involved in the education process.
- Educational efforts should be divided based on councilmatic district.
- Education should be tied into existing efforts such as Neighborspace and Green Renaissance Initiatives to maximize exposure and outreach opportunities.

Rationale

The discussions of the Baltimore County Builders for the Bay Roundtable process have resulted in productive and healthy discussions among County staff, community associations and the development community (among others). A continued education process could help expand these discussions beyond the Roundtable process.

A007517

Implementation Overview and Plan

The Roundtable process is a monumental step towards the promotion of environmentally-sensitive development in Baltimore County through code, policy and regulatory updates. The Roundtable itself generated innovative ideas and fostered better communication and relationships amongst the County, community associations, environmental groups and development community. The strength of the Roundtable process lies in the expertise and diversity of the membership who collaboratively crafted the recommendations summarized in this document.

The recommendations must be incorporated and translated into the County's codes, policies and regulations in order for implementation of the Roundtable process to be recognized. One of the desired ends of this process is to have development occur that incorporates the recommendations of the Roundtable.

The table on the following pages was developed to guide the implementation of the Roundtable recommendations. Each recommendation has a designated appropriate action, responsible agency/partner and a general timeframe for completion. In some cases the complexity of the issue warrants an additional committee solely dedicated to examining the issue at hand.

The Baltimore County Builders for the Bay Steering Committee, which consists of Department heads, key development community leaders and community association representatives, will head up the implementation phase of the Roundtable process. The Steering Committee will continue to meet on a bi-monthly basis and provide updates to the Roundtable membership on a quarterly basis. The implementation plan will serve as the guide for their progress.

Utilize the information below in conjunction with the table on the following pages.

Notes:

*Should be a inter-departmental effort that also includes outside stakeholders

Action

C: Code change/modification requires legislation and approval by the County Council

P: Policy change/modification (preferred) applies to any internal policies or guidelines that do not affect the rights or obligations of the public; policy changes do not require a public hearing.

R: Regulation change is a statement of county government that:

(1) Has general application;
(2) Has future effect;
(3) Details or carries out a law that the county government administers; and
(4) Is in any form including:
  i. A requirement;
  ii. A standard;
  iii. A statement of interpretation; or
  iv. A statement of policy

FS: Further Study

E: Education

O: Other

N/A: Not applicable

Acronyms

CEQ: Commission on Environmental Quality

DPW: Department of Public Works

DEPRM: Department of Environmental Protection and Resource Management

HBAM: Home Builders Association of Maryland

LOSM: Local Open Space Manual

PDM: Permits and Development Management

DR: Density Residential zone

SWAP: Small Watershed Action Plans

Timeframe

1: Within the next year

2: Within the next 3 years

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Principle	Recommendation	Action	Responsible Agency/ Support Agency(ies)	Timeframe
Residential Streets, Parking Lots and Infrastructure				
S1. Street Width	Address principle through ongoing rural road standards discussions	P	DPW	1
	Utilize bump-outs	R	DPW	1
	Inclusion of principle	C	DPW*/PDM	1
S2. Street Length	Inclusion of principle	C	DPW	1
S3. Right-of-Way Width	Inclusion of principle	C	DPW/PDM	1
	Address principle through ongoing rural road standards discussions	P	DPW*	1
S4. Cul-de-Sacs	Add design alternatives	C	DPW/PDM	1
S5. Parking Ratios	Annual research	FS/P	Office of Planning	1
	Allow reduced ratios as policy	P	Office of Planning/DPW	1
	Inclusion of principle	C	Office of Planning/DPW	1
S6. Parking Codes	Maintain model agreement	P	PDM	1
	Include mention of model agreement in code	C	PDM	1
S7. Parking Lots	Maintain list of approved pervious parking surfaces	P	PDM/DEPRM	1
	Utilize parking islands	P	Office of Planning	1
	Revise stormwater regulations	R	DPW/DEPRM	1
S8. Structured Parking	Define public benefits and incentives	FS	Office of Planning/ DEPRM*	1
	Study cost effectiveness of structured parking	FS	Office of Planning	2
	Promote greenroofs	P	DEPRM	1
	Inclusion of principle	C	PDM	1
S9. Maximize Transportation Choices	Task force to address regional implications	FS	Office of Planning/ DPW*	1
	Addendum to Master Plan	C	Office of Planning	2
Lot Development				
L1. Open Space Design	Revise LOSM	FS/P	Recreation and Parks/Office of Planning/DEPRM	2
	Allow more unit type options in lower density DR zones	R/P	Office of Planning	1
L2. Reduce Setbacks	Rural: Reduce setbacks to 50' except for scenic roads	C	Office of Planning	2
	Urban: More space for tree planting	P	Office of Planning	1

A007519

Principle	Recommendation	Action	Responsible Agency/ Support Agency(ies)	Timeframe
L3. More Flexible Sidewalk Standards	Promote one-side sidewalks in select types of development	P	Office of Planning/DPW	1
L4. Driveway Alternatives	Eliminate donut turnarounds on private drives in rural areas	P	DEPRM	1
	Allow reduction in parking pad width under certain circumstances	R	DEPRM	1
	Develop better policies and regs for shared parking	R	DEPRM	2
L5. Address Impervious Cover Creep	Address impervious creep by ensuring adequate public facilities exist	R	Office of Planning/ DPW	2
	Set goals by zoning category	FS/R	Office of Planning/ DEPRM	2
	Intersect with SWAP process	O	Office of Planning/ DEPRM	2
L6. Long Term Management of Open Space	Provide assistance to developers to develop educational materials	E	DEPRM/Recreation and Parks	2
	Monument natural areas such as stream buffer and forest conservation areas	P	DEPRM	1
L7. Efficient Use of Impervious Cover	Use clustering as incentive to reduce impervious cover	R/P	Office of Planning	2
L8. Better Site Design Techniques for Infill & Redevelopment	Define infill	FS	Office of Planning*	2
	Case studies	FS	Office of Planning*	2
Natural Areas				
N1. Stream Buffer Systems	Update Steep Slope and Erodible Soil Methodology	R	DEPRM	1
	Create definition for adjacent wetland	C	DEPRM	1
	Clarify application of 300 foot buffer in Critical Area	C/R	DEPRM	1
	Create provisions for good vegetative cover on disturbed buffer	P	DEPRM	2
	Review forest regulations to resolve conflicts with agricultural preservation and update policies	R/P	DEPRM	1
N2. Buffer Management	Minor subdivision plat note	R	DEPRM	1
	Environmental easement education	E	DEPRM	1
	Protective covenant notification	P	DEPRM	1
	Invasive plant control policies for easements	R	DEPRM/CEQ	2
	Permanent marking of easements	C	DEPRM	2
	Adoption of environmental enforcement laws	C/P	DEPRM	1
	Mitigation standards for forest buffer, critical area buffers and wetlands	R/P	DEPRM	2
	Forest buffer fee-in-lieu	C	DEPRM	1

A007526

Principle	Recommendation	Action	Responsible Agency/ Support Agency(ies)	Timeframe
N3. Clearing and Grading	Maintain current practice	N/A	DEPRM	1
N4. Tree Conservation	Encourage consolidation of environmental easements	R	DEPRM	1
	Adopt conservation landscaping definitions developed by CEQ	O	DEPRM/CEQ	1
	Adopt CEQ plan for conservation landscaping	O	DEPRM/CEQ	1
	Guidance on browse resistant planting	P/E	DEPRM	1
N5. Land Conservation Incentives	Incorporate forest retention, forest planting, and wetland mitigation "banks" into existing regulatory programs	C	DEPRM	1
	Incorporate redevelopment measures for historically impacted buffers into the County's Chesapeake Bay Critical Area Buffer Management Plan	C/R	DEPRM	2
	Waive Forest Conservation requirements under certain circumstances to encourage redevelopment of properties	R	DEPRM	2
N6. Preserve Natural Areas, Revegetate	Promote conservation landscaping to public	P/E	DEPRM	1
	Encourage conservation landscaping in State and private plant list	P/E	DEPRM	1
N7. Long-Term Maintenance of Vegetated Areas	Maintain current practice	N/A	DEPRM	1
N8. Increase Tree Canopy	Explore options and funding opportunities for increasing urban tree canopy cover in the county	O	DEPRM	1
Stormwater Management				
SW1. Vegetated Open Channels	Flexible design criteria to promote open section roads and use credits more widely	R	DEPRM	1
SW2. Parking Lot Runoff	Revise County Landscape Manual	R	PDM/DEPRM	1
SW3. Rooftop Runoff	Direct rooftop runoff to pervious areas rainbarrels, cisterns or greenroof	E	DEPRM	1
SW4. Stormwater Management for Infill Projects	Develop stormwater criteria for infill development	FS	Office of Planning/ DEPRM*	2
SW5. Watershed-Based Stormwater Criteria	Meet with MDE to develop revised stormwater criteria for certain watersheds	FS/R	DEPRM	2
	Develop watershed based stormwater criteria to reflect receiving water goals	FS/R	DEPRM*	2

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Principle	Recommendation	Action	Responsible Agency/ Support Agency(ies)	Timeframe
SW6. Stormwater Management for Open Space Design	Revise LOSM	FS/R	Recreation and Parks/ DEPRM*	2
SW7. Stormwater Infrastructure Maintenance	Establish a technical group to assess feasibility of stormwater utility	FS	DEPRM/DPW*	2
	Educate HOAs and others on routine BMP maintenance	E	DEPRM	1
SW8. Fee-In-Lieu for Redevelopment	Grant fee-in-lieu only as last option and review and approve new practices that are appropriate for redevelopment	P/E	DEPRM	1
SW9. Pollution Prevention	Establish nonstructural criteria that can be used as credits to apply towards stormwater criteria	FS	DEPRM*	3
SW10. Rooftop Runoff for Infill and Redevelopment	Encourage use of greenroofs in redevelopment situations	P	DEPRM	1
SW11. Courtyards and Plazas for Infill & Redevelopment	Site layouts will dictate where this can be used	E	DEPRM/Office of Planning	1
SW12. Parking and Streetscapes for Infill & Redevelopment	Develop impervious cover reduction credits for alternative paver use in certain areas	R	DEPRM/Office of Planning/ PDM	1
Review and Approval Process				
P1. Land Development Review Permitting System Update	Replace current permitting system to Windows-based format	O	PDM	2
	Address adequate staffing and training as related to permitting system	O	PDM	2
P2. PDM Hearings - Geographic Reference	Add geographic reference to development related hearings calendar	O	PDM	1
P3. Minor Subdivision or Limited Exemption Community Notification	Require that a copy of minor subdivision or Limited Exemption package be sent to primary community association	P	PDM	1
	Update and maintain list of primary community associations	O	Office of Planning	1
P4. Optional Early Environmental Submittals	Accept early and complete environmental submittals	P	DEPRM*	1
P5. Infill Definition	Define and examine infill	FS	Office of Planning*	2
P6. Green Building Tax Incentive	Develop residential and commercial building incentives	FS/R	CEQ	1
P7. Development Process Education	Foster better understanding between parties re: the current development processes and community.	E	DEPRM*	1

Note:
* Should be an inter-departmental effort that also includes outside stakeholders

Builders for the Bay

In December 2001, the Alliance for the Chesapeake Bay, the Center for Watershed Protection, and the National Association of Homebuilders launched a partnership known as Builders for the Bay. The primary mission of the Builders for the Bay coalition is to coalesce local builders, developers, environmental groups, local governments, and other important stakeholders in a process to review their existing codes and ordinances and begin a locality specific roundtable process. More information and resources related to the Builders for the Bay program can be accessed at www.buildersforthebay.net.

Center for Watershed Protection

Founded in 1992, the Center for Watershed Protection (CWP) is a non-profit organization that works with local, state, and federal governmental agencies, environmental consulting firms, watershed organizations, and the general public to provide objective and scientifically sound information on effective techniques to protect and restore urban watersheds. The Center for Watershed Protection also acts as a technical resource for local and state governments around the country to develop more effective urban stormwater and watershed protection programs. For more information on CWP, visit www.cwp.org.

Alliance for the Chesapeake Bay

The Alliance for the Chesapeake Bay (ACB) is the only organization in the Chesapeake region dedicated to restoring the Bay watershed exclusively through collaboration and consensus-building. ACB has a successful track record in building consensus on Bay policies, engaging volunteers in important hands-on restoration, educating citizens about the watershed, and strengthening the capacity of grassroots watershed organizations. Known as "The Voice of the Bay" for its unbiased information on Bay issues, ACB has worked to protect and restore the Bay watershed since 1971. Visit ACB at www.alliancechesbay.org.

Home Builders Association of Maryland

Since 1919 the Home Builders Association of Maryland (HBAM) has been the voice of the Housing Industry in central Maryland. HBAM, through its affiliate, the National Association of Home Builders, was an originator of the Builders for the Bay Roundtable process and also sponsored the Harford County, MD Roundtable. HBAM is a leader in research and development of innovative land use policy and planning techniques to prepare for the household and employment growth expected over the next 20 years in Maryland. Visit HBAM at www.homebuilders.org.

Baltimore County

Baltimore County is known nationally and internationally for innovative resource management approaches, programs and development practices. The County has a long standing tradition of developing and implementing a variety of programs to ensure the long-term quality of life for its residents and visitors. The Builders for the Bay Roundtable process has offered the County an opportunity to partner with a variety of interest groups to evaluate the effectiveness of resource and development programs and create new management tools for the future. Baltimore County is committed to continue to work with the Roundtable partners as we identify and implement new approaches to restoring and protecting our natural resources and our communities. Visit Baltimore County at www.baltimorecounty.gov.

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List of Acronyms and Abbreviations

ACB: Alliance for the Chesapeake Bay
BMP: Best Management Practice
C: Code change/modification
CEQ: Baltimore County Commission on Environmental Quality
CMDP: Comprehensive Manual of Development Policies
COW: Codes and Ordinances Worksheet
CWP: Center for Watershed Protection
DEPRM: Baltimore County Department of Environmental Protection and Resource Mgt.
DPW: Baltimore County Department of Public Works
DPW: Baltimore County Department of Public Works
DR: Density Residential zone
DRC: Development Review Committee
E: Education
FS: Further Study
HBAM: Home Builders Association of Maryland
HOA: Homeowners' Association
LEED: Leadership in Energy and Environmental Design
LOSM: Local Open Space Manual
MDE: Maryland Department of the Environment
MDE: Maryland Department of the Environment
MDP: Model Development Principles
N/A: Not Applicable
NRCS: Natural Resource Conservation Service
O: Other
P: Policy change/modification
PDM: Baltimore County Department of Permits and Development Management
PUE: Public Utilities Easement
R: Regulation change
RC-5: Resource Conservation rural residential zone
ROW: Right of Way
SWAP: Small Watershed Action Plans
TMDL: Total Maximum Daily Load
URDL: Urban-Rural Demarcation Line

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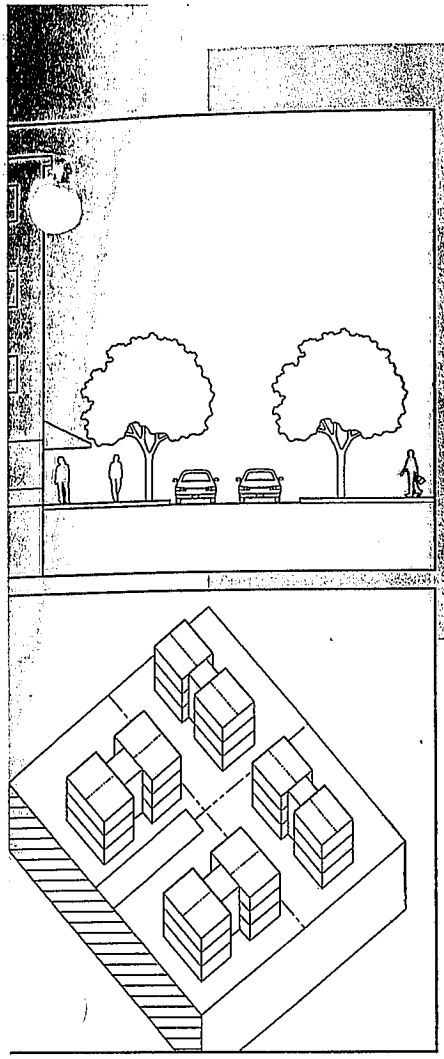

PLANNING AND URBAN DESIGN STANDARDS

AMERICAN PLANNING ASSOCIATION

EMINA SENDICH
Graphics Editor

WILEY

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STORMWATER OVERVIEW, RUNOFF, AND RECHARGE

Stormwater management encompasses the broad field of managing runoff from precipitation events to control or mitigate a range of issues:

- Conveyance or drainage of runoff from one location to another
- Treatment of runoff to capture and remove a variety of pollutants prior to discharge to receiving water
- Recharge of precipitation into underlying groundwater to maintain supplies for drinking water, irrigation, and dry-weather flow to streams, wetlands, and ponds
- Mitigation of accelerated overland and stream channel erosion caused by either a disruption in hydrology, sediment supply, or both
- Reuse of precipitation for a range of beneficial uses such as drinking water and irrigation
- Control or management of large precipitation events to reduce the risk of downstream flooding

The information here focuses on the issues of recharge of precipitation to groundwater and treatment of runoff to reduce pollutant load delivery to receiving waters.

STORMWATER AND WATER QUALITY

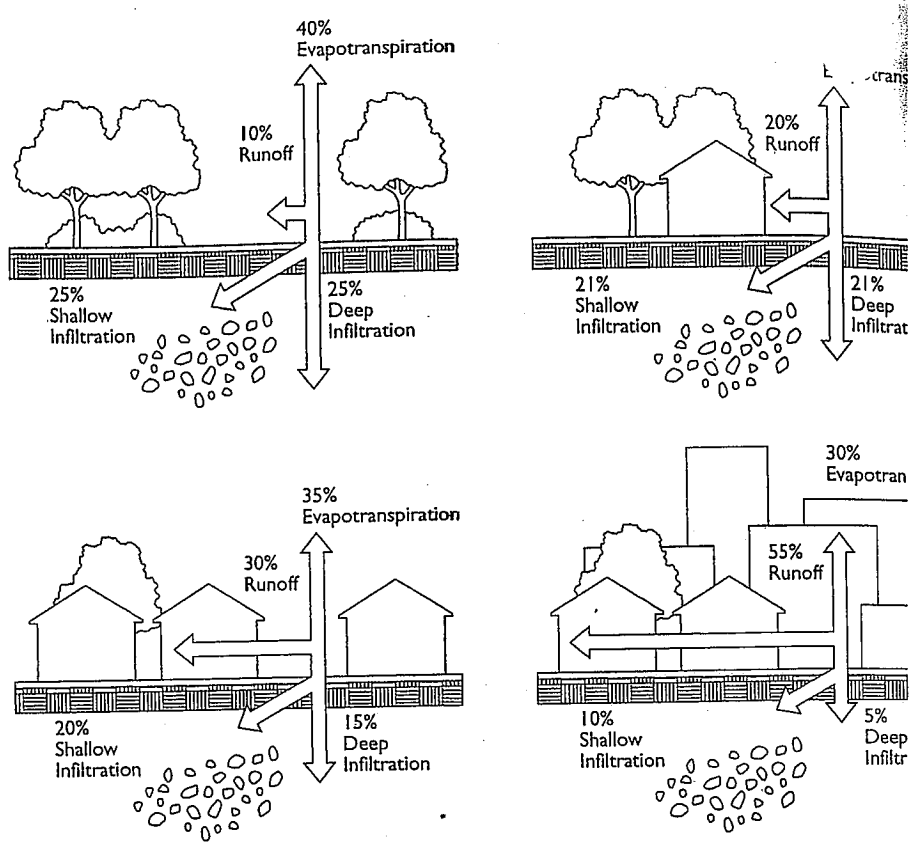
Stormwater runoff, particularly from urban land uses, is widely viewed as one of most significant contributors to water quality impairment (Burton and Pitt 2002). Many believe the cause of impairment is a result of pollutant delivery to receiving waters. While pollutants in stormwater runoff are certainly ubiquitous and frequently at concentrations that do contribute to water quality impairment, the impact on water quality from reduced groundwater recharge, accelerated stream channel erosion, and increased flooding is also part of the stormwater problem.

PRINCIPLES OF STORMWATER MANAGEMENT

Two fundamental principles must be understood in order to gain a grasp of the wide topic of stormwater management. The first is how the basic water balance changes as a result of altered land use. The second is that precipitation varies widely, and the probability of a given precipitation event governs how that event can be effectively managed.

Water Balance

In relatively undeveloped or rural areas, total precipitation is divided into three principal components: evapotranspiration, infiltration, and runoff. The quantity of each of these variables depends on the amount of precipitation, climate, vegetative cover, soils, land slope, amount of impervious area, and the characteristics of precipitation events, such as intensity of rainfall. As land is altered from less intensive to more intensive uses, impervious cover increases, and the relative balance of these three variables is changed. The most dramatic effect is that runoff volume increases and infiltration decreases.



As the percent of impervious land cover increases, the water balance shifts away from infiltration and evapo rati toward increased runoff.

IMPACT OF IMPERVIOUS COVER ON DISRUPTION TO THE NATURAL WATER BAL

Source: Prince Georges County, Maryland, Department of Environmental Resources (PGDER) 1999.

The consequence of more runoff occurring more frequently is an acceleration of overland and channel erosion, increased pollutant washoff from the land to receiving waters, and increased flooding frequency, leading to property damage and potential threats to public safety. Decreased infiltration reduces the amount of groundwater recharge and leads to a loss of total water volume to supply streams, wetlands, ponds, and lakes during dry weather. In many regions, streams that were perennial under more rural conditions become intermittent as a watershed develops. An assessment of the distribution of precipitation characteristics must be the initial step in developing any stormwater management approach.

Precipitation Conversion to Runoff

It is also important to understand how precipitation is converted to runoff. Many models and methods exist to describe this phenomenon; the basic variables include the amount and intensity of precipitation and the infiltrative characteristics of the land surface. More intense rainfall, more impermeable land surface, and steeper land surface all will generate more runoff. In nearly all conditions, the smallest storms do not produce any runoff. Even a parking lot can absorb a small amount of precipitation before runoff occurs. Referred to as the initial abstraction, this is the volume of storage contained within the land surfac runoff occurring.

The runoff frequency spectrum dep runoff-producing events, or those pre events greater than a given amount, usually 0.1 inches and 0.2 inches. When addressing ter, the main concerns are usually the am rate of runoff. The distribution and magnitu runoff frequency spectrum vary as a functio term climate and rainfall characteristics. Re receive little total rainfall or, conversely, a tionate number of tropical storms will ea different curve. To effectively manage s runoff across this broad spectrum, differe must be produced for different regions. runoff frequency distribution is calculated a stood, criteria can be applied to address t issues identified above.

STORMWATER RUNOFF RECH

Recharge is the volume of precipitation tha into underlying soils, which supports and groundwater levels, and is not either direct as evapotranspiration or convey wi runoff or interflow. Interflow is an etv gory in the water balance, where prec

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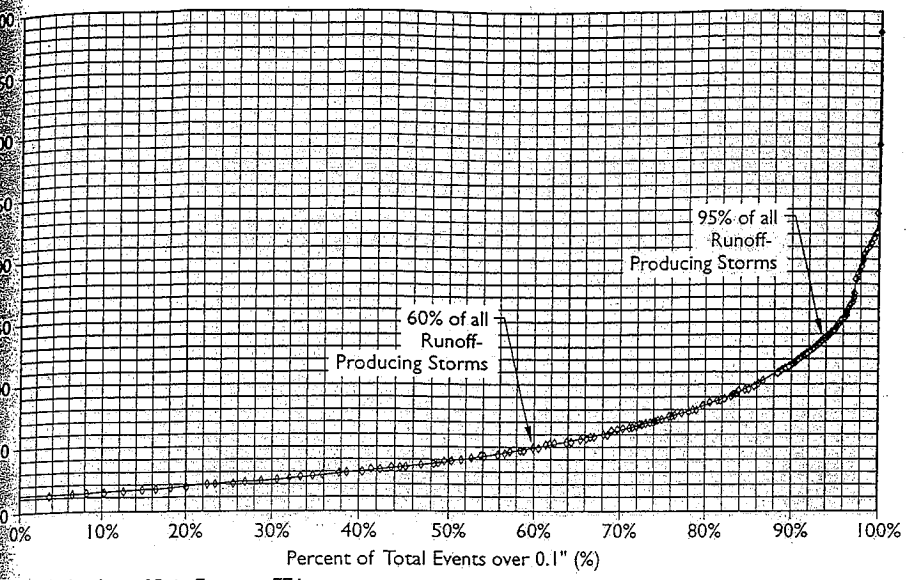


Typical runoff frequency spectrum over a period of record of approximately 10 years. The percent of time a precipitation event exceeds a given value is represented on the x-axis, and the magnitude of precipitation is represented on the y-axis. For example, approximately 60 percent of all precipitation events are less than 0.5 inches, and only 5 percent of all storms exceed 1.5 inches.

UNOFF FREQUENCY SPECTRUM

ce: Richard Claytor.

nally infiltrated below the surface but then flows rizontally toward a stream, river, or lake at a slower rate than direct runoff. Some interflow timately become runoff, evapotranspiration, or charge.

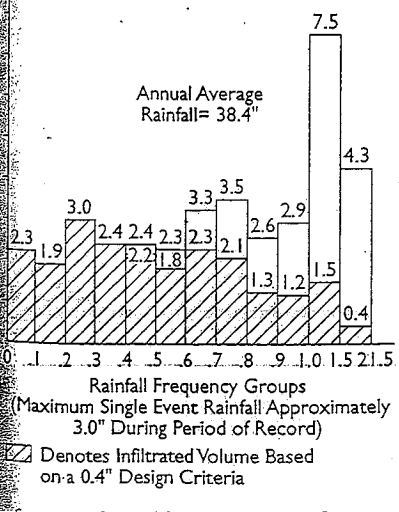
simplifications of complex conditions in the natu- environment often must be developed and applied to understand stormwater movement. However, it must be recognized that some of the time, conditions will vary. For example, those events that produce little or no runoff and also occur most frequently may contribute to recharge or may support evapotranspiration, depending on the time of year. In colder climates, evapotranspiration is dramatically reduced during the winter months. A small rainfall event occurring in November will likely contribute to recharge, whereas the same-sized rainfall event in June or July will often be transpired directly by vegetation and never reach the groundwater.

Recharge across the Runoff Frequency Spectrum

The amount of recharge needed to mimic natural conditions varies. The best approach is to rely on what occurs naturally and derive criteria to meet that condition. If the natural rate of recharge is 50 percent of the precipitation volume, strive to infiltrate half the total precipitation volume. This is accomplished by setting a design criterion to ensure that half the total long-term precipitation is directed back into the ground.

If practices are sized to capture and infiltrate a 0.4-inch precipitation event, as shown in the illustration, then slightly more than half of the total long-term precipitation will be recharged. All rainfall will infiltrate for storms up to 0.4 inches. This comprises approximately 25 percent of the total long-term precipitation volume. A correspondingly smaller percentage of each storm larger than 0.4 inches will be infiltrated. For example, storms that are between 0.7 and 0.8 inches will recharge only about 60 percent. If in an average year 3.3 inches of precipitation falls from storms in this range, only about 2.1 inches of this would be infiltrated by a practice designed to infiltrate 0.4 inches. Adding all of these together, the total annual average infiltration volume would be approximately 20.9 inches, which is approximately 54 percent of the total annual average precipitation and slightly more than the 50 percent target.

Unfortunately, data on the amount of annual recharge that occurs at a given location are not always available; more importantly, natural recharge varies dramatically as a function of soil



on five years of record from Washington, DC, Airport.

ERIVATION OF RECHARGE CRITERION

ce: Richard Claytor.

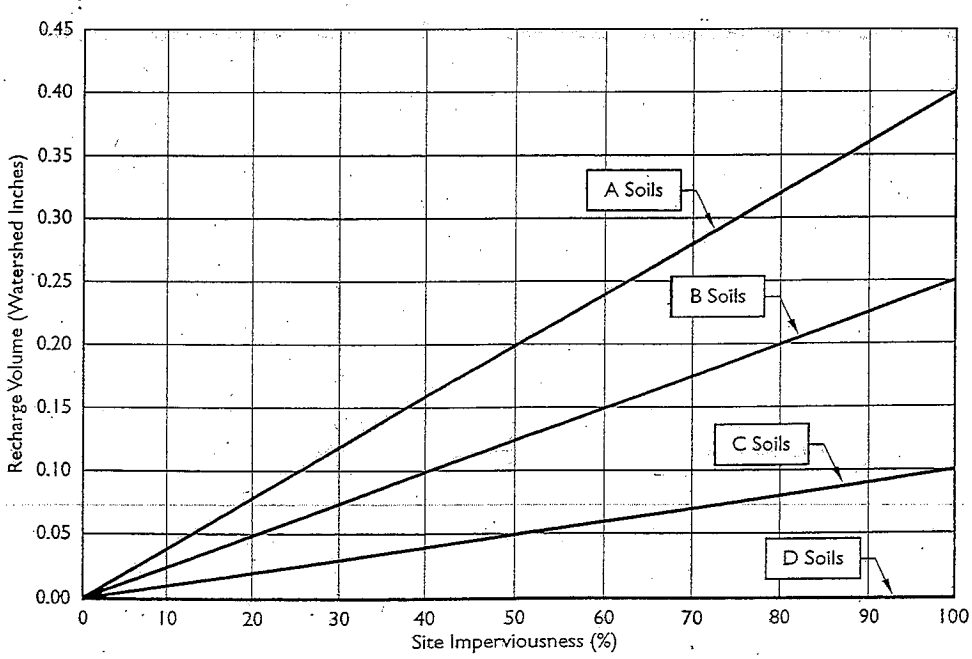


Illustration is for a region receiving 44 inches of annual average rainfall.

RECHARGE VOLUME AS A FUNCTION OF SITE IMPERVIOUS COVER

Source: Center for Watershed Protection 2002.

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STORMWATER TREATMENT

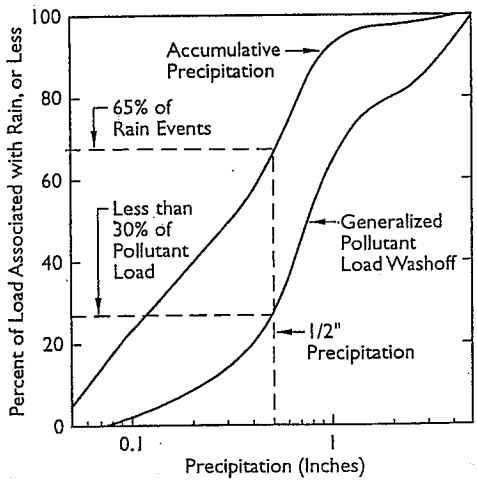
Stormwater treatment is the capture and reduction of pollutants in stormwater runoff prior to discharge to receiving waters. Streams, rivers, lakes, ponds, coastal waters, and groundwater are all receiving waters. Treatment of stormwater runoff involves some reasonably complex considerations:

- Identifying the pollutants of concern to a given receiving water body
- Quantifying the volume of runoff that can be cost-effectively treated
- Evaluating the most appropriate treatment practice to reduce pollutants of concern
- Evaluating which practices are the most cost-effective in reducing targeted pollutants
- Understanding the maintenance and/or operation characteristics of the various treatment options

FIRST FLUSH

Some pollutants are closely associated with the initial runoff after a storm begins and exhibit a phenomenon commonly referred to as a first flush effect. The principle is that a majority of pollutants wash off the land surface soon after a storm begins. It takes a relatively small volume of runoff to accomplish this effect. Runoff from the first one-half inch of precipitation is commonly referred to as the first flush runoff volume (Horsley & Witten, Inc. 1997). Consequently, most stormwater management criteria have adopted the first one-half inch of rainfall as the target for water quality treatment.

The first flush effect does not always exist, however, particularly for pollutants more associated with pervious surfaces, such as nitrogen, phosphorus from lawns, and bacteria from failing septic systems. These pollutants often take more time and larger volumes of runoff to mobilize and to wash off the land. If the receiving water is a lake or coastal area, and swimming beaches or shellfish beds are nearby, bacteria and nutrients are the likely pollutants of concern. Treatment of only the first flush volume misses a significant portion of the total pollutant load. To address this, increase or decrease the target sizing based on the receiving water type or specific pollutant of concern.



POLLUTANT LOADING AS RELATED TO PRECIPITATION EVENT SIZE

Source: Burton, G. Allen, and Robert E. Pitt. 2002. Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientist, and Engineers. Boca Raton, FL: Lewis Publishers.

RECEIVING WATER RESOURCES AND TYPICAL TARGET POLLUTANTS

RECEIVING WATER RESOURCE AREAS	TYPICAL CRITICAL POLLUTANTS TO CONTROL
Groundwater	Soluble pollutants, nitrogen, viruses
Freshwater Streams	Sediment, phosphorus, temperature, heavy metals
Freshwater Ponds	Sediment, phosphorus, bacteria, heavy metals
Wetlands	Sediment, phosphorus, heavy metals
Coastal Waters	Sediment, bacteria, viruses, nitrogen

STRUCTURAL APPROACHES

Another approach to treatment is to apply management practices most likely to catch the wide range of pollutants from a specified volume of runoff, which can mean that practices can be tailored to be effective but practical and economically feasible. The runoff frequency spectrum is often used as the basis for treatment practice sizing. If 90 percent of runoff-producing storms can be captured and effectively treated, it is reasonable that a much higher level of the total long-term pollutant load can be captured. The ninetieth percentile precipitation event is often more than the one-half inch event, typically in the range of between 0.8 inches and 1.3 inches.

Whatever the sizing criteria, the effectiveness of how well the captured load is treated depends on the pollutant and the management practice used. All structural stormwater management measures have some ability to remove pollutants, but their effectiveness varies widely depending on the type of practice, design characteristics, site characteristics, target pollutant constituents, and construction and maintenance factors.

There are certainly several options available, but many practices may simply be infeasible or impractical in certain situations. Other considerations, such as cost, unintended environmental consequen neighborhood acceptance, or maintenance, a the ultimate selection and implementation of given stormwater management strategy. As a basi reviewing treatment system effectiveness, it is ne sary to first have a common nomenclature for suite of commonly applied treatment practices. table lists a group of stormwater treatment prac either capable of meeting a prescribed water qu treatment threshold or with other limited utility.

POLLUTANT REMOVAL

A variety of practitioners have tested the pollu removal capabilities of different alternatives. Tw the most extensive datasets available are the *Nati Pollutant Removal Database for Stormwater Treatm Practices*, 2nd edition (Winer 2002), and the EPA/ASCE National Stormwater BMP Database, w is available online. Each of these datasets pres water quality pollutant removal efficiency data most of the treatment practices presented here. T removal projections can be used to estimate pote load reductions for individual site assess w shed plans, or other needs. Actual pollu du is a function of several other factors:

- The contributing drainage area physically dire to a practice
- The fraction of the annual rainfall effectively tured by practices
- The criteria employed for the design and im mentation of new practices

STORMWATER TREATMENT PRACTICES: NOMENCLATURE AND DESCRIPTION

BMP GROUP	PRACTICE NAME	PRACTICE DESCRIPTION
Ponds	Dry Detention Pond	Dry ponds or vaults that are generally designed to temporarily detain ru provide peak flow attenuation for flood control purposes.
	Dry Extended Detention Pond	Dry ponds that treat a prescribed water quality volume through extende detention, a design option that holds runoff over a fixed detention time.
	Wet Pond	Ponds that provide water quality storage in a permanent pool.
	Wet Extended Detention Pond	Wet ponds that treat a water quality volume by detaining runoff above permanent pool for a specified minimum detention time.
	Multiple Pond System	Interconnected ponds that collectively treat a water quality volume.
Wetlands	Shallow Marsh	Constructed wetlands that provide water quality treatment primarily in shallow marsh.
	Extended Detention Wetland	Wetland systems that treat a portion of a water quality volume by detai storm flows above the marsh surface.
	Pond/ Wetland System	Wetland systems that treat a portion of a water quality volume in dee pool that precedes the shallow marsh wetland.
	Gravel Wetland	Wetland systems composed of wetland plant mats grown in a gravel m
Infiltration	Infiltration Trench	Stores a water quality volume in the void spaces of a gravel trench, ch or vault before being infiltrated.
	Infiltration Basin	Stores a water quality volume in a surface depression, before i into underlying soils.

Source: Center for Watershed Protection 2002.

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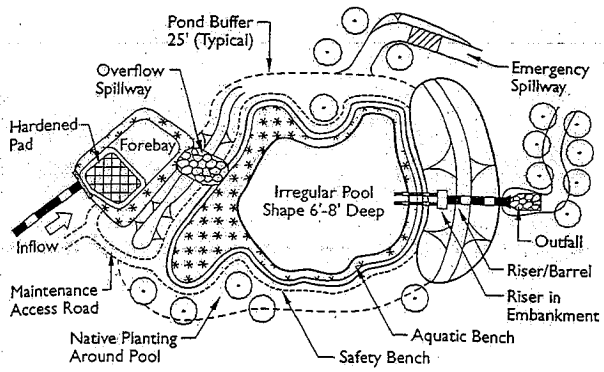
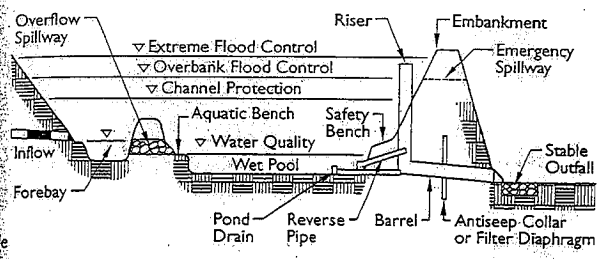


Plan View



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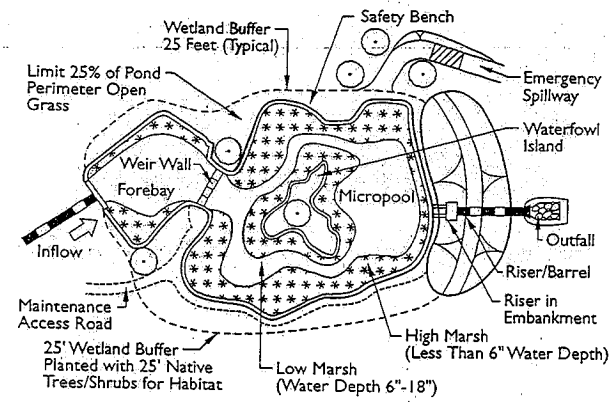
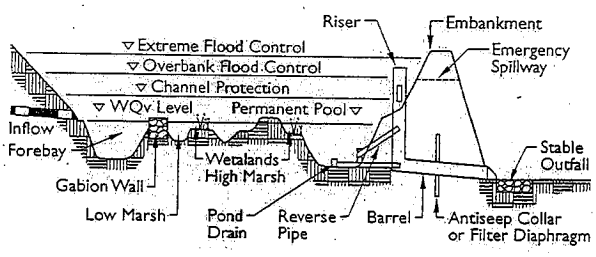
Wet Pond



Plan View



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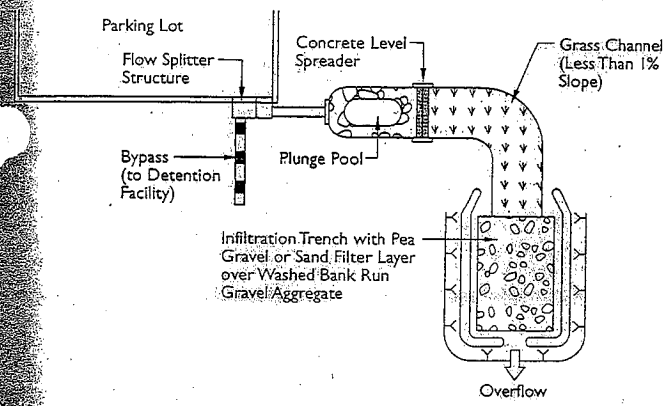
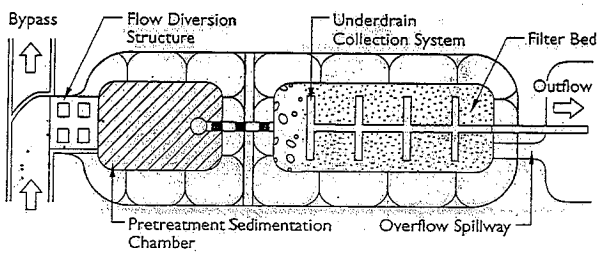
Shallow Wetland



Plan View



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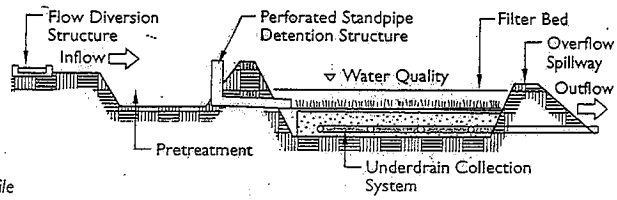

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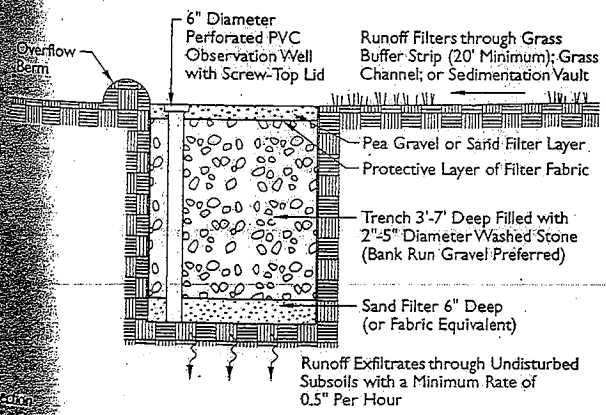

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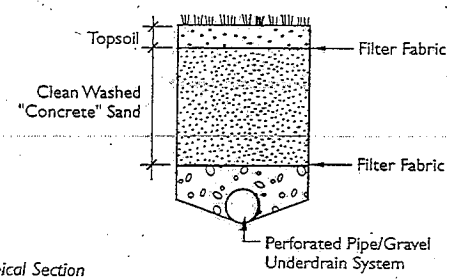

Typical Section

Surface Sand Filter

the more common structural stormwater treatment practices used to reduce pollutant loading to receiving waters.

AMPLES OF STRUCTURAL STORMWATER TREATMENT PRACTICES

...ter for Watershed Protection 2002.

...tor, P.E., Horsley Witten Group, Sandwich, Massachusetts

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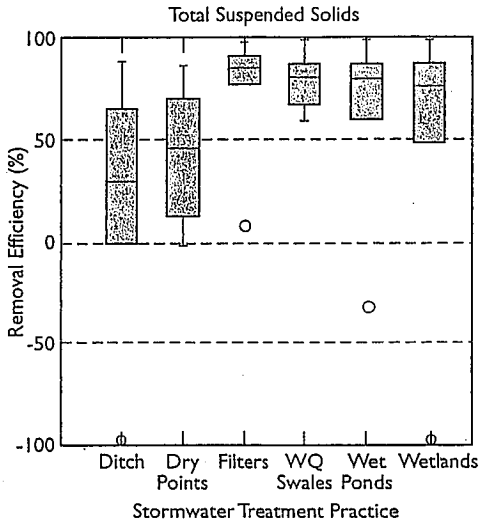
MEDIAN POLLUTANT REMOVAL RATES FOR BMPs BY PRACTICE GROUP

	POLLUTANT CONSTITUENT						
	TSS	TP	Sol P	TN	NO_x	Cu	Zn
BMP GROUP	REMOVAL RATE (PERCENT)						
Ponds	47	19	-6	25	4	26	26
Wet Ponds	80	51	66	33	43	57	66
Stormwater Wetlands	76	49	36	30	67	40	44
Filtering Practices	86	59	3	38	-14	49	88
Infiltration Practices	95	70	85	51	82	nd	99
Open Channel Practices	81	34	38	84	31	51	71
Other Practices	not reported for entire group						

Source: Adapted from Winer 2002.

Note: Table excludes data on the standard deviation of each value and notes on the number of studies used to develop the removal rates.



BOX AND WHISKER PLOTS FOR TOTAL SUSPENDED SOLIDS BY BMP GROUP

Source: Center for Watershed Protection 2002.

- The construction inspection and enforcement capabilities to ensure that the design criteria are applied and implemented
- The maintenance performance of BMPs over the long term

A scheme of discounts is often used to account for the long-term pollutant removal potential of stormwater treatment practices in real-world applications. The table lists planning-level pollutant removal capabilities for each of the broad treatment practice groups.

Data can also be presented for the median effluent concentration, for each treatment practice. Box and whisker plots are an excellent way to graphically illustrate the range (whiskers) of removal rates as well as the median (dark line), first, and third quartile values (box). The plots illustrate the wide range of pollutant removal variability among various study results as well as the general comparison of removal capabilities between groups of stormwater treatment practices.

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See also:

Groundwater Movement and Recharge
Soils Classification and Mechanics
Stormwater Drainage and Flood Management
Stormwater Overview, Runoff, and Recharge
Watersheds

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A007534

STORMWATER DRAINAGE AND FLOOD MANAGEMENT

ast four decades or so, traditional stormwater nt has involved the efficient conveyance of n one point to another and the control of creased peak rates of runoff associated with land- alteration. More recently, a philosophy on rainage and flood controls based on natural systems been adopted, where runoff is retained or infil- at the source, flow along the watershed is in a more natural channel, and flood control is provided protection and maintenance of floodplains. Both hilosophies have some merits and limitations.

DIRECTLY CONNECTED DRAINAGE

Directly connected drainage involves the efficient col- tion of runoff at the source and the nonerosive nveyance of water to an outlet, such as a detention ond, river, coastal area, or groundwater supplies.

The Rational Formula is used to calculate instanta- eous peak flow rates to design drainage channels, pes, curbing, drainage inlets, and other infrastruc- re to control different storm events:

- 2-year storm: roadside curbing, channels and inlets
- 10-year storm: pipes and larger collector channels
- 25-year to 50-year storm: major culverts and high- ways

The Rational Formula is:

$$Q = CiA$$

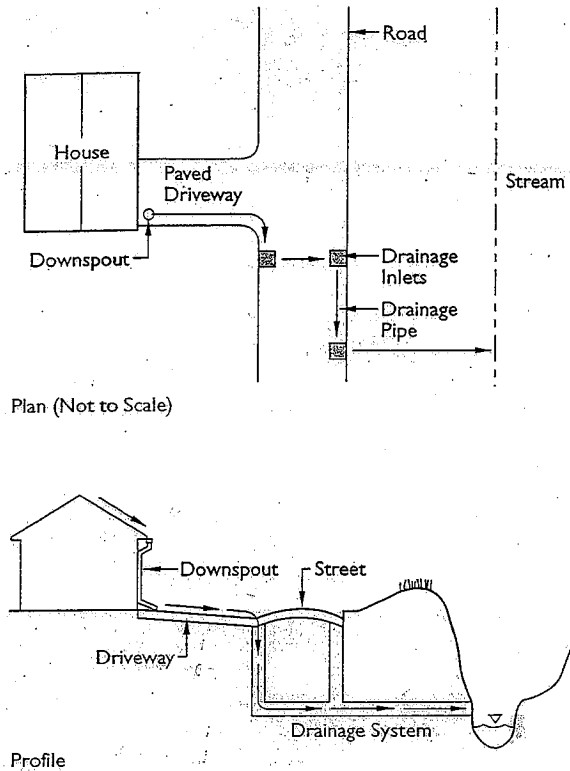
= runoff coefficient
= instantaneous intensity of a prescribed flood return interval, in inches/hour
A = drainage area, in acres

DETENTION FACILITIES

More traditional stormwater flood control measures ave included large detention facilities, frequently esigned to provide peak flow attenuation for storm turn intervals from the 2-year to the 100-year storm. Most current local stormwater management ordi- nces, bylaws, or regulations require peak flow ontrols for the following storm events:

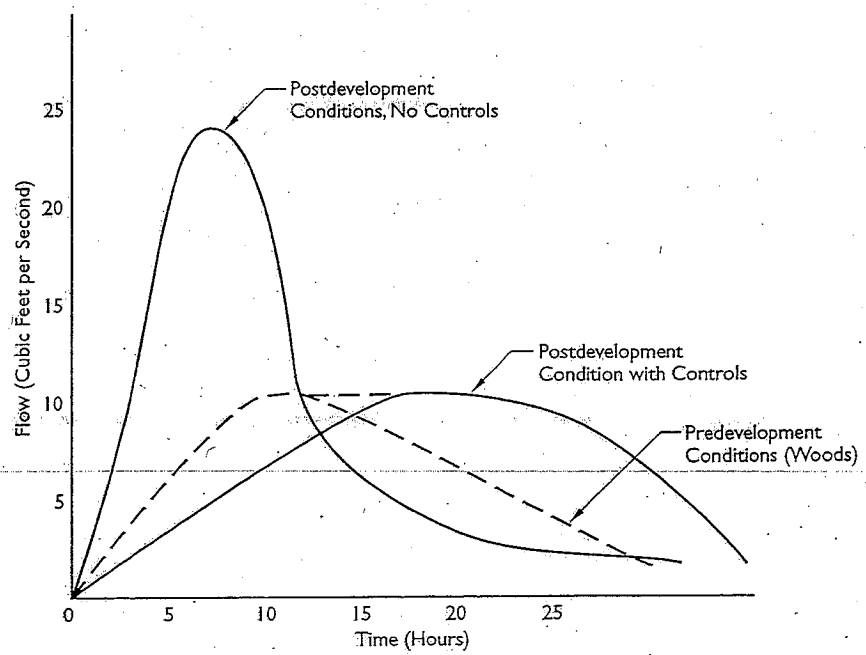
- 2-year storm for channel erosion control
- 10-year storm for conveyance control (5- and 25- ear control may also be required in many jurisdictions)
- 50-year storm for major infrastructure
- 100-year storm for flooding protection

A variety of models are used to calculate runoff nd volumes to design these flood control facil- s. The most common is *Urban Hydrology for Small atersheds, Technical Release 55* (TR-55), published n 1986 by the Natural Resource Conservation ervice. Other models and techniques are used to cal- ulate peak flows and estimate volumes, such as nit tes Geological Survey (USGS) gauging regression equations, continuous simula- deling using real precipitation data, and tatistical recurrence methods.



HYDRAULICALLY CONNECTED DRAINAGE NETWORK

Source: Richard Claytor.



TRADITIONAL PEAK FLOW ATTENUATION APPROACH HYDROGRAPHS

Source: Richard Claytor.

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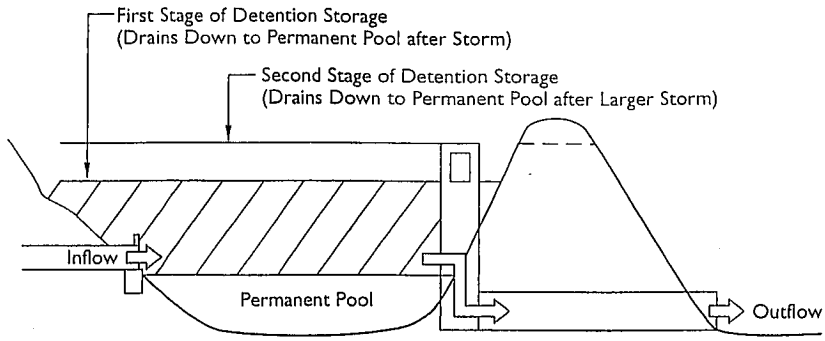
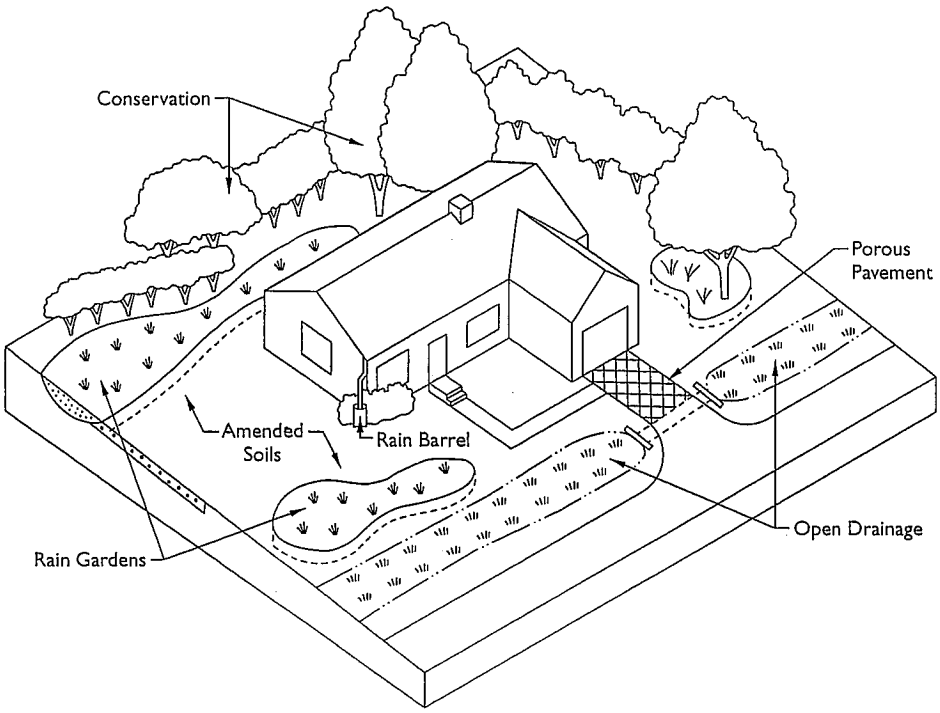


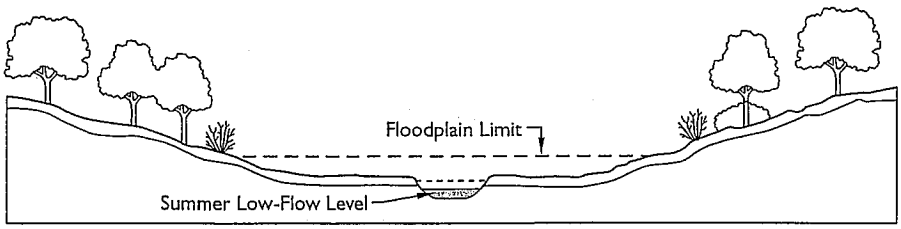
TRADITIONAL PEAK FLOW CONTROL DETENTION POND

Source: Richard Claytor.

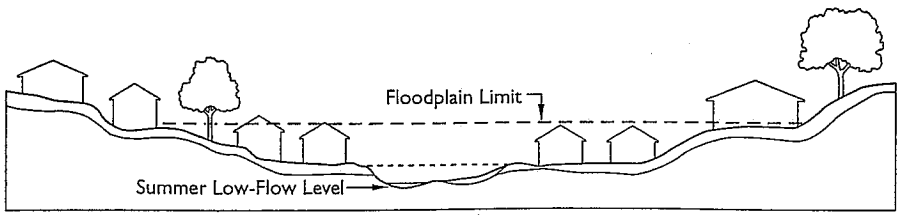


NATURALIZED DRAINAGE DESIGN AT THE SINGLE-LOT SCALE

Source: Prince Georges County, Maryland, Department of Environmental Resources (PGDER) 1999.



Predevelopment



Postdevelopment

COMPARISON OF FLOODPLAIN DEVELOPMENT SCENARIOS

Source: Center for Watershed Protection 2002.

Good drainage design results in generally safer conditions for drivers and pedestrians, and often reduced habitats for mosquitoes and other pests. It is argued whether traditional stormwater management control strategies have reduced the risk and downstream damage. Several researchers have documented increased flooding associated with development, even with the advent of traditional stormwater management techniques (Claytor and Ohrel 1995).

NATURAL SYSTEMS APPROACH

Problems with the real or potential degradation of natural resources has led many engineers, planners and other professionals to a new way of thinking about drainage and flooding. This more naturalistic approach to drainage and flooding design works to mimic the natural conditions of infiltration of rainfall and to slow the distribution of flows throughout the drainage network. It also provides buffers and corridors within which flooding can occur. The natural systems approach to drainage and flooding appears to offer substantial benefits related to enhancing groundwater recharge, reducing pollutant loading, minimizing channel erosion, and protecting natural floodplains from encroachment.

These methods and techniques have not necessarily been subjected to the test of time and maintenance and failure potential has not been clearly documented. In addition, most of the developed environment was constructed under the "good drainage" paradigm, and application of the natural systems approach may be difficult in many watersheds. Planners and engineers who seek to apply these techniques and need more information on design methods, maintenance requirements, and failure potential may consult resources including those listed here.

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Groundwater Movement and Recharge
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Watersheds

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A007536

CLEAN WATER ACT

The Clean Water Act (CWA), 33 U.S.C. §§ 1251–1376, was enacted in 1977 as an amendment to the Federal Water Pollution Control Act of 1972. The CWA is the cornerstone of surface water quality protection in the United States. Its goal is to restore and maintain the chemical, physical, and biological integrity of the nation's waters so they can support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." The act attempts to achieve that goal by using a variety of regulatory and nonregulatory tools to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff.

The early decades of implementing the CWA focused on regulating discharges of specific chemical pollutants from traditional "point source" facilities, including municipal sewage plants and industrial facilities. Since the late 1980s, CWA implementation has shifted to more holistic, watershed-based strategies that have increasingly focused on managing nonpoint" runoff from streets, construction sites, farms, and other "wet-weather" sources.

The Clean Water Act first requires that water quality standards (WQS) be established and that waterbodies be monitored to determine whether the WQS are met. If a waterbody meets all WQS, antidegradation policies and programs are used to maintain acceptable water quality levels. If a waterbody is not meeting WQS, a strategy such as a total maximum daily load (TMDL) is developed to meet the WQS. To achieve the necessary reductions in pollutant loading, a number of CWA-authorized tools are used, including the National Pollutant Discharge Elimination System (NPDES) permit program (for point sources), the Section 319 grant program (for nonpoint sources), the Section 404 permit program (for placement of dredged or fill material into wetlands and other U.S. waters), the Section 401 state water quality certification program, and state revolving funds (SRFs).

CWA APPLICATION

The Clean Water Act applies only to "waters of the United States"—a term whose extent has been subject to much litigation and has changed several times in response to court rulings. Generally, such waters include the following:

- All interstate waters
- Intrastate waters used in interstate or foreign commerce
- Tributaries of the above
- Territorial seas at the cyclical high tide
- Wetlands adjacent to all of the above

The most recent major redefinition of the term came about in response to a U.S. Supreme Court ruling that isolated wetlands are not "waters of the United States" (*Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers (SWANCC)*, 531 US 159 2001).

WATER QUALITY STANDARDS

States, territories, and authorized Native American tribes are required to establish water quality standards through a public review and comment process. Establishment of WQS has three components: designated uses, water quality criteria, and antidegradation. The WQS must be submitted to the Environmental Protection Agency (EPA) for approval. If the EPA decides it cannot approve a WQS, it may promulgate substitute WQS through a formal rule-making process. A state, territory, or tribe must review its WQS every three years and submit revisions to the EPA for approval. Responsibility for monitoring waterbodies for compliance with WQS rests with the state, territory, or tribe.

Designated Uses

The establishment of WQS for a waterbody begins with classifying it for "designated uses"—that is, those uses society determines the waterbody's water quality should be able to support. The common designations are listed here:

- Public drinking water supply—no treatment before use
- Public drinking water supply—treatment provided
- Water-based recreation—long-term/whole body contact (e.g., swimming, kayaking, wind surfing)
- Water-based recreation—short-term/partial body contact (e.g., jet skiing, speed boating, canoeing)
- Water-based recreation—no body contact (e.g., riding in large boats)
- Fishing/eating
- Aquatic life—warm water species/habitat
- Aquatic life—cold water species/habitat
- Agriculture water supply
- Industrial water supply

Uses designated for a waterbody must include those uses it was capable of supporting at any time since November 28, 1975 ("existing uses") and the "fishable/swimmable" use (unless a special "downgrading" process is followed). Transportation of wastes is not allowed as a designated use. With multiple designated uses, CWA requirements and programs are driven by the designated use requiring the cleanest water. Establishment of designated uses may—but is not required to—consider economic and social factors.

To reclassify a designated use to one requiring less clean water, the state, territory, or Native American tribe must first conduct a use attainability analysis (UAA) that shows the current designated use cannot be achieved through applicable technology-based limits on point sources and cost-effective and reasonable best management practices for nonpoint sources. Then the UAA must undergo public review and be approved by the EPA, based on whether attainment of the current designated use is prevented by natural background conditions or irreversible human-caused conditions, or would cause substantial environmental damage, or would involve widespread social and economic costs.

Water-Quality Criteria

The next step in establishing WQS is to define those levels of individual pollutants, or water quality characteristics, or descriptions of waterbody conditions that, if met, will generally protect each of the waterbody's designated uses. Only scientific considerations may be used to determine these water quality criteria (WQC).

Criteria may be distinguished in a number of ways. They may be numeric criteria that express conditions for specific measures over time (e.g., weekly average of 5 mg/L dissolved oxygen), or narrative criteria that call for the waterbody to be free from undesirable conditions (e.g., no putrescent bottom deposits), or for balanced populations of aquatic life. They may be categorized according to which portion of the aquatic system they apply (e.g., water column, bottom sediments, fish tissue). Biological criteria may be expressed as parameter-specific for a protected species (e.g., daily average of 30 ?g/L of copper) or in terms of "metrics" that measure numbers, weight, and diversity of organisms in a waterbody (community indices).

Established WQS generally require surface waters to be free from the following:

- Putrescent or otherwise objectionable bottom deposits
- Oil, scum, and floating debris in unsightly amounts
- Nuisance levels of odor, color, and other conditions
- Undesirable or nuisance aquatic life
- Substances in any amount toxic to humans or aquatic life

EPA regulations allow WQS to be waived under certain circumstances, the most common being within "mixing zones" (the area of a waterbody where the initial dilution of a discharge occurs) and during extreme low or high stream flows.

Antidegradation

To keep clean waters, WQS programs must establish antidegradation policies. The bottom line, or "Tier 1" rule, is that the condition of a high-quality waterbody should not deteriorate to such a degree that one or more of the existing uses can no longer be supported. The "Tier 2" rule is that ambient water quality should not decline from a condition of being considerably better than WQS to a condition that barely meets WQS. Exceptions exist only (1) where allowing lower WQS cannot be avoided by applying technology-based limits to point sources and by applying cost-effective and reasonable best management practices to nonpoint sources, and (2) where such allowance is necessary to accommodate important economic or social development. The "Tier 3" rule applies only to waters designated as Outstanding Resource Waters and only allows very minimal, or significant but short-term, decreases in WQS.

MONITORING

States, territories, and authorized tribes are required to (1) monitor the ambient condition of waterbodies to determine whether their WQS are being met, and (2) submit a water quality report to the EPA every two years. The report must describe the condition of all waterbodies in the state, territory, or tribal land, identifying which pollutants and other stressors are the most common causes of impairment to waterbodies, and discuss progress toward meeting CWA goals. The report must also list waters not meeting WQS due to pollutants (impaired waters) and waters likely to become impaired by the next report (threatened waters).

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TOTAL MAXIMUM DAILY LOADS

If a state, territory, or authorized tribe reports a waterly or segment of a waterbody to be impaired or eatened, it is required to develop a strategy leading to WQS attainment. Because required technology-based limits on point sources have not been enough to achieve WQS, the CWA requires such a strategy to include total maximum daily loads (TMDL) or the functional equivalent. A TMDL is the amount of a specific pollutant that a specific waterbody or segment can receive and still meet WQS. The EPA encourages TMDLs to be developed on a watershed basis and incorporated into comprehensive watershed strategies that would address protection of high-quality waters (antidegradation) as well as restoration of impaired and threatened waters.

A TMDL includes, for individual pollutants, an allowable pollutant load (cap), a margin of safety, and an allocation of the cap among sources. TMDLs must be submitted to the EPA for approval. If the agency decides it cannot approve a TMDL, it will develop a substitute TMDL through the formal rulemaking process.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

Section 402 of the CWA created a National Pollutant Discharge Elimination System (NPDES), which requires point sources to obtain a discharge permit from the authorized permitting authority (usually the state, but sometimes the EPA). NPDES permits cover istrial and municipal discharges, discharges from n sewer systems in larger cities, stormwater associated with many kinds of industrial activities, runoff from construction sites disturbing more than one acre, mining operations, and animal feedlots and aquaculture facilities (above certain thresholds). NPDES permits are required only for "direct" dischargers, not for "indirect" dischargers, which send wastewater into a city sewer system that carries it to a treatment plant (the "direct" discharger).

The EPA delegates NPDES permit authority to a state if it can demonstrate it has a program at least as stringent as the EPA's regulation. The authorized state performs all of the permit-issuance and enforcement activities, but the EPA retains an oversight role and may issue its own permit if it determines the state permit is insufficient or the state has failed to enforce its permits. A NPDES permit may be unique to a particular facility (individual permit) or cover a large number of very similar facilities where application of the same permit conditions would be appropriate (general permits).

The main component of individual NPDES permits is a set of effluent limits—specific numeric, measurable limits on the amount of various pollutants the covered facility might discharge. Most individual permits include detailed monitoring and reporting requirements that specify which pollutants are to be monitored, at what frequency, and with what sampling and analytic techniques, as well as the content and frequency of reports.

SECTION 319

The CWA does not address nonpoint sources through a federal regulatory program, but rather through a program providing matching grants to states, territories, and authorized tribes that have an EPA-approved nonpoint source pollution management program. Approved programs must include a nonpoint source management plan to be updated every five years. The plan must identify waters impaired or threatened by nonpoint sources, set short- and long-term goals for cleaning them up, identify the best management practices (BMPs) that will be used to do so, contain strategies for working with other agencies and private entities, and include a monitoring and evaluation plan.

Section 319 funds may be used to develop and implement the nonpoint source management plans, develop and implement TMDLs in watersheds where nonpoint sources are a substantial contributor of pollutant loading, develop state stormwater regulatory programs, and provide local grants for on-the-ground controls (e.g., BMPs) related to a holistic watershed plan or a location-specific TDML.

SECTION 404

Section 404 of the CWA requires permits for the placement of dredged or fill material into waters of the United States. Although applicable to all waters covered by the CWA, the Section 404 permit program is most commonly associated with wetlands. The U.S. Army Corps of Engineers has primary responsibility for administering and enforcing the permit program, though the EPA also plays a significant role in issuing guidelines and policies; delegating Section 404 program responsibilities to qualifying states, territories, and tribes; and may even veto a Corps-issued permit (a step rarely taken).

Section 404 permitting involves a three-step "sequencing" process focused on avoidance, minimization, and compensation. First, proposed development must avoid impacts on wetlands or other U.S. waters whenever practical (which raises the issue of whether the proposed activity is water-dependent). If impacts cannot be avoided, then the development must be designed to minimize the impacts and impacted area. In exceptional circumstances, where impacts cannot be avoided or minimized, a developer may be allowed to mitigate wetlands lost to development impacts by restoring (or, more rarely, creating) an area of wetlands that is at least equivalent to that lost.

One controversial aspect of Section 404 permits is determining whether land is a wetland. Program regulations define wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." For an area to be declared a wetland, it must exhibit all three key features—hydrology, wetland-dependent vegetation, and soil types associated with water-saturated conditions.

SECTION 401 CERTIFICATION

Section 401 of the CWA requires federal agencies to obtain a state certification of CWA consistency before issuing a license or permit for a project that may result in any discharge to U.S. waters located in the state. Section 401 certification applies to NPDES permits and Section 404 permits, and has been a key issue in the relicensing of private hydropower dams by the Federal Energy Regulatory Commissio (FERC).

CWA BEST PRACTICES CHECKLIST

- Establish programs to inform the pub ou the importance of clean surface wat at threatens to pollute those waters, and what actions they can take to prevent or minimize point and nonpoint source discharges, such as recycling used oil, limiting use of pesticides and herbicides, and retaining vegetative buffers along waterbodies.
- Consider watersheds and cumulative water quality impacts within them when developing and implementing comprehensive, land-use, community facility, and transportation plans.
- Correct overflow problems with combined stormwater and sanitary sewer systems.
- Provide area developers information about low-impact development (LID) techniques that rely on natural features and processes and emphasize simple, nonstructural, low-tech, and low-cost methods to minimize threats to water quality.
- Restrict development and promote establishment of riparian buffers along and around waterbodies to maximize filtration of pollutants from stormwater runoff.
- Require and encourage development to be designed to minimize impervious surfaces, including maximizing use of existing impervious surfaces.
- Create a stormwater utility, with user fees, to fund establishment, operation, and maintenance of a stormwater management system.
- Take advantage of Clean Water State Revolving Funds to help finance a variety of p o protect water quality.

STATE REVOLVING FUNDS

Congress decided, in 1987, to phase out the existin construction grants program for funding municip sewer and wastewater treatment plant upgrades an replace it with the Clean Water State Revolving Fun (CWSRF). Under this program, the EPA provide annual matching capitalization grants to states, whic in turn provide low-interest loans to local gove ments and private entities to finance a wide variety o water quality projects. CWSRF loans can be used t construct, expand, repair, or upgrade municip sewage collection and treatment systems; to imple ment management plans developed under th National Estuary Program; and for nonpoint sour control projects such as repairing and upgradin home septic systems, purchasing and restorin degraded wetlands, cleaning up soil and groundwa ter contamination on brownfields, and purchase o farm equipment and structures to minimize runo from fields.

See also:
Estuaries, Flats, and Marshes
Water Treatment
Watersheds
Wetlands Delineation
Wetlands Mitigation

A007538

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Alabama Highway Drainage Conservation Design Practices - Particulate Transport in Grass Swales and Grass Filters

November 6, 2005

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Project Number 04117

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Project Summary

Project Objective

The objective of this project is to show how a common AL DOT design and maintenance practice, the use of grass drainage swales, can help meet the requirements of the new Phase II Stormwater Regulations. Managing this permit can be very expensive and time-consuming. However, current drainage practices on many AL DOT transportation corridors likely meet the objectives of the conservation design strategy of the permits. This project shows the water quality and drainage benefits of grass-lined drainages. This will result in significant time and cost savings for AL DOT managers.

Project Abstract

An important element of the Phase II NPDES Stormwater Regulations is the reliance and promotion of conservation design elements. Agencies, including transportation departments, will be required to emphasize the use of stormwater drainage practices that help reduce the discharges of pollutants and excessive runoff volumes, while maintaining successful drainage objectives. The federal guidance emphasizes the use of "soft" controls over historically expensive stormwater treatment options. These include the use of grass swale drainages, minimizing the amount of paved areas, and routing runoff from paved areas to specially constructed infiltration areas. In Alabama, AL DOT already uses grass swale drainages in many suburban and rural areas. The objective of this project is to document the stormwater quality attributes of these existing drainage system elements under local conditions so that AL DOT can obtain credit for their use under this new regulatory program, reducing the need to retrofit more expensive options. We will be able to calculate the direct stormwater quality benefits of these existing cost-effective practices, reducing the need for other more expensive stormwater controls in many instances.

This project supports the UTCA main theme of the Management of Transportation Systems, and the secondary theme to support Phase II NPDES Stormwater Program components.

Project Task Descriptions:

1) laboratory-scale controlled experiments (12 months)
2) full-scale experiments (8 months)
3) data evaluation and report preparation (3 months)

Milestones and Dates

Startup – January 1, 2004
See the approximate durations for each project phase above. There will be overlap in the durations of each effort.
Conclude project – December 1, 2005

Funding Agency

Alabama Department of Transportation

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Relationship to other Research Projects

This is the first UTCA funded project for this research. However, the co-PIs have received prior funding from the Water Environment Research Foundation (WERF) for some related preliminary work in this area.

Potential Benefits of the Project

The outcome of this project documents the cost-effective use of grass-limed swales to meet current storm drainage requirements.

Keywords

Stormwater management, grass swales, conservation design, sediment delivery

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Abstract

The Department of Civil and Environmental Engineering at the University of Alabama has been conducting research investigating the effectiveness of grass swales for stormwater sediment transport to quantify swale hydraulic and sediment transport under relatively small flows. This research has been supported by the Water Environment Research Foundation (Johnson, *et al.* 2003) and the University Transportation Center of Alabama (this reported research). Grass swales are vegetated open channels that collect and transport stormwater runoff. They are often used as an alternative to concrete gutters for stormwater management, such as grass swales in the median of roadways, because of their advantages of infiltration and filtration of stormwater. The objectives of this research are to understand the effectiveness of grass swales in sediment transport, the associated effects of the different swale and hydraulic variables, and to develop a predictive model. To achieve these objectives, experimental grass swales were constructed and tested in an indoor greenhouse facility. The variables tested in the experiments were slope, grass type, depth of flow, sampling time, and length of swales. A water-sediment mixture with a known sediment concentration of sieved sands and fine particles of silica were used to analyze the variables. During the preliminary set of controlled experiments, 108 samples were collected and analyzed for turbidity, total solids, and particle size distributions to investigate the effects of the experimental variables. After completing the initial tests, a second set of controlled experiments was conducted. During this second set of tests, 108 samples were collected and analyzed for turbidity, total solids, total suspended solids, total dissolved solids, and particle size distribution.

To examine how the results obtained from the indoor swale experiments can be applied to full-scale swales, sediment samples were also collected at an outdoor grass swale located adjacent to the Tuscaloosa City Hall, Alabama, during actual storm events. Sixty-nine samples during 13 storm events from August to December 2004 were collected and analyzed for turbidity, total solids, total suspended solids, total dissolved solids, and particle size distributions. The total suspended solids concentrations observed during different rain events showed significant sediment reductions as a function of the length of the swale. The particle size distributions of the suspended solids at the outdoor swale site showed preferential transport of small particles for all lengths of the swale, and preferential trapping of large particles.

The first section of this report begins with a summary outlining the design of grass swales to minimize scour and channel erosion, specifically examining grass-lined swales and the use of turf-reinforced mats. This report section also describes the predictive equations developed to describe sediment trapping in the swales. Several example problems are used to illustrate how these data are used to design stable grass-lined drainage swales that maximize particulate and associated pollutant trapping. The second section of this report describes the controlled indoor experiments and the full-scale tests used to develop the predictive equations, while the third section of the report contains the detailed results in the appendices. Much of the material in this report was from the master's thesis prepared by Yukio Nara (2005).

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Section 1: Design Guidance for the Use of Grass Swales for Stormwater Control

This section of the report reviews past performance information concerning grass swale use for the control of stormwater quality. This section also presents methods for the design of stable grass-lined swales and the development of the predictive equations for trapping sediment in the swales based on the controlled indoor swale experiments and the full-scale tests described in the later sections of the report.

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Chapter 1: Roadside Drainage Design for Channel Stability

Allowable Velocity and Shear Stress

This chapter is a summary of selected material from Pitt, R., S. Clark, and D. Lake, *Construction Site Erosion and Sediment Controls: Planning, Design, and Performance*, to be published by DEStech Publications, Lancaster, PA, in 2006. This chapter reviews the basic approaches and techniques available for the stable design of natural and grass-lined drainage channels. There are several alternatives that can be used which are briefly described. Example problems are also presented.

An important reference on general shear stress relationships and channel bed movement is *Engineering and Design: Channel Stability Assessment for Flood Control Projects* (COE 1994; EM 1110-2-1418). Although this reference is for large channels, many of the basic concepts are similar to what occurs for smaller drainage channels, and these are specifically addressed in the following discussion. More extensive information on these topics is available in numerous textbooks and manuals on sediment transport and channel design.

Allowable Velocity Approach to Channel Design

The concept of allowable velocities for various soils and materials dates from the early days of hydraulics. An example of simple velocity criteria is given by Table 1 (COE undated, EM 1110-2-1601). Table 2 is a similar table, from U.S. Bureau of Reclamation research (Fortier and Scobey 1926) that also shows the corresponding allowable shear stresses and Manning's roughness values.

Table 1. Example of Simple Allowable Velocity Objectives (From COE undated, EM 1110-2-1601)

Channel Material	Mean Channel Velocity (ft/sec)
Fine Sand	2.0
Coarse Sand	4.0
Fine Gravel	6.0
Earth	
Sandy Silt	2.0
Silt clay	3.5
Clay	6.0
Grass-lined Earth (Slopes less than 5%)	
Bermuda Grass	
Sandy Silt	6.0
Silt Clay	8.0
Kentucky Blue Grass	
Sandy Silt	5.0
Silt Clay	7.0
Poor Rock (usually sedimentary)	10.0
Soft Sandstone	8.0
Soft Shale	3.5
Good Rock (usually igneous or hard metamorphic)	20.0

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Table 2. Maximum Permissible Velocities and Corresponding Unit Tractive Force (Shear Stress) (U.S. Bureau of Reclamation research, Fortier and Scobey 1926)

Material	n	Clear Water (diversion structures) V (ft/sec)	Clear Water (diversion structures) τ_o (lb/ft^2)	Water Transporting Colloidal Silts (on site and down slope) V (ft/sec)	Water Transporting Colloidal Silts (on site and down slope) τ_o (lb/ft^2)
Fine sand, colloidal	0.020	1.50	0.027	2.50	0.075
Sandy loam, noncolloidal	0.020	1.75	0.037	2.50	0.075
Silt loam, noncolloidal	0.020	2.00	0.048	3.00	0.11
Alluvial silts, noncolloidal	0.020	2.00	0.048	3.50	0.15
Ordinary firm loam	0.020	2.50	0.075	3.50	0.15
Volcanic ash	0.020	2.50	0.075	3.50	0.15
Stiff clay, very colloidal	0.025	3.75	0.26	5.00	0.46
Alluvial silts, colloidal	0.025	3.75	0.26	5.00	0.46
Shales and hardpans	0.025	6.00	0.67	6.00	0.67
Fine gravel	0.020	2.50	0.075	5.00	0.32
Graded loam to cobbles when noncolloidal	0.030	3.75	0.38	5.00	0.66
Graded silts to cobbles when noncolloidal	0.030	4.00	0.43	5.50	0.80
Coarse gravel, noncolloidal	0.025	4.00	0.30	6.00	0.67
Cobbles and shingles	0.035	5.00	0.91	5.50	1.10

Note:

- an increase in velocity of 0.5 ft/sec can be added to these values when the depth of water is greater than 3 ft.
- a decrease in velocity of 0.5 ft/sec should be subtracted when the water contains very coarse suspended sediments.
- for high and infrequent discharges of short duration, up to 30% increases in velocity can be added

Figure 1 is another guidance illustration showing SCS data (USDA 1977). This figure also differentiates between "sediment-free" and "sediment-laden" flow, with clear water having more restrictive allowable velocities.

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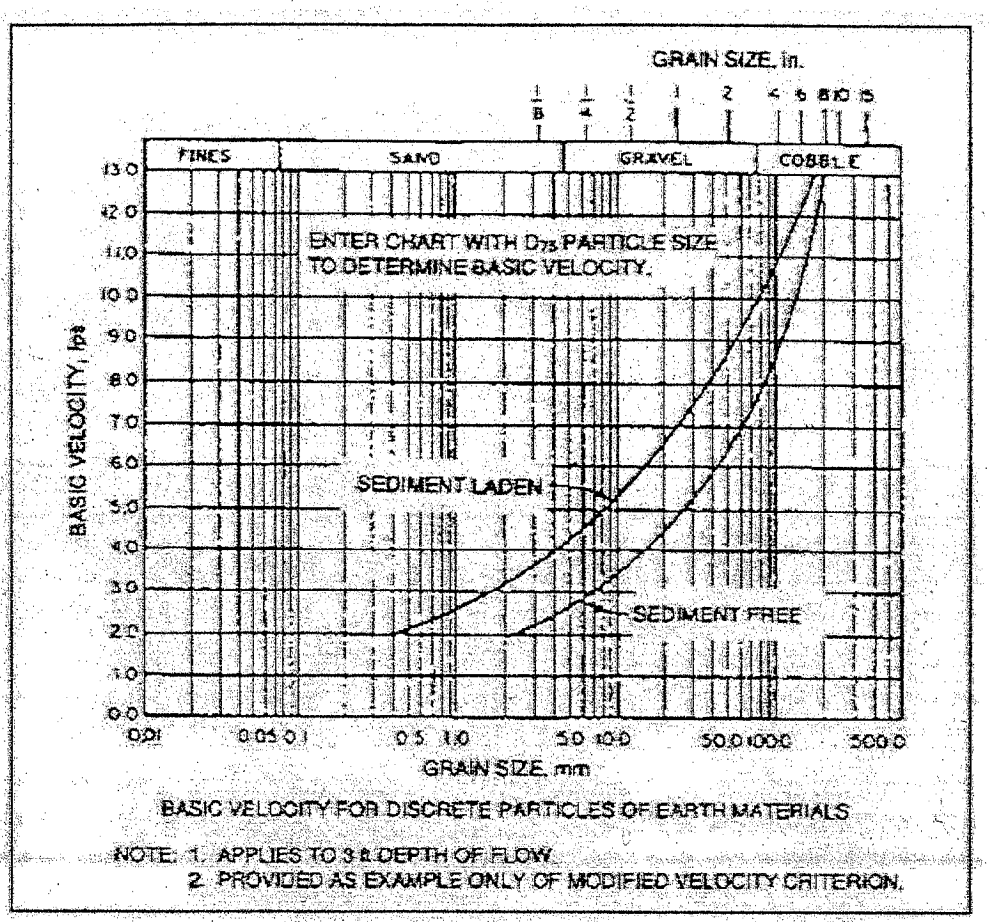

Figure 1. Example of allowable velocity data with provision for sediment transport (USDA 1977)

Allowable Shear Stress Calculations

By the 1930's, boundary shear stress (sometimes called tractive force) was generally accepted as a more appropriate erosion criterion than allowable velocity. The average boundary shear stress in uniform flow (Figure 3) is calculated by

$$\tau_o = \gamma RS \quad (\text{lb/ft}^2)$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
R = hydraulic radius (ft)
S = hydraulic slope (ft/ft)

Figure 2 (Chow 1959) shows a typical distribution of the shear stresses in a channel, indicating how the maximum shear stress is applied along the center of the channel for straight channel reaches having constant depths.

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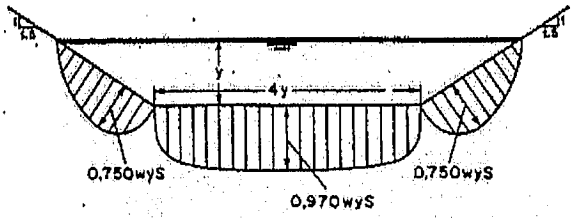
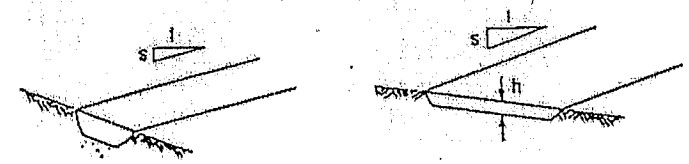


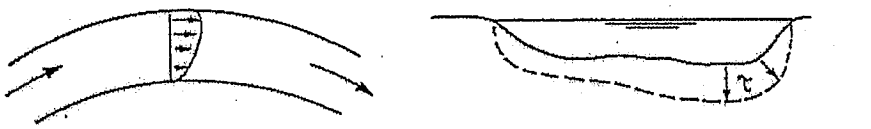
Figure 2. Typical shear stress distributions in a trapezoidal channel (Chow 1959).

If the maximum shear stress is desired (typical for design conditions), then the flow depth is used instead of the hydraulic radius. For sheetflow conditions, the hydraulic radius (R) is very close to the depth of flow, and the above equation is also modified, as shown in Figure 3, by using the depth of flow to replace the hydraulic radius.



average $\tau = \gamma RS$ $\tau \doteq \gamma hs$

where τ = boundary shear stress
γ = specific weight of water
h = depth of flow
S = slope



distribution across bend width distribution in irregular cross-section

Figure 3. Boundary shear stress in uniform flow (COE 1994).

The COE (1994) shows that the use of the Shield's diagram likely greatly over-predicts the erodibility of the channel bottom material. The expected reason they give is that the Shield's diagram assumes a flat bottom channel and the total roughness is determined by the size of the granular bottom material. The actual Manning's roughness value is likely much larger because it is largely determined by bed forms, channel irregularities, and vegetation. They recommend, as a more realistic assessment, that empirical data based on field observations be used. In the absence of local data, they present Figure 4 (from Chow 1959) for applications for channels in granular materials. This figure shows the permissible unit tractive force (shear stress) as a function of the average particle diameter, and the fine sediment content of the flowing water.

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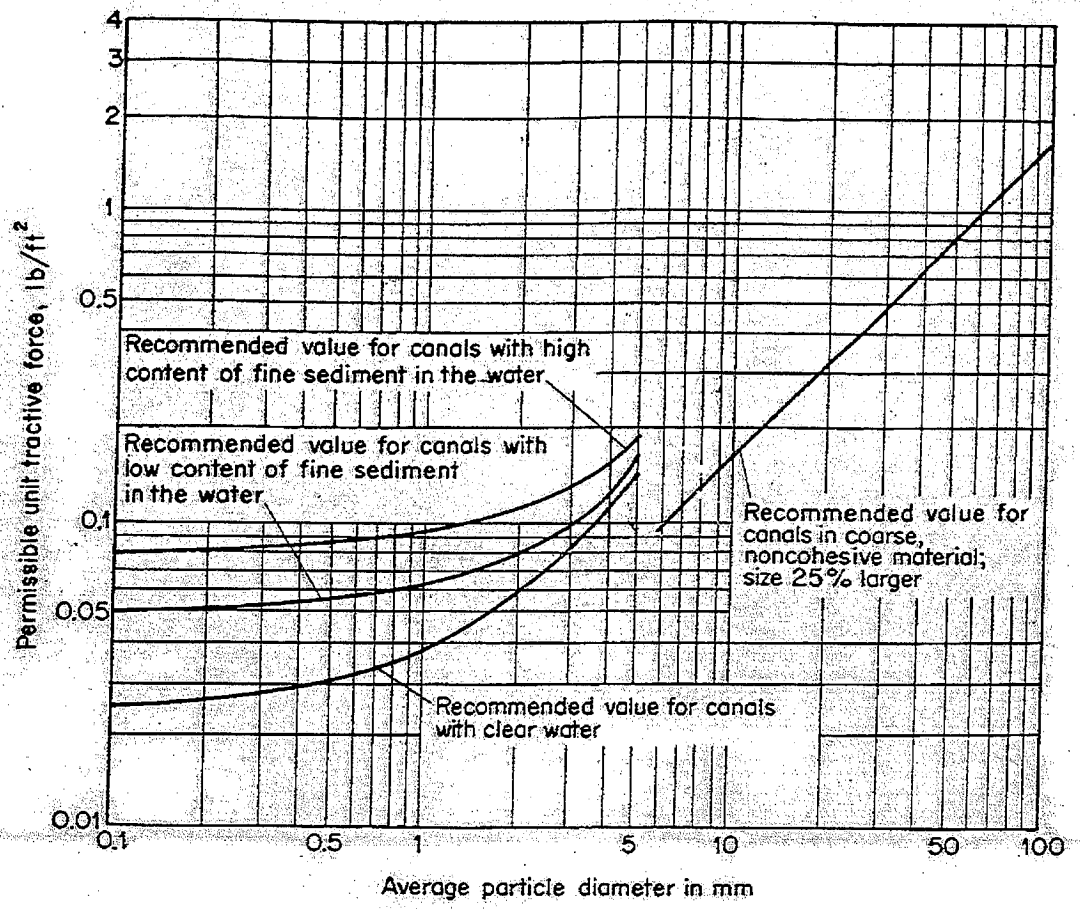

Figure 4. Allowable shear stresses (tractive forces) for canals in granular materials (U.S. Bureau of Reclamation).

The allowable shear stress concept has also been applied to semicohesive and noncohesive soils, but values do not correlate well with standard geotechnical parameters because the resistance to erosion is affected by such factors as water chemistry, history of exposure to flows, and weathering (Raudkivi and Tan 1984). Figure 5 gives an example of allowable shear stresses for a range of cohesive materials. Again, the COE recommends that local field observations or laboratory testing results be given preference.

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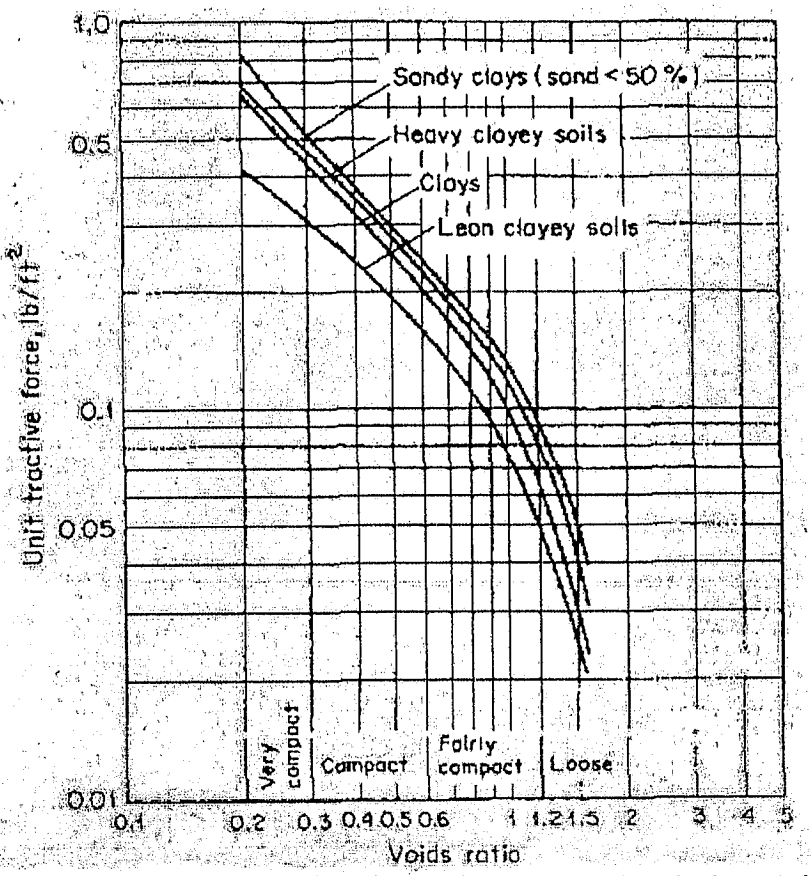

Figure 5. Example of allowable shear stresses (tractive forces) for cohesive materials (COE 1994). Note: Leon clayey soils are hardpan soils where the soil grains become cemented together with bonding agents such as iron oxide or calcium carbonate, forming a hard, impervious mass.

Shear Stress in Channels having Bends

The basic shear stress formulas can be modified to account for the increased shear stress after bends in channels. Normally, the maximum shear stress is along the center part of a channel (usually the deepest area), but a hydrodynamic force is applied to the outside bend after a change in direction. Along the outside of the bend, increased water velocity and shear stress will increase the erosion potential, while sedimentation may occur along the inside of the bend where the water velocity slows. The basic shear stress formula is modified with a bend coefficient, as follows:

$$\tau_o = \frac{\gamma RS}{K_b}$$

where:

γ = specific weight of water (62.4 lbs/ft^3)
R = hydraulic radius (ft) (can be estimated by water depth, for relatively wide channels or sheetflows)
S = hydraulic slope (ft/ft)
K_b = bend coefficient

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The bend coefficient can be estimated by (Croke 2001):

$$K_b = \frac{R_c}{B}$$

where:

R_c = bend curvature (radius of the bend)
B = bottom width of the channel

As the bend curvature, R_c, increases, the effect of the bend decreases. These parameters are illustrated in Figure 6 (North American Green).

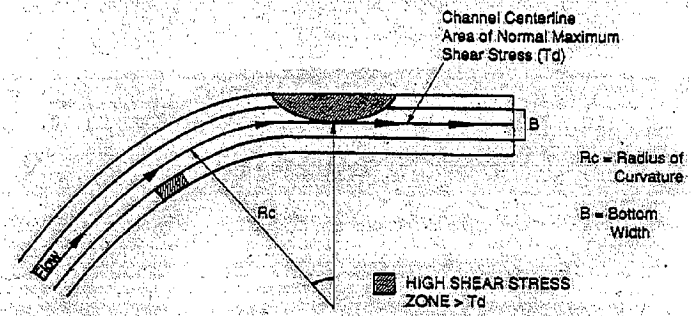

Figure 6. Location of increased shear stress due to channel bend (North American Green).

This formula obviously cannot be used for a V-shaped channel, where the bottom width is zero. The area being affected by the increased shear stress due to channel bends is usually assumed to begin immediately after the bend at the tangent to the downstream channel, as shown in Figure 6. The length of extra shear stress can be estimated by the following formula (after Croke 2001):

$$L_p = \frac{0.604R^{1.17}}{n}$$

where:

L_p = length of extra protection needed due to increased shear stress on outside of bend (same units as R)
R = hydraulic radius = ratio of cross-sectional area of flow to wetted perimeter (A/P)
n = Manning's roughness coefficient for liner in the channel bend

As an example, assume the following conditions:

R = 3.0 ft
n = 0.042

then:

$$L_p = \frac{0.604(3)^{1.17}}{0.042} = 52 \text{ ft}$$

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In addition to the increased shear stress being exerted along the outside bend, water elevations will also rise due to momentum. This will require an additional channel depth needing protection at outside bends.

Design Steps for Maximum Permissible Velocity/Allowable Shear Stress Method

McCuen (1998) presents the following steps when designing a stable channel using the permissible velocity/allowable shear stress method:

1) for a given channel material, estimate the Manning's roughness coefficient (n), the channel slope (S), and the maximum permissible velocity (V) (such as from Tables 1 or 2).

2) Compute the hydraulic radius (R) using Manning's equation:

$$R = \left[\frac{Vn}{1.49S^{0.5}}\right]^{1.5}$$

where:

R = hydraulic radius, ft.
V = permissible velocity, ft/sec
S = channel slope, ft/ft
n = roughness of channel lining material, dimensionless

Some typical values for Manning's n for open channels (Chow 1959) are as follows:

Very smooth surface (glass, plastic, machined metal)	0.010
Planed timber	0.011
Rough wood	0.012 – 0.015
Smooth concrete	0.012 – 0.013
Unfinished concrete	0.013 – 0.016
Brickwork	0.014
Rubble masonry	0.017
Earth channels, smooth no weeds	0.020
Firm gravel	0.020
Earth channel, with some stones and weeds	0.025
Earth channels in bad condition, winding natural streams	0.035
Mountain streams	0.040 – 0.050
Sand (flat bed), or gravel channels, d=median grain diameter, ft.	$0.034d^{1/6}$

Chow (1959) also provides an extensive list of n values, along with photographs. Most engineering hydrology and hydrologic texts (including McCuen 1998) will also contain extensive guidance on the selection of Manning's n values for different channel conditions. A later section in this chapter presents the usual trial-and-error method for determining Manning's n values for grass-lined channels, using measured VR-n relationships for different grass types.

3) Calculate the required cross-sectional area, using the continuity equation and the previously determined design storm peak flow rate (Q):

$$A = \frac{Q}{V}$$

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where:

A = cross-sectional area of channel (wetted portion), ft^2
Q = peak discharge for design storm being considered, ft^3/sec
V = permissible velocity, ft/sec

4) Calculate the corresponding wetter perimeter (P):

$$P = \frac{A}{R}$$

where:

P = wetted perimeter, ft
A = cross-sectional area of channel (wetted portion), ft^2
R = hydraulic radius, ft.

5) Calculate an appropriate channel base width (b) and depth (y) corresponding to a specific channel geometry (usually a trapezoid channel, having a side slope of z:1 side slopes).

Figure 7 (Chow 1959) can be used to significantly shorten the calculation effort for the design of channels, by skipping step 4 above and more effectively completing step 5. This figure is used to calculate the normal depth (y) of a channel based on the channel side slopes and known flow and channel characteristics, using the Manning's equation in the following form:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}}$$

Initial channel characteristics that must be know include: z (the side slope), and b (the channel bottom width, assuming a trapezoid or a rectangular cross-section). It is easy to examine several different channel options (varying z and b) by calculating the normal depth (y) for a given peak discharge rate, channel slope, and roughness. The most practical channel can then be selected from the alternatives.

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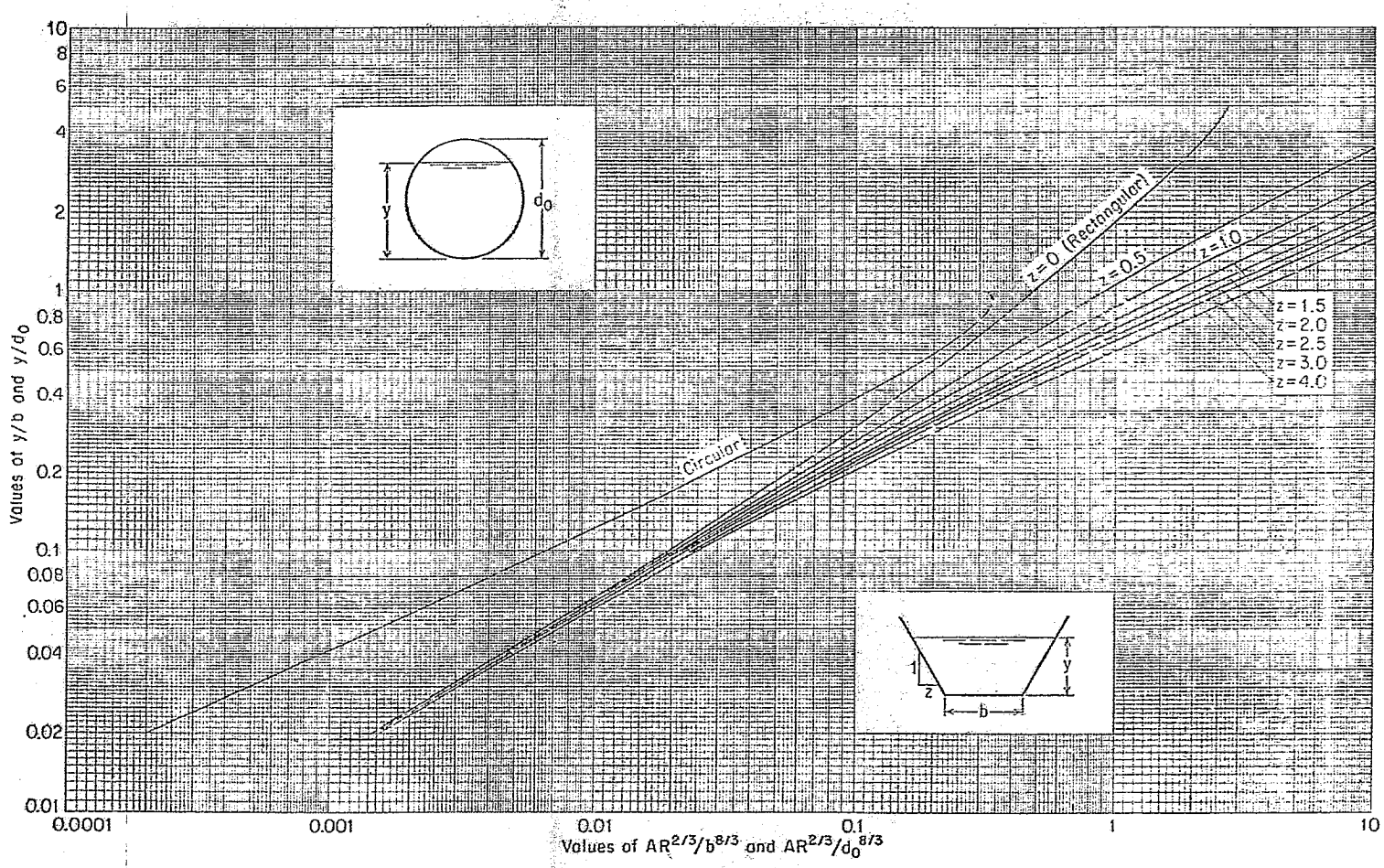

Figure 7. Chow (1959) curves for determining normal depth for various channel geometries.

As an example, assume the following conditions:

Noncolloidal alluvial silts, water transporting colloidal silts:
Manning's roughness coefficient (n) = 0.020
maximum permissible velocity (V) = 3.5 ft/sec
(the allowable shear stress is 0.15 lb/ft^2)

Peak discharge flow rate (Q) = 13 ft^3/sec

Channel slope = 1%, or 0.01 ft/ft

Therefore:

The hydraulic radius (R) using Manning's equation:

$$R = \left[\frac{Vn}{1.49S^{0.5}}\right]^{1.5} = \left[\frac{3.5(0.020)}{1.49(0.01)^{0.5}}\right]^{1.5} = 0.32\ ft.$$

The required cross-sectional area, using the continuity equation and the design storm peak flow rate (Q):

$$A = \frac{Q}{V} = \frac{13}{3.5} = 3.7\ ft^2$$

Therefore, $AR^{2/3} = (3.7)(0.32)^{2/3} = 1.7$, and the wetted perimeter is A/R = 3.7/0.32 = 12 ft. Table 3 shows the calculated normal depth (y) for different channel options that all meet the allowable velocity criteria. Also shown on this table is the calculated maximum shear stress:

$$\gamma RS = (62.4\ lb/ft^3)\ (R\ ft)\ 0.01\ ft/ft) = 0.62R$$

since the allowable shear stress is 0.15 lb/ft^2, the hydraulic radius must be less than 0.24 ft (only about 3 inches). This will require a relatively wide channel, as the hydraulic radius approximates the depth of flow for wide and shallow channels. Also, the depth of flow can be used instead of the hydraulic radius as a conservative approach to calculate the maximum shear stress, which is important for design purposes.

As the channel becomes wider, the side slopes have little effect on the normal depth and the calculated maximum shear stress, as expected. The safety factors are the ratios of the allowable shear stress (0.15 lb/ft^2) divided by the calculated maximum shear stress. None of these channels can satisfy the allowable shear stress with this natural material, unless the channel is wide. A minimum channel width between 15 and 25 ft would result in a stable channel. However, a channel liner can be used to reinforce the channel, resulting in a larger allowable shear stress, enabling a narrower channel.

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Table 3. Alternative Channel Geometries Meeting Maximum Permissible Velocity Criterion (3.5 ft/sec)

Side slope (z)	Bottom width (b), ft	$b^{8/3}$	$AR^{2/3}/b^{8/3}$	y/b	Normal depth (y), ft	Top width (T), ft	Area (A), ft^2	Wetted perimeter (P), ft	Hydraulic radius (R), ft	b/y	R/y	Maximum shear stress using y (τ), lb/ft^2	Safety factor, using the normal depth [1]	Maximum shear stress using R (τ), lb/ft^2	Safety factor, using the hydraulic radius [2]
4	2	6.4	0.27	0.32	0.62	7.0	2.8	10.6	0.26	3.2	0.42	0.32	0.39	0.16	0.92
4	4	41	0.041	0.13	0.52	8.2	3.2	10.5	0.30	7.7	0.58	0.32	0.47	0.19	0.80
4	8	260	0.0066	0.046	0.37	11.0	3.5	11.9	0.30	21.6	0.80	0.23	0.65	0.18	0.81
4	15	1400	0.0012*	0.017	0.26	17.1	4.2	17.3	0.24	57.7	0.93	0.16	0.94	0.15	0.99
4	25	5300	0.00032*	0.008	0.2	26.6	5.2	26.5	0.19	125.0	0.97	0.12	1.25	0.12	1.24
2	2	6.4	0.27	0.38	0.76	5.0	2.7	6.9	0.39	2.6	0.51	0.47	0.32	0.24	0.62
2	4	41	0.041	0.14	0.56	6.2	2.9	7.0	0.41	7.1	0.73	0.35	0.43	0.26	0.59
2	8	260	0.0066	0.049	0.39	9.6	3.4	9.7	0.35	20.5	0.91	0.24	0.63	0.22	0.68
2	15	1400	0.0012*	0.017	0.26	16.0	4.0	15.9	0.25	57.7	0.98	0.16	0.94	0.16	0.95
2	25	5300	0.00032*	0.008	0.2	25.8	5.1	25.6	0.20	125.0	0.99	0.12	1.25	0.12	1.21
1	2	6.4	0.27	0.44	0.88	3.8	2.5	5.2	0.49	2.3	0.55	0.55	0.27	0.30	0.49
1	4	41	0.041	0.16	0.64	5.3	3.0	5.8	0.51	6.3	0.79	0.40	0.38	0.32	0.47
1	8	260	0.0066	0.049	0.39	8.8	3.3	8.8	0.37	20.5	0.95	0.24	0.63	0.23	0.65
1	15	1400	0.0012*	0.017	0.26	15.5	4.0	15.4	0.26	57.7	0.99	0.16	0.94	0.16	0.93
1	25	5300	0.00032*	0.008	0.2	25.4	5.0	25.3	0.20	125.0	1.00	0.12	1.25	0.12	1.20
0.5	2	6.4	0.27	0.5	1	3.0	2.5	4.7	0.53	2.0	0.53	0.62	0.24	0.33	0.45
0.5	4	41	0.041	0.16	0.64	4.6	2.8	5.2	0.53	6.3	0.83	0.40	0.38	0.33	0.45
0.5	8	260	0.0066	0.049	0.69	8.7	5.8	9.4	0.62	11.6	0.89	0.24	0.63	0.38	0.39
0.5	15	1400	0.0012*	0.017	0.26	15.3	3.9	15.2	0.26	57.7	0.99	0.16	0.94	0.16	0.93
0.5	25	5300	0.00032*	0.008	0.2	25.2	5.0	25.1	0.20	125.0	1.00	0.12	1.25	0.12	1.20

* estimated, as these values are under range from the plotted curves.

[1] safety factor is the ratio of the allowable shear stress/ max. shear stress using y, allowable shear stress = 0.15 lb/ft^2

[2] allowable shear stress/ max. shear stress using R, allowable shear stress = 0.15 lb/ft^2

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Table 3 compares the shear stress calculated using the hydraulic radius, R, to the larger shear stress calculated using the normal depth, y. Also shown is the ratio of the hydraulic radius to the normal depth for different channel conditions. Figure 8 is a plot showing how the normal depth approaches the hydraulic depth, for this example, as the channel width to normal depth ratios increase. The maximum shear stress is therefore much larger when the normal depth is used instead of the hydraulic radius for relatively narrow channels, but the results are similar for wider channels.

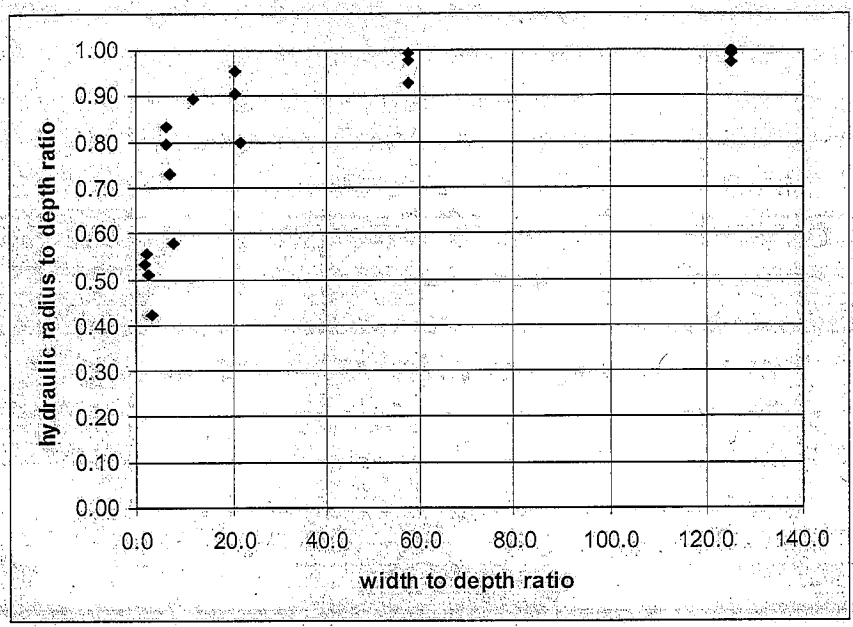

Figure 8. Relationship of hydraulic radius to normal depth for different channel width to depth conditions.

A more direct approach is to use Figure 7 in reverse order. As shown previously, the maximum depth can be calculated based on the maximum allowable shear stress and the channel slope:

$$D = \frac{\tau_c}{\gamma S} = \frac{0.15 lb/ft^2}{(62.4 lb/ft^3)(0.01 ft/ft)} = 0.24 ft$$

With the known value for $AR^{2/3}$ ($3.7 \times 0.32^{2/3} = 1.7$), Table 4 shows the calculated maximum side slope for different channel bottom widths (b). All of these options will therefore meet both the allowable velocity and shear stress criteria.

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Table 4. Example Calculations for Required Side Slopes for Different Bottom Widths, Meeting Allowable Velocity and Maximum Shear Stress Criteria

b (ft)	y/b (with y = 0.24ft)	$AR^{2/3}/b^{8/3}$	Required side slope (z), or longer
8	0.030	0.0066	>4
10	0.024	0.0036	>4
15	0.016	0.0012*	5 (?)
20	0.012	0.00057*	any (0.5 to 4)

* estimated, as these values are under range from the plotted curves.

For this example, side slopes of about 5:1 and with a bottom width of 15 ft may be stable, or "any" side slope may be suitable for bottom widths of 20 ft, or wider. This example has shown that it may not be possible to design a stable channel only based on allowable maximum velocity. It is a good idea to also calculate the maximum shear stress, based on the normal depth. Without a channel liner, most stable channels in soils will need to be relatively wide. Because of the increased use of land needed for wide channels (see the calculated top width "T" in Table 3), it is usually necessary to consider channel liners, either grass-lined, or re-enforced with netting mats, as described in the following sections.

Design of Grass-Lined Channels

According to Temple, *et al.* (1987) in *Stability Design of Grass-Lined Open Channels*, USDA Agricultural Handbook # 667, it is assumed that grass channel linings are used to protect an erodible soil boundary and prevent channel degradation. They found that detachment begins at levels of total stress low enough to be withstood by the vegetation without significant damage to the plants themselves; it is possible for the vegetation to be undercut and the weaker vegetation washed away. This vegetation loss decreases the density and uniformity of the vegetative cover, which in turn leads to greater stresses at the soil-water interface, resulting in an increased erosion rate. Supercritical channel flows cause a more severe problem compared to subcritical flows because small irregularities in the channel lining cause stress concentrations to develop during supercritical flow conditions. For very erosion-resistant soils, the lining vegetation may sustain damage before the effective stress at the soil-water interface becomes large enough to detach soil material. Although the limiting condition in this case is the stress on the plants, failure progresses in a similar manner: damage to the plant cover results in an increase in effective stress on the soil boundary until conditions critical to erosion are exceeded. The resulting erosion further weakens the cover, and unraveling occurs. When plant failure occurs, it is a complex process involving removing young and weak plants, shredding and tearing of leaves, and fatigue weakening of stems.

Because of the many uncertainties and different methods of failure, the use of an approximate design approach is considered appropriate for most practical applications. Temple, *et al.* (1987) state that conservative design criteria are required, as the potential for rapid unraveling of a channel lining can occur once a weak point has developed; especially considering the variability of vegetative covers. Very dense and uniform covers will likely withstand stresses substantially larger than immature or spotty covers, without significant damage. However, they recommend that poor maintenance should be assumed in conservative designs.

The design of a grass-lined open channel differs from the design of an unlined or structurally lined channel in that (1) the flow resistance is dependent on channel geometry and discharge, (2) a portion of the boundary stress is associated with drag on individual vegetation elements and is transmitted to the erodible boundary through the plant root system, and (3) the properties of the lining vary both randomly and periodically with time. Each of these differences requires special considerations in the design process. Temple, *et al.* (1987) presents detailed descriptions of the generalized step-by-step procedure for grass-lined channel design, including computer codes.

Plant Species Selection for Vegetative-Lined Channels

The following is a general discussion and does not provide site-specific guidance for different climatic regions. However, it does describe the general problems associated with establishing plants in a channel environment. Local guidance (such as from local USDA or University Extension services) needs to be sought for specific recommendations for a specific location. Obviously, channels carrying water for long periods of the year may not be

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suitably lined with terrestrial vegetation. Extended wet periods will also affect plant selection. Again, local plant specialists need to be consulted for the proper selection of suitable plants for the anticipated growing conditions. The *Alabama Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Sites and Urban Areas* (USDA 2003) contains further general guidance on plant selection for Alabama uses, for example.

Site Considerations

When a site will receive heavy use, plant species should be selected that are wear resistant and have rapid wear recovery, such as bermudagrass. Bermudagrass also has a fast establishment rate and is adapted to many geographical areas. Where a neat appearance is desired, plants that respond to frequent mowing should be used. Likely choices for quality turf in north Alabama are bermudagrass or tall fescue, while in central or south Alabama bermudagrass, centipede, or zoysia are good choices. At sites where low maintenance is desired, low fertility requirements and vegetation persistence are particularly important. Sericea lespedeza and tall fescue are good choices in north Alabama, while bahiagrass and centipede do well in central and south Alabama.

Seasonal Considerations

Growing seasons must be considered when selecting species. The most effective times for planting perennial grasses and legumes in Alabama generally extend from March through May and from late August through October. Outside these dates, the probability of failure is higher. Grasses and legumes are usually classified as warm or cool-season in reference to their season of growth. Cool-season species produce most of their growth during the spring and fall and are relatively inactive or dormant during the hot summer months. Therefore, fall is the most dependable time to plant them. Warm-season plants grow most activity during the summer, and go dormant at the first frost in the fall. Spring and early summer are the preferred planting times for warm-season species.

Plant Hardiness Zones

The US Department of Agriculture has produced plant hardiness zone maps that are normally used to help determine the suitability of different plants for an area. These maps are based on the annual average low temperatures and are therefore most appropriate for permanent vegetation. Therefore, short-term vegetation use does not necessarily have to follow the same selection guidelines needed for permanent vegetation. In all cases, it is important to contact the local NRCS office, or other erosion control specialists, for the most suitable vegetation to consider for a specific site. Figure 9 and Table 5 shows the current USDA hardiness zone map and selected cites associated with the different annual average minimum temperatures.

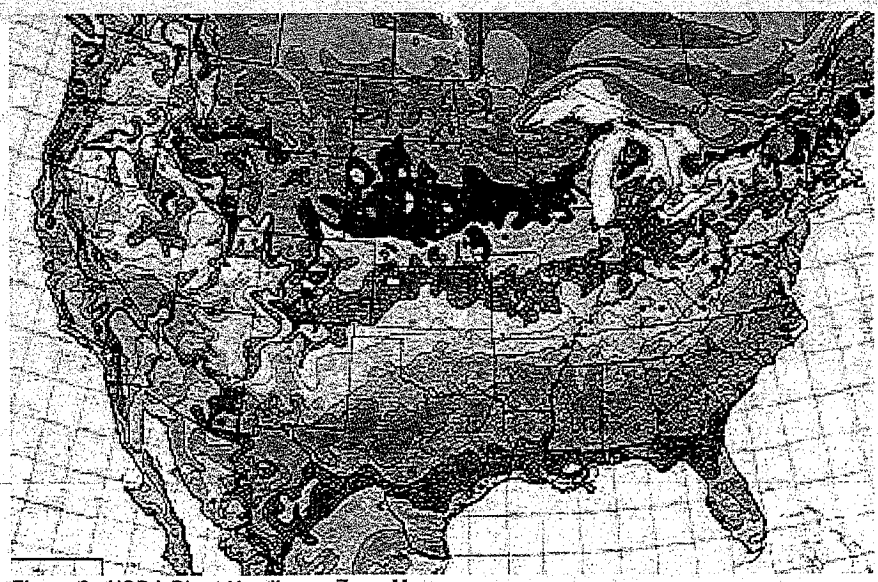

Figure 9. USDA Plant Hardiness Zone Map

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Table 5. Annual Average Minimum Temperatures for Selected Cities

Fahrenheit	Celsius	Example Cities
Below -50 F	Below -45.6 C	Fairbanks, Alaska; Resolute, Northwest Territories (Canada)
-50 to -45 F	-42.8 to -45.5 C	Prudhoe Bay, Alaska; Flin Flon, Manitoba (Canada)
-45 to -40 F	-40.0 to -42.7 C	Unalakleet, Alaska; Pinecreek, Minnesota
-40 to -35 F	-37.3 to -39.9 C	International Falls, Minnesota; St. Michael, Alaska
-35 to -30 F	-34.5 to -37.2 C	Tomahawk, Wisconsin; Sidney, Montana
-30 to -25 F	-31.7 to -34.4 C	Minneapolis/St.Paul, Minnesota; Lewistown, Montana
-25 to -20 F	-28.9 to -31.6 C	Northwood, Iowa; Nebraska
-20 to -15 F	-26.2 to -28.8 C	Des Moines, Iowa; Illinois
-15 to -10 F	-23.4 to -26.1 C	Columbia, Missouri; Mansfield, Pennsylvania
-10 to -5 F	-20.6 to -23.3 C	St. Louis, Missouri; Lebanon, Pennsylvania
-5 to 0 F	-17.8 to -20.5 C	McMinnville, Tennessee; Branson, Missouri
0 to 5 F	-15.0 to -17.7 C	Oklahoma City, Oklahoma; South Boston, Virginia
5 to 10 F	-12.3 to -14.9 C	Little Rock, Arkansas; Griffin, Georgia
10 to 15 F	-9.5 to -12.2 C	Tifton, Georgia; Dallas, Texas
15 to 20 F	-6.7 to -9.4 C	Austin, Texas; Gainesville, Florida
20 to 25 F	-3.9 to -6.6 C	Houston, Texas; St. Augustine, Florida
25 to 30 F	-1.2 to -3.8 C	Brownsville, Texas; Fort Pierce, Florida
30 to 35 F	1.6 to -1.1 C	Naples, Florida; Victorville, California
35 to 40 F	4.4 to 1.7 C	Miami, Florida; Coral Gables, Florida
above 40 F	above 4.5 C	Honolulu, Hawaii; Mazatlan, Mexico

Selecting the Right Grasses for Channel Lining

According to Temple, *et al.* (1987), the selection of grass species for use in channels is based on important site-specific factors, including: (1) soil texture, (2) depth of underlying material, (3) management requirements of vegetation, (4) climate, (5) slope, and (6) type of structure or engineering design. The expected flow rates, salt tolerance in northern areas, availability of seed, ease of stand establishment, species or vegetative growth habit, plant cover, and persistence of established species, are other factors that also should be considered in selecting appropriate grasses necessary for stable channel designs for use along roads. Channel construction should be scheduled to allow establishment of the grass stand before subjecting the channel to excessive flows. The uses of modern channel lining systems, as discussed below, help alleviate this problem. The establishment of permanent covers involves liming and fertilizing, seed bed preparation, appropriate planting dates, seeding rates, and mulching.

Plants for Temporary Channel Linings

Based on flow tests on sandy clay channels, Temple, *et al.* (1987) recommends wheat (*Triticum aestivum L.*) for winter and sudangrass [*Sorghum sudanensis* (Piper) *Hitchc.*] for late-summer temporary covers. These temporary covers have been shown to rapidly increase the permissible discharge rate to five times that of an unprotected channel. Other recommended annual and short-lived perennials that can be used for temporary channel linings include:

- barley (*Hordeum vulgare L.*), noted for its early fall growth;
- oats (*Avena) sativa L.*), in areas of mild winters;
- mixtures of wheat, oats, barley, and rye (*Secale cereale L.*);
- field bromegrass (*Bromus spp.*); and
- ryegrasses (*Lolium spp.*).

Summer annuals, including German and foxtail millets (*Setaria spp.*), pearl millet [*Pennisetum americanurn (L.) Leeke*], and certain cultivated sorghums other than sudangrass, may also be used for temporary mid- to late-summer covers, according to Temple, *et al.* (1987). Since millets do not continue to grow as aggressively as sorghums after mowing, they may leave a more desirable, uniformly thin mulch for subsequent permanent seeding. Temporary seedings involve minimal cultural treatment, short-lived but quick germinating species, and little or no maintenance. The temporary covers should be close-drilled stands and not be allowed to go to seed. The protective cover provided by the temporary vegetation should provide stalks, roots, and litter into which permanent grass seeds can be drilled the following spring or fall.

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Plants for Permanent Channel Linings

Many grasses can be used for permanent vegetative channel linings. Temple, *et al.* (1987) lists the following tight-sod-forming grasses as the most preferred warm- and cool-season grasses for channel linings: bermudagrass [*Cyodon dactylon var dactylon (L.) Pers.*], bahiagrass (*Paspalum notatum Fluggle*), buffalograss [*Buchloe dactyloides (Nutt.) Engelm.*], intermediate wheatgrass [*Agropyron intermedium (Host) Beauv.*], Kentucky bluegrass (*Poa ratensis L.*), reed canarygrass (*Phalaris arundinacea L.*), smooth bromegrass, (*Bromus inermis Leyss.*), vine mesquitegrass (*Panicum obtusum H.B.K.*), and Western wheatgrass (*Agropyron Smithii Rydb.*). These grasses are among the most widely used species for channel linings and grow well on a variety of soils. A grass mixture should include species adapted to the full range of soil moisture conditions on the channel side slopes. The local NRCS and University Extension offices know the best soil-binding grass species for a particular areas, along with the associated planting and maintenance information. The most important characteristic of the selected grasses is its ability to survive and thrive in the channel environment.

Bermudagrass is probably the most widely used grass in the southern region of the U.S. It will grow on many soil types, but may require extra management. It forms a dense and persistent sod, if managed properly. Temple, *et al.* (1987) recommend that when bermudagrass is used, winter-hardy varieties should be obtained. Improved varieties, such as "Coastal," "Midland," "Greenfield," "Tifton," and "Hardie," do not produce seed, and must be established by sprigging. Where winters are mild, channels can be established quickly with seed of "Arizona Common" bermudagrass. "Seed of bermudagrass," a new seed-propagated variety with greater winter hardiness than Arizona Common, should now be available commercially. Bermudagrass is not shade tolerant and should not be used in mixtures containing tall grasses. However, the inclusion of winter annual legumes such as hairy vetch (*Vicia villosa Roth.*), narrowleaf vetch [*V. sativa L. subspecies nigra (L.) Ehrh.*], and/or a summer annual such as Korean lespedeza (*Lespedeza stipulacea Maxim.*) may be beneficial to stand maintenance.

The selection of grasses used in channels often depends on availability of seed or plant material. Chronic national seed shortages of some warm-season grasses, especially seed of native species, have often led to planting seed marginally suited to site situations. Lack of available seed of desired grass species and cultivars adapted to specific problem sites is a major constraint often delaying or frustrating seeding programs. In addition to the grass species or base mixture of grasses used for erosion control, carefully selected special-use plants may be added for a specific purpose or situation. Desirable wildlife food plants may be included in the mixture if they do not detrimentally compete with the base grasses used for erosion control. Locally adapted legumes are often added if they are compatible with the grasses and noncompetitive. Additional information on establishment and maintenance of grass-lined channels is provided in Temple, *et al*, (1987).

Determination of Channel Design Parameters

The conditions governing the stability of a grass-lined open channel are the channel geometry and slope, the erodibility of the soil boundary, and the properties of the grass lining that relate to flow retardance potential and boundary protection.

Vegetation Parameters

The design of a stable grass-lined open channel needs to consider the effective stress imposed on the soil layer (Temple, *et al*, 1987). This requires the determination of two vegetation parameters: 1) the retardance curve index (C_I) which describes the potential of the vegetal cover to develop flow resistance, and 2) the vegetation cover factor (C_c) which describes the degree to which the vegetation cover prevents high velocities and stresses at the soil-water interface. These are described below.

Retardance Potential. The parameter describing the retardance potential of a vegetal cover is the retardance curve index, C_r. This parameter determines the limiting vegetation stress. Its relation to the measurable physical properties of the vegetal cover is given by:

$$C_I = 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}}$$

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where:

h is the representative stem length
M is the stem density in stems per unit area.

When consistent units are used, the relation is dimensionless. This factor is commonly used in the following equation to estimate the maximum allowable stress on the vegetation (τ_{va}, in lb/ft^2):

$$\tau_{va} = 0.75 C_I$$

The stem length will usually need to be estimated directly from knowledge of the vegetation conditions at the time of anticipated maximum flow. When two or more grasses with widely differing growth characteristics are involved, the representative stem length is determined as the root mean square of the individual stem lengths.

When this equation is used to estimate the retardance potential, an estimate of the stem density is also required. The reference stem densities shown in Table 6 may be used as a guide in estimating this parameter.

Table 6. Properties of Grass Channel Linings (Temple, *et al*, 1987)

Cover Factor (C_I) (good uniform stands)	Covers Tested	Reference stem density (M), stem/ft^2
0.90	bermudagrass	500
0.90	centipedegrass	500
0.87	buffalograss	400
0.87	kentucky bluegrass	350
0.87	blue grama	350
0.75	grass mixture	200
0.50	weeping lovegrass	350
0.50	yellow bluestem	250
0.50	alfalfa	500
0.50	lespedeza sericea	300
0.50	common lespedeza	150
0.50	sudangrass	50

Since cover conditions will vary from year to year and season to season, establishing an upper and a lower bound for the curve index (C_I) is often more realistic than selecting a single value. When this approach is taken, the lower value should be used in stability computations and the upper value should be used in determining channel capacity. Such an approach will normally result in satisfactory operation for lining conditions between the specified bounds. Whatever the approach used to obtain the flow retardance potential of the lining, the values selected should represent an average for the channel reach in question, since it will be used to infer an average energy loss per unit of boundary area for any given flow.

Vegetation Cover Factor. The vegetation cover factor, C_I, is used to describe the degree to which the vegetation cover prevents high velocities and stresses at the soil-water interface. Because the protective action described by this parameter is associated with the prevention of local erosion damage which may lead to channel unraveling, the cover factor should represent the weakest area in a reach, rather than an average for the cover type.

Observations of flow behavior and available data indicate that the cover factor is dominated by the density and uniformity of density in the immediate vicinity of the soil boundary. For relatively dense and uniform covers, uniformity of density is primarily dependent on the growth characteristics of the cover, which are in turn related to grass type. This relationship was used by Temple, *et al* (1987) in the development of Table 6. This table can not obviously account for such considerations as maintenance practices, or uniformity of soil fertility or moisture conditions.

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Soil Parameters

Two soil parameters are required for the application of effective stress concepts to the design of stable lined or unlined channels having an erodible soil boundary: 1) soil grain roughness (n_s), and 2) allowable effective stress (τ_a). When the effective stress approach is used, the soil parameters are the same for both lined and unlined channels, satisfying sediment transport restrictions. The relations presented here were presented by Temple, *et al* (1987) and were taken from the SCS (1977) channel stability criteria: the desired parameters, soil grain roughness and allowable stress, are determined from basic soil parameters. Ideally, the basic parameters should be determined from tests on representative soil samples from the site.

For effective stress design, soil grain roughness is defined as the roughness associated with particles or aggregates of a size that may be independently moved by the flow at incipient channel failure. Although this parameter is expressed in terms of a flow resistance coefficient (n_s), its primary importance in design of vegetated channels is its influence on effective stress, as shown below. Its contribution to the total flow resistance of a grass-lined channel is usually negligibly small.

The allowable stress is key to the effective stress design procedure. It is defined as that stress above which an unacceptable amount of particle or aggregate detachment would occur.

Noncohesive Soil. Noncohesive soils are defined as fine- or coarse-grained, based on whether d75 (the diameter for which 75 percent of the material is finer) is less than, or greater than, 0.05 in. For fine-grained soils, the soil grain roughness and allowable effective stress are constant, while for a coarse-grained soil, these parameters are a function of particle size. The allowable effective stress and roughness parameters for noncohesive soils are given in Figures 10 and 11, as a function of particle size.

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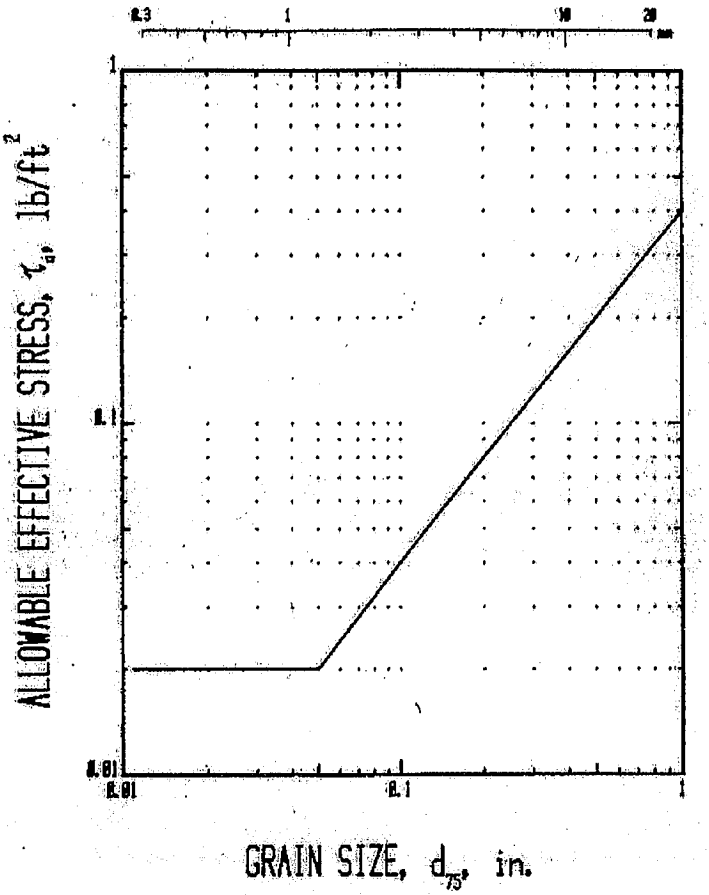

Figure 10. Allowable effective stress for noncohesive soils (Temple, *et al*. 1987).

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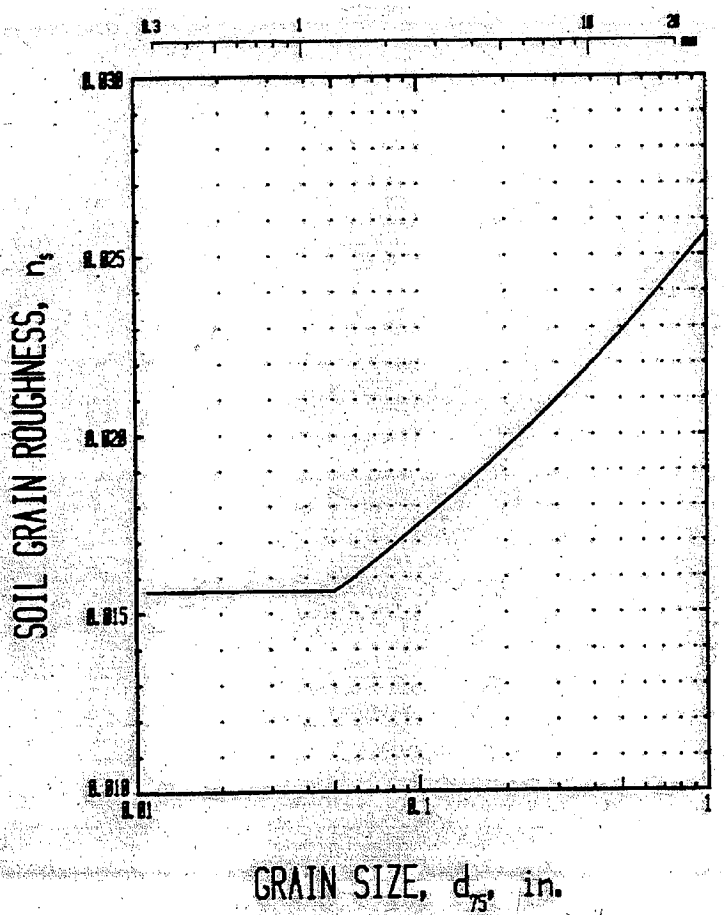

Figure 11. Soil grain roughness for noncohesive soils (Temple, *et al.* 1987).

Cohesive Soil. All cohesive soils are treated as fine-grained soils, having a constant soil grain roughness (about 0.0155, according to Figure 11). The allowable effective stresses presented here are taken directly from SCS (1977) permissible velocity design criteria. The soil properties required to determine the allowable effective stress are the soil's classification in the unified soil classification system, its plasticity index (I_w), and its void ratio (e). This calculation requires that a basic allowable effective stress (τ_{ab}) be determined from the soil classification and plasticity index. This basic value is then corrected for void ratio, according to the relation:

$$\tau_a = \tau_{ab} C_e^2$$

The basic allowable shear stress (τ_{ab}) is given in Figure 12, while the void ratio correction factor (C_e) is given in Figure 13. The soil classification information (plasticity index, I_w, and void ratio, e) are readily available for cohesive soils in standard soils references, and in Temple, *et al.* (1987).

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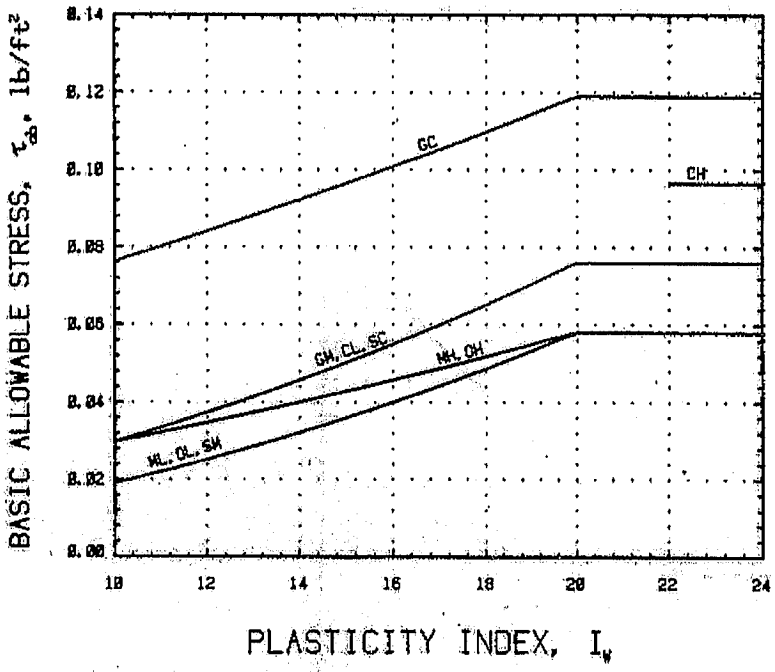

Figure 12. Basic allowable effective stress for cohesive soils (Temple, *et al*. 1987 and SCS 1977).

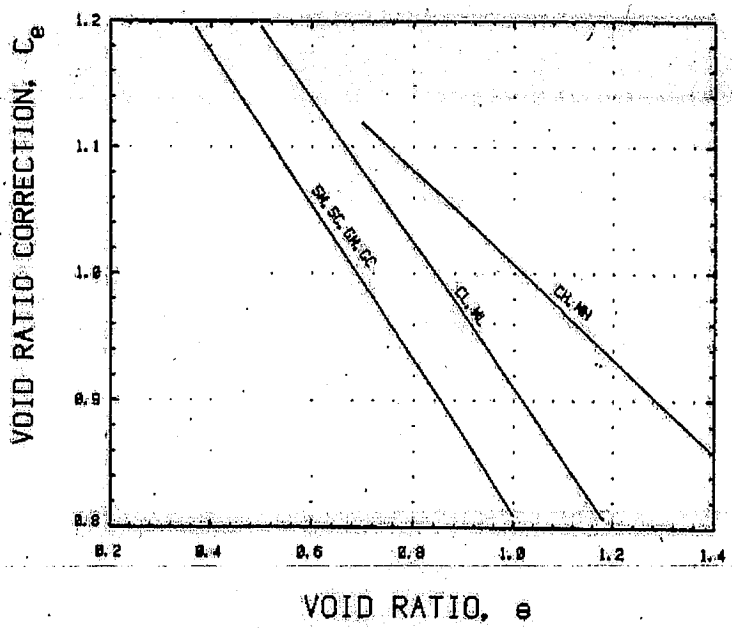

Figure 13. Void ratio correction factor for cohesive soils (Temple, *et al*. 1987 and SCS 1977).

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Selection of Roughness Factor for Grass Lined Channels

The value of Manning's "n" in grasses is a function of grass type, and the product of velocity and hydraulic radius (VR). Grasses are divided into retardance classes based on their physical characteristics (height, width, density, etc.). Most sod forming grasses are classified as type C. These grasses can have "n" values ranging from 0.03 - 0.3 depending on VR, with a typical value of 0.03 in open channels. The following example shows how the correct n value is selected through a trial-and-error method, depending on the product of the velocity (V) and hydraulic radius (R).

Example Problem for the Selection of Roughness for Grass-Lined Channels

The appropriate Manning's "n" to use varies on the time frame: bare soil retention and vegetation establishment (short-term) and for fully grassed conditions (long-term) (Chow 1959). Bare soil conditions can be examined using the procedures presented earlier. Mature grass-lined channel roughness values can be determined using typical procedures as illustrated in the following example which shows how VR-n curves can be used for the proper selection of a roughness value for a grass-lined channel:

> Determine the roughness value for a 10-year design storm of 70 ft^3/sec (2 m^3/sec) in a grass-lined drainage channel having a slope of 0.05 ft/ft and a 4 foot (1.2 m) bottom width and 1:1 side slopes. The grass cover is expected to be in retardance group D.

Long-term design, based on vegetated channel stability:

- use $Q_{peak} = Q_{10year} = 70$ ft^3/s (2 m^3/s)
- initially assume that $n_{vegetated} = 0.05$

Determine the normal depth of flow, using Figure 7 (from Chow 1959):

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}} = \frac{0.05(70cfs)}{1.49(0.05)^{0.5}} = 10.51$$

and $b^{8/3} = (4\text{ ft})^{8/3} = 40.32$

therefore $AR^{2/3}/b^{8/3} = 10.51/40.32 = 0.26$

With a 1:1 side slope trapezoidal channel, the ratio of y/b from Figure 7 is 0.43, and the depth is therefore: 4(0.43) = 1.7 ft.

The cross-sectional area is therefore 9.7 ft^2, the velocity is (70 ft^3/sec)/(9.7 ft^2) = 7.2 ft/sec, P is 8.8 ft, and R is 9.7/8.8 = 1.1 ft. VR is therefore (7.2 ft/sec)(1.1 ft) = 7.9 ft^2/sec. From Figure 14, the estimated new value for n is therefore 0.032, using a retardance class of D. The depth must therefore be recalculated, using this new value for n:

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}} = \frac{0.032(70cfs)}{1.49(0.05)^{0.5}} = 6.72$$

and $b^{8/3} = (4\text{ ft})^{8/3} = 40.32$

therefore $AR^{2/3}/b^{8/3} = 6.72/40.32 = 0.17$

With a 1:1 side slope trapezoidal channel, the ratio of y/b from Figure 7 is 0.34, and the depth is therefore: 4(0.34) = 1.4 ft.

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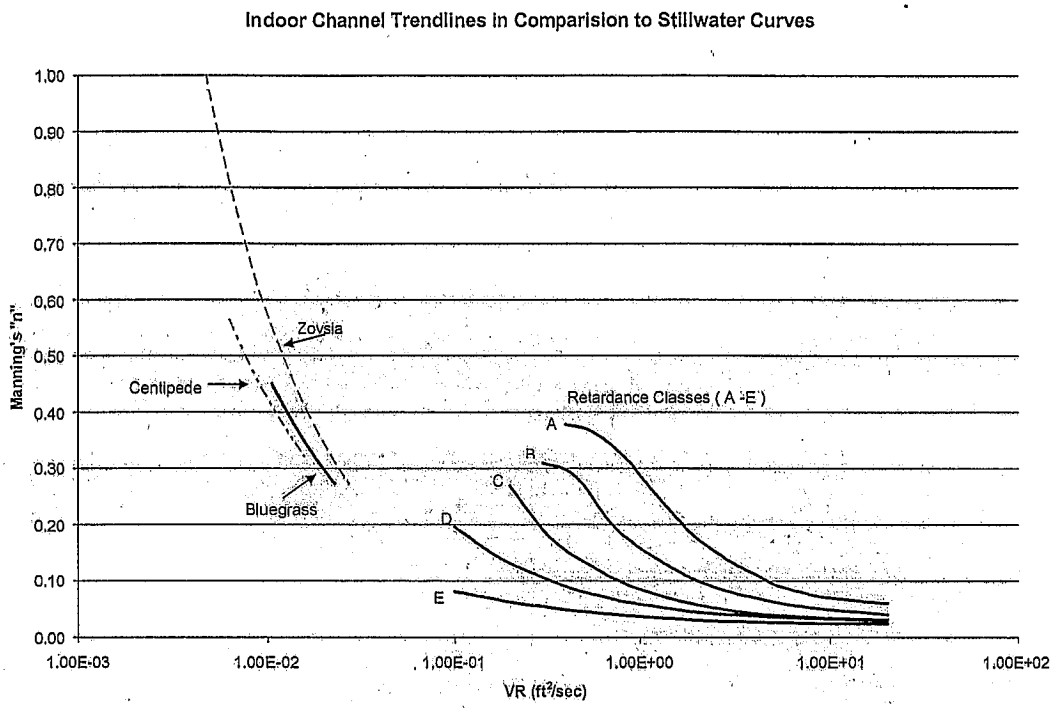

Figure 14. Hydraulic roughness of grass (Kirby 2003).

The area is therefore 7.6 ft^2, the velocity is 70/7.6 = 9.2 ft/sec, P is 8.0 ft, and R is 7.6/8.0 = 0.95 ft. The revised VR is therefore (9.2 ft/sec)(0.95 ft) = 8.7 ft^2/sec. Figure 14 shows that the revised value of n is still close to 0.032.

The maximum shear stress (using normal depth instead of hydraulic radius) is therefore:

$$\gamma DS = (62.4\ lb/ft^3)\ (1.4\ ft)\ 0.05\ ft/ft) = 4.4\ lb/ft^2$$

This channel would therefore be stable if the acceptable value is greater than this rather high value. A following discussion presents additional guidance on the selection and evaluation of a turf reinforcing mat that would likely be needed for this high shear stress condition. Currently, the use of channel lining mats protecting immature vegetation allows immediate protection of the sensitive soil boundary layer, as described in the following discussions. Also, free computer programs, such as supplied by North American Green (http://www.nagreen.com/), greatly help in the design of the most appropriate channel cross section and liner system.

Drainage Design using Turf-Reinforcing Mats

Current practice is to design channel linings based on shear stress and less on allowable velocity. Shear stress considers the weight of the water above the lining and therefore does a better job of predicting liner stability compared to only using velocity. However, allowable velocity and the flow regime (if the flow is supercritical or subcritical) still should be examined to minimize the occurrence of unusual conditions.

If a channel will have intermittent flows, it is common to use turf-reinforcing mats liners to increase the channel stability. However, if the channel will have perennial (or long-term) flows, grass will not be successful and mechanical liners must be used.

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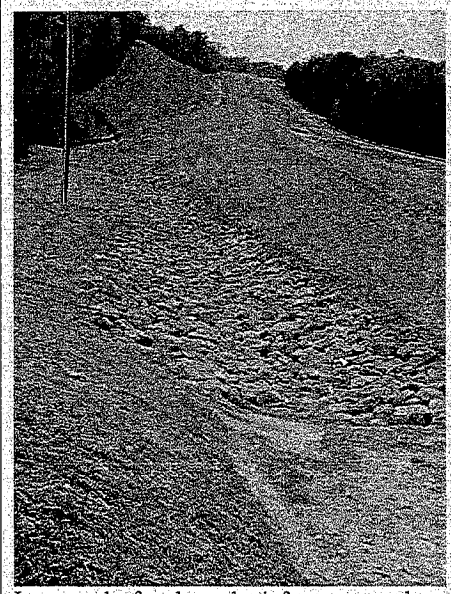
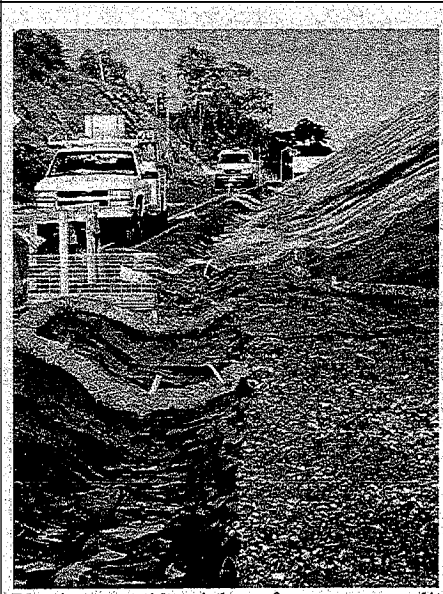
Installation of reinforced liner along thalweg of channel, with other material along sides (VA photo).



Large rocks for channel reinforcement and to reduce the velocity.



Plastic tarp, with coir logs, for a temporary liner and to slow the velocity.

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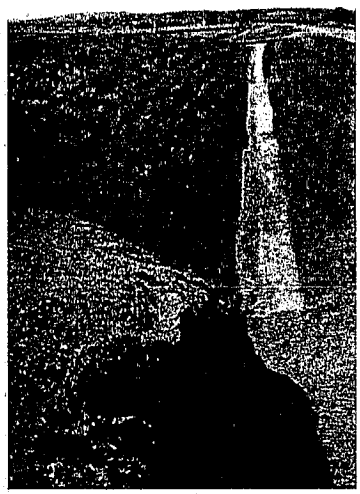

Reinforced liner along channel thalweg.



Plastic tarp used as a temporary liner.

Examples of Channels Lined with Vegetation and other Materials

According to Croke (2000), drainage channel design using turf reinforcement mats must consider three phases: (1) the original channel in an unvegetated state to determine if the matting alone will provide the needed protection before the vegetation is established, (2) the channel in a partially vegetated state, usually at 50% plant density, and (3) the permanent channel condition with vegetation fully established and reinforced by the matting's permanent net structure. The basic shear stress equation can be modified to predict the shear stress applied to the soil beneath a channel mat (Temple, *et al.* 1987):

$$\tau_e = \gamma DS\left(1 - C_f\right)\left(\frac{n_s}{n}\right)^2$$

where:

τ_e = effective shear stress exerted on soil beneath vegetation
γ = specific weight of water (62.4 lbs/ft^3)
D = the maximum flow depth in the cross section (ft)
S = hydraulic slope (ft/ft)
C_f = vegetation cover factor (this factor is 0 for an unlined channel)
n_s = roughness coefficient of underlying soil
n = roughness coefficient of vegetation and/or erosion control blanket (if vegetated, or not)

The flow depth, rather than the hydraulic radius, is used in this equation because this will result in the maximum shear stress developed, rather than the average stress (Temple, *et al.* 1987), plus the depth value is very close to the hydraulic radius for most channels, especially as sheetflow conditions are approached. The cover factor is a function of the grass and stem density, as previously described, while the roughness coefficients are standard Manning's roughness values for channels. The permissible shear stress for a liner mat should also be available from manufacture's specifications, but it will vary for different growth phases, if vegetated. Obviously, the liner matting

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significantly reduces the shear stress exerted on the soil. The following tables summarize some typical values for some of these equation parameters for turf-reinforcing mats, for different products supplied by North American Green (from www.nagreen.com). Included on these tables are conservation factor, C, values used in RUSLE for slope protection, along with roughness coefficients and maximum permissible shear stress values used in channel lining analyses. Only the P300 and C350 mats shown here are permanent liners and therefore have different values for different plant growth stages.

S75 straw erosion control blanket (12 month life; 314 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):		Channel Roughness Coefficients (n)	
	Slope Gradient (S)	Flow depth	Manning's n (unvegetated)
Slope length (L)	All ≤ 3:1 slope:	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.029	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.110	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.190	Max. permissible shear stress: 1.55 lbs/ft^2 (74.4 Pa)	

S150 straw erosion control blanket (12 month life; 323 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):			Channel Roughness Coefficients (n)	
	Slope Gradient (S)		Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.004	0.106	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.062	0.118	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.120	0.180	Max. permissible shear stress: 1.75 lbs/ft^2 (84.0 Pa)	

S150BN straw erosion control blanket (10 month life; 352 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):			Channel Roughness Coefficients (n)	
	Slope Gradient (S)		Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≤ 0.50 ft (0.15 m)	0.055
≤ 20 ft (6 m)	0.00014	0.039	0.50 – 2.00 ft	0.055 - 0.021
20 to 50 ft	0.010	0.070	≥ 2.00 ft (0.60 m)	0.021
≥ 50 ft (15 m)	0.020	0.100	Max. permissible shear stress: 1.85 lbs/ft^2 (88.0 Pa)	

SC150 straw erosion control blanket (24 month life; 424 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.050
≤ 20 ft (6 m)	0.001	0.048	0.100	0.50 – 2.00 ft	0.050 - 0.018
20 to 50 ft	0.051	0.079	0.145	≥ 2.00 ft (0.60 m)	0.018
≥ 50 ft (15 m)	0.100	0.110	0.190	Max. permissible shear stress: 2.00 lbs/ft^2 (96.0 Pa)	

SC150BN straw erosion control blanket (18 month life; 424 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.050
≤ 20 ft (6 m)	0.00009	0.029	0.063	0.50 – 2.00 ft	0.050 - 0.018
20 to 50 ft	0.005	0.055	0.092	≥ 2.00 ft (0.60 m)	0.018
≥ 50 ft (15 m)	0.010	0.080	0.120	Max. permissible shear stress: 2.10 lbs/ft^2 (100 Pa)	

C125 coconut fiber erosion control blanket (36 month life; 274 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.022
≤ 20 ft (6 m)	0.001	0.029	0.082	0.50 – 2.00 ft	0.022 – 0.014
20 to 50 ft	0.036	0.060	0.096	≥ 2.00 ft (0.60 m)	0.014
≥ 50 ft (15 m)	0.070	0.090	0.110	Max. permissible shear stress: 2.25 lbs/ft^2 (108 Pa)	

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C125BN coconut fiber erosion control blanket (24 month life; 360 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):				Channel Roughness Coefficients (n)	
	Slope Gradient (S)			Flow depth	Manning's n (unvegetated)
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	≤ 0.50 ft (0.15 m)	0.022
≤ 20 ft (6 m)	0.00009	0.018	0.050	0.50 – 2.00 ft	0.022 – 0.014
20 to 50 ft	0.003	0.040	0.060	≥ 2.00 ft (0.60 m)	0.014
≥ 50 ft (15 m)	0.007	0.070	0.070	Max. permissible shear stress: 2.35 lbs/ft^2 (112 Pa)	

P300 polypropylene fiber erosion control blanket (permanent use; 456 g/m^2 mass per unit area)

RUSLE Conservation coefficients (C):	Slope Gradient (S)			Channel Roughness Coefficients (n)		Maximum Permissible Shear Stress	
Slope length (L)	≤ 3:1	3:1 to 2:1	≥ 2:1	Flow depth	Manning's n (unvegetated)		
≤ 20 ft (6 m)	0.001	0.029	0.082	≤ 0.50 ft (0.15 m)	0.049 – 0.034	Unvegetated	3.00 lb/ft^2 (144 Pa)
20 to 50 ft	0.036	0.060	0.096	0.50 – 2.00 ft	0.034 – 0.020	Partially vegetated	5.50 lb/ft^2 (264 Pa)
≥ 50 ft (15 m)	0.070	0.090	0.110	≥ 2.00 ft (0.60 m)	0.020	Fully vegetated	8.00 lb/ft^2 (383 Pa)

Additional permissible shear stress information for vegetated North American Green products (permanent liners):

	Manning's roughness coefficient (n) for flow depths:			Maximum Permissible Shear Stress	
Vegetated blanket type[1]:	0 to 0.5 ft	0.5 to 2 ft	>2 ft.	Short duration (<2 hours peak flow)	Long duration (>2 hours peak flow)
C350 Phase 2	0.044	0.044	0.044	6.00 lb/ft^2 (288 Pa)	4.50 lb/ft^2 (216 Pa)
P300 Phase 2	0.044	0.044	0.044	5.50 lb/ft^2 (264 Pa)	4.00 lb/ft^2 (192 Pa)
C350 Phase 3	0.049	0.049	0.049	8.00 lb/ft^2 (384 Pa)	8.00 lb/ft^2 (384 Pa)
P300 Phase 3	0.049	0.049	0.049	8.00 lb/ft^2 (384 Pa)	8.00 lb/ft^2 (384 Pa)

[1] Phase 2 is 50% stand maturity, usually at 6 months, while Phase 3 is mature growth

Values of C_f, the grass cover factor, were given in Table 6 (Temple, *et al.* 1987). They recommend multiplying the stem densities given by 1/3, 2/3, 1, 4/3, and 5/3, for poor, fair, good, very good, and excellent covers, respectively. C_f values for untested covers may be estimated by recognizing that the cover factor is dominated by density and uniformity of cover near the soil surface: the sod-forming grasses near the top of the table have higher C_f values than the bunch grasses and annuals near the bottom. For the legumes tested (alfalfa and lespedeza sericea), the effective stem count for resistance (given on the table) is approximately five times the actual stem count very close to the bed. Similar adjustment may be needed for other unusually large-stemmed, branching, and/ or woody vegetation.

As an example, consider the following conditions for a mature buffalograss on a channel liner mat:

$\tau_o = \gamma DS = 2.83$ lb/ft^2 (previously calculated), requiring a NAG P300 permanent mat, for example
n_s for the soil is 0.016
n for the vegetated mat is 0.042
C_f for the vegetated mat is 0.87

The permissible shear stress for the underlying soil is 0.08 lb/ft^2

Therefore:

$$\tau_e = 2.83(1-0.87)\left(\frac{0.016}{0.042}\right)^2 = 0.053 \text{ lb/ft}^2$$

The calculated shear stress being exerted on the soil beneath the liner mat must be less than the permissible shear stress for the soil. In this example, the safety factor is 0.08/0.053 = 1.5 and the channel lining system is expected to be stable.

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An example of a permanent channel design and the selection of an appropriate reinforced liner is given below. The following example is for a channel that collects runoff from 14.6 acres. This channel is 900 ft. long and has an 8% slope. The peak discharge was previously calculated to be 29 ft^3/sec.

Using the Manning's equation and the VenTe Chow (1959) shortcut on channel geometry (Figure 7):

$$AR^{\frac{2}{3}} = \frac{nQ}{1.49S^{0.5}}$$

Where n = 0.02
Q = 29 CFS
S = 8% (0.08)

$$AR^{\frac{2}{3}} = \frac{(0.02)(29)}{1.49(0.08)^{0.5}} = 1.38$$

The following drawing illustrates the channel components for this basic analysis:

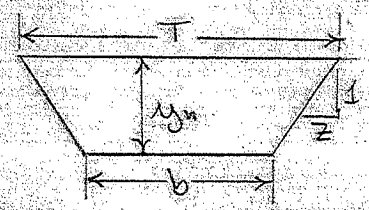
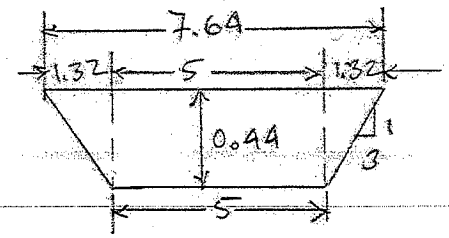


Figure 7 can be used to determine the normal depth (y_n) for many combinations of bottom with (b), and side slope (z). As an example, assume that the bottom width is 5 ft. and the side slope parameter, z, is 3. The calculated $AR^{2/3}$ value (1.38) needs to be divided by $b^{8/3}$ ($5^{8/3}$ = 73.14) for the shape factor used in Figure 7. This value is therefore: 1.38/73.14 = 0.018. For a side slope of z = 3, the figure indicates that the ratio of the depth to the bottom width (y/b) is 0.088. In this example, the bottom width was 5 ft, so the normal depth is: y_n = 0.088 (5 ft.) = 0.44 ft., which is only 5.3 inches. The following shows these dimensions on the channel cross-section:



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It is now possible to calculate the velocity and shear stress associated with this set of channel conditions:

$A = [(7.64+5)/2]\ (0.44) = 2.78\ ft^2$
$V = Q/A = 29\ ft^3/sec/2.78\ ft^2 = 10.4\ ft/sec$
$R = A/P$, and $P = 5 + 2(3.16)(0.44) = 7.78$ ft.; $R = A/P = 2.78\ ft^2/7.78$ ft. $= 0.36$ ft.

and $\tau = \gamma RS = (62.4 lb/ft^3)(0.36\ ft.)(0.08) = 1.8\ lb/ft^2$

With a velocity of 10.4 ft/sec and a shear stress of 1.8 lb/ft^2, it is obvious that some type of channel reinforcement will be needed (refer to Table 2), or another design option. Using Figure 7, plus liner information (such as listed previously), it is possible to create a simple spreadsheet with multiple cross section and liner alternatives, as shown in Table 7. Table 7 shows the unvegetated conditions and calculations, along with the phase 2 and phase 3 vegetation conditions, for several channel cross-sections, considering both NAG P300 and C350 permanent channel liner mats. The shear stress values are calculated using the normal depth of flow, for worst-case design conditions, and not the hydraulic radius.

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Table 7. Characteristics for Alternative Designs for Drainage Channel (Q = 29 ft³/sec and S = 8%)

		Unvegetated NAG P300, n = 0.02 (allowable shear stress = 3.0 lb/ft²) [data not given for C350, assumed to be similar to P300 for this example]					Channel with Reinforced Liner and Vegetation						
Bottom width (b), ft	Side slope (z)	Normal depth (y_n), ft	Top width (T), ft	Hydraulic radius (R), ft	Shear stress (τ), lb/ft² (using depth)	Velocity (V), ft/sec	Assumed NAG material and growing conditions	Manning's roughness (n)	Normal depth (y_n), ft	Shear stress (τ), lb/ft² (using depth and peak Q)	Peak Velocity (V), ft/sec	Allowable shear stress for NAG product (short and long exposures), lb/ft²	Effective soil shear stress (τ_e), $n_s = 0.016$; $C_f = 0.50$ phase 2 $C_f = 0.87$ phase 3
3	1	0.63	4.3	0.48	3.1	12.7	P300 phase 2	0.044	0.80	4.0	9.5	5.5/4.0	0.26
							P300 phase 3	0.049	0.89	4.4	8.4	8.0/8.0	0.06
6	4	0.31	8.5	0.26	1.5	12.9	P300 phase 2	0.044	0.57	2.8	6.1	5.5/4.0	0.19
							P300 phase 3	0.049	0.65	3.2	5.2	8.0/8.0	0.04
8	4	0.30	10.4	0.14	1.5	11.0	P300 phase 2	0.044	0.54	2.7	5.3	5.5/4.0	0.18
							P300 phase 3	0.049	0.88	4.4	3.4	8.0/8.0	0.06
5	3	0.44	7.6	0.36	2.2	10.4	C350 phase 2	0.044	0.66	3.3	6.3	6.0/4.5	0.22
							C350 phase 3	0.049	0.70*	3.5*	5.8*	8.0/8.0	0.05*
6	1.5	0.43	7.3	0.38	2.1	10.1	C350 phase 2	0.044	0.68	3.4	6.1	6.0/4.5	0.22
							C350 phase 3	0.049	0.72	3.6	5.7	8.0/8.0	0.05
10	3	0.26	11.6	0.26	1.3	10.4	C350 phase 2	0.044	0.49	2.4	5.2	6.0/4.5	0.16
							C350 phase 3	0.049	0.52	2.6	4.8	8.0/8.0	0.04

* example calculations for permanent C350 liner, 5 ft bottom width, z=3 side slope, and phase 3 vegetation plant stage (mature):

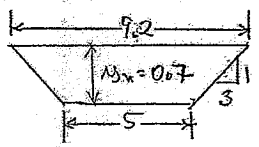
$$\frac{AR^{\frac{2}{3}}}{b^{8/3}} = \frac{nQ}{1.49S^{0.5}} \frac{(0.049)(29)}{1.49(0.08)^{0.5}} = 3.38$$

$b^{8/3} = 5^{8/3} = 73.1$

$AR^{2/3}/b^{8/3} = 3.38/73.1 = 0.046$

With $z = 3$, $y/b = 0.14$

Therefore $y_n = 0.14\ (5) = 0.7$ ft



$A = [(5+9.2)/2]\ (0.7) = 4.97\ ft^2$

$P = 5 + 2(1.21) = 7.42$ ft

$R = A/P = 4.97/7.42 = 0.67$

$\tau = \gamma RS = (62.4 lb/ft^3)(0.67\ ft.)(0.08) = 3.34\ lb/ft^2$ (analysis case using hydraulic radius)

$\tau = \gamma DS = (62.4 lb/ft^3)(0.70\ ft.)(0.08) = 3.49\ lb/ft^2$ (design case using normal depth)

$V = Q/A = 29\ ft^3/sec/4.97\ ft^2 = 5.8$ ft/sec

$$\tau_e = \gamma DS\left(1 - C_f\right)\left(\frac{n_s}{n}\right)^2 = 3.49 lb/ft^2 (1 - 0.87)\left(\frac{0.016}{0.049}\right)^2 = 0.048 lb/ft^2$$

$n_s = 0.016$; $C_f = 0.87$ phase 3

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Based on these calculations, either the P300 or the C350 liner will be suitable for most conditions for this example. When newly placed, with no vegetation growth, the Manning's n roughness is 0.02 for these liners. The maximum calculated maximum shear stress is 3.1 lb/ft^2 for the narrowest cross section examined, slightly greater than the maximum allowable value of 3.0 lb/ft^2. The calculated shear stresses are less than this allowable maximum value for the other cross-sections. Therefore, one of the wider channels should be used. Unfortunately, the velocities are all very high, ranging from 10.1 to 12.9 ft/sec before the establishment of vegetation. The use of check dams is therefore highly recommended for this channel. These can range from coir logs, to rock check dams.

The calculations after vegetative growth show that the either liner is also acceptable. A range of conditions were examined for phase 2 (50% stand maturity) and phase 3 (mature growth), with Manning's roughness values of 0.044 and 0.049. The smallest (and steepest side sloped) channel resulted in the highest shear stress of 4.4 lb/ft^2, less than the maximum acceptable values. The short exposure critical values are for peak flows of <2 hours peak flow durations. After mature plant establishment in the channel, the maximum allowable shear stress increases to 8.0 lb/ft^2 for all conditions. The effective soil shear stress is also shown, which would be applicable for temporary channel liners. During the phase 2 plant growth stage (50% plant growth), the resulting values are larger than typical soil tolerance conditions, while they are acceptable during the phase 3 growth stage (mature plant growth). This emphasizes the need for a permanent liner in this case where the additional protection provided by the vegetation is not necessary. The steep slope (8% in this case) results in these relatively extreme solutions. If the slope for this example was about 2%, or less, temporary liners may be suitable (assuming that suitable growth conditions exist).

Summary

This chapter reviewed several techniques for designing stable channels. The shear stress method was shown to be generally necessary for channel design, compared to only using an allowable velocity approach. However, liner vegetation in erosion resistant soils may still fail due to vegetation damage, requiring careful plant selection, and possibly turf-reinforcing mats.

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Chapter 2: Historical Use of Grass Swales for Stormwater Quality Control

Introduction

The treatment of stormwater is becoming more demanding as land development and urbanization increase nationwide. Urbanization changes the dynamics of stormwater conveyance systems by increasing the amounts of impervious areas. Impervious surfaces (such as a paved streets or parking lots) significantly reduce stormwater infiltration, resulting in increased stormwater runoff volumes and associated contaminant discharges. Even low density residential areas (less than 4 units/hectare) can have significant impacts on water quality by increasing phosphorus discharges 5 to 10 times over undisturbed forested areas (Dennis 1985). Moreover, urbanization radically changes the stream hydrologic balance. Research conducted by Sovern and Washington (1997) showed that the frequency of high flow rates in urbanized areas can be 10 to 100 times more than in predevelopment areas in Western Washington. They also reported decreases of low flows during dry periods, and increases in the sediment and pollutant discharges from urbanized watersheds.

Among the various stormwater management practices, grass swales are cost efficient and a proven method to treat stormwater runoff. A grass swale is a broad, shallow open channel covered by dense vegetation on the sides and bottom of a channel as an alternative to conventional stormwater conveyance such as curbs and gutters (Kirby 2003). Grass swales are often the preferred stormwater design control practice over other practices particularly because of performance and low cost, but many public works departments and developers resist their use due to perceived maintenance issues and the implication of substandard developments. Grass swales can be applied in most regions of the country where grass can be established and maintained in local climates and soils, and where sufficiently frequent rains occur for irrigation. They are not applicable in arid areas where insufficient moisture is available to keep the grass healthy. Vegetated swales cost much less to construct and maintain than curbs and gutters with underground storm sewers. As an example, a 10 ft wide, 1-1/2 ft deep grass swale was reported to have an average cost of about $12 per ft (SEWRPC 1991), while a a 36 inch diameter concrete pipe costs about $50 per ft (Heaney, *et al.* 2001). Curbs and gutter costs plus inlet costs would still have to be added to the conventional drainage system costs. SEWRPC (1991) estimated the annual maintenance costs for grass swales to be about $0.60 per ft per year. Conventional drainage pipes also have maintenance costs associated with cleaning the inlets and pipes of sediment, plus other periodic repairs. Overall, cost comparisons of swales with curb and gutter systems always show significant cost savings if swales are used (Heaney, *et al.* 2001). Besides the cost savings, existing natural features and processes can be utilized and integrated into the grass swale system to treat stormwater, rather than constructing and installing other more expensive stormwater controls, if properly planned prior to urbanization.

Many studies have shown that grass swales are an effective stormwater control practice in reducing runoff volume, sediments (total suspended solids, etc), nutrients (nitrate and phosphate), heavy metals (copper, cadmium, lead, and others), hydrocarbons, oil and grease. Particulates and other pollutants can have mass removal efficiencies ranging from 60 to 90%, as reported in numerous studies on both experimental and actual grass swales. For instance, Khan *et al.* (1992) observed average oil and grease removals of greater than 75% and an average total petroleum hydrocarbon removal of greater than 74% on a 60 m (196 ft) long grass swale. A number of researchers have concluded that grass swales are an effective method for treating stormwater based on actual measurements.

The Department of Civil and Environmental Engineering has been conducting research investigating the effectiveness of grass swales for treating stormwater pollutants, supported by the Water Environment Research Foundation (WERF) and the University Transportation Center of Alabama (UTCA). The prior WERF-supported research conducted by Johnson *et al.* (2003) focused on the removal of stormwater heavy metals (Cd, Cr, Cu, Pb, Fe, Hg, Ni, and Zn) and hydraulic characteristics of shallow open channel flow in grass swales.

The current UTCA-supported research provides information to (1) understand the effectiveness of grass swales for different sized particles, (2) understand the associated effects of different variables on these removals, and (3) to develop a predictive model in sediment transport in grass swales.

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To achieve these objectives, experimental grass swales were constructed and tested in an indoor greenhouse facility (Kirby 2003). The sediment-water mixture of known sediment concentrations of sieved sands and fine particles of silica were used to simulate sediment characteristics of stormwater. For the preliminary experiments, 108 samples were collected and analyzed for turbidity, total solids, and particle size distributions to investigate the effects of swale length, grass type, flow rate, slope, and duration of the experiments. After completing the initial tests, additional experiments were conducted, with 108 samples collected and analyzed for total suspended solids, total dissolved solids, and total solids greater than and less than 106 μm, plus those listed for the first set of experiments. Using the results obtained from the second set of experiments, a predictive model of sediment transport in grass swales was developed. This model is similar to past models developed by Barfield *et al.* (1979) and Deletic (2001), but is more detailed due to the investigations of very small particle sizes and it is based on actual experimental conditions in grass swales having different height grasses. The main feature of the model is that it combines recently developed swale hydraulic information by Kirby (2003) and conventional particle settling information. The experimental tests determined the varying efficiencies of trapping different particle sizes under different hydraulic conditions. Particles from about 1 to 425 μm in diameter were included in these tests.

This report also describes stormwater monitoring at a full-size outdoor grass swale (116 ft long) located adjacent to the Tuscaloosa, Alabama, City Hall during 13 storm events. Sixty nine samples were collected during these events from August to December 2004 and analyzed for turbidity, total solids, total suspended solids, total dissolved solids, and particle size distributions. Finally, the predictive model was compared with the analytical results obtained from the outdoor swale. It was found that initial sediment concentrations were also a significant factor in sediment transport. The final predictive model is therefore dependent on initial sediment concentration (low and high concentration categories) and particle size distribution, water depth (using Kirby's 2003 swale hydraulic measurements), grass height, particle settling rate (using Stoke's law), and swale length (to determine the frequency of particle settling along the length of the swale).

Terminology

The term grass swale refers to a vegetated, open channel stormwater management practice that comprises a grass-lined drainage channel. Grass filters and buffer strips applied in agricultural management practices are similar (EPA 1999; Pope and Stoltenberg 1991). The EPA Office of Water (1999) presents the following definition for these related control practices:

Grass Channel:

> "Grass channels are the most similar to a conventional drainage ditch, with the major differences being flatter slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events."

Dry Swale:

> "Dry swales are similar in design to bioretention areas. The existing soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is used under the soil bed. This system is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows through the bottom into the underdrain, which conveys treated stormwater to the drainage system."

Wet Swale:

> "Wet swales intersect the ground water, and behave almost like a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide treatment. This design also has potentially high pollutant removal. It cannot be used in residential or commercial settings because the shallow standing water in the swale is viewed as a potential nuisance by homeowners."

Vegetated Buffer Strip (VBF):

> R.P. Beasley (1978) describes a vegetated buffer strip as: "Areas seeded to grasses or legumes between strips of cultivated crops, the number and location of these are selected to give desired protection from erosion."

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Filter Strip:

Anderson (1983) defines a filter strip as: "A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater."

Reported Pollutant Removal Efficiencies for Grass Swales

Numerous studies on both experimental and actual grass swales have reported a wide range of efficiencies in reducing stormwater sediments and other pollutants. One of the main reasons for these differences is that most studies only examined concentrations in the grass swales, and did not measure volume reductions. During very low flows where shallow flow depths occur in relation to the grass height, pollutant concentration reductions can be high. However, as the flow depth increases, especially to more than 4 or 5 times the grass height, concentration reductions are greatly reduced. However, infiltration of water is usually significant in a swale-drained area. Unfortunately, not all published research reports make it clear that they only considered concentration reductions and that they did not measure flow changes, and associated pollutant mass reductions.

Most of the studies reported relatively high efficiencies in sediment removal, ranging 60% to 90%, as shown in Table 8. For example, Woodard and Rock (1995) studied phosphorus and total suspended solids retention in buffer strips (which would have shallow flows). The areas draining to the buffer strips were composed of a residential area, but in different construction phrases. Therefore, the initial total suspended solids concentrations were very high, ranging from 700 mg/L to 3,700 mg/L. The buffer strip slopes ranged from 2.3% to 12.0%, and high reductions were observed for both phosphorus and total suspended solids, ranging from 60% to 97%. Beyond 98 ft (30 m), both phosphorus and total suspended solids concentrations reached background (irreducible) concentrations. They found higher percentage reductions when the initial phosphorus and total suspended solids concentrations were higher.

Studies show that the effectiveness of grass swales in reducing soluble nutrients and metals is significant, but is highly variable, as indicated in Table 8 (Goldberg 1993; Wang *et al.* 1981). Khan *et al.* (1992) recorded average oil and grease and total petroleum hydrocarbon removals of greater than 75% for a 197 ft (60 m) long grass swale. However, studies also show that bacteria levels could increase instead of decrease in grass swales (Goldberg 1993; Wang *et al.* 1981; Seattle Metro Washington Dept. of Ecology 1981). One explanation is that bacteria thrive in the warm swale soils (EPA 1999).

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Table 8. Summary of Reported Efficiencies of Grass Swales (EPA 1999: Many of the reports were summarized by EPA, but the list was expanded to include new reports)

Study	Type	Total suspended solids (%)	Total phosphorus (%)	Total nitrogen (%)	Nitrate (%)	Metals (%)	Bacteria (%)
Goldberg (1993)	Grassed channel	67.8	4.5	N/A	31.4	42 to 62	-100
Seattle Metro and Washington Dept of Ecology (1992)	Grassed channel	60 to 83	29 to 45	N/A	25	46 to 73	-25
Wang *et al.* (1981)	Dry swale	80	N/A	N/A	N/A	70 to 80	-25
Dorman *et al.* (1989)	Dry swale	98	18	N/A	45	37 to 81	N/A
Harper (1988)	Wet swale	81 to 87	17 to 83	40 to 84	52 to 80	37 to 90	N/A
Kercher *et al.* (1983)	Dry swale	99	99	99	99	99	N/A
Koon (1995)	Wet swale	67	39	N/A	9	-35 to 6	N/A
Daniels and Gilliam (1996)	Dry swale	60 to 90	50	50	N/A	N/A	N/A
Dillaha *et al.* (1989)	Dry swale	70 to 84	61 to 79	54 to 73	N/A	N/A	N/A
Barrett *et al.* (1998)	Grass swale	25 to 80	N/A	N/A	N/A	N/A	N/A
Fletcher *et al.* (2002)	Grass swale	73 to 94	58 to 72	44 to 57	N/A	N/A	N/A
Horner and Mar (1982)	N/A	80	N/A	N/A	N/A	N/A	N/A
EPA (1999)	grass swale	81	9	38	N/A	42 to 71	N/A

Note: N/A = not available

Modeling

Despite the numerous studies that have discussed grass swale performance in reducing sediments and other pollutants, few have suggested a predictive model to describe sediment retention in the grass swales. The most cited mathematical model was developed in the 1970s at the University of Kentucky (in Lexington, USA), the "Kentucky model" (Tollner *et al.* 1976, Barfield *et al.* 1979, Hayes *et al.* 1984). Metal rods were used to simulate grass, and data were obtained by measuring sedimentation of very high concentrations of beads. Deletic (2001) suggested that the Kentucky model was not accurate for urban conditions, especially for smaller particles and low concentrations, and proposed an alternative approach.

Kentucky Model

According to the Kentucky model (Tollner, *et al.* 1976, Barfield, *et al.* 1979, Hayes, *et al.* 1984), the grass strip is divided into four separate zones: A, B, C, and D as shown in Figure 15.

- Zone A: All sediments are transported.
- Zone B: sediment is deposited all along the deposition front with slope corresponding to that required to yield a transport capacity.
- Zone C: Sediment is transported as bedload.
- Zone D: All sediment reaching the bed is trapped.

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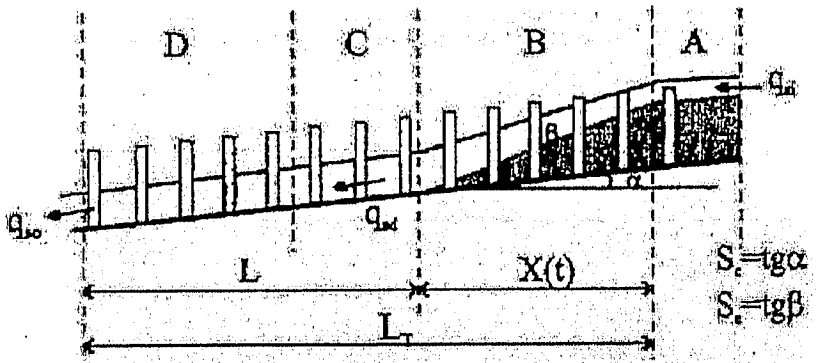

Figure 15. Schematic of sediment deposition (Tollner, *et al.* 1976; Barfield, *et al.* 1979; Hayes, *et al.* 1984).

The trapping efficiency is calculated as:

(2.1) $$Tr = \frac{q_{si} - q_{so}}{q_{si}} = 1 - \frac{q_{sd}}{q_{si}}\left[1 - \frac{q_{sd} - q_{so}}{q_{sd}}\right]$$

Where:

q_{si} = Incoming sediment load per unit channel width (g/m^2)

q_{so} = Outgoing sediment load per unit channel width (g/m^2)

q_{sd} = Total sediment load transported immediately downstream of the deposition wedge (g/m^2)

The sediment loads are calculated using the following equations:

(2.2) Zone B: $$X(t) = \frac{2(q_{si} - q_{sd})t}{\rho_{sb} g S_e}$$

Where:

$X(t)$ = Length of the swale in Zone B (m)

t = Time after beginning of the flow (s)

ρ_{sd} = Blunk density of deposited sediment (g/m^3)

g = Gravity acceleration (m/s^2)

S_e = Slope of the swale in Zone B

(2.3) Zone C: $$q_{sd} = \rho_s \sqrt{(\rho_s/\rho - 1) g d_p^{\,3}} * \left[\frac{1.08 S_e R_s}{(\rho_s/\rho - 1) d_p}\right]^{3.571}$$

Where:

ρ = Density of water (g/m^3)

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ρ_s = Density of particles (g/m^3)
d_p = Particle diameter (m)
S_c = Channel slope
R_s = Spacing hydraulic radius (m) calculated as:

(2.4) $$R_s = \frac{bh}{b+2h}$$

Where:

b = Spacing between two grass blades (m)
h = Flow depth (m)

(2.5) Zone D: $$\frac{q_{sd}-q_{so}}{q_{sd}} = \exp\left[-1.05\times10^{-3}\left(\frac{VR_s}{\nu}\right)^{0.82}\left(\frac{hV}{LV_s}\right)^{0.91}\right]$$

Where:

V = Mean flow velocity (m/s)
V_s = Terminal settling velocity of particles (Stoke's settling velocity) (m/s)
ν = Kinetic viscosity of the water sediment mixture (m^2/s)
h = Flow depth (m)
R_s = Spacing hydraulic radius (m)
$L = L_t \sim X(t)$ effective length of grass filter strip (m)
L_t = Total length of grass filter strip.

Deletic Model

Unlike the Kentucky model, Ana Deletic (2001) used substantial amounts of very fine sediments (sediment particles less than 20 μm) as well as large particles to develop a comprehensive model. The model was developed by using an artificial medium (Astroturf) mounted on a 41 ft (12.5 m) long and 1 ft (0.3 m) wide channel, to simulate actual grass. Samples were collected at various swale locations and were analyzed for particulate concentrations and size distributions. Data obtained from the experiments were used to develop the sediment transport model by incorporating the concept of particle falling number. Three major processes of sediment behavior in grass swales were modeled: (a) particle deposition, (b) sediment transport, and (3) surface level and slope changes.

(a) Particle Deposition:

The particle fall number ($N_{f,s}$) is calculated as:

(2.6) $$N_{f,s} = \frac{lV_s}{hV}$$

Where:

l = Grass length (m)
h = Depth of the flow (m)
V_s = Stoke's settling velocity (m/s)

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V = Average mean flow velocities were calculated as:

(2.7) $$V = \frac{q}{B_o h}$$

(2.8) $$V_s = \frac{g}{18\mu}(\rho_s - \rho)d_s^2$$

Where:

B_o = Open (unblocked by grass) flow width per unit width
μ = Dynamic viscosity of water (kg $s^{-1}m^{-1}$),
ρ = Water density (kg m^{-3})
d_s = Particle diameter (m)
ρ_s = Particle density (kg m^{-3}).

The trapping efficiency ($T_{r,s}$) for the sediment fraction s (particles of diameter ds) is expressed as:

(2.9) $$T_{r,s} = \frac{N_{f,s}^{0.69}}{N_{f,s}^{0.69} + 4.95}$$

(b) Sediment Transport:
Assuming that the particles transported in grass swales are very small (most of the particles are less than 20 μm (Neibling and Alberts 1979)), the model describes transport of suspended solids in grass swales. The model does not consider infiltration of water and re-suspension of deposited particles. The model is expressed as:

(2.10) $$\frac{\partial(hq_{s,s}/q)}{\partial t} + \frac{\partial q_{s,s}}{\partial x^2} = Dis\frac{\partial^2(hq_{s,s}/q)}{\partial x^2} - \lambda_s q_{s,s}$$

Where:

$q_{s,s}$ = Sediment loading rate of fraction s per unit width (g $s^{-1}m^{-1}$)
Dis = Dispersion coefficient (m^2 s)
λ_s = Trapping efficiency of fraction s per unit length (m^{-1}) calculated as:

(2.11) $$\lambda_s = \frac{T_{r,s}\left(\frac{lV_s}{Vh}\right)}{l}$$

(c) Surface Level and Slope Changes:
This model considers the channel slope changes due to deposition of sediments, especially at the upstream end of grass strips. The changes in slope (S) is expressed as:

(2.12) $$S(x,t) = -\frac{\partial z(x,t)}{\partial x}$$

Where:

$\partial z(x,t)$ = Rise in the surface level expressed as:

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$$\frac{\partial z(x,t)}{\partial t} = \frac{1}{1-p}\int_s \frac{1}{\rho_s}\lambda_s q_{s,s} d_s \quad (2.13)$$

Where:

P = Porosity of deposited sediment

$q_{s,s}$ = Sediment loading rate of fraction s per unit width ($g\ s^{-1}m^{-1}$)

d_s = Particle diameter (m)

λ_s = Trapping efficiency of fraction s per unit length (m^{-1})

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Chapter 3: Sediment Trapping Model for Grass Swales and Grass Filters

Introduction

The first set of experiments using controlled flows at indoor swale facilities were designed to initially identify the significant factors affecting trapping of particulates in grass swales. From the results of these initial experiments, more carefully designed and detailed experiments were conducted in follow-up experiments. Full-scale outdoor experiments were then conducted to verify that the variables identified in the controlled indoor experiments were valid during actual rain events and in full-scale conditions. This chapter presents a sediment trapping model for grass swales (and grass "filters") using these experimental results.

Modeling Sediment Reductions in Grass Swales

The primary focus on the second set of indoor experiments was to develop a model to predict the reduction of stormwater sediments in actual grass swales. This chapter describes the model using the analytical results (total solids, total solids less than 106 µm, total suspended solids, total dissolved solids, turbidity, and particle size distribution analyses) obtained during the second series of experiments and supplemented with the outdoor observations.

Settling Frequency

The settling frequency is the number of times that sediment particles of a specific size category would fall to the bottom of the swale through the depth of water while flowing through the swale. Particles having a large settling frequency are assumed to have higher sediment removal rates than particles having a small settling frequency.

It is likely that more than 90% of all runoff particulates are in the 1 to 100 µm range, corresponding to particles that will settle with low Reynolds's numbers, and hence laminar flow conditions, and the settling rates can therefore be calculated using Stoke's law. In most cases, stormwater particulates have specific gravities in the range of 1.5 to 2.5, while construction site runoff particles would be closer to 2.5, and silica test particles have specific gravities of 2.65. This corresponds to a relatively narrow range of settling rates for a specific particle size. Settling frequency can therefore be calculated using Stoke's law to determine the settling velocity for a specific particle size class, the length of the swale, the flow rate, and the depth of flow. Larger particles have higher chances of settling for the same flow and swale conditions than smaller particles since they have larger settling velocities. Stoke's law is commonly expressed as;

$$Vs = \frac{2}{9}\frac{\left(R^2 g\left(\rho_p - \rho_f\right)\right)}{U} \qquad (6.2)$$

Where:

Vs = Settling velocity of a particle (cm/s)
R = Equivalent radius of a particle, considering shape (cm)
g = Gravitational constant = 980 cm/s^2
ρ_p = Density of a particle = 2.65 g/cm^3 (assuming silica)
ρ_f = Density of fluid = 1.0 g/cm^3 (assuming water at standard temperature conditions)
U = Dynamic Viscosity = 0.01 g/(cm*s) (assuming water at standard temperature conditions)

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The following example is a calculation of the settling frequency for one of the experimental conditions: a silica particle whose diameter is 2 μm (2×10^{-4} cm in diameter, or 1×10^{-4} cm in radius) in a 6 ft long section of a 2 ft wide synthetic turf lined swale at 1% slope and at 10 GPM (0.038 m^3/min) flow rate. The first step is to calculate the settling velocity of the particle:

(6.3) $$Vs = \frac{2}{9} * \frac{\left((1x10^{-4} cm)^2 * 980 cm/s^2 * (2.65 g/cm^3 - 1.0 g/cm^3)\right)}{0.01 g/(cm * s)}$$

Thus:

(6.4) $Vs = 3.59*10^{-4}$ cm/s ($1.41*10^{-4}$ inch/s)

To calculate the settling duration of the 2 μm particle for the synthetic turf at 1% slope and 10 GPM (0.038 m^3/min) of flow, the averaged flow depth of the water for these experimental conditions was divided by the settling velocity of 2 μm particles. The average flow depth of water on the synthetic turf, at 1% slope and 10 GPM (0.038 m^3/min) flow rate, was 0.87 inches (2.2 cm). Thus,

(6.5) $$Settling\_Duration(second) = \frac{flow\_depth}{Settling\_velocity} = \frac{0.87(inch)}{1.41*10^{-4}(inch/s)} = \frac{2.2(cm)}{3.6*10^{-4}(cm/s)}$$

$$= 6{,}170 \text{ (seconds)}$$

The average velocity of the water flow on the synthetic turf, at 1% slope and 10 GPM (0.038 m^3/min) flow rate, was 1.86 inch (4.7 cm) /s. Since the length of the indoor swale was 6 ft (72 inches or 182.8 cm):

(6.6) $$Traveling\_time(second) = \frac{Swale\_length}{Flow\_velocity} = \frac{72(inch)}{1.86(inch/s)} = \frac{182.8(cm)}{4.7(cm/s)}$$

$$= 38.7 \text{ (seconds)}$$

The settling frequency is the number of times which a particle settles through the flow depth on a grass swale.

(6.7) $$Settling\_frequency = \frac{Traveling\_time}{Settling\_duration} = \frac{38.7(seconds)}{6170(seconds)}$$

Settling frequency = 0.0063

Therefore, the retention of 2 μm particles in this swale under these conditions is expected to be rather poor, as the particle would barely start to settle before it reached the end of the swale. The swale would have to be about 1,000 ft long (305 m) before these small particles would strike the bottom of the swale (assuming the worst case condition of the particle starting at the top of the flow depth).

The following is an example for a larger particle (100 μm in diameter, 0.01 cm diameter, or 0.005 cm in radius) during another test condition:

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(6.8) $$V_S = \frac{2}{9} * \frac{\left((0.005cm)^2 * 980cm/s^2 * (2.65g/cm^3 - 1.0g/cm^3)\right)}{0.01g/(cm*s)}$$

Vs = 0.9 cm/s (0.35 inch/s)

The flow conditions for the Zoysia-lined swale, at 3% slope and 15GPM (0.064 m^3/min) flow rate, resulted in an average flow depth of 1.91 inches.

Thus,

(6.9) $$Settling\_Duration(second) = \frac{flow\_depth}{Settling\_velocity} = \frac{1.91(inch)}{0.35(inch/s)} = \frac{4.8(cm)}{0.9(cm)}$$

= 5.4 seconds

The average flow velocity for this swale and flow condition was 1.28 inch/s (3.2 cm/s). Since the length of the indoor swale was 6 ft (72 inches or 183 cm):

(6.10) $$Traveling\_time(second) = \frac{Swale\_length}{Flow\_velocity} = \frac{72(inch)}{1.28(inch/s)} = \frac{182.8(cm)}{3.2(cm/s)}$$

= 56 seconds

The settling frequency is the number of times which a particle settles through the flowing water column while flowing along the grass swale:

(6.11) $$Settling\_frequency = \frac{Traveling\_time}{Settling\_duration} = \frac{56(seconds)}{5.4(seconds)}$$

Settling frequency = 10

This settling frequency corresponds to a very high sediment removal rate for 100 µm particles, for this flow swale condition.

Summarized Information used to Predict Grass Swale Performance

The following figures and tables summarize important information from this research, and the previous WERF work (Johnson, *et al.* 2003), to determine the hydraulic conditions in small grass swales and to predict sediment capture.

Roughness Curves

Figure 16 is the final VR-n curve developed by Kirby (2003), showing the data for the small swales (both for the controlled indoor swale tests and for outdoor tests that were conducted during the WERF research). This figure shows how the roughness relationships are extended to very high Manning's n values for small flows that occur in roadside grass swale drainages.

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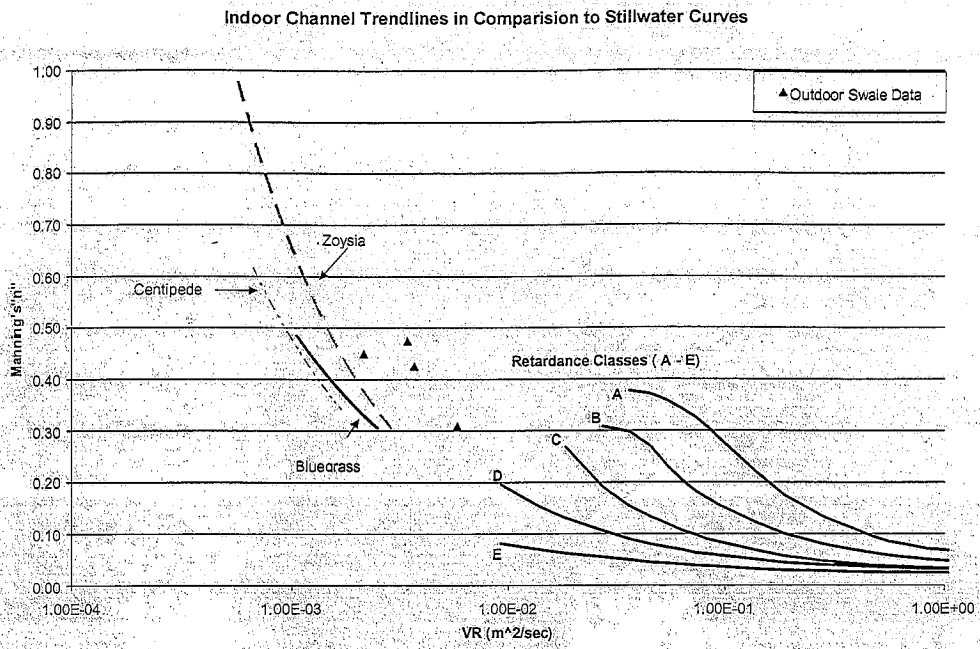

Figure 16. VR-n curve for different grasses, showing results for shallow flows (Kirby 2003) (Multiply ft^2/sec by 0.092 to obtain m^2/sec units).

Settling Frequency and Particulate Retention

Table 9 summarizes the percentage reduction values (including the confidence intervals of the means, along with the coefficient of variation (COV) values) for each set of settling frequencies for each flow depth to grass height range. These were calculated by statistically summarizing all the data observations contained in each cluster of settling frequency for all the tests combined for the indoor experiments conducted with relatively high suspended solids concentrations. Table 10 is a similar table summarizing the observations for the full-scale tests that represent shallow flows and low concentrations.

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Table 9. Statistical Summaries of the Percent Reductions for High Sediment Concentrations (200 to 1,000 mg/L) and for Different (flow depth)/(grass height) Ratio Categories

Ratio: 0 to 1.0

Settling frequency	Mean reduction (%)	95% CI (lower limit)	95% CI (upper limit)	COV
TDS (< 0.45 µm)	5	1	8	0.99
0.0013 to 0.0026	75	70	80	0.19
0.01 to 0.02	72	69	75	0.23
0.045 to 0.093	72	69	75	0.18
0.33 to 0.69	75	72	78	0.11
1.6 to 3.3	80	78	82	0.15
5.4 to 11.1	85	82	88	0.14
60.6 to 124.1	97	92	100	0.05

Ratio: 1.0 to 1.5

Settling frequency	Mean reduction (%)	95% CI (lower limit)	95% CI (upper limit)	COV
TDS (< 0.45 µm)	18	7	28	0.39
0.0013 to 0.0026	56	49	63	0.37
0.01 to 0.02	64	60	68	0.28
0.045 to 0.093	70	66	74	0.25
0.33 to 0.69	77	73	81	0.13
1.6 to 3.3	84	80	88	0.09
5.4 to 11.1	88	83	93	0.12
60.6 to 124.1	97	89	100	0.08

Ratio: 1.5 to 4.0

Settling frequency	Mean reduction (%)	95% CI (lower limit)	95% CI (upper limit)	COV
TDS (< 0.45 µm)	6	2	9	0.75
0.0013 to 0.0026	43	38	48	0.5
0.01 to 0.02	46	42	50	0.24
0.045 to 0.093	52	48	56	0.19
0.33 to 0.69	63	60	66	0.14
1.6 to 3.3	74	71	77	0.11
5.4 to 11.1	84	80	88	0.05
60.6 to 124.1	99	95	100	0.03

Table 10. Statistical Summary of the Percent Reductions for Low Sediment Concentrations (40 to 160 mg/L)

Ratio: 0 to 1.0

Settling frequency	Mean reduction (%)	95% CI (Lower limit)	95% CI (Upper limit)	COV
0.02 to 0.05	41	25	58	0.32
0.09 to 0.39	58	48	68	0.28
0.7 to 5.15	71	62	81	0.14
12.99 to 24.8	78	67	87	0.11
62.6 and larger	78	67	87	0.13

Settling Rates for Different Particle Sizes

Tables 11 through 13 summarize calculated settling rates based on Stokes' Law, as presented previously. These rates can be used to predict the capture of the sediment in these particle sizes for specific grass swale flow conditions. Tables 12 and 13 show how the settling rates vary for different specific gravities. Stormwater particulates have specific gravities of about 2.5, but they can be as low as about 1.5 under some conditions.

Table 11. Particle Settling Rates (2.65 specific gravity)

Particle size range	Approx. midpoint	Settling rate of midpoint size (cm/sec)	(in/sec)
0.45 to 2 µm	1.2	1.52×10^{-4}	5.98×10^{-5}
2 to 5 µm	3.5	1.10×10^{-3}	4.34×10^{-4}
5 to 10 µm	7.5	5.05×10^{-3}	1.99×10^{-3}
10 to 30 µm	20	3.59×10^{-2}	1.42×10^{-2}
30 to 60 µm	45	0.182	0.0717
60 to 106 µm	83	0.619	0.243
106 to 425 µm	266	6.22	2.45

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Table 12. Particle Settling Rates (2 µm particle) for Different Specific Gravities

Settling units	2.65 g/cm^3	2.5 g/cm^3	2.0 g/cm^3	1.5 g/cm^3
cm/sec	3.6×10^{-4}	3.27×10^{-4}	2.18×10^{-4}	1.09×10^{-4}
in/sec	1.42×10^{-4}	1.29×10^{-4}	8.58×10^{-5}	4.29×10^{-5}

Table 13. Particle Settling Rates (100 µm particle) for Different Specific Gravities

Settling units	2.65 g/cm^3	2.5 g/cm^3	2.0 g/cm^3	1.5 g/cm^3
cm/sec	0.899	0.818	0.545	0.273
in/sec	0.354	0.322	0.215	0.107

Example Problem

The channel and flow characteristics from the channel-lining example design in Chapter 1 will be used to predict the sediment retention in this grass swale:

- the discharge rate is 29 ft^3/sec (0.80 m^3/sec)
- the channel bottom width is 5 ft (1.5 m) wide, with 3 (H) to 1 (V) side slopes
- the calculated normal depth is 0.7 ft (210 mm, 21 cm) and the velocity is calculated to be 5.8 ft/sec (1.8 m/sec) after mature vegetation is established
- the swale length for this area is 1250 ft (378 m)

With water is assumed to enter the swale at the midpoint location, resulting in an effective treatment swale length of 625 ft (189 m). With a water velocity of 5.8 ft/sec (1.8 m/sec), the average travel time is 189 m/1.8 m/sec = 105 sec (1.8 m) for this length.

The mature grass is about 3 inches (75 mm) in height, so the flow depth to grass height ratio is 210 mm/75 mm = 2.8. The suspended solids concentration is determined to be 250 mg/L and the particle size distribution of the water entering the swale is typical, as shown on Figure 17 for the December 6, 2004 observations.

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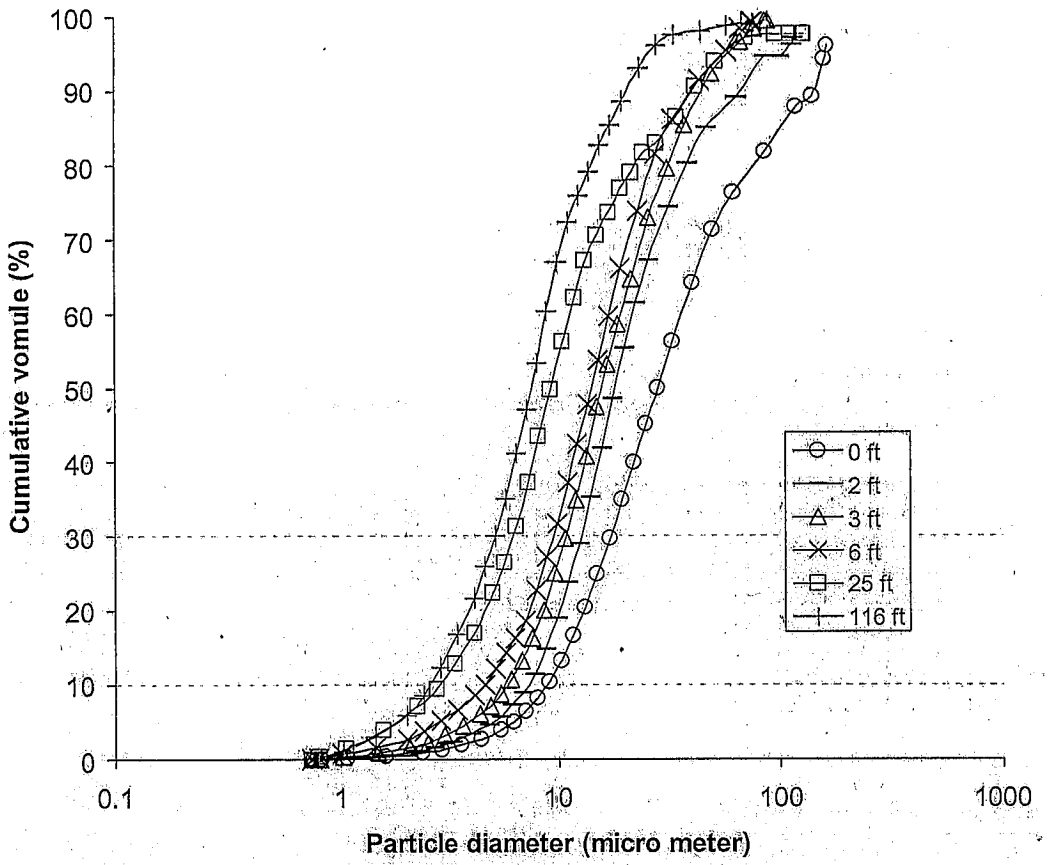

Figure 17. Example particle size distributions for different swale lengths observed on December 6, 2004.

Tables 14 and 15 show the particle size information for each size range (extracted from Figure 17) and the resulting sediment concentrations calculated using these values.

Table 14. Particle Size Distribution for Influent Water

Particle Size (µm)	% smaller than size indicated (Dec. 6, 2004 influent)
0.45	0
2	0.5
5	3.2
10	12.4
30	52.8
60	74.6
106	85.2
425	100.0

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Table 15. Particulate Concentration for Each Particle Range

Particle Size Range	Approx. % of Suspended Solids in Range	Particulate Concentration in Size Range
0.45 to 2 µm	0.5	1.3
2 to 5 µm	2.7	6.8
5 to 10 µm	9.2	23.0
10 to 30 µm	40.4	101.0
30 to 60 µm	21.8	54.4
60 to 106 µm	10.6	26.5
106 to 425 µm	14.8	37.0
Total:	100.0	250 mg/L

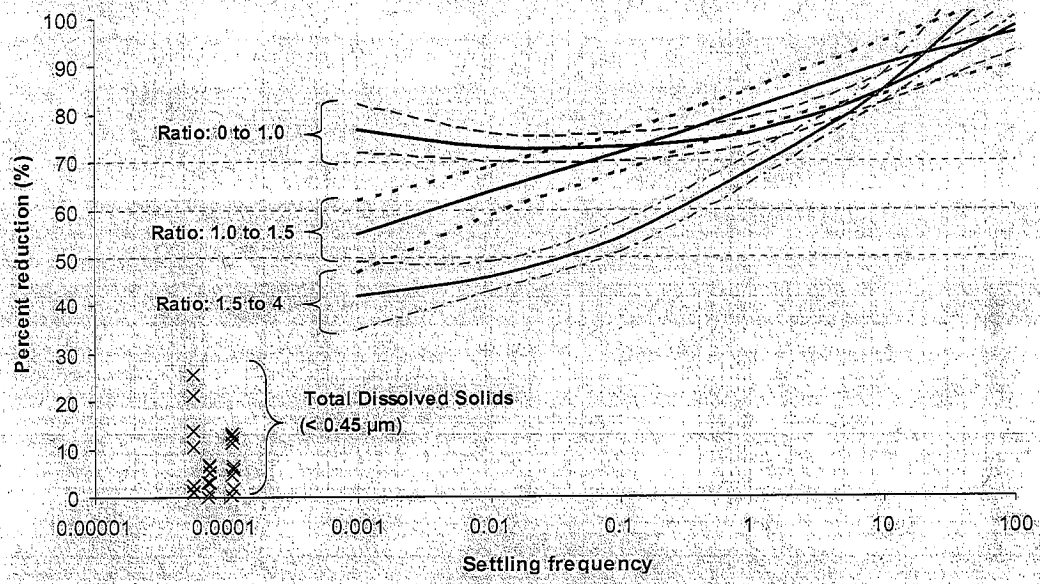

Figure 18. Comparison of regression lines with 95% confidence intervals for different (flow depth)/(grass height) ratios and for high concentrations (200 to 1,000 mg/L).

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Table 16 shows the performance calculations for each particle size range.

Table 16. Particulate Trapping Calculations for Example Problem

Particle Size Range	Approx. Settling Rate (cm/sec)	Settling Time for 21 cm Flow Depth (sec)	Settling Frequency for Swale (105 sec travel time)	Percent Reduction for Particles in Size Range (from Figure 18)	Influent Particulate Concentration in Size Range (mg/L)	Irreducible Concentration for Size Range (mg/L)	Particulate Concentration for Size Range after Treatment (mg/L)	Final Resultant Concentration for Size Range (mg/L)
0.45 to 2 µm	1.52×10^{-4}	138,000	0.00076	42	1.3	7	0.8	1.3*
2 to 5 µm	1.10×10^{-3}	19,000	0.0055	44	6.8	5	3.8	5**
5 to 10 µm	5.05×10^{-3}	4,160	0.025	48	23.0	5	12.0	12.0
10 to 30 µm	3.59×10^{-2}	585	0.18	57	101.0	10	43.4	43.4
30 to 60 µm	0.182	115	0.91	68	54.4	5	17.4	17.4
60 to 106 µm	0.619	33.9	3.1	74	26.5	5	6.9	6.9
106 to 425 µm	6.22	3.38	31	96	37.0	10	1.5	10**
Total:				66% (weighted by mass), reduced by irreducible concentrations	250 mg/L	20 mg/L	86 mg/L	96 mg/L

Notes:
* the influent concentration for this particle size range is less than the irreducible concentration, so the influent concentration is not reduced by the swale treatment.
** the treated concentration for these particle size ranges are less than the irreducible concentrations, so the treated concentrations are not reduced to values smaller than the irreducible concentrations.

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An overall 62% reduction in suspended solids concentration was achieved. Table 17 shows the resultant particle size distribution for the treated water, compared to the influent water.

Table 17. Particle Size Distribution for Treated Water

Particle Size (μm)	% smaller than size indicated (Dec. 6, 2004 influent)	Concentration smaller than size indicated (treated), mg/L	% smaller than size indicated, treated
0.45	0	0	0
2	0.5	1.3	1.4
5	3.2	6.3	6.6
10	12.4	18.3	19.1
30	52.8	61.7	64.3
60	74.6	79.1	82.4
106	85.2	86.0	90.0
425	100.0	96.0	100.0

Summary of Findings

This chapter presented a method to predict stormwater sediment retention in grass-lines swales or grass filters. The main factors affecting the sediment trapping in the swales was the settling frequency, which in turn is dependent on particle settling rate, flow rate, flow depth, and swale length; the ratio of the flow depth to the grass height; and the initial sediment concentration. During shallow flow conditions, relatively flat swales will provide large amounts of sediment retention, down to an irreducible concentration of about 20 mg/L of total suspended solids. Steep swales and deeper flows result in less sediment retention.

The indoor swale experiments resulted in larger sediment reductions than observed during the outdoor tests due to several reasons, including:

- The initial sediment concentrations during the second set of indoor experiments were much higher than during the outdoor swale observations. The mean of the indoor experiment total suspended solids concentrations was 480 mg/L, and ranged from 200 mg/L to 1,000 mg/L. The outdoor swale observations had mean total suspended solids concentrations of 60 mg/L, and ranged from 10 mg/L to 160 mg/L.

- There was a large fraction of larger sand particles applied to the indoor swales, while very little, if any, sand-sized particles were found at the head of the outdoor swale for most of the events. The settling frequency calculations partially accounted for this, but irreducibly low concentrations of the larger material occurred before the end of the longer outdoor swale, limiting the overall percentage removal calculations.

The regression model does not consider erosion or scour that likely occurs at the beginning of the swale. There is obviously some initial length, likely dependent on flow conditions and shear stress, where the turbulent flows are more erosive before they become more stable. This length is probably on the order of several feet for small flows, like observed during this research, but may extend longer for larger flows.

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Chapter 4: Conclusions and Recommendations for Future Study

The Indoor Experiments

The indoor laboratory swale experiments demonstrated the effectiveness of grass swales in trapping sediments and reducing sediment concentrations in runoff. Significant sediment reductions in 6 ft (1.8 m) long grass-lined channels were observed for total solids, total suspended solids, turbidity, and particle size during the second experiments, but not in total dissolved solids. The experiments showed not only the effectiveness of grass swales, but also significant factors affecting sediment transport in grass swales. The affecting factors observed are grass type, channel slope, runoff flow rate, grass type*channel slope, grass type*runoff flow rate, and channel slope*runoff flow rate. Moreover, particle size distribution analysis as well as visual observations confirmed that large particles are preferentially trapped in grass swales compared to smaller particles, especially at the beginning of grass swales.

Predictive Model

A model was developed to predict the reduction of stormwater sediment in actual grass swales using data obtained from the second set of controlled experiments. The predictive model utilizes three main concepts to model sediment transport in grass swales. They are first order decay, settling frequency, and flow depth / grass height ratio. The concept of first order decay is a statistical approach used to describe the observed reductions in concentrations in the grass swales with length. Both the indoor experiments and outdoor observations showed greater sediment reductions at the beginning of the grass swales, and the sediment concentrations then tended to stabilize after some distance. Thus, first order decay was employed to describe this behavior of the stormwater sediment in grass swales. Unlike first order decay, settling frequency is a theoretical approach to describe sediment transport in grass swales. Settling frequency is defined as a number of times a particle could conceivably settle to the bottom of the flow depth until it reaches the end of the grass swales (6.0 ft, 1.8 m, during the indoor experiments and 116 ft, 35.3 m, during the outdoor observations). The settling frequency is computed as the ratio of the travel time of runoff in the swale reach to the settling duration of a particle using Stoke's law and the site hydraulic conditions (mainly depth of flow). The concept of flow depth / grass height ratio was also incorporated into the predictive model, and initial sediment concentration was also found to be important. The settling frequency concept considers the opportunities of runoff water and sediment to contact the grass cover, and recognizes the very slow rates for submerged flows. Sediment retention in grass swales is most effective when flow depth is lower than the grass height (flow depth / grass height ratio less than 1). As the flow depth increases, sediment retention is expected to be less effective because of less contact area to the grass cover and the higher flow velocities.

Outdoor Swale Observations and Model Verification

To test the predictive model, stormwater samples were collected at the full-size outdoor grass swale (116 ft or 35.3 m long) located adjacent to the Tuscaloosa, Alabama, City Hall during actual storm events from August to December 2004. Significant concentration reductions were observed in total suspended solids and turbidity. However, changes in total solids, total dissolved solids, and particle size were statistically insignificant in the grass swale. Total suspended solids analyses showed three distinct regions for sediment reduction behavior in grass swales. They are:

1) 0 ft to 3 ft (0 m to 0.9 m): Region of instability (frequent scour, but also sedimentation observed)
2) 3 ft to 25 ft (0.9 m to 7.6 m): High sediment reduction region
3) 25 ft to 116 ft (7.6 m to 35.3 m): Lower sediment reduction region

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The high sediment reductions observed between 3 ft (0.9 m) and 25 ft (7.6 m) were used to test the predictive model. The total sediment reductions observed in the indoor experiments were much higher than observed at the outdoor swale. The predictive model therefore overestimated the sediment reductions due to several reasons, including:

- The initial sediment concentrations during the indoor experiments were much higher than during the outdoor swale observations.

- There was a large fraction of larger sand particles applied to the indoor swales, while very little sand particles were found at the head of the outdoor swale for most of the events.

Recommended Future Research Activities

The predictive model still has high variation and overestimates sediment reductions at actual grass swales during certain conditions. Additional research efforts are needed to reduce the variability of sediment retention of the predictive model further. Future research objectives could include the following:

- Investigating the effect of initial sediment concentration on sediment trapping.

- Investigating the effects of stem density on sediment transport during low flows.

- Sensitivity analyses of the predictive model using data obtained from outdoor swale observations for different grass swales with different grass types and channel slopes.

- Modifying the predictive model using further outdoor swale observations.

Grass swales are an effective stormwater treatment practice to capture stormwater sediments and other pollutants within grass swales. However, some suggest that deposited sediments and other pollutants in grass swales are potentially hazardous to the public. It is possible that exposure to deposited contaminated sediments can be hazardous. However, most grass swales are used in low density residential areas where stormwater concentrations are low. If grass swales are used to treat high concentrations of pollutants in industrial areas, the grass cover should be routinely tested and replaced, as necessary.

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Section 2: Controlled Indoor Grass Swale Experiments and Full-Scale Tests

This report section describes the two sets of controlled indoor swale experiments and the full-scale tests. These data were used to develop the predictive equations and examples presented in the first report section.

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Chapter 5: Initial Indoor Controlled Experiments

Introduction

This research project extends some of the preliminary sediment transport work conducted as part of the prior work funded by the Water Environment Research Foundation (Kirby 2003; Johnson, *et al.* 2003). The previous research primarily focused on the removal of stormwater heavy metals (Cd, Cr, Cu, Pb, Fe, Hg, Ni, and Zn) in grass swales. The current research reported in this report was partially funded by the University Transportation Center of Alabama (UTCA) and is intended to develop better design guidelines to enable conservation design elements to be incorporated in transportation projects.

This current research focused on the movement of stormwater sediments in grass swales. To understand sediment transport, experiments were conducted in several phases. The first experiments, described in this chapter, used the indoor grass swales setups that were constructed by Kirby (2003) and were intended to identify the most significant factors affecting sediment transport that could be further examined in later experimental phases. The ultimate goal of these experiments was to develop a model to predict the trapping of stormwater sediments in roadside grass swales.

Objectives

The major research objectives of the first experiments was to examine the effectiveness of grass swales in sediment transport under a small variety of grass type, swale slope, stormwater flow rate, and sediment particle size conditions.

Indoor Laboratory Swales

Descriptions of the Experimental Set-up

Experimental swales were constructed in an indoor greenhouse facility located in the Bevil building on the campus of the University of Alabama, as part of a prior research project (Johnson *et al.* 2003). Artificial sunlight (ambient variations of UV and visible wavelengths) was provided, and room temperature was maintained at approximately 78 °F (25 °C) at this facility. The experimental setup consisted of three identical rectangular channels on a base which was adjustable over a range of channel slopes. A soil mixture of 70% top soil and 30% sand (by weight) was placed in the channel sections which were completely sealed by non-reactive marine-epoxy paint to prevent leakage. Each channel was 2.0 ft wide (0.6 m), 6 ft long (1.8 m), and 6.0 inches (15 cm) deep and had a specific type of lawn grass. Jason Kirby constructed these swales and tested the grasses for hydraulic resistance during his MSCE thesis (2003).

Tap water was used to fill a 150 gallon (0.57 m^3) water storage tank. Test sediments of aluminum oxide and sieved sands were mixed in the tank to reproduce the sediment characteristics of stormwater. Two 65 gallon/min (GPM) (0.25 m^3/min) sump pumps were placed at the opposite ends of the tank to ensure continuous suspension of sediments during the experiments. The sediment-water mixture was pumped using a Jacuzzi ® (Little Rock, AR) pump through a 2 inch (5.1 cm) diameter PVC piping network. A T-shaped PVC pipe with 26 quarter-inch-diameter holes (0.6 cm) was attached to the end of the piping network as shown in Figure 19 and 20. The sediment-water mixture was drained from the T-shaped pipe onto an aluminum sheet attached to the head of the swale to produce a sheet flow. The runoff was collected at the end of the swale in a second 150 gallon (0.567 m^3) tank (Kirby 2003). After each experiment during the current sediment transport tests, sediment depositions on the grass swale were washed off to avoid sediment carryover to the next experiment by re-suspension.

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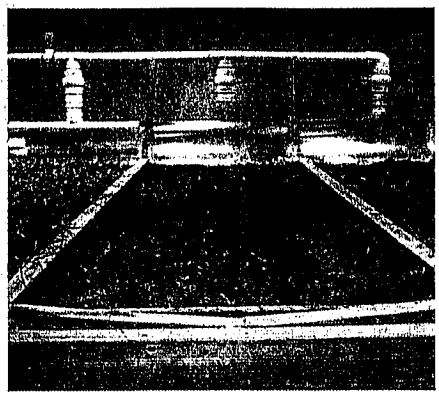

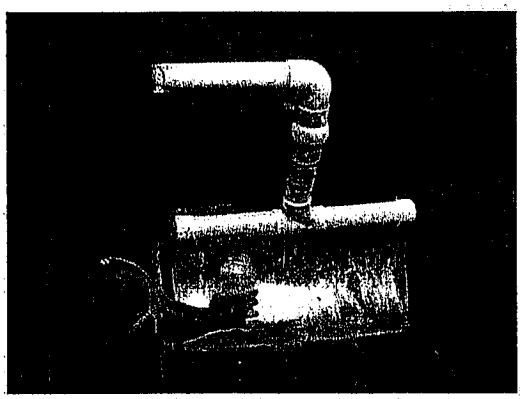

Figure 19. (*left*) Overview of the experimental setup.
Figure 20. (*Right*) Sediment-water mixture coming through the T-shaped PVC header onto the metal sheet to produce a sheet flow.

Sediment Characteristics of the Sediment-water Mixture

Aluminum oxide particles (glass grinding abrasives) ranging from 5 μm to 80 μm and sieved sands ranging from 80 μm to 240 μm were combined to produce the test sediments. The initial sediment concentration was 200 mg/L. Therefore, 0.25 lb (110 grams) of the sediment mixture was mixed with the 150 gallons (0.57 m^3) of tap water for each experiment. Table 18 shows the percentage and weight contribution of the test sediments for different particle size ranges. The resulting particle size distribution was similar to the reported sediment particle size distribution and concentration found in stormwater (Burton and Pitt 2001).

Table 18. Percentage and Weight Contributions of the Test Sediments

Sediment	Particle Size (μm)	Specific Gravity (gram/cm^3)	Percentage Contribution	Weight (gram/test)
Aluminum Oxide	0 to 5	3.7 to 4.0	45%	51
Aluminum Oxide	5 to 10	3.7 to 4.0	10%	11.3
Aluminum Oxide	10 to 25	3.7 to 4.0	20%	22.7
Aluminum Oxide	25 to 80	3.7 to 4.0	8%	9.1
Sieved Sands	80 to 240	2.65	17%	19.3
		Total	*100%*	*113.4*

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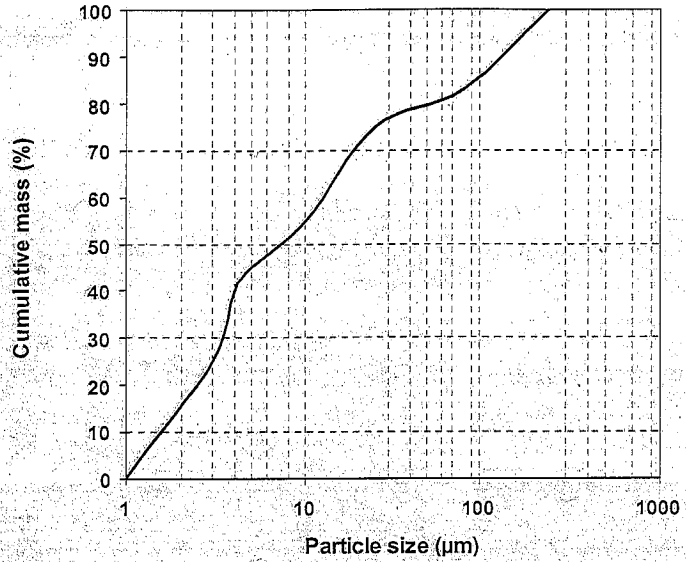

Figure 21. Resulting particle size distribution of the test sediments.

Parameters in the Initial Experiments

Five different parameters were tested in the initial experiments to identify their effects on sediment transport in grass swales. The parameters were grass type, slope, flow rate, sampling time, and swale length, as described below:

- *Grass types*: Three different types of grass were placed in the rectangular channels. These were Centipede (*Eremochloa ophiuroides*), Zoysia (*Zoysia japonica*), and Kentucky bluegrass (*Poa pratensis*). These three grasses were selected because their species are commonly found in the South and Southeast areas of the United Sates, the location of these experiments. Centipede (CENT-05-PK, Seedland®) is thick forming, uniform growing, and medium to light green in color. It has a thick and wide blade, short upright stems, and requires low maintenance. The blades of Centipede are sparser than Kentucky bluegrass or Zoysia and Centipede survives better in mild climates. Zoysia can be found from Florida to Connecticut and along the Gulf coast to Texas and in the Midwest and California (Richard n.d.). Zoysia is commonly used at golf courses. Leaf blades of Zoysia are very stiff and smooth with occasional hair near the root providing a very strong structure that has high wear-tolerance. Kentucky bluegrass is a dense grass with smooth, upright stems, very fine blades that can grow up to 18 to 24 inches (46 cm to 61 cm) tall, but is commonly mowed too much shorter heights. It is readily identified by the boat-shaped leaf tip. Kentucky bluegrass grows primary in the North and Midwest areas of the United Sates. In the Southern United Sates, Bluegrass grows in a transition zone from North Carolina, through much of Tennessee, northern Arkansas to the panhandle of Texas and Oklahoma (Richard n.d.).

The grasses in the test swales were watered daily, and fertilizer was applied bi-weekly to keep the grass in a healthy condition. The grass was also trimmed regularly so that the heights of the grasses were maintained at about 2 inches (5 cm) in height.

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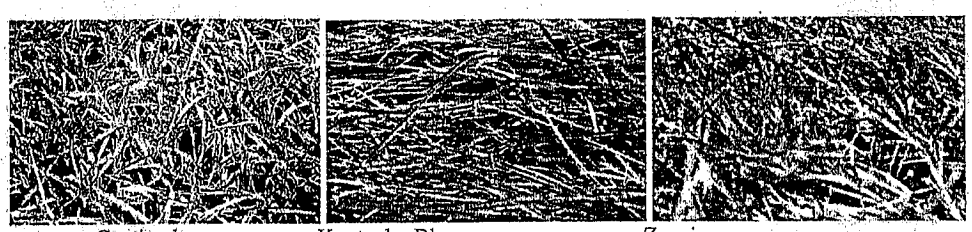

Centipede Kentucky Bluegrass Zoysia

Figure 22. Different grass types tested in the first set of experiments

• *Slopes*: The effects of 1% and 5% slopes were tested. The slopes were maintained by jacking the swale test frame and placing pre-cut blocks of the correct thickness. The connecting flow distribution pipes also had alternative pre-cut sections to enable efficient slope adjustments.

• *Flow rates*: The runoff flow rates were controlled using a valve in the piping network. The flow rates were approximately 8 gallons per minute (GPM) (0.03 m^3/min) during the low flow rate tests and approximately 15GMP (0.06 m^3/min) during the high flow rate tests.

• *Time interval*: Samples were collected at three different times during each test. The duration of an experiment with 8 GPM flows (low flow rate) (0.03 m^3/min) was approximately 10 minutes (the time available until all of the sediment-water mixture was pumped from the tank to the test swale). Thus, sampling was conducted at 1, 5, and 10 minutes after the mixture was introduced to the swales. During the high flow rates, the maximum duration was 6 minutes. Therefore, samples were collected at all locations at 1, 3 minute, and 6 minute intervals.

• *Swale lengths*: To determine the sediment reduction as a function of swale length, samples are collected at the head works, 2 ft (0.6 m), and 6 ft(1.8 m) from the head works. Samples collected at the head works determined the initial sediment concentrations. Figure 23 shows the sampling locations. For each swale length, subsamples were collected at various locations across the channel and composited to represent the specific swale cross section.

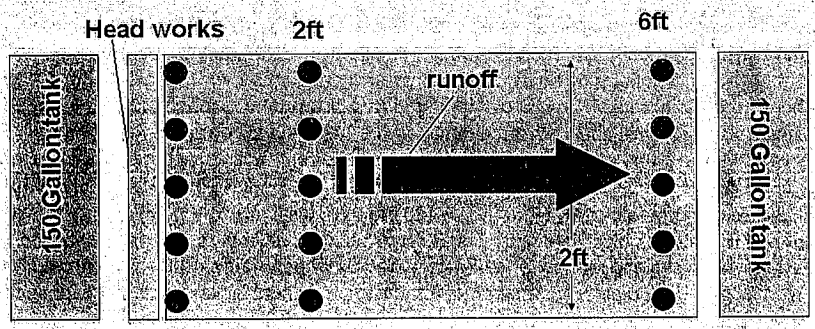

Figure 23. Sampling locations of each grass-lined channel. Red dots indicate sampling locations.

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Experimental Design and Analytical Methods

The experimental design was a box design (Box, Hunter, and Hunter 1978). Since there were 3 grass types, 2 slopes, 2 flow rates, 3 time intervals, and 3 swale lengths, 108 runoff samples were collected during 12 separate tests in the initial indoor experiments. After each test, the grasses were rinsed with tap water to wash off any deposited sediment attached to the grass blades, and the setup was allowed to rest for approximately thirty minutes before the next test. The data was analyzed using a nested full-factorial design (Box, Hunter, and Hunter 1978).

The 108 runoff samples were analyzed for the following constituents:

- Total Solids (*Standard Methods* 2540B)
- Turbidity using a HACH 2100N Turbidimeter
- Particle Size Distribution using a Coulter Counter (Beckman® Multi-Sizer III™), composite of several different aperture tube measurements (30, 140, and 400 μm aperture tubes, giving a complete range of about 1.8 to 240 μm).

Much effort was spent in confirming the laboratory sediment measurement procedures. Appendix J describes the methods used to prepare the samples before analyses using a USGS Dekaport cone splitter.

Data Analysis and Results

The basic aim of the initial experiments was to examine the basic efficiency of grass swales in trapping stormwater sediments under a variety of test conditions. The complete set of analytical results from these initial experiments is presented in Appendix A. The following discussion summarizes the general findings from these experiments.

The total solids and turbidity measurements at the head works revealed that the variability of sediment concentrations between the different experiments was much higher than desired. Thus, all the measurements by the variables were normalized sediment concentrations at the head works by presenting the data as percentages of the initial values. Figure 24 and 25 are box and whisker plots of the changes in concentrations, or changes in normalized concentrations compared to initial values. Box and whisker plots of the observed actual concentrations are presented in Appendix D. Also, line plots of these data are presented in Appendix E. The boxes show the 25th, 50th, and 75th percentiles (the lower box edge, the line in the box, and the upper box edge, respectively), and the top whisker extends to the 95th percentile while the lower whisker extends to the 5th percentile. The open circles show the actual data.

Total Solids Variation by Swale Length

Figures 24 and 25 show box and whisker plots of total solids concentrations for different swale lengths.

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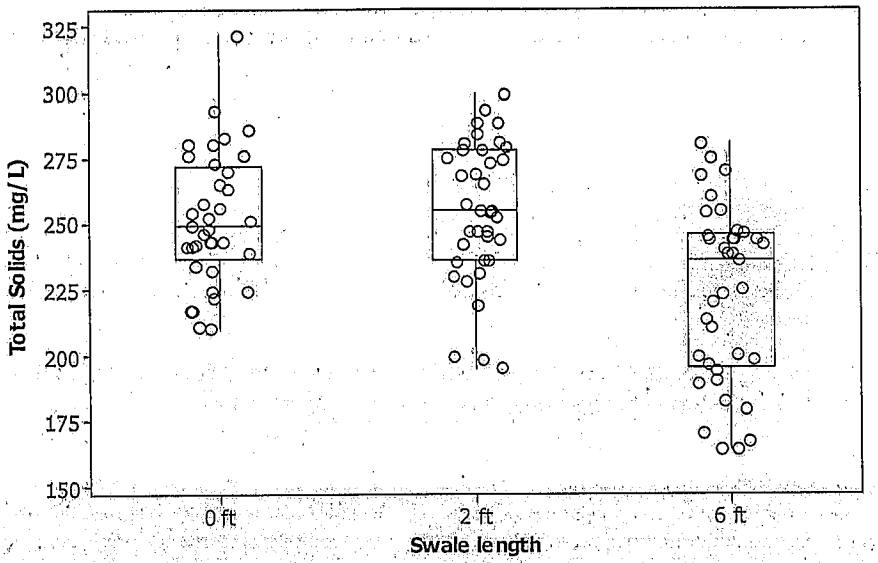

Figure 24. Box-and-whisker plots of total solids vs. swale length.

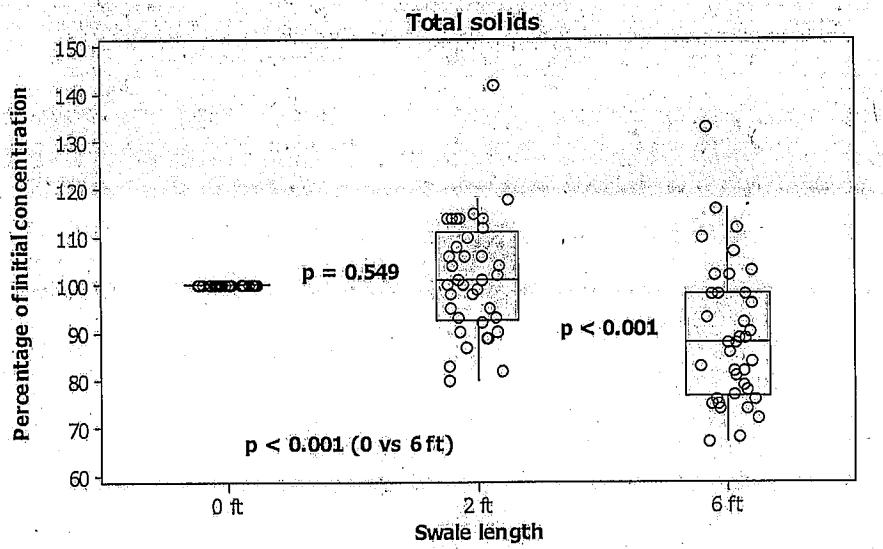

Figure 25. Box-and-whisker plots of percentages of initial concentrations of total solids and associated p-values (Kruskal-Wallis test) by swale length.

Kruskal-Wallis non-parametric statistical tests were employed to determine the equality of medians for two or more sample populations. Most of the data were not normally distributed, requiring the use of a nonparametric statistical test. The Kruskal-Wallis test hypotheses are:

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- Null hypothesis (H_0): the population medians are all equal
- Alternative hypothesis (H_1): the medians are not equal

The significance level was set to be 0.05 (5%) since it is a widely accepted value for the significance level used in most research. To illustrate, when a computed probability is found to be less than 0.05, there is significant evidence suggesting that the null hypotheses is not true. Therefore, we accept the alternative hypothesis, concluding that the medians are not equal. When the computed probability is greater than 0.05, the proper conclusion is that there was not sufficient numbers of samples to verify the difference between the sample sets, at the power of the test (determined by the initial experimental design data quality objectives and number of samples collected).

Figure 25 shows a significant effect of swale length on sediment reduction, after the 2 ft (0.6 m) location (there was no significant sediment reduction between the head works and the 2 ft (0.6 m) location because the probability (p-value) was found to be 0.549). There were significant differences between the head works and 6ft (1.8 m) ($p < 0.001$) and between 2ft (0.6 m) and 6ft (1.8 m) ($p < 0.001$), although the actual reduction was quite small (an average of 11% reductions of the normalized sediment concentrations at 6ft (1.8 m) compared to the head works). These tests established that the sediment removal was only measurable between 2 ft (0.6 m) and 6 ft (1.8 m) from the head works for these tests.

Total Solids Variation by Grass Type

Figure 26 shows the variations in total solids concentrations for different grass types at the different sampling locations.

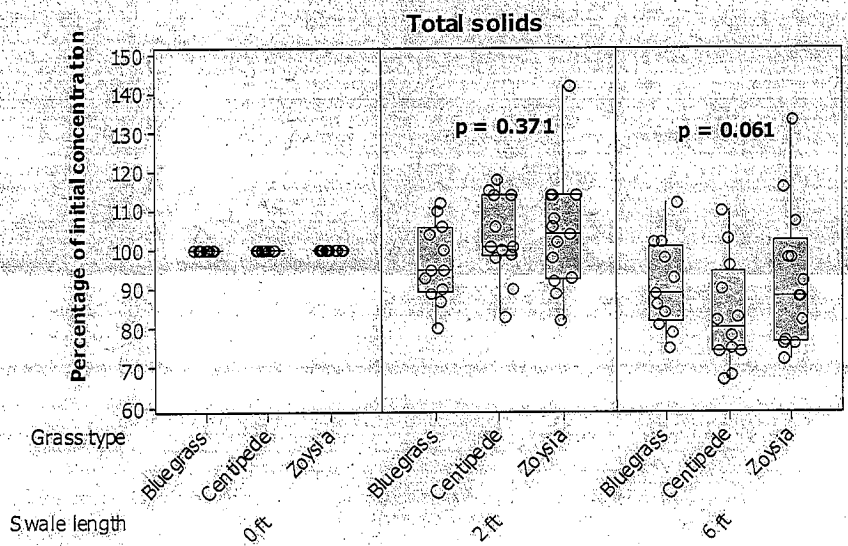

Figure 26. Box-and-whisker plots of percentages of initial concentrations of total solids and associated probabilities calculated using Kruskal-Wallis test vs. swale length and grass type (1 ft = 0.30 m).

As shown in Figure 26, there were no significant differences in the percentages of the initial total solids between Bluegrass, Centepede, and Zoysia at 2ft (0.6 m) since the probability was 0.37. At 6 ft, a marginal level of significance for grass type was observed, since the calculated probability was 0.06, close to 0.05. Centipede showed

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better sediment reduction rates than bluegrass and Zoysia. There was no significant difference between bluegrass and Zoysia.

Total Solids Variation by Flow Rate

Figure 27 shows the total solids concentration changes for different flow rates at the different sampling locations.

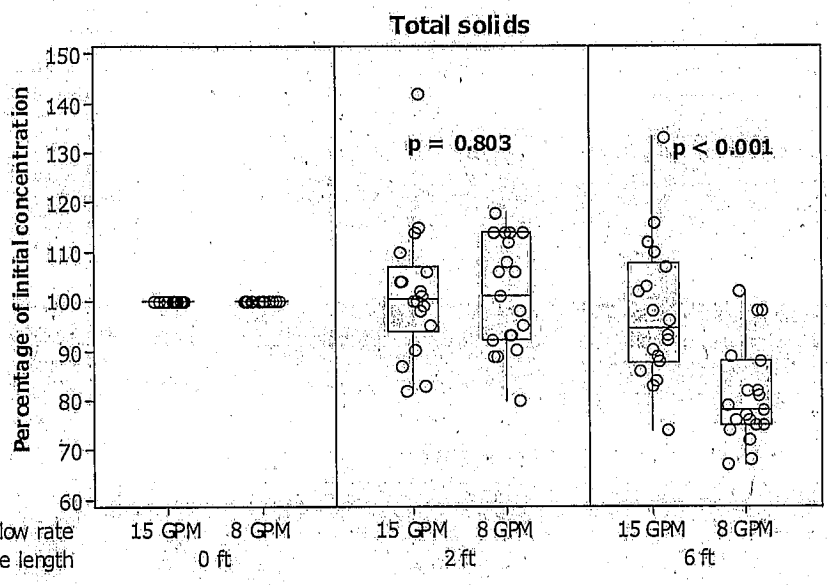

Figure 27. Box-and-whisker plots of percentages of initial concentrations of total solids and associated probabilities determined by Kruskal-Wallis test vs. swale length and flow rate (Note 1 GPM = 0.0038 m^3/min).

Reductions in normalized sediment concentrations were significantly different at 6 ft (1.8 m) ($p < 0.001$) when the 8 GPM (0.03 m^3/min) and 15 GPM (0.06 m^3/min) flow rate tests were compared. There was no significant difference at 2 ft (0.6 m) ($p = 0.803$). The median reductions at 8 GPM (0.03 m^3/min) were 16.5% lower than the mean reductions at 15 GPM (0.06 m^3/min) at 6 ft (1.8 m).

Total Solids Variation by Slope

Figure 28 shows the total solids concentration changes for different grass swale slopes for the different sampling locations.

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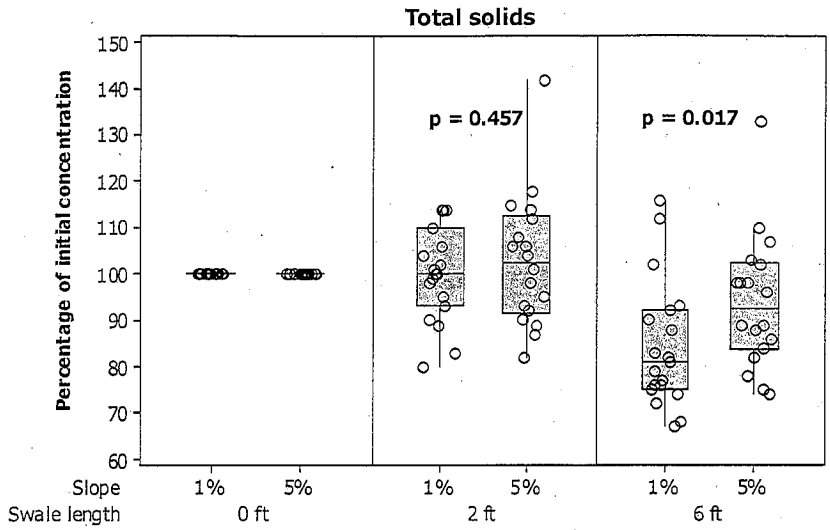

Figure 28. Box-and-whisker plots of percentages of initial concentrations of total solids and associated probabilities determined by Kruskal-Wallis test vs. swale length and slope (Note 1 ft = 0.30 m)

Sediment concentration reductions at 1% vs. 5% slope were found to be significantly different at 6 ft (1.8 m) ($p = 0.017$), but not at 2 ft (0.6 m) ($p = 0.457$). The median concentration reductions during the 1% slope tests were about 11.5% lower than during the 5% slope tests.

Total Solids Variation by Time Interval

Figure 29 shows the total solids concentration changes for different time intervals at the different sampling locations.

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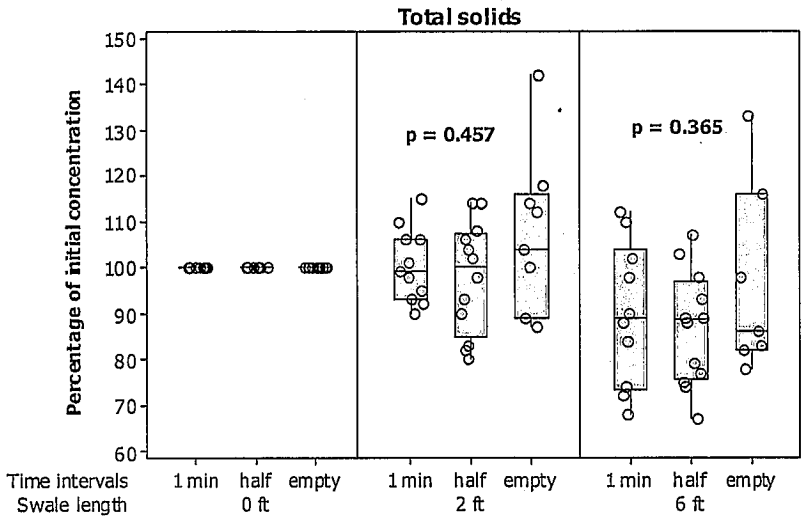

Figure 29. Box-and-whisker plots of percentages of initial concentrations of total solids and associated probabilities determined by Kruskal-Wallis test vs. swale length and time interval (Note 1 ft = 0.30 m).

There were no significant differences in sediment removal rates for the different time intervals at both the 2 ft (0.6 m) ($p = 0.457$) and 6 ft (1.8 m) ($p = 0.365$) sampling locations.

Turbidity Variation by Swale Length

Figures 30 and 31 show box and whisker plots of turbidity concentrations for different swale lengths.

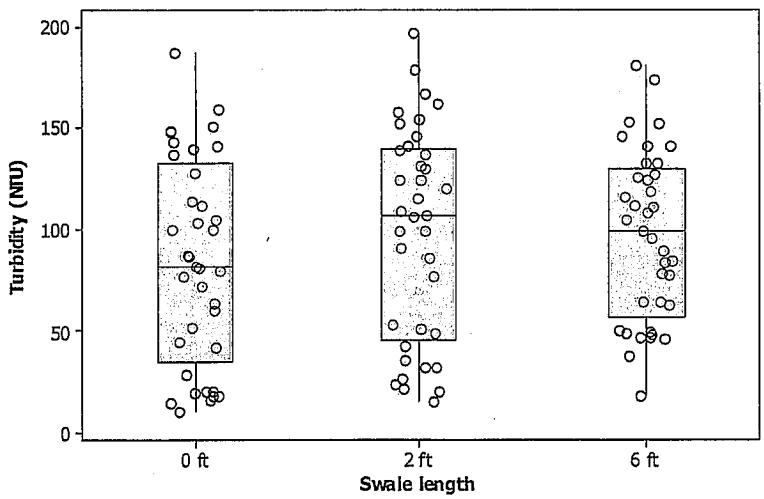

Figure 30. Box-and-whisker plots of turbidity vs. swale length (Note 1 ft = 0.30 m).

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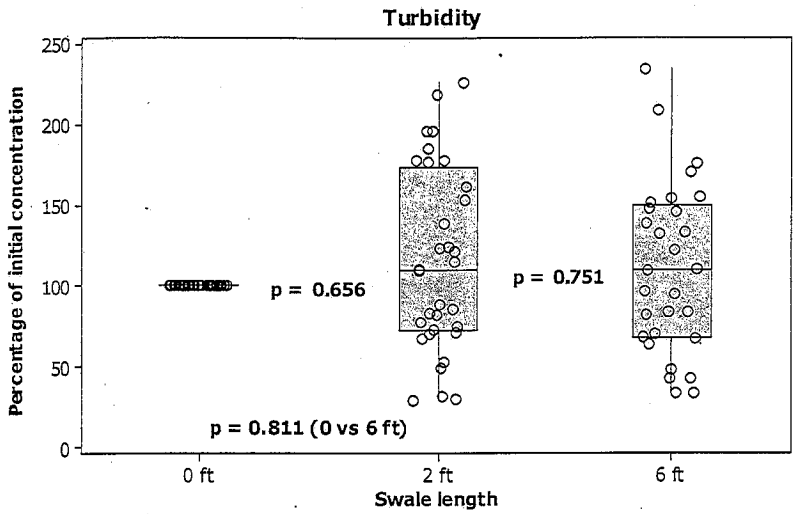

Figure 31. Box-and-whisker plots of percentages of initial concentrations of turbidity and associated probabilities determined by Kruskal-Wallis test vs. length (Note 1 ft = 0.30 m).

The probability determined by Kruskal-Wallis for overall swale length was P = 0.811, indicating no observed significant effects on turbidity reductions with sampling location.

Turbidity Variation by Grass Type

Figure 32 shows the variations in turbidity concentrations for different grass types at the different sampling locations.

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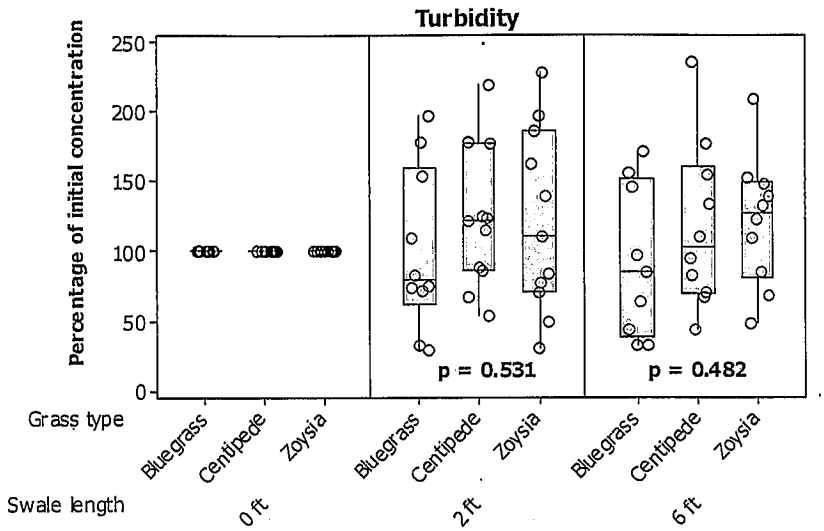

Figure 32. Box-and-whisker plots of percentages of initial concentrations of turbidity and associated probabilities determined by Kruskal-Wallis test vs. swale length and grass type (Note 1 ft = 0.30 m).

The grass type was found to be an insignificant factor affecting turbidity reductions at both 2 ft (0.6 m) ($p = 0.531$) and 6 ft (1.8 m) ($P = 0.482$).

Turbidity Variation by Flow Rate

Figure 33 shows the turbidity concentration changes for different flow rates at the different sampling locations.

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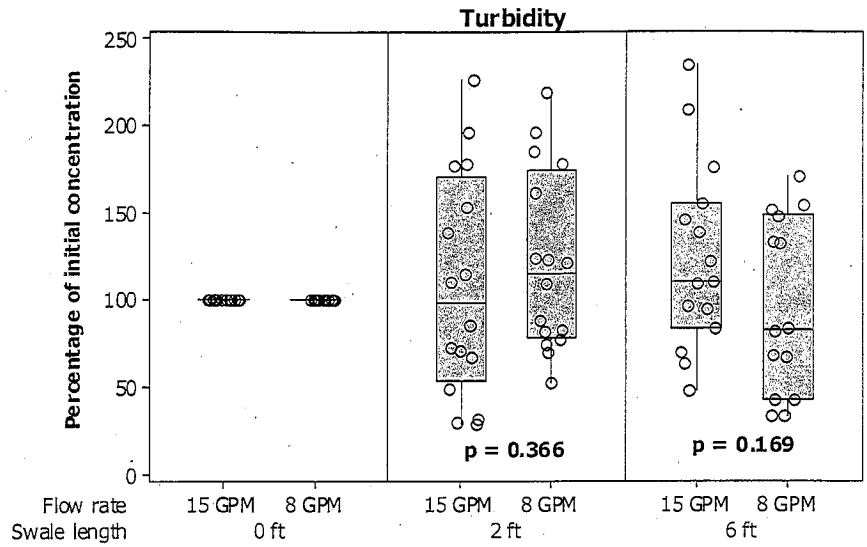

Figure 33. Box-and-whisker plots of percentages of initial concentrations of turbidity and associated probabilities determined by Kruskal-Wallis test vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

The flow rate was found to be an insignificant factor affecting turbidity reductions at both 2 ft (0.6 m) ($p = 0.366$) and 6 ft (1.8 m) ($p = 0.169$).

Turbidity Variation by Slope

Figure 34 shows the turbidity concentration changes for different grass swale slopes for the different sampling locations.

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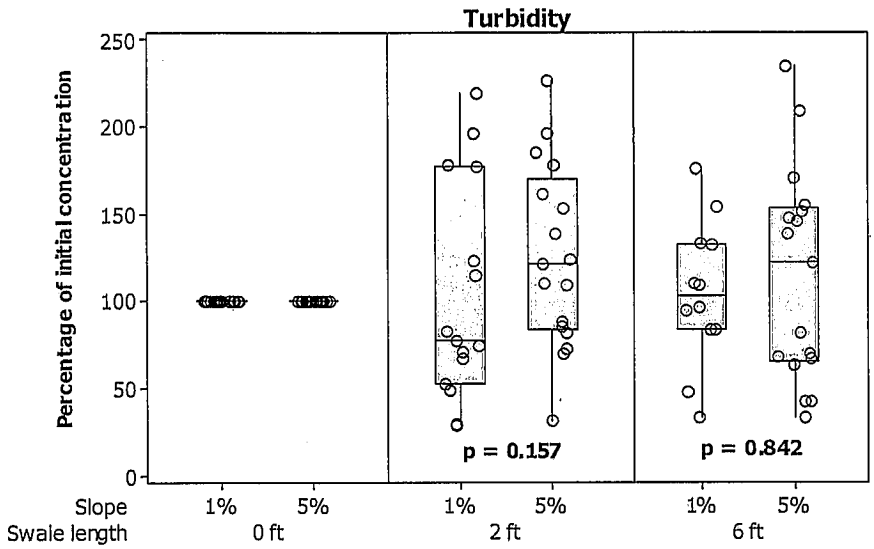

Figure 34. Box-and-whisker plots of percentages of initial concentrations of turbidity and associated probabilities determined by Kruskal-Wallis test vs. length and slope (Note 1 ft = 0.30 m).

The slope was found to be an insignificant factor affecting turbidity reductions at both 2 ft (0.6 m) ($p = 0.157$) and 6 ft (1.8 m) ($p = 0.842$).

Turbidity Variation by Time Interval

Figure 35 shows the turbidity concentration changes for different time intervals at the different sampling locations.

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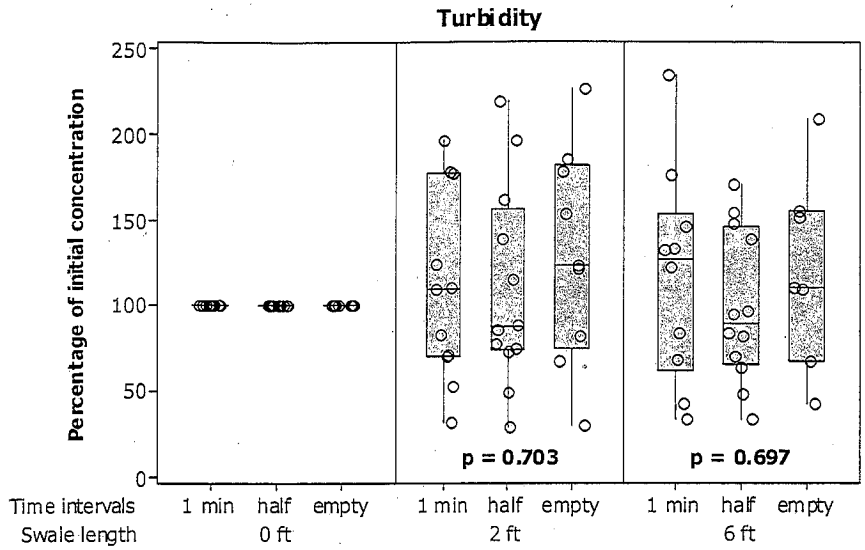

Figure 35. Box-and-whisker plots of percentages of initial concentrations of turbidity and associated probabilities determined by Kruskal-Wallis test vs. swale length and time interval (Note 1 ft = 0.30 m).

The time interval was found to be an insignificant factor affecting turbidity reductions at both 2 ft (0.6 m) ($p = 0.703$) and 6 ft (1.8 m) ($P = 0.697$).

Variables Affecting Sediment Transport

Analysis of Variance (ANOVA) tests were performed to determine the effects of the experimental variables on the normalized concentration changes. The significance level was set at 0.05 for this statistical procedure. The normalized concentration changes were normally distributed, so the more powerful ANOVA procedure was used for these comparisons.

Table 19 shows the experimental variables and associated probabilities for the normalized concentration changes at the 6 ft (1.8 m) swale location. Grass type, slope, and flow rate were all found to be significant factors affecting total solids concentration changes, but they did not affect the turbidity observations in these initial experiments. The time of sampling was not a significant factor for either total solids and turbidity changes. No interactions between variables were found to be significant, except time versus flow rate for turbidity changes.

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Table 19. Experimental Variables and Associated Probabilities for the Normalized Concentration Changes at 6 ft (1.8 m)

Constituent	Variable	Probability
Total solids	Grass type	**0.048**
	Slope	**0.015**
	Flow rate	**< 0.001**
	Sampling time	0.584
	Grass type vs. Slope	0.278
	Grass type vs. Flow rate	0.162
	Slope vs. Flow rate	0.436
	Sampling time vs. Grass type	0.647
	Sampling time vs. Flow rate	0.532
	Sampling time vs. Slope	0.736
Turbidity	Grass type	0.369
	Slope	0.407
	Flow rate	0.236
	Sampling time	0.593
	Grass type vs. Slope	0.289
	Grass type vs. Flow rate	0.736
	Slope vs. Flow rate	0.181
	Sampling time vs. Grass type	0.638
	Sampling time vs. Flow rate	**0.035**
	Sampling time vs. Slope	0.263

Note: Bold probabilities represent 'significant effects' as these are less than 0.05

Particle Size Distribution Analyses

Particle size distribution (PSD) analyses were an important part of these tests. A Coulter Counter (Beckman® Multi-Sizer III™) was used to determine the particle size distributions in all of the samples collected. The results are presented in Appendix-F, and statistical summaries of PSDs are presented in Table 20.

It is important to determine how the experimental factors affected sediment transport of the different particle sizes. It is possible that some factors would affect some particle size categories more than for other size categories. The PSDs of the samples for the tests featuring the same control parameters were averaged and compared. For instance, all the PSDs of the end weir outflows (6 ft = 1.8 m) for the 5% slope tests were averaged and compared against the PSDs of the weir outflows for the 1% slope tests. Similarly, swale length, flow rate, and grass type were also compared. The affect of location was evident from the results of the 12 individual runs as described above.

Decreases in the median particle size (the 50th percentile of the PSD) were used to indicate preferential trapping of larger particles in the swales during the tests. If the median size decreased at a downgradient swale location, larger particles were being preferentially trapped upgradient. For each individual test, the PSDs at the three time intervals at each location were averaged to obtain a single PSD curve. The overlay of the three curves for samples collected at the three locations also demonstrates which particles tend to move through the swale.

The original hypothesis was that grass swales would preferentially capture the larger particles and would allow the finer particles to flow through the swale with minimal trapping. Therefore, the medians of the PSDs should decrease with increasing length. Significant differences in median particle sizes were observed between 2 ft and 6 ft ($p = 0.006$), but not between 0 ft and 2 ft (0.6 m) ($p = 0.237$). In five runs, the median particle sizes at 0 ft (head works) were higher than at 2 ft (0.6 m). This could be a result of particles being scoured and eroded from the bed of the grass swale due to the force of water coming entering the swale. The metal plates used to ensure sheet flow, though effective, could not always prevent erosion.

The smallest median particle size at 6 ft (1.8 m) occurred during Test 9, for high flow with Zoysia grass at 1% slope test conditions (with a median diameter of 4.93 μm), and Test 2 which also showed a median diameter of approximately 5 μm, during a low flow with Centipede grass at 5% slope. Tests 2 and 9 are almost opposite conditions (high versus low flows and steep versus shallow slopes), indicating the need for further tests and to better control the test conditions to reduce the variability that was periodically evident during some of these initial tests. Tests 2 and 9 establish that variability in particle settling in these small swales may be too great to consistently

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measure at lengths of 6 ft or less. These two tests had the lowest median sediment concentrations, but cover much of the range of experimental conditions.

The changes in median particles sizes between the head of the swale and 2 ft (0.6 m) not only reflect the high variability in settling, but also an experimental artifact. In five of twelve tests, scouring was actually indicated, probably due to incomplete dissipation of header flow momentum before the sheet flow entered the swale grass covers. Future tests should consider redesign of the metal plates to spread the flow and to prevent scour. Grass type, flow rate, and slope differences were not significant in reducing median particle sizes. Most of the probabilities presented in Figures 36 through 39 were greater than the significant level of 0.05.

Table 20. Summaries of Statistics of PSDs by Swale Length

Test-1: Centipede grass, high flow (15 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	10.0	2.8	3.4	7.6	54.0
2 ft (0.6 m)	9.7	2.9	3.2	6.7	62.5
6 ft (1.8 m)	7.9	2.4	3.1	6.1	24.3

Test-2: Centipede grass, low flow (8 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	8.2	2.6	3.0	5.9	30.9
2 ft (0.6 m)	13.4	3.2	3.5	11.0	79.0
6 ft (1.8 m)	5.8	2.1	2.8	5.0	16.1

Test-3: Zoysia grass, high flow (15 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	23.8	4.3	3.8	19.5	169.0
2 ft (0.6 m)	9.2	2.8	3.2	6.5	55.0
6 ft (1.8 m)	7.9	2.4	3.1	6.1	24.3

Test-4: Zoysia grass, low flow (8 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	7.0	2.7	2.8	5.0	34.8
2 ft (0.6 m)	13.6	3.5	3.3	10.7	96.1
6 ft (1.8 m)	10.0	3.0	3.2	7.0	62.5

Test-5: Bluegrass, high flow (15 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	9.3	2.9	3.1	6.4	58.8
2 ft (0.6 m)	8.4	2.4	3.2	6.6	27.9
6 ft (1.8 m)	9.2	3.0	3.1	6.1	79.8

Test-6: Bluegrass, low flow (8 GPM), 5% slope

Location	Mean (μm)	Std.dev. (μm)	10% (μm)	50% (μm)	90% (μm)
Head works	16.9	4.7	3.2	9.5	166.0
2 ft (0.6 m)	7.6	2.4	3.1	5.8	26.0
6 ft (1.8 m)	6.3	2.2	2.9	5.2	18.0

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Test-7: Bluegrass, high flow (15 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	13.9	3.9	3.3	9.1	133.0
2 ft (0.6 m)	8.1	2.7	3.0	5.8	37.8
6 ft (1.8 m)	7.6	2.5	3.0	5.8	25.6

Test-8: Bluegrass, low flow (8 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	10.6	3.1	3.2	7.4	70.0
2 ft (0.6 m)	8.0	2.5	3.1	6.1	28.0
6 ft (1.8 m)	6.6	2.2	3.0	5.4	19.8

Test-9: Zoysia grass, high flow (15 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	15.5	3.6	3.4	13.5	113.0
2 ft (0.6 m)	6.8	2.0	3.0	5.8	19.4
6 ft (1.8 m)	5.9	2.1	2.8	4.9	17.2

Test-10: Zoysia grass, low flow (8 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	11.0	3.2	3.1	7.4	73.4
2 ft (0.6 m)	9.1	2.7	3.1	6.7	42.1
6 ft (1.8 m)	7.5	2.5	3.0	5.6	26.8

Test-11: Centipede grass, high flow (15 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	11.5	3.2	3.2	8.6	73.6
2 ft (0.6 m)	12.1	3.2	3.2	9.0	79.3
6 ft (1.8 m)	9.3	3.1	3.0	6.0	77.4

Test-12: Centipede grass, low flow (8 GPM), 1% slope

Location	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Head works	10.2	3.2	3.1	6.6	78.3
2 ft (0.6 m)	9.7	2.9	3.2	6.9	56.4
6 ft (1.8 m)	7.9	2.9	2.9	5.5	65.4

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Table 21. Summary Statistics for Particle Sizes vs. the Experimental Variables

Grass type	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
Bluegrass	7.3	2.5	3.0	5.6	26.1
Centipede	7.9	2.7	3.0	5.6	42.1
Zoysia	7.7	2.5	3.0	5.8	29.0

Slope	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
1%	7.5	2.6	3.0	5.5	33.0
5%	8.5	2.8	3.1	5.9	49.6

Flow rate	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
8 GPM	9.0	3.0	3.1	6.0	72.5
15 GPM	7.3	2.5	3.0	5.5	27.6

Sampling time	Mean (µm)	Std.dev. (µm)	10% (µm)	50% (µm)	90% (µm)
1 min	7.9	2.6	3.0	5.9	29.0
Half tank	7.4	2.5	2.97	5.6	26.8
Empty	9.1	3.2	3.0	5.8	85.1

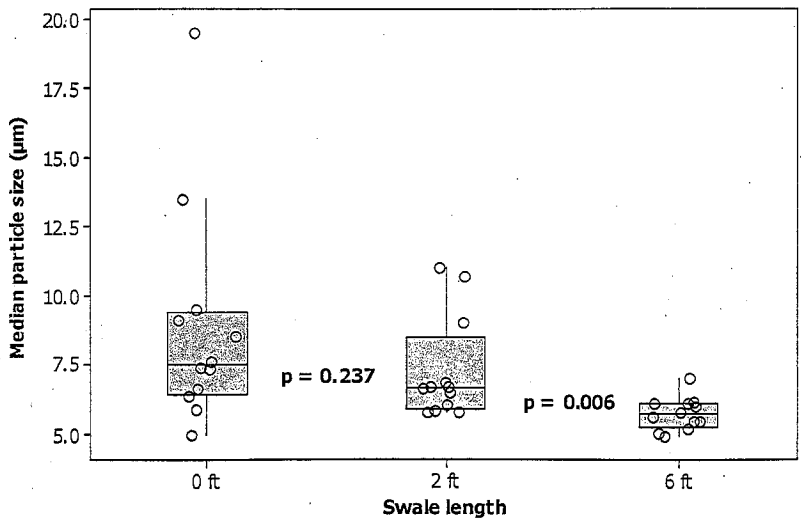

Figure 36. Box-and-whisker plots of median particle sizes and associated probabilities determined by Kruskal-Wallis test vs. swale length (Note 1 ft = 0.30 m).

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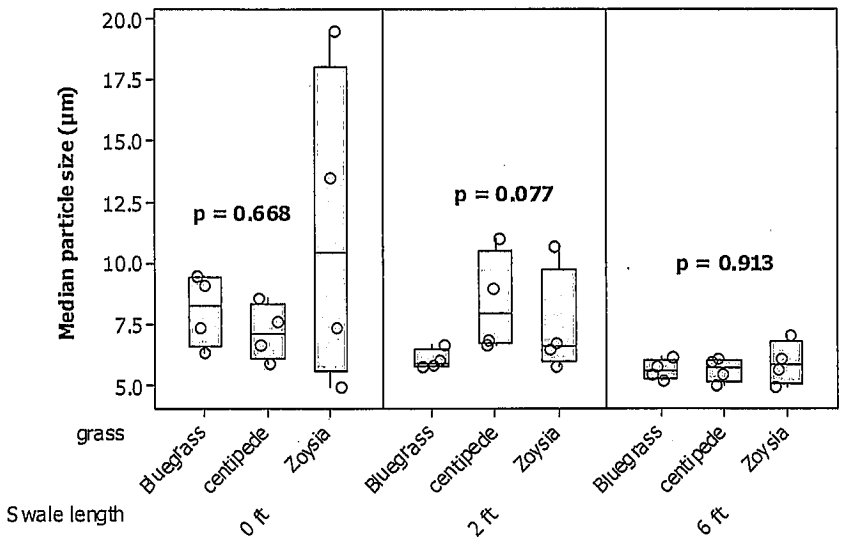

Figure 37. Box-and-whisker plots of median particle sizes and associated probabilities determined by Kruskal-Wallis test vs. swale length and grass type (Note 1 ft = 0.30 m).

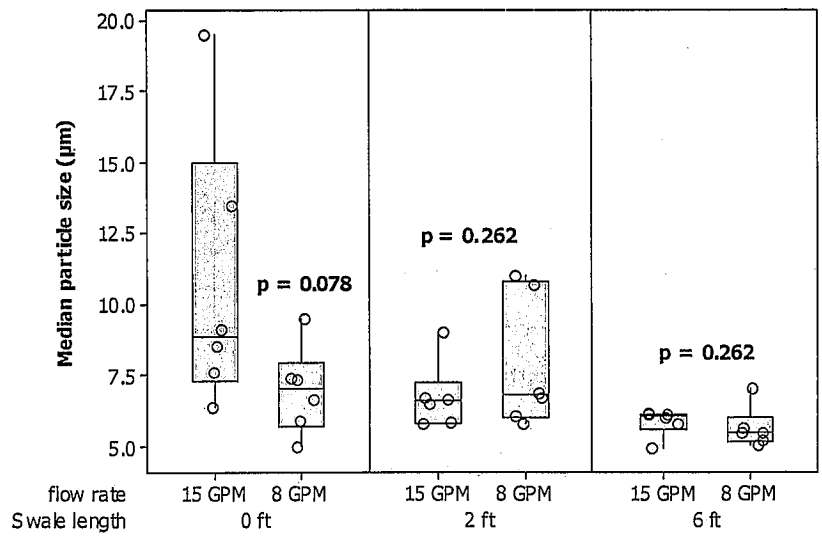

Figure 38. Box-and-whisker plots of median particle sizes and associated probabilities determined by Kruskal-Wallis test vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

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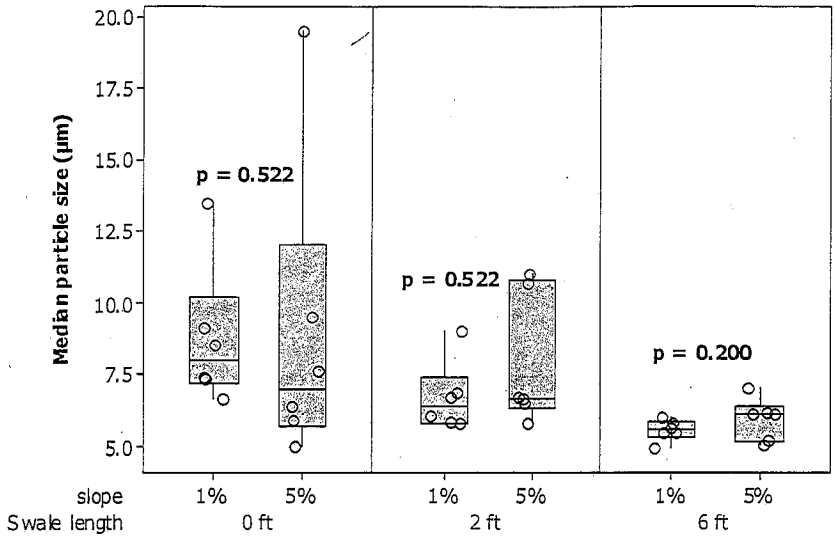

Figure 39. Box-and-whisker plots of median particle sizes and associated probabilities determined by Kruskal-Wallis test vs. swale length and slope (Note 1 ft = 0.30 m).

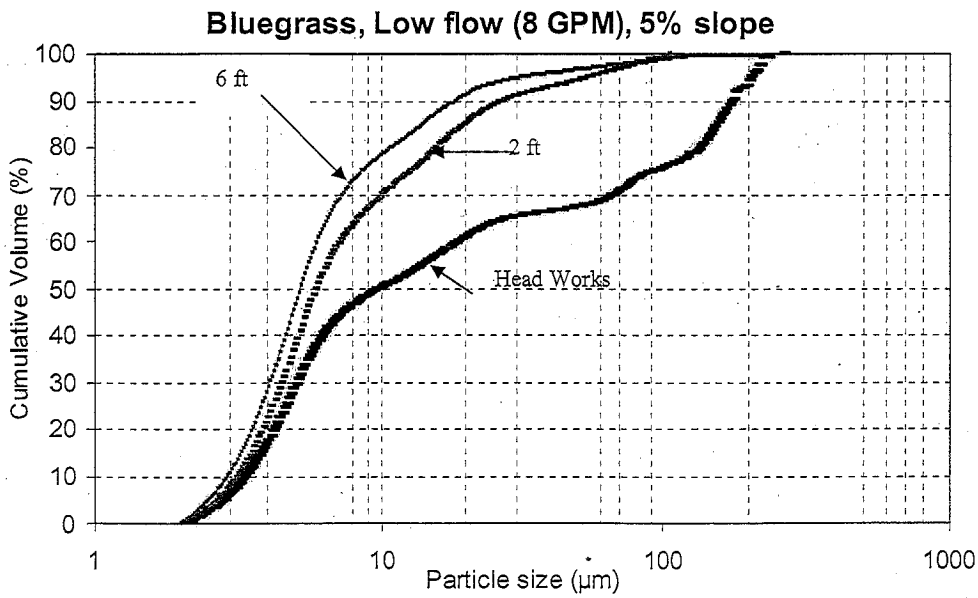

Figure 40. Example PSDs at different locations along the swale.

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As shown in Figure 36, there was a significant effect of swale length in reducing median particle sizes between the head works and 6 ft (1.8 m) ($p = 0.006$), but not between the headworks and 2 ft (0.6 m) ($p = 0.237$). Figure 40 shows an example PSD at the different swale lengths (head works, 2 ft (0.6 m), and 6 ft (1.8 m)) for a Bluegrass swale during low flow (8 GPM) at 5% channel slope. In this particular test, particle sizes were significantly reduced in the grass swale especially between the head works and 2 ft (0.6m). The other three factors (flow rate, slope, and grass type) were not found to be significant in reducing median particle sizes, as shown in Figure 37, 38, and 39.

Conclusions

As expected, increased swale length, lower slopes, and lower flow rates were observed to be the most important conditions which result in increased sediment retention by grass swales.

Total Solids and Turbidity

Swale length:

• Total solids: Significant sediment reductions were observed between 2 ft (0.6 m) and 6 ft (1.8 m) ($p < 0.001$), but not between 0 ft and 2 ft (0.6 m) ($p = 0.546$). This suggests that sedimentation becomes measurable beyond 2 ft (0.6 m). An overall 12% reduction in total solids was observed.

• Turbidity: Swale length was not found to be a significant factor ($p = 0.811$ between 0 ft and 6 ft (1.8 m)) in reducing turbidity levels.

• Longer lengths provided more time for sediment to settle in the grass swales. This was more evident for the larger particles in these short swales.

Grass type:

• Total solids: A significant difference in total solids concentrations for the different grass types was observed at 6 ft (1.8 m) ($p = 0.061$), but not at 2 ft (0.6 m) ($p = 0.371$). Centipede grass was found to be the most efficient among the three grass types. At 6 ft, 20% of the sediments were retented in Centipede grass whereas Bluegrass swale was 11% and Zoysia grass swale was 12%.

• Turbidity: Grass type was not found to be a significant factor affecting turbidity levels for both 2 ft (0.6 m) ($p = 0.531$) and 6 ft (1.8 m) ($p = 0.482$).

• The stem length of Bluegrass is higher than for Zoysia. During high flows (15 GPM), the water flooded the Zoysia grass more often than Bluegrass, reducing sediment retention efficiency.

• Even though the stems of the Centipede grass are larger than for the other grasses tested, the stem density of the grass was less. The density of the grass may therefore be more important than the grass stem length in sediment capture and retention.

Flow rate:

• Total solids: A significant difference was observed in total solids reductions at 6 ft (1.8 m) ($p < 0.001$), but not at 2 ft (0.6 m) ($p = 0.803$) for the different flow rate tests. The median reductions during the 8 GPM (0.03 m^3/min) tests were 16.5% better than during the 15 GPM (0.06 m^3/min) tests at 6 ft (1.8 m).

• Turbidity: Flow rate was not found to be a significant factor affecting turbidity levels at both 2 ft (0.6 m) ($p = 0.366$) and 6 ft (1.8 m) ($p = 0.169$).

Slope:

• Total solids: A significant difference was observed in total solids reductions at 6 ft (1.8 m) ($p = 0.017$), but not at 2 ft (0.6 m) ($p = 0.457$) for the different swale slopes. The median reductions for the 1% sloped swales were 11.5% better than for the 5% sloped swales at 6 ft (1.82 m).

• Turbidity: Slope was not found to be a significant factor affecting turbidity levels for both 2 ft (0.6 m) ($p = 0.157$) and 6 ft (1.8 m) ($p = 0.842$).

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• Swales at 1% slopes retained particles better than the swales at 5% slopes. The flatter slopes resulted in longer travel times for the particles to travel within the swale and allowed smaller particles to settle before the end of the swale was reached.

Sampling time:

• Total solids: The sampling time was not found to be a significant factor affecting total solids retention for both 2 ft (0.6 m) ($p = 0.457$) and 6 ft (1.8 m) ($p = 0.365$) sampling locations.

• Turbidity: The time interval of sampling was not found to be a significant factor affecting turbidity levels for 2 ft (0.6 m) ($p = 0.703$) and 6 ft (1.8 m) ($p = 0.697$) sampling locations.

Table 22. Significant Factors Affecting Total Solids and Turbidity Reductions in Grass Swales

Constituent	Variable	Probabilities
Total Solids	Grass type	0.048
	Slope	0.015
	Flow rate	< 0.001
Turbidity	Time * Flow rate	0.035

Particle Size Distribution Analyses

• There was some ambiguity in the PSD median values between the headworks and the 2 ft (0.6 m) samples; in most runs, the headworks showed a higher median particle sizes, but in 5 runs the 2 ft (1.8 m) sample showed a higher median particle size. This could be because of scouring and associated erosion of the grass bed between these locations.

• Swale length was found to be a significant factor in reducing median particle sizes. The median particle size was reduced from 7.5 μm at the head works to 5.7 μm at 6 ft. The other factors (flow rate, slope, and grass type), however, were found to be insignificant.

Findings and Suggestions

The following modifications and further studies were identified after these initial experiments in order to better understand the response of the swales to varying conditions:

• These initial analyses did not include separate total suspended solids and total dissolved solids analyses. It is expected that the retention of total dissolved solids would be minimal in a grass swale and without separating out this contribution, the total solids results from these initial experiments could be confused by "constant" total dissolved solids values.

• The length of the grass swale was too short to be able to clearly distinguish the settling of particles, especially between the head works (0 ft) and 2 ft (0.6 m). More precise control of some variables and more repetitions are needed to eliminate or confirm some of the conflicting results.

• The test setup needs a better measurement and control method for flow rate. It is critical to maintain the same flow rate for all the similar experiments. Although this was attempted, there was some unwanted flow variability.

• The density of the grass, especially for Zoysia, could have been better; the swale Zoysia grass density was sparse at certain locations.

• Overall, the control factors needed to be better controlled to get more meaningful results, although most of the results obtained during these initial tests appear reasonable. The second series of experiments described in the next chapter were set up to address many of these shortcomings.

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Chapter 6: Second Set of Controlled Indoor Swale Experiments

Introduction

The initial set of experiments described in the previous chapter identified the primary factors affecting the transport of stormwater sediment in grass swales. To understand these factors further, additional experiments were conducted in the second sets of experiments described in this chapter. In addition, a number of modifications in the experimental setup were made to reduce the variability of the measured values. Centipede grass was replaced with synthetic turf to determine if the synthetic turf resulted in similar sediment transport conditions compared to actual grass. The initial experiment showed that the time of sampling since the start of the test not important, and this factor was therefore not included during these experiments. Also, additional analyses were conducted; total suspended solids, total dissolved solids, and total solids greater than and less than 106 μm. Particle size distribution and turbidity analyses were also conducted during these experiments.

Indoor Laboratory Swales

Descriptions of the Experimental Set-up

There were two experimental problems during the initial set of swale experiments that were addressed during these newer experiments. Although the two 65 GPM (0.25 m^3/min) sump pumps were employed to agitate the sediments in the 150-gallon (0.57 m^3) tank, large sediment particles, such as sands, were not well-mixed and suspended in the tank. Consequently, significant amounts of large particles were settled out on the bottom of the tank during the initial experiment and not pumped to the swale. The "headworks" sampling eliminated errors in analyzing the samples, but it was difficult to represent these larger particles in the tests. Another problem was the accuracy and repeatability of the flow rates. Flow rates were controlled by a valve attached to the piping network. However, valve movement was too sensitive and hard to control the desired flow rate.

To solve these problems, the headworks of the experimental setup was modified. The modified system for the second experiment consisted of a slurry feeding device with pump, mixing chamber, and a wood channel. Figures 41, 42, and 43 show the sediment slurry mixture feeding device, including the small pump and the mixing chamber. Known amounts of the sediment mixture and water were mixed in the feeding device and were pumped into the mixing chamber as a slurry. A regulated flow pumped from the 150 gallon (0.57 m^3) tank (filled with tap water) was mixed with the slurry in the mixing chamber. The solution was then dispersed onto the wood channel to create a 2 ft (0.6 m) wide sheet flow before entering the grass lined channel. Also, the flow rates were more accurately controlled during the second set of tests.

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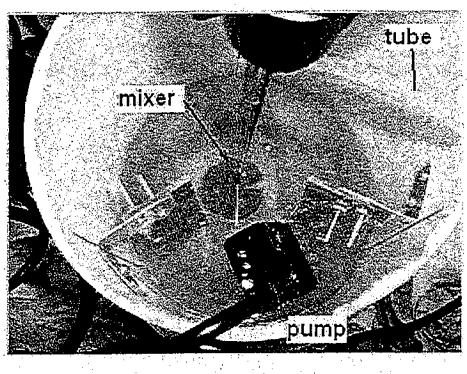

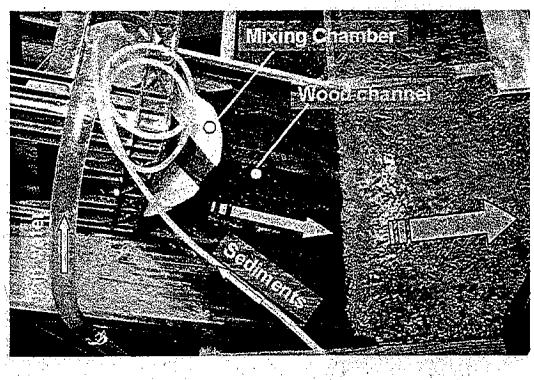

Figure 41. (*left*) Picture showing the sediment feeding device consisting of a mixer, bucket, small pump, and plastic tube.
Figure 42. (*Right*) Sediment slurry and tap water are being mixed at the mixing chamber (A sheet flow is created at the wood channel).

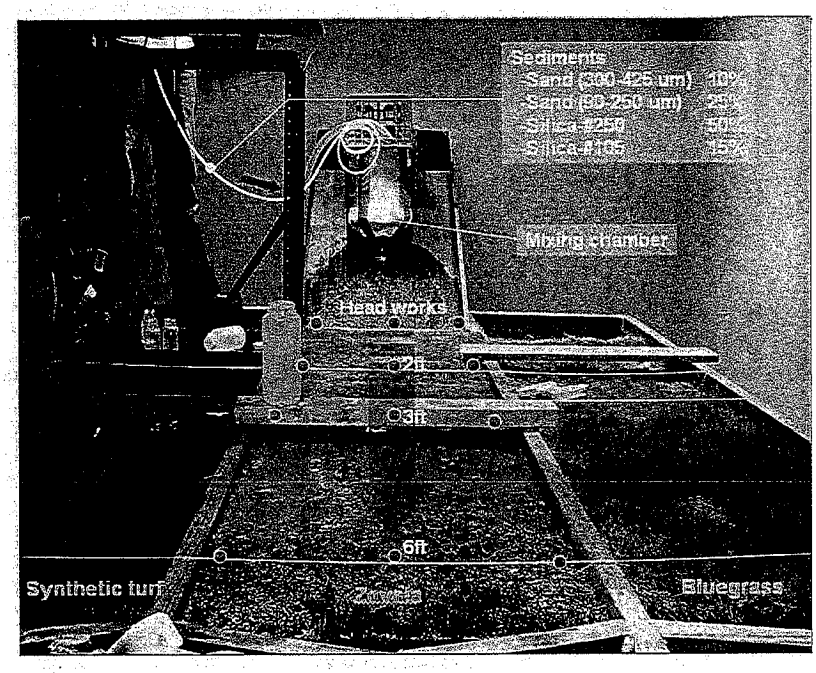

Figure 43. Picture showing the indoor experimental setup (Three different types of grass are mounted on a base which can be adjusted in slope. In this test, the sediment solution is being introduced onto the Zoysia swale).

Sediment Characteristics of the Sediment-Water Mixture

Fine-ground silica (SIL-CO-SIL® from US Silica Co.), along with sieved sands, were used in the test mixture. These fine-ground silicas are bright white, low in moisture, and chemically inert. Two different sizes of silca, SIL-CO-SIL®106 ("all" material smaller than 106 μm) and SIL-CO-SIL®250 ("all" material smaller than 250 μm) were used. Sieved sands were also used to provide larger particles, ranging from 90 to 250 μm and 300 to 425 μm. The

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sediment concentration of the test flow was targeted at 500 mg/L. Table 23 shows the percentage contribution of the test sediments in different particle size ranges, while Figure 44 shows the particle size distribution of the test sediment mixture. This mixture had more of the larger particles (the median size was about 50 µm) than typical stormwater (usually median particle size of about 10 µm, although some samples have larger median sizes). This enabled us to more accurately measure the performance of the grass swales over a wide range of particles. Since each particle size range was evaluated individually, this somewhat distorted distribution did not hinder our ability in evaluating the results.

Table 23. Percentage Contribution and Specific Gravity of the Test Sediments

Sediment	Percentage contribution	Specific gravity
Silica (SIL-CO-SIL®106)	15%	2.65
Silica (SIL-CO-SIL®250)	50%	2.65
Sand (90 - 250 µm)	25%	2.65
Sand (300 - 425 µm)	10%	2.65
Total	100%	

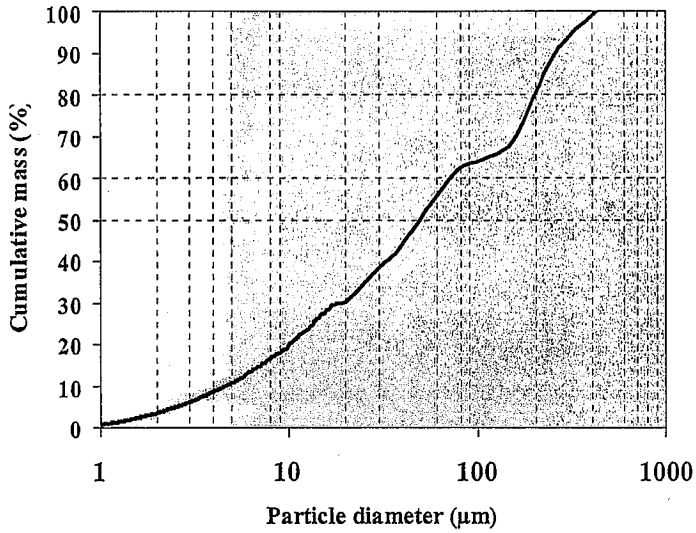

Figure 44. Particle size distribution of the test sediment mixture.

Table 24. Particle Size Distributions of SIL-CO-SIL®106 and SIL-CO-SIL®250[1]

	SIL-CO-SIL®106	SIL-CO-SIL®250
Particle size (µm)	Percentage in size range	Percentage in size range
0 to 45	73.0%	50.0%
45 to 53	7.0%	8.0%
53 to 75	12.5%	11.0%
75 to 106	5.6%	12.0%
106 to 150	1.5%	9.5%
150 to 212	0.1%	6.0%
> 212	0.0%	3.5%
Total	100%	100%

[1] particle size information from U.S. Silica Co. data sheets

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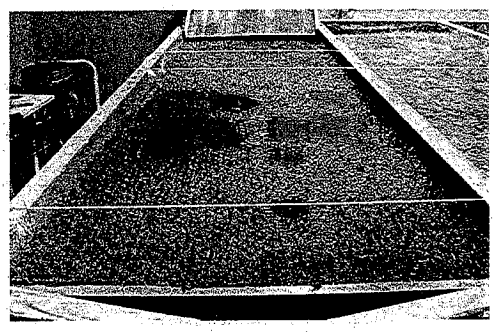
Factors Tested During the Second Experiments

One result of the initial experiments indicated that the time factor since the beginning of the steady state experiment was not important in affecting the particle retention in the swales. Thus, this factor was excluded from the second experiment by taking composite samples during the experimental run. Also, Centipede grass was replaced with synthetic turf to determine whether the synthetic turf produced similar results to actual grass. Several prior swale experiments used synthetic media, so these experiments were conducted to investigate how this material compared to actual grass. The following were the variables tested during the second set of experiments:

- *Grass types*: The three different types of grass tested were synthetic turf, Zoysia, and Kentucky Bluegrass. Synthetic turf was obtained from a local household maintenance warehouse store. The height of stems of the synthetic turf was approximately 0.25 inches (0.635 cm) which was much shorter than the other grass, and the stems were quite still. The stems were made of thin and uniformly dense plastic films shown in Figure 45 and 46.



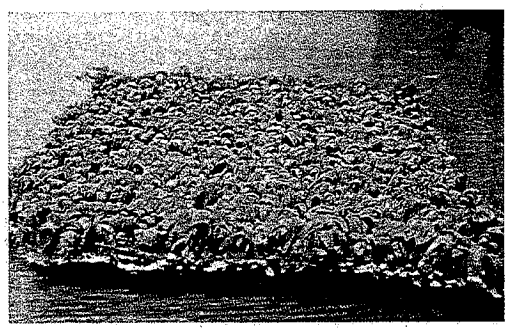


Figure 45. (*left*) Picture showing the channel with the synthetic turf.
Figure 46. (*Right*) Close-up of the synthetic turf.

- *Slopes*: 1%, 3%, and 5% channel slope were tested.
- *Flow rates*: Adequate control of flow rates was achieved by the modified headworks. Flow rates were 10 GPM (0.038 m^3/min), 15 GPM (0.064 m^3/min), and 20 GPM (0.076 m^3/min).
- *Swale lengths*: The samples were collected at the entrance (0 ft), 2 ft (0.6 m), 3 ft (0.9 m), and 6 ft (1.8 m).

Analytical Methods

During the second experiment, 108 samples were collected and analyzed for the following analytical parameters.

- Total solids (Standard Methods 2540B)
- Total solids after screening with a 106 μm sieve (total solids < 106 μm, to better match the particulates measured by the Coulter Counter)
- Total suspended solids (solids retained on a 0.45 μm filter) (Standard Methods 2540D)
- Total dissolved solids (solids passing through a 0.45 μm filter) (Standard Methods 2540C)
- Turbidity using a HACH 2100N Turbidimeter
- Particle size distribution by Coulter Counter (Beckman® Multi-Sizer III™), composite of several different aperture tube measurements (30, 100, and 400 μm apertures)

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Each sample was collected in a 1 litter plastic sampling bottle and was equally divided into a subset of 10 subsamples by using the USGS/Dekaport Cone Splitter shown in Figure 47 (Rickly Hydrological Company). The cone splitter was utilized to ensure that sediment characteristics of sub-samples were identical to each other for analyzing the different analytical parameters. For each parameter, two replicates were produced and analyzed to increase the reliability of the tests. The performance of USGS/Dekaport Cone Splitter for producing identical sub-samples is presented in Appendix J.

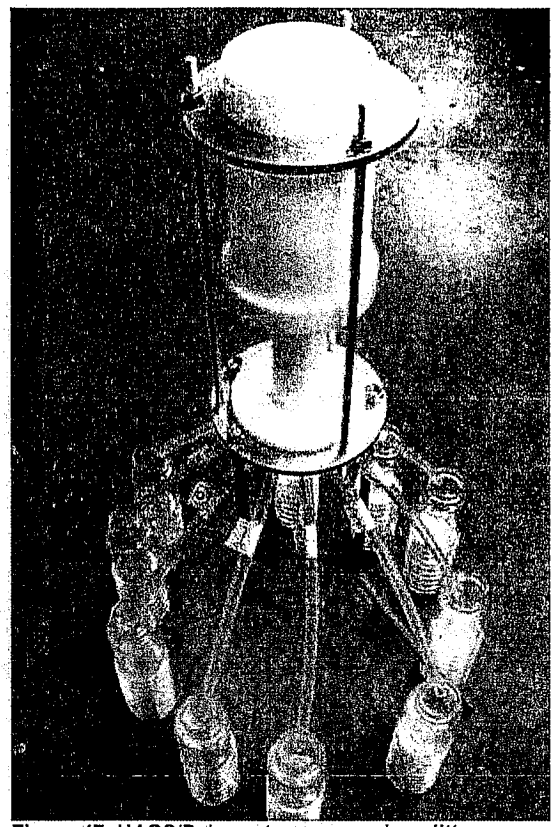

Figure 47. UAGS/Dekaport cone sample splitter.

Head Works Study

Despite the modification of the headworks, it was still difficult to maintain consistent sediment concentrations of the sediment-water mixture entering the grass channels during the tests. Analytical results showed a larger variability of sediment concentrations than desired at the head works, especially for large particles.

Figure 48 shows that total dissolved solids (< 0.45 μm) at the head work were relatively consistent, but the concentrations of particles ranging in size from 0.45 to 106 μm and from 106 to 425 μm had greater variability during the experiments. Large particles in the 106 to 425 μm size range had the largest overall variability due to the difficulty of consistently suspending large particles in the mixture. Because of this variability, all concentration data were normalized against the initial sediment concentrations at the head works. Analysis of Variance (ANOVA) tests were performed to determine the effects of the experimental variables on these normalized concentration changes. However, residuals of the ANOVA were not normally distributed as required (normality tested using the Anderson-

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Darling statistical test). Therefore, for each swale length, the normalized data were ranked. The ANOVA was then used on these ranked normalized data to determine the significance of the variables.

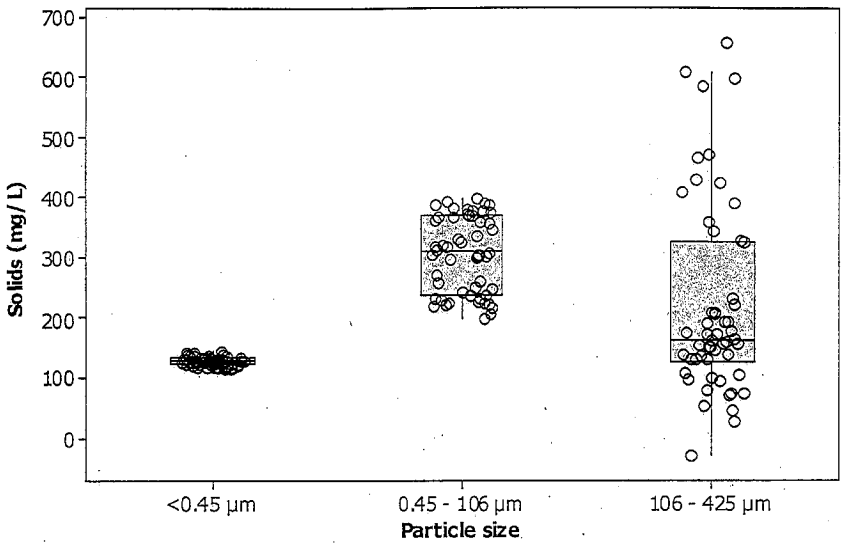

Figure 48. Box-and-whisker plots of initial sediment concentrations differentiated by the particle size ranges at the head works.

Data Analysis and Results

The complete analytical results obtained during the second set of experiments are presented in Appendix B.

Swale Length

Figures 51, 52, 53 and 55 show that significant sediment reductions were observed at 2 ft (0.6 m), 3 ft (0.9 m), and 6 ft (1.8 m) for total solids, total solids after screening with a 106 µm sieve, total suspended solids, and turbidity. Figure 54 shows that there were no significant changes in total dissolved solids as a function of swale length (the numbers of samples were too small to measure the significance of the small differences). Sediments were rapidly reduced between the head works (0 ft) and 2 ft (0.6 m) due to the settlement of large particles at the beginning of the swale. Smaller-sized sediments were gradually reduced between 2 ft (0.6 m) and 6 ft (1.8 m), as the smaller particles were more likely to be carried over longer distances than the larger particles. The median concentration of total suspended solids was reduced from 460 mg/L at 0 ft to 200 mg/L at 2 ft (0.6 m) (56% reduction), and, the median total suspended solids concentration at 6 ft (1.8 m) was 110 mg/L (76% reduction). Unlike solids, turbidity reductions shown in Figure 55 were relatively constant with swale length, since turbidity was not as affected by the larger particles which were preferentially removed. The median of turbidity was reduced from 64 NTU at 0 ft (0 m) to 38 NTU at 6 ft (1.8 m) (40% reduction).

After each experiment, sands were visually observed up to 1 ft (0.3 m) from the head works. Figure 49 and 50 show that deposition was not uniform across the swale. This visual observation confirms that large particles were predominantly captured at the beginning of the grass swales.

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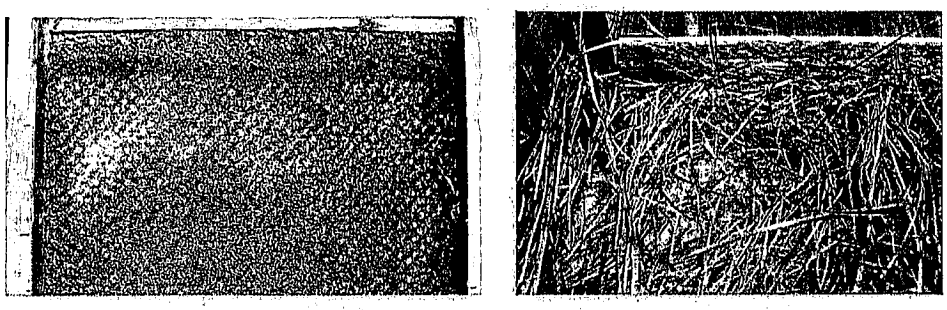

Figure 49. (*left*) Picture showing sand accumulation on the synthetic turf swale.
Figure 50. (*right*) Close-up of sand accumulation on the Bluegrass swale.

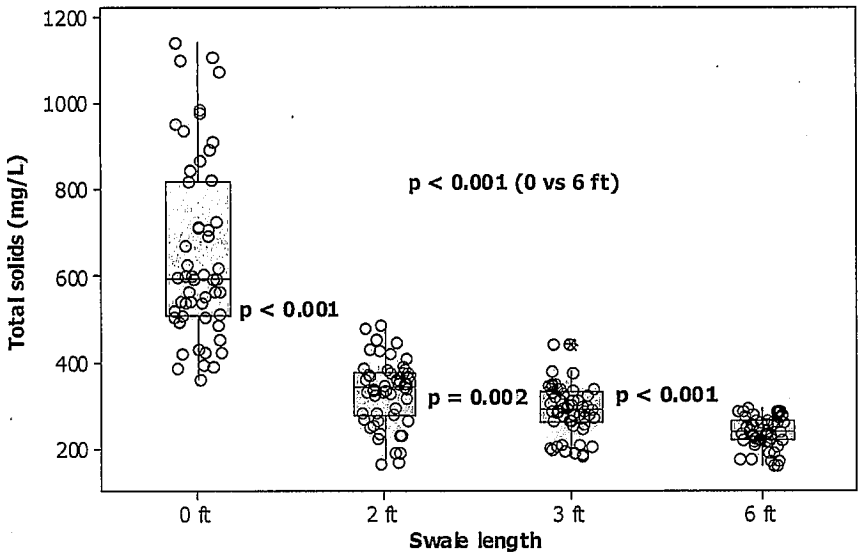

Figure 51. Box-and-whisker plots of total solids concentrations vs. swale length (Note 1 ft = 0.30 m).

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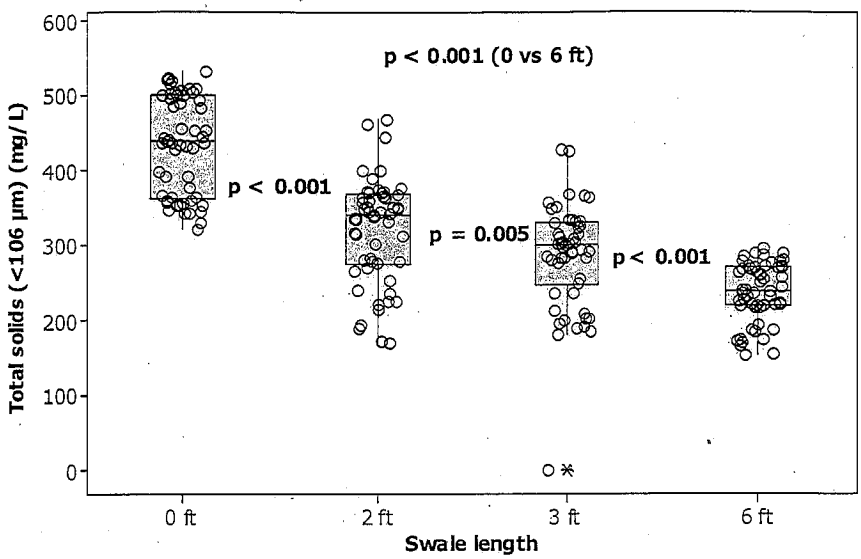

Figure 52. Box-and-whisker plots of total solids (< 106 µm) concentrations vs. swale length (Note 1 ft = 0.30 m).

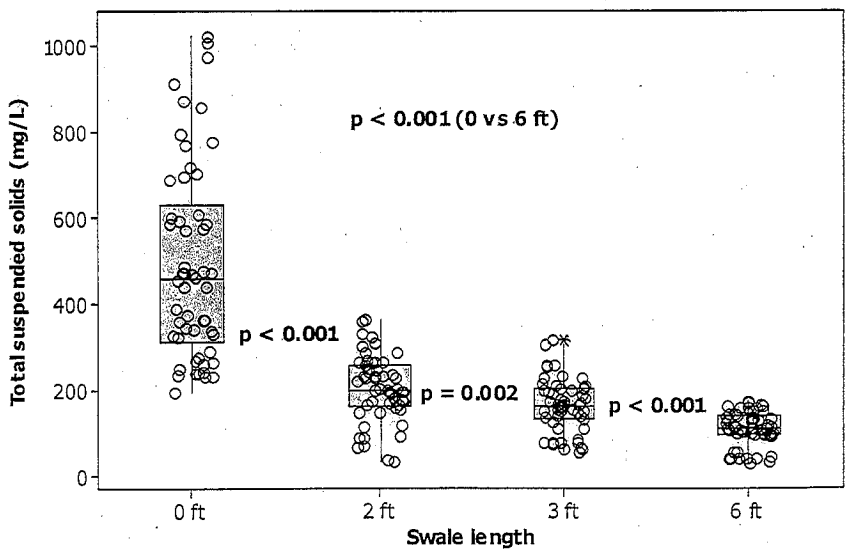

Figure 53. Box-and-whisker plots of total suspended solids concentrations vs. swale length (Note 1 ft = 0.30 m).

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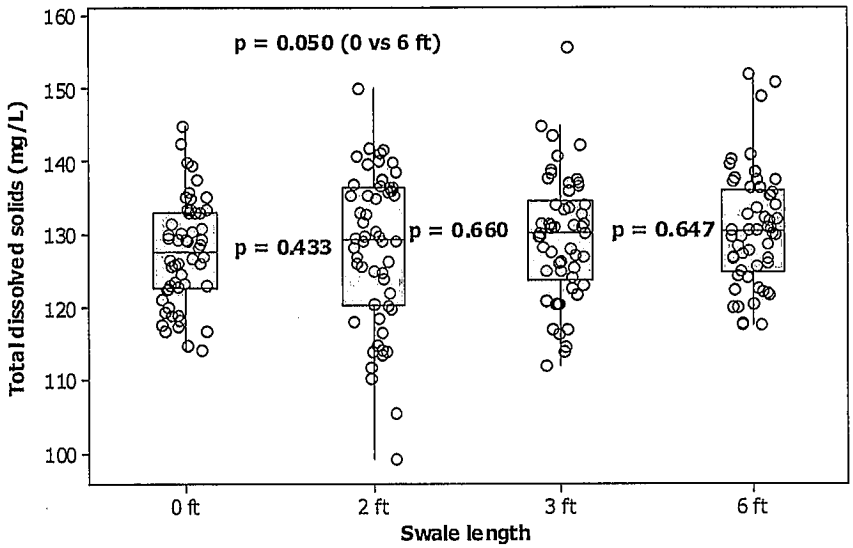

Figure 54. Box-and-whisker plots of total dissolved solids concentrations vs. swale length (Note 1 ft = 0.30 m).

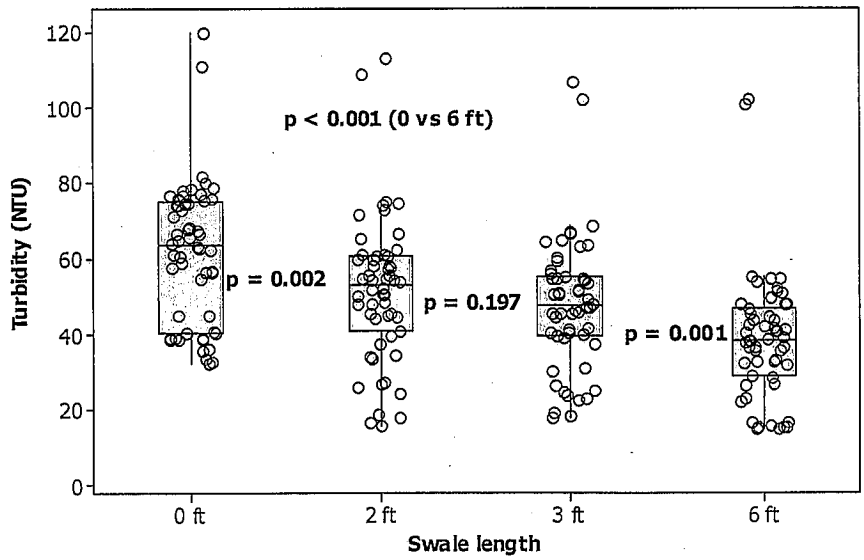

Figure 55. Box-and-whisker plots of turbidity concentrations vs. swale length (Note 1 ft = 0.30 m).

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Variables Affecting Sediment Transport

ANOVA was performed to determine the effects of the experimental variables on the ranked normalized concentration changes. The significance level was set at 0.05 for this statistical procedure. Swale length, grass type, slope, and flow rate were significant factors for most of the particulate constituents. In contrast, all variables were insignificant for total dissolved solids. Among the three grass types, synthetic turf was found to be the least effective, and Zoysia and Kentucky Bluegrass had similar sediment reduction rates. The effects of channel slope and flow rate were marginal for total solids and total suspended solids. However, these effects were clearly significant for turbidity. A 1% slope was found to be much more efficient in trapping the particulates than the 3% and 5% slopes, and the low flow rate of 10 GPM (0.038 m3/min) was more effective in reducing turbidity than the higher flow rates of 15 GPM (0.064 m3/min) and 20 GPM (0.076 m3/min). Some of the interactions between the factors were also important and need to be considered when explaining sediment transport in grass swales. Table 25 shows the variables and interaction terms and associated probabilities for each constituent. The followings are Box and whisker plots of the changes in concentrations compared to initial values. Also, Box and whisker plots of the actual observed concentrations are presented in Appendix G.

Table 25. Variables and Associated Probabilities at 6 ft (1.8 m)

Constituent	Variable	Probabilities
Total solids	**Grass type**	**< 0.001**
	Slope	**0.006**
	Flow rate	**< 0.001**
	Grass type*Slope	0.333
	Grass type*Flow rate	**0.023**
	Slope*Flow rate	0.429
Total solids (< 106 µm)	**Grass type**	**< 0.001**
	Slope	0.746
	Flow rate	0.879
	Grass type*Slope	0.641
	Grass type*Flow rate	**< 0.001**
	Slope*Flow rate	**< 0.001**
Total suspended solids	**Grass type**	**< 0.001**
	Slope	**0.047**
	Flow rate	0.247
	Grass type*Slope	0.194
	Grass type*Flow rate	**0.005**
	Slope*Flow rate	**0.013**
Total dissolved solids	Grass type	0.701
	Slope	**0.049**
	Flow rate	0.498
	Grass type*Slope	0.842
	Grass type*Flow rate	**0.044**
	Slope*Flow rate	0.244
Turbidity	**Grass type**	**< 0.001**
	Slope	**0.02**
	Flow rate	0.144
	Grass type*Slope	**0.001**
	Grass type*Flow rate	**< 0.001**
	Slope*Flow rate	0.387

*Bolded probabilities represent 'significant effects' because these are less than 0.05

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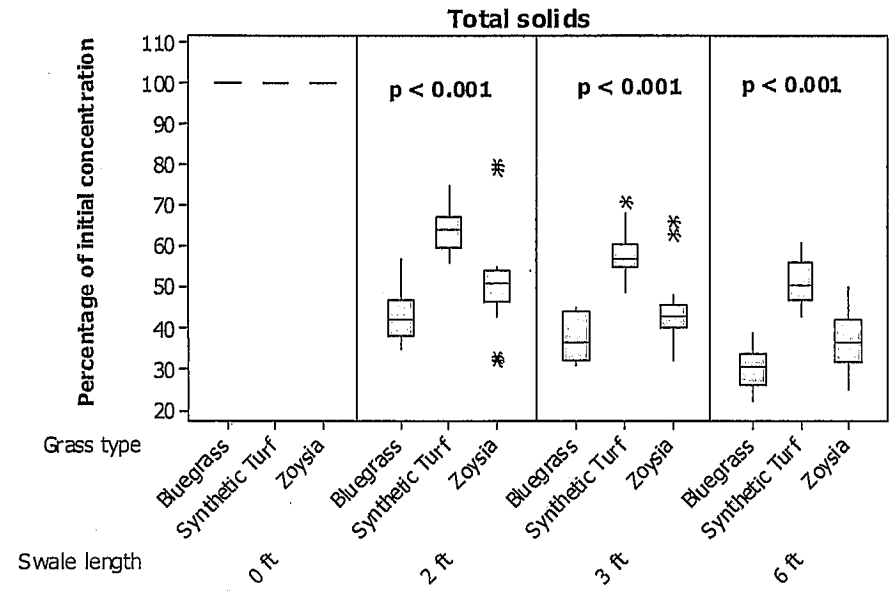

Figure 56. Box-and-whisker plots of total solids vs. swale length and grass type (Note 1 ft = 0.3048 m).

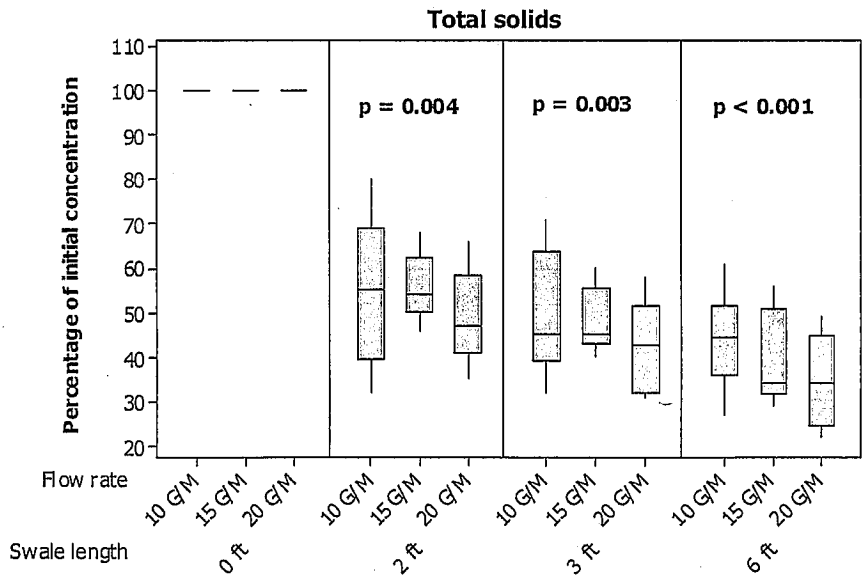

Figure 57. Box-and-whisker plots of total solids vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

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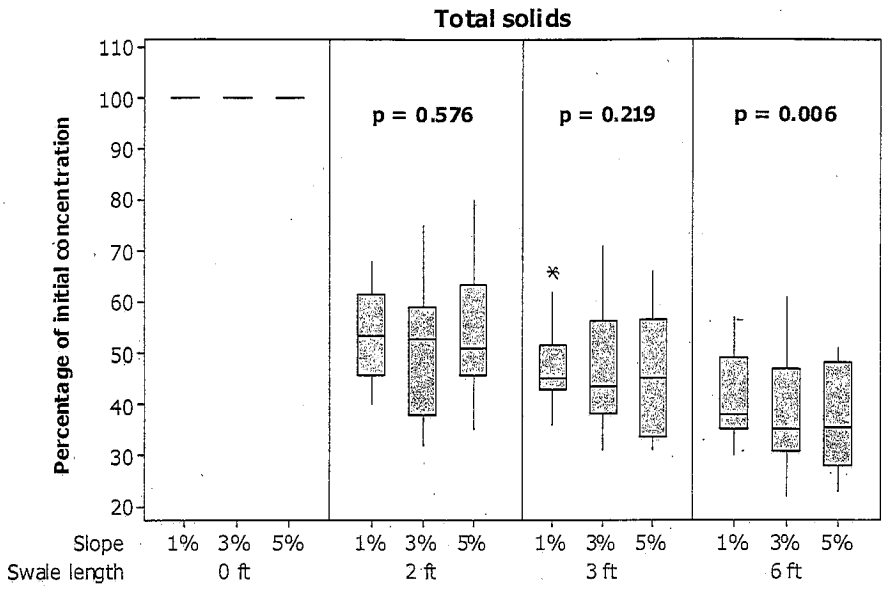

Figure 58. Box-and-whisker plots of total solids vs. swale length and slope (Note 1 ft = 0.30 m).

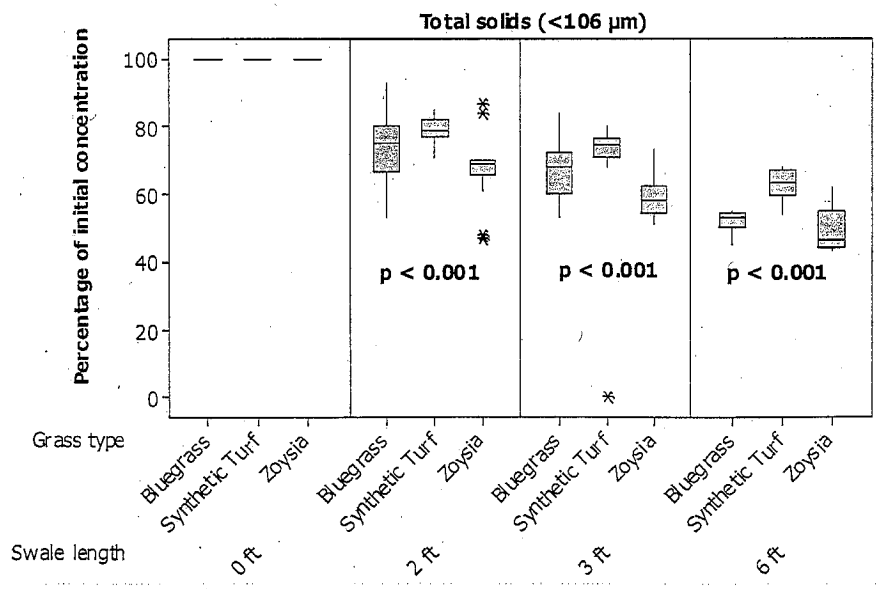

Figure 59. Box-and-whisker plots of total solids (< 106 µm) vs. swale length and grass type (Note 1 ft = 0.30 m).

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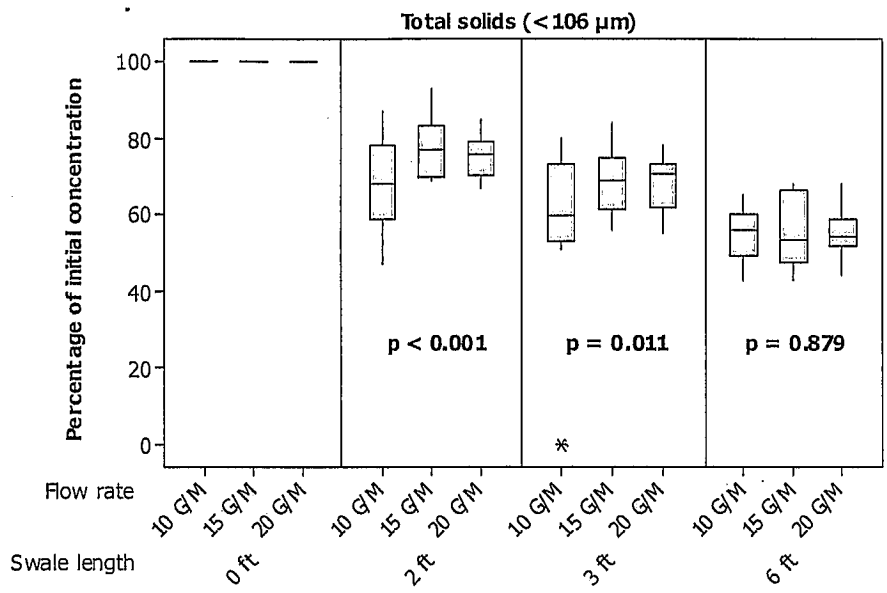

Figure 60. Box-and-whisker plots of total solids (< 106 µm) vs. swale length and flow rate (Note 1 ft = 0.3048 m, 1 GPM = 0.003785 m^3/min).

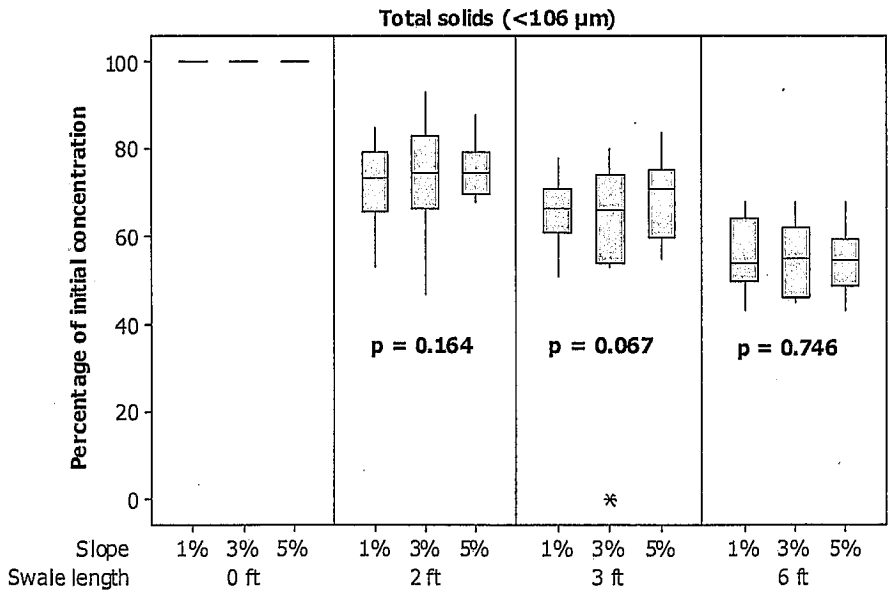

Figure 61. Box-and-whisker plots of total solids (< 106 µm) vs. swale length and slope (Note 1 ft = 0.30 m).

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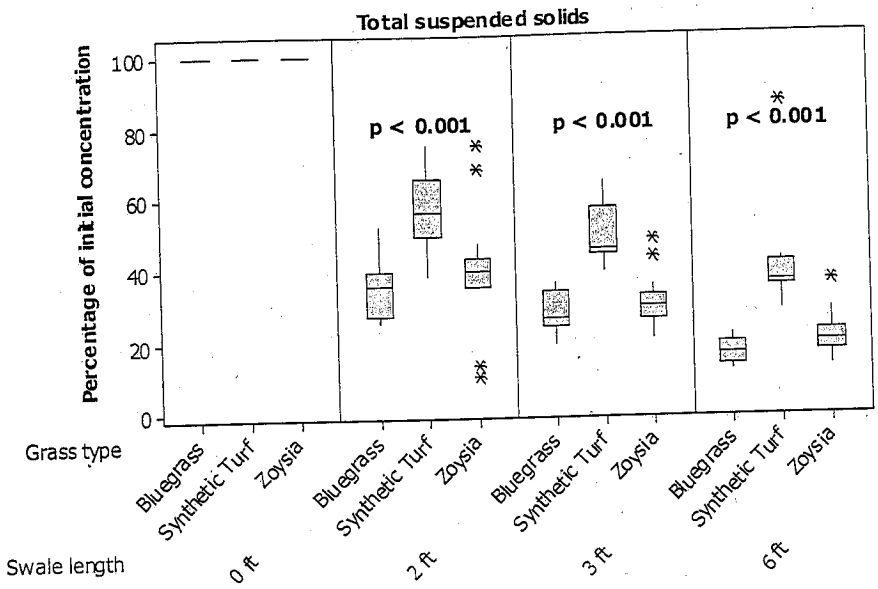

Figure 62. Box-and-whisker plots of total suspended solids vs. swale length and grass type (Note 1 ft = 0.30 m).

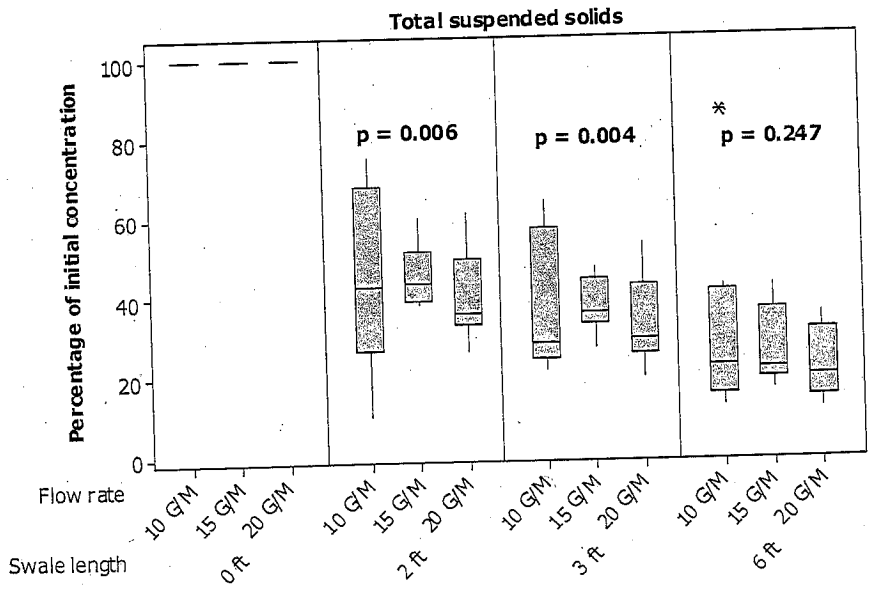

Figure 63. Box-and-whisker plots of total suspended solids vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

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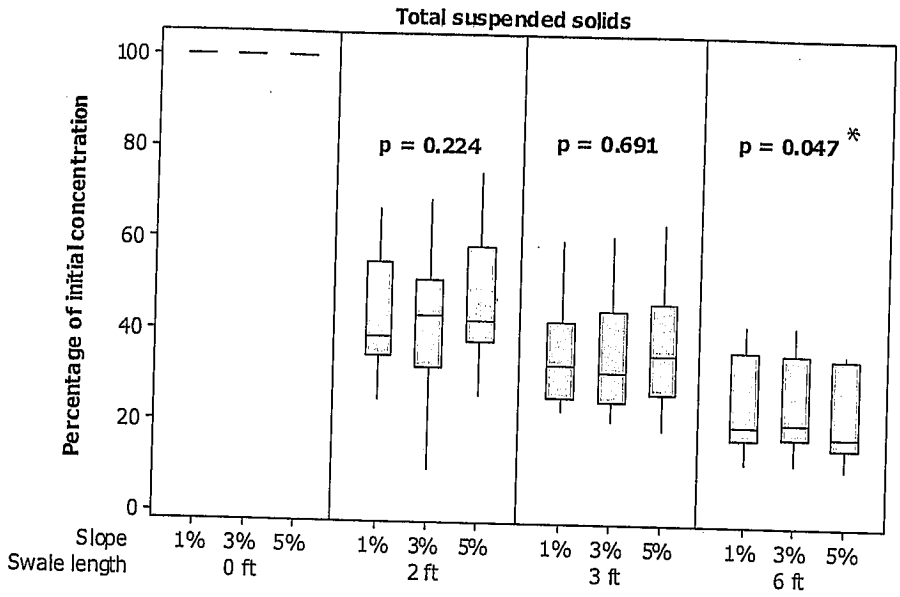

Figure 64. Box-and-whisker plots of total suspended solids vs. swale length and slope (Note 1 ft = 0.30 m).

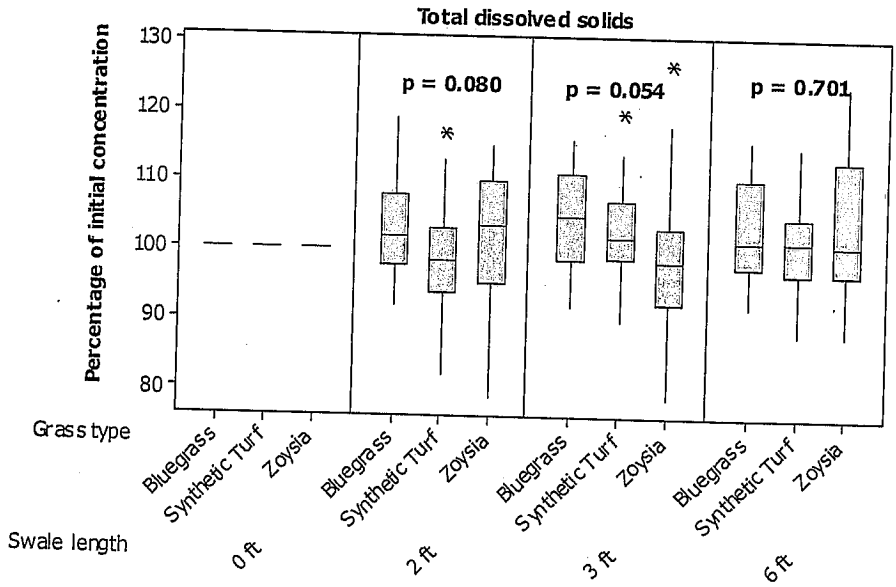

Figure 65. Box-and-whisker plots of total dissolved solids vs. swale length and grass type (Note 1 ft = 0.30 m).

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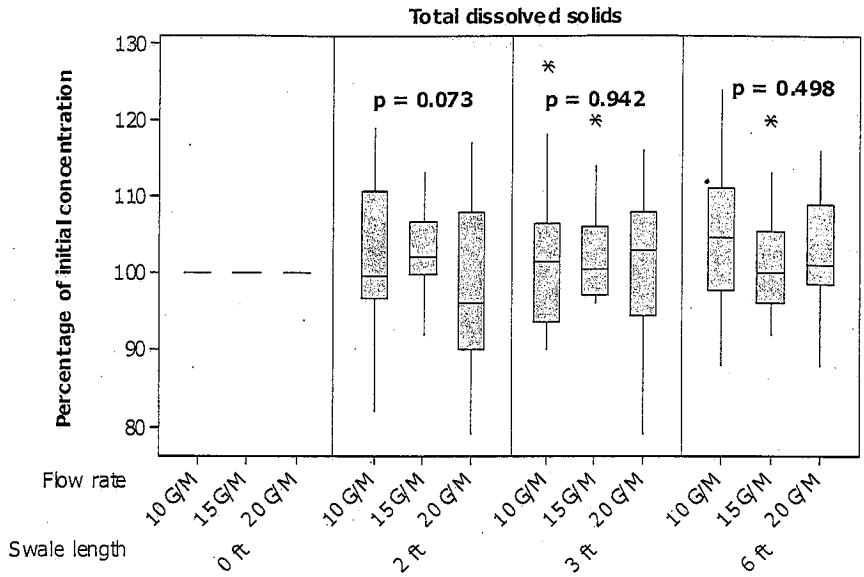

Figure 66. Box-and-whisker plots of total dissolved solids vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

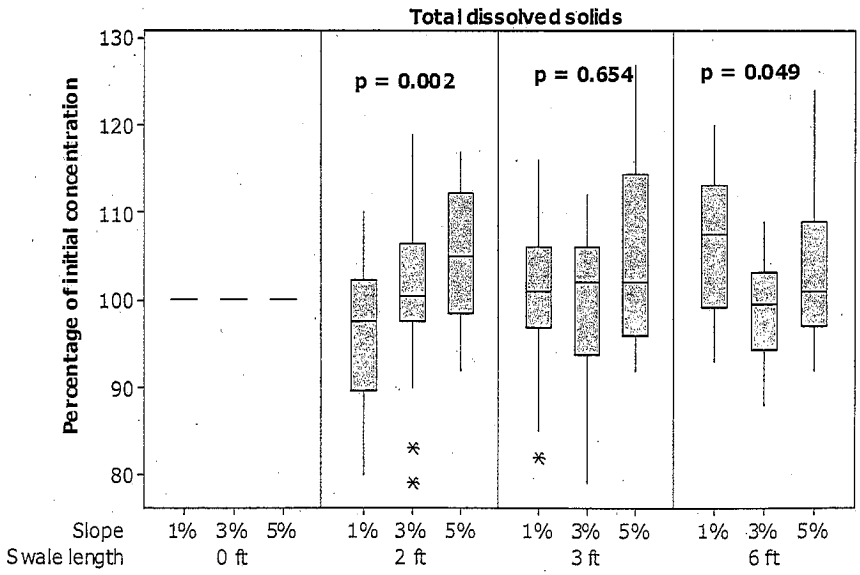

Figure 67. Box-and-whisker plots of total dissolved solids vs. swale length and slope (Note 1 ft = 0.30 m).

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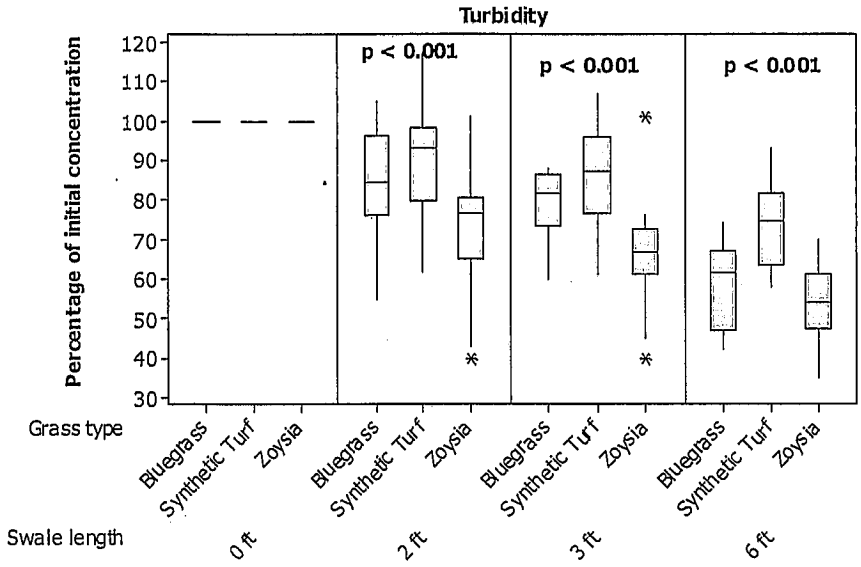

Figure 68. Box-and-whisker plots of turbidity vs. swale length and grass type (Note 1 ft = 0.30 m).

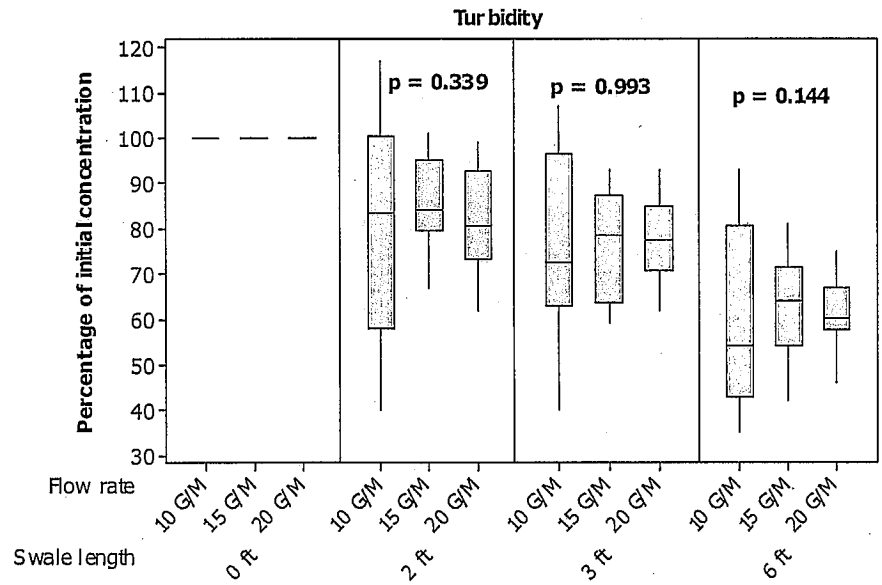

Figure 69. Box-and-whisker plots of turbidity vs. swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.00385 m^3/min).

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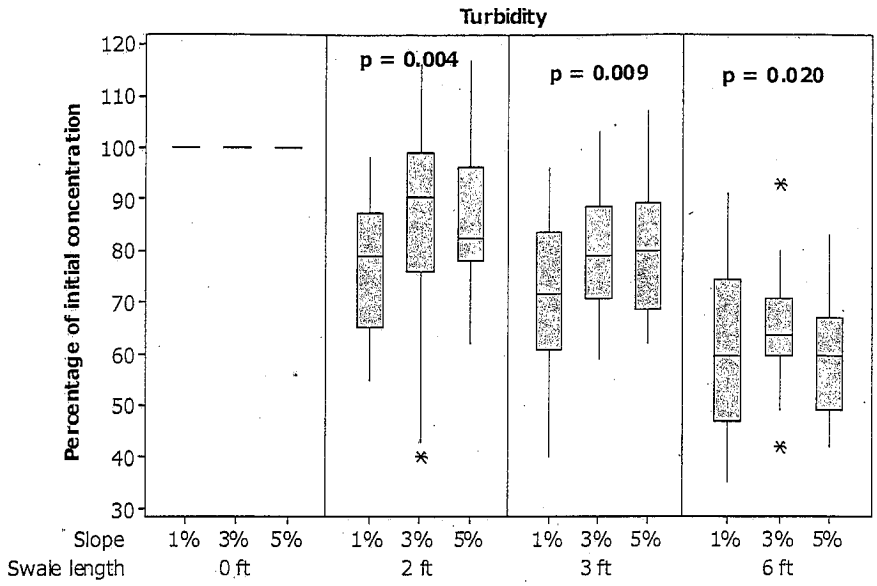

Figure 70. Box-and-whisker plots of turbidity vs. swale length and slope (Note 1 ft = 0.30 m).

Particle Size Distribution Analyses

Swale length was the only significant factor affecting particle size distributions ($P \leq 0.001$), while the three other factors (flow rate, slope, and grass type) as well as the interactions between the variables were insignificant. Figure 71 shows the median particle sizes of runoff particulates for each swale length. The median particle sizes consistently decreased by swale length, as expected, indicating a preferential trapping of larger particles near the upper end of the swale. Overall, the median particle sizes decreased from 15 μm at 0 ft (0 m) to 11 μm at 6 ft (1.8 m) (30% reduction). Figures 72 and 73 show that grass type and flow rate were insignificant factors affecting particle size distributions. Figure 73 shows that slope was also an insignificant factor affecting particle size distributions at 6 ft (1.8 m), however, there were significant changes in median particle sizes by the different slopes at 2 ft (0.6 m) and 3 ft (0.9 m). At 2 ft (0.6 m) and 3 ft (0.9 m), median particle sizes were smaller for 1% slope than at 3% and 5% slopes. Statistical summaries of particle size distributions observed in the second experiments are presented in Appendix H. Also, particle size distributions of each experiment are presented in Appendix I.

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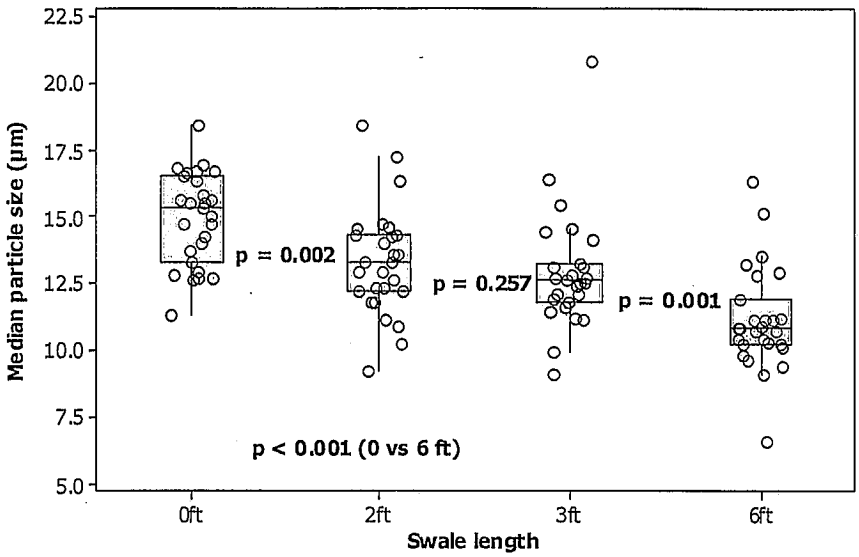

Figure 71. Box-and-whisker plots of median particle sizes vs. swale length (Note 1 ft = 0.30 m).

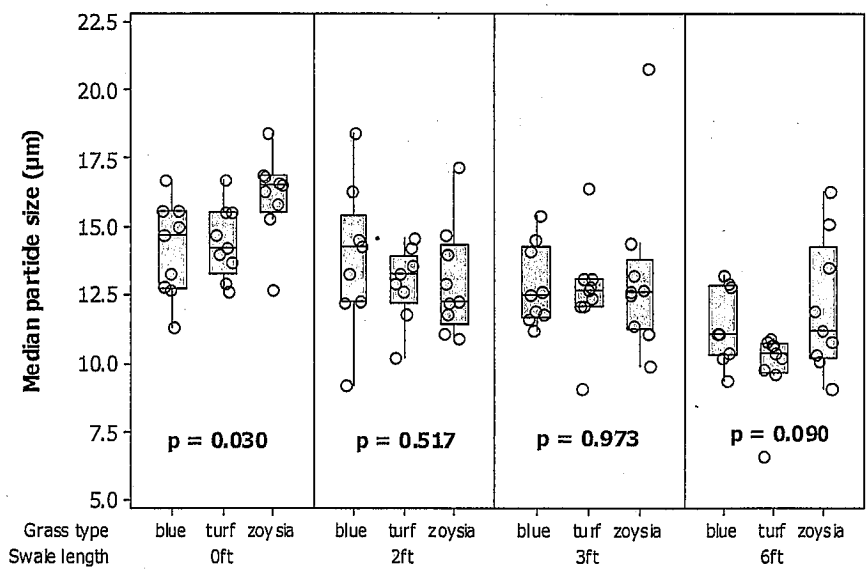

Figure 72. Box-and-whisker plots of median particle sizes by swale length and grass type (Note 1 ft = 0.30 m).

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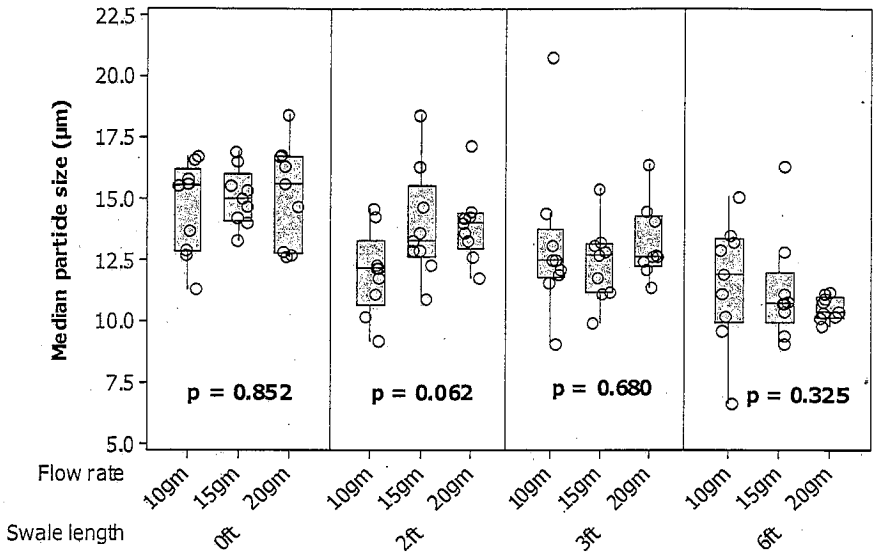

Figure 73. Box-and-whisker plots of median particle sizes by swale length and flow rate (Note 1 ft = 0.30 m, 1 GPM = 0.0038 m^3/min).

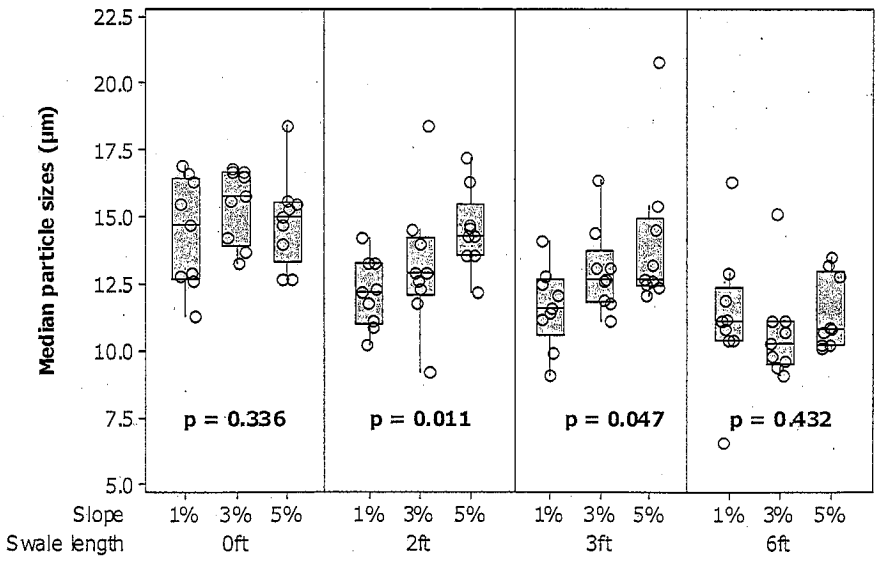

Figure 74. Box-and-whisker plots of median particle sizes by swale length and slope (Note 1 ft = 0.30 m).

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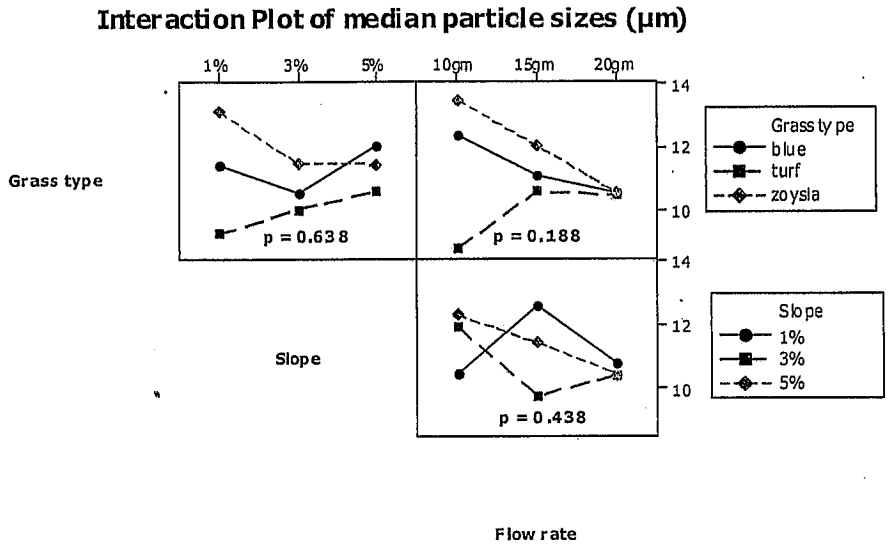

Figure 75. Interaction plots of median particle sizes.

Summary of Findings

• Significant reductions were observed at 2 ft (0.6 m), 3 ft (0.9 m), and 6 ft (1.8 m) from the head works for total solids, total solids after screening with a 106 µm sieve, total suspended solids, and turbidity, but not for total dissolved solids.

• Sediment concentrations rapidly declined between the head works (0 ft) and 2 ft (0.6 m) due to the settlement of large particles at the beginning of the swale. Sand accumulation was visually observed at the beginning of the swales.

• Turbidity was gradually reduced in the swales.

• Swale length, grass type, slope, and flow rate were all found to be significant factors for most of the particulate constituents. However, all variables were insignificant for total dissolved solids, except for the interaction of flow rate and grass type.

A007644

Table 26. Significant Factors and Associated Probabilities

Constituent	Variable	Probabilities
Total solids	Grass type	< 0.001
	Slope	0.006
	Flow rate	< 0.001
	Grass type*Flow rate	0.023
Total solids (< 106 µm)	Grass type	< 0.001
	Grass type*Flow rate	< 0.001
	Slope*Flow rate	0.006
Total suspended solids	Grass type	< 0.001
	Slope	0.047
	Grass type*Flow rate	0.005
	Slope*Flow rate	0.013
Total dissolved solids	Grass type*Flow rate	0.044
Turbidity	Grass type	< 0.001
	Slope	0.02
	Grass type*Slope	0.001
	Grass type*Flow rate	< 0.001

Swale Length

• Total solids: Significant sediment reductions were observed between all the swale lengths ($p < 0.001$ from 0 ft (0 m) to 2 ft (0.6 m), $p = 0.002$ from 2 ft (0.6 m) to 3 ft (0.9 m), $p < 0.001$ from 3 ft (0.9 m) to 6 ft (1.8 m)). The highest sediment reduction was observed between 0 ft (0m) and 2 ft (0.6 m) (42% reduction in median total solids). Overall 60% of sediment reduction was observed.

• Total solids < 106 µm: Significant sediment reductions were observed between all the swale lengths ($p < 0.001$ from 0 ft (0 m) to 2 ft (0.6 m), $p = 0.005$ from 2 ft (0.6 m) to 3 ft (0.9 m), $p < 0.001$ from 3 ft (0.9 m) to 6 ft (1.8 m)). Sediment reductions in total solids < 106 µm were not as rapid as for total solids, especially between 0 ft (0 m) and 2 ft (0.6 m). This suggests that the larger particles greater than 106 µm contributed to the high sediment removals between 0 ft (0 m) and 2 ft (0.6 m). Overall, a 54% reduction in total solids < 106 µm was observed between 0 and 6 ft.

• Total suspended solids: Significant sediment reductions were observed between all the swale lengths ($p < 0.001$ from 0 ft (0 m) to 2 ft (0.6 m), $p = 0.002$ from 2 ft (0.6 m) to 3 ft (0.9 m), $p < 0.001$ from 3 ft (0.9 m) to 6 ft (1.8 m)). Like total solids, the highest sediment reduction was observed between 0 ft (0 m) and 2 ft (0.6 m) (56% reduction in median TSS). Overall, a 76% reduction of total suspended solids was observed between 0 and 6 ft.

• Total dissolved solids: Slight increase (2%) in TDS concentrations were observed, possibly due to soil mineralization contributions. Significant increases in total dissolved solids were observed between 0 ft (0 m) and 6 ft (1.8 m) ($p = 0.050$). Initial total dissolved solids concentrations did not change or slightly increased in the grass swales.

• Turbidity: Significant sediment reductions were observed between 0 ft (0 m) and 2 ft (0.6 m) ($p = 0.002$) and between 3 ft (0.9 m) and 6 ft (1.8 m) ($p = 0.001$). Overall, turbidity was consistently decreased by swale length (70% reductions in the median turbidity levels).

Grass Type

• Total solids: Grass type was found to be a significant factor at 2 ft (0.6 m) ($p < 0.001$), 3 ft (0.9 m) ($p < 0.001$), and 6 ft (1.8 m) ($p < 0.001$). Blue grass was most efficient in reducing total solids, whereas synthetic turf was the least effective.

• Total solids < 106 µm: Grass type was found to be a significant factor at 2 ft (0.6 m) ($p < 0.001$), 3 ft (0.9 m) ($p < 0.001$), and 6 ft (1.8 m) ($p < 0.001$). Unlike total solids, Zoysia grass was found to be the most efficient in reducing total solids < 106 µm. Synthetic turf was the least effective among the three grass types.

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• Total suspended solids: Grass type was found to be a significant factor at 2 ft (0.6 m) ($p < 0.001$), 3 ft (0.9 m) ($p < 0.001$), and 6 ft (1.8 m) ($p < 0.001$). Blue grass was the most efficient in reducing total suspended solids, while synthetic turf was the least effective.

• Total dissolved solids: There was no significant evidence showing the significance of grass type in reducing total dissolved solids.

• Turbidity: Grass type was found to be a significant factor at 2 ft (0.6 m) ($p < 0.001$), 3 ft (0.9 m) ($p < 0.001$), and 6 ft (1.8 m) ($p < 0.001$). Zoysia grass was the most efficient in reducing turbidity, whereas synthetic turf was the least effective.

Flow Rate

• Total solids: Flow rate was found to be a significant factor at 2 ft (0.6 m) ($p = 0.004$), 3 ft (0.9 m) ($p = 0.003$), and 6 ft (1.8 m) ($p < 0.001$). At 6 ft (1.8 m), 15 GPM (0.064 m^3/min) and 20 GPM (0.0767 m^3/min) were more efficient in reducing total solids than 10 GPM (0.038 m^3/min) flows.

• Total Solids < 106 µm: Flow rate was found to be a significant factor at 2 ft (0.6 m) ($p < 0.001$), 3 ft (0.9 m) ($p = 0.011$), but not at 6 ft (1.8 m) ($p = 0.879$). 10 GPM (0.038 m^3/min) was the most efficient in reducing total solids < 106 µm among the three flow rates. These suggest that the effect of flow rate is significant at the beginning of the grass swales, but diminishes beyond 6 ft.

• Total suspended solids: Like total solids < 106 µm, flow rate was a significant factor at 2 ft (0.6 m) ($p = 0.006$), 3 ft (0.9 m) ($p = 0.004$), but not at 6 ft (1.8 m) ($p = 0.247$).

• Total dissolved solids: There was no evidence showing the significance of flow rates in reducing total dissolved solids.

• Turbidity: There was no evidence showing the significance of flow rates in reducing turbidity.

Slope

• Total solids: Slope was found to be a significant factor only at 6 ft (1.8 m) ($p = 0.006$). 3% slope and 5% slope were slightly better in reducing total solids than 1% slope.

• Total solids < 106 µm: Slope was not found to be significant factor at any of the swale lengths.

• Total suspended solids: Slope was found to be a significant factor in reducing TSS concentrations; however, 5% slope was only slightly better than 1% and 3% slopes.

• Total dissolved solids: Although slope was found to be a significant factor at 2 ft and 6 ft, the effect of slope was hard to determine.

• Turbidity: Slope was found to be a significant factor at 2 ft (0.6 m) ($p = 0.004$), 3 ft (0.9 m) ($p = 0.009$), and 6 ft (1.8 m) ($p = 0.020$). 1% slope was found to be the most effective in reducing turbidity, however, the differences among the three slopes in reducing turbidity decreased as swale length increased.

Particle Size Distributions

• Overall, the median particle sizes consistently decreased from 15 µm at 0 ft (0 m) to 11 µm at 6 ft (1.8 m) (30% reduction), indicating a preferential trapping of larger particles near the upper end of the swale.

• Swale length was found to be the only significant factor ($p < 0.001$) while the three other factors (flow rate, slope, and grass type) as well as the interactions between them, were not found to be significant.

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Chapter 7: Outdoor Swale Observations

Introduction

Both the initial and second sets of indoor experiments were conducted to identify the significant factors affecting, the transport of sediment in grass swales, and to develop an associated model. Sampling of stormwater at a full-size outdoor grass swale located adjacent to the Tuscaloosa, Alabama, City Hall during actual storm events was used to test the model obtained from the indoor experiments. Sixty-seven samples were collected at various locations along the swale during 13 storm events from August to December 2004. These samples were analyzed for the same constituents as analyzed during the second indoor tests (total solids, total solids < 106 μm, suspended solids, total dissolved solids, turbidity, and particle size distributions).

Descriptions of the Site

The outdoor grass swale test site is located adjacent to the Tuscaloosa City Hall, Tuscaloosa, Alabama. This full-size swale has a length of 116 ft (35.3 m) and is planted with Zoysia grass. Although this is a full-scale swale, the drainage area is very small, only comprising about 0.1 acres (4,200 ft^2 or 390 m^2) of paved roads and side walks, shown on Figure 80. Table 27 and Figure 77 show the channel slopes at various swale lengths. The slopes are steeper at the beginning of the swale and are flatter at the end. Figure 78 shows an example of cross-sectional elevations surveyed, illustrating the typical parabolic shape of the swale. This cross-sectional shape forces runoff to flow along a concentrated area on the bottom of the channel. Grass stems were collected at 11 different locations to determine the stem density of Zoysia grass cover as shown in Table 28. The mean stem density was 524 (stems/ft^2) (5640 stems/m^2) with coefficient of variation of 0.28.

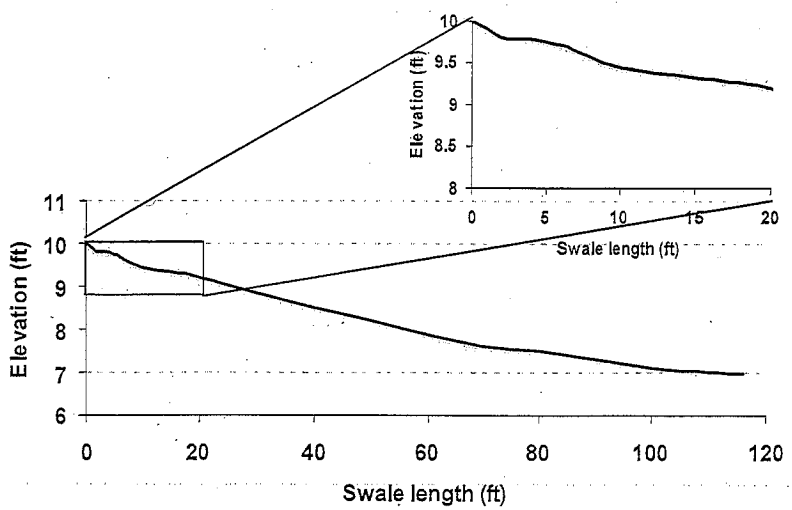

Figure 76. Longitudinal elevation profile of the outdoor swale.

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Table 27. Channel Slopes over Various Swale Regions

Swale region	Mean channel slope
0 to 5 ft (0 to 1.5 m)	5.20%
5 to 10 ft (1.5 to 3.0 m)	4.80%
10 to 70 ft (3 to 21.3 m)	3.00%
70 to 116 ft (21.3 to 35.3 m)	1.40%

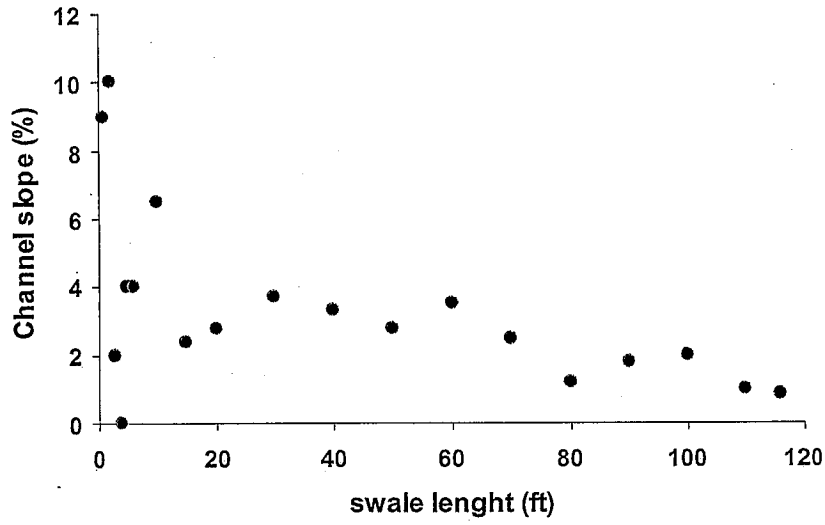

Figure 77. Longitudinal slopes surveyed on the outdoor swale.

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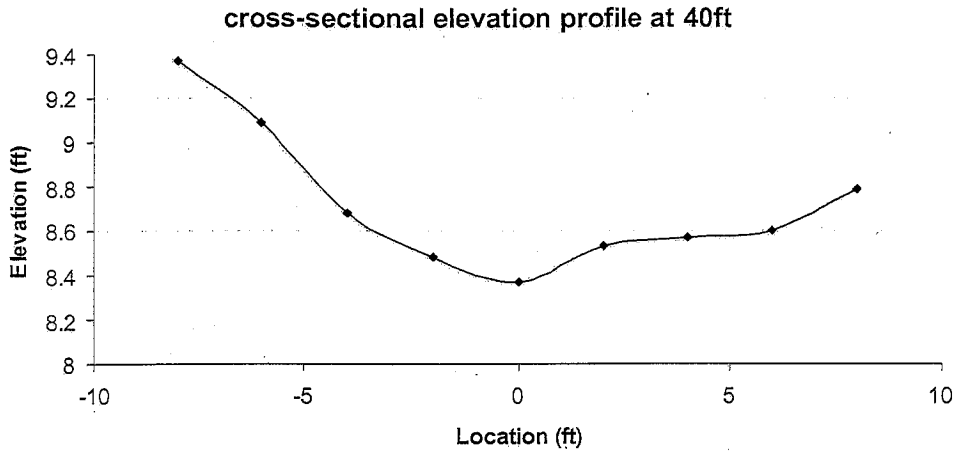

Figure 78. Example of cross-sectional elevations surveyed (40 ft (12 m) from the entrance) (All cross-sectional elevation profiles are presented in Appendix M).

Table 28. Stem Densities Observed at the Outdoor Grass Swale

	Stem density
Sample ID	Count (stems per inch^2)
1	4
2	5
3	3
4	2
5	4
6	4
7	4
8	4
9	3
10	2
11	5
Mean	*3.64*
Std. dev	*1.03*
COV	*0.28*

A soil survey conducted in accordance with U.S. Department of Agriculture (USDA) classification methods at the outdoor swale determined the soil was compacted loamy sand. In addition to surveying the slope and topsoil of the grass swale, infiltration rates of the swale soils were also measured using small double-ring infiltrometers (Turf-Tec, Inc.). The infiltration tests were conducted during both dry and wet conditions. Most of the infiltration rates were less than 1 inch/hour (2.54 cm/hour), as shown in Figure 82 and in Appendix L. The detailed soil survey also found sediment accumulation at the head of the swale, with grass growing through the top of the accumulated sediments. During storm events, the accumulated sediment created a small puddle at the head of the swale, preventing large particles from entering the swale due to sedimentation on the sidewalk.

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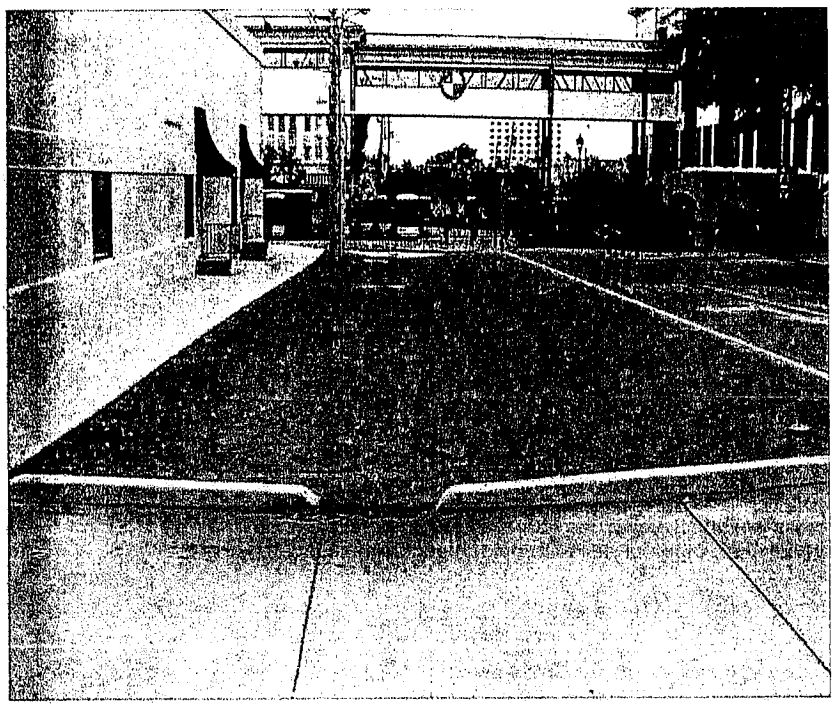

Figure 79. Picture showing the outdoor test swale (116 ft (35.3 m) in length draining 0.1 acres (390 m^2) of paved road).

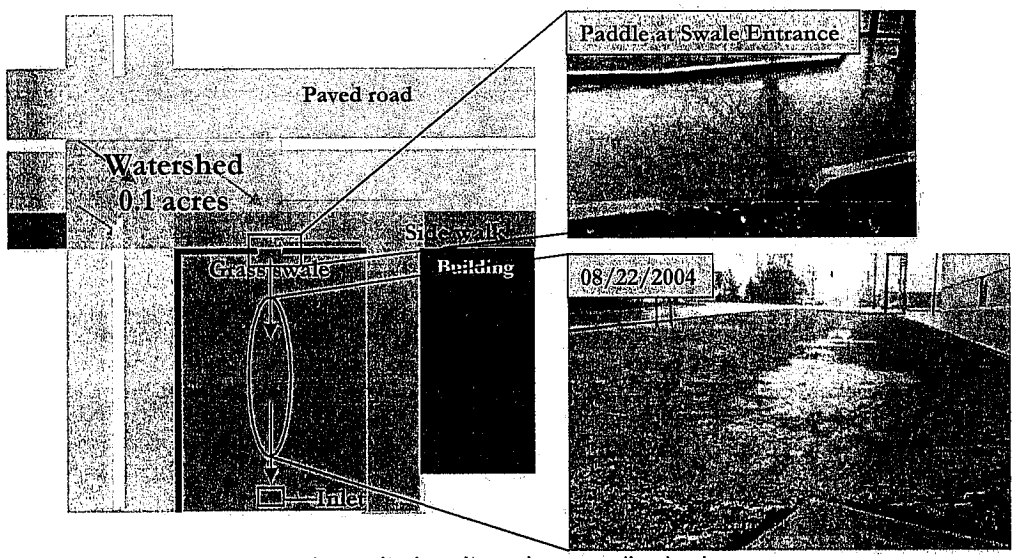

Figure 80. Outdoor grass swale monitoring site and surrounding land uses (Pictures of the entrance and overview of the swale during 08/22/2004 storm event).

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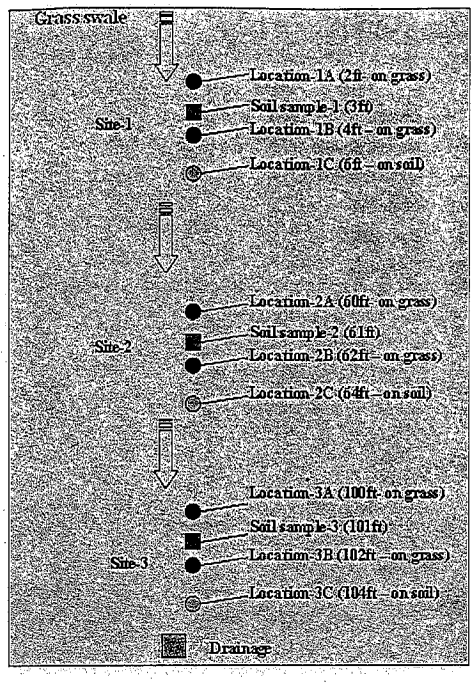

Figure 81. Locations of the infiltration testing and soil sampling (Note 1 ft = 0.30 m).

Table 29. Soil Densities of the Soil Samples

	Soil density (g/cm^2)	
	Dry condition	Wet condition
Site-1 (2 ft to 6 ft) (0.6 to 0.9 m)	1.76	1.94
Site-2 (60 ft to 64 ft) (18.2 to 19.5 m)	1.93	1.51
Site-3 (100 ft to 104 ft) (30.5 to 31.7 m)	1.95	1.87

Table 30. Moisture Content of the Soil Samples

	Moisture content (%)	
	Dry condition	Wet condition
Site-1 (2 ft to 6 ft) (0.6 to 0.9 m)	15.8	30.1
Site-2 (60 ft to 64 ft) (18.2 to 19.5 m)	15.6	24.7
Site-3 (100 ft to 104 ft) (30.5 to 31.7 m)	10.4	25.1

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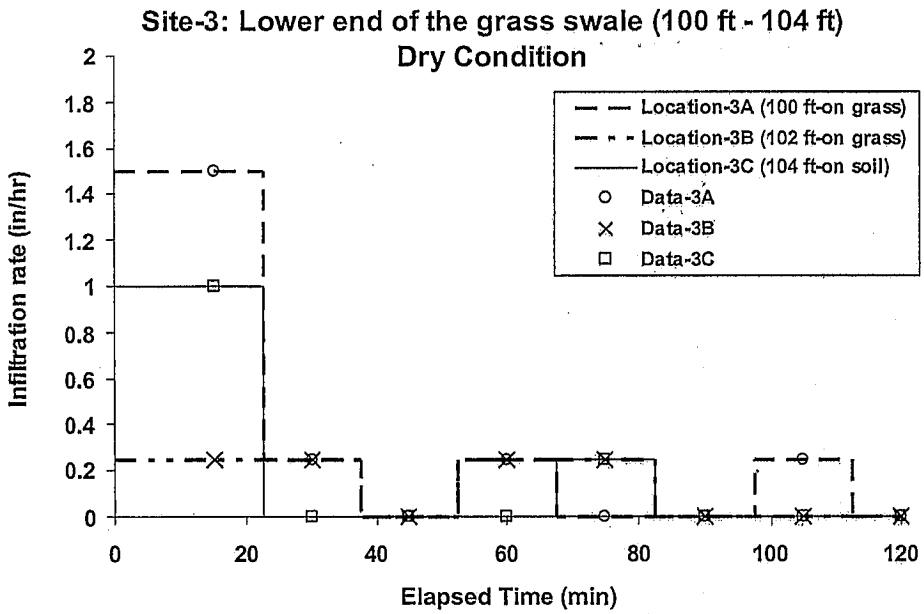

Figure 82. Example of infiltration rates of the grass swale (lower end of the swale) (All the results of the infiltration tests are presented in Appendix L).

Table 31. Summary of Averaged Infiltration Rates of the Grass Swale in Different Test Durations

	Dry Condition		
Location	First 30 min (inch/hour)	First 1 hour (inch/hour)	2 hours (inch/hour)
2 ft (grass)	0.25	0.19	0.16
4 ft (grass)	0.25	0.19	0.09
60 ft (grass)	0.63	0.38	0.25
62 ft (grass)	1	0.56	0.31
100 ft (grass)	0.88	0.5	0.28
102 ft (grass)	0.25	0.19	0.13
Mean	*0.54*	*0.34*	*0.20*
Std.dev	*0.34*	*0.17*	*0.09*
COV	*0.63*	*0.50*	*0.44*

	Dry Condition		
Location	First 30 min (inch/hour)	First 1 hour (inch/hour)	2 hours (inch/hour)
6 ft (soil)	0.38	0.25	0.16
64 ft (soil)	0.75	0.44	0.25
104 ft (soil)	0.5	0.25	0.16
Mean	*0.54*	*0.31*	*0.19*
Std.dev	*0.19*	*0.11*	*0.05*
COV	*0.35*	*0.35*	*0.27*

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Location	Wet Condition First 30 min (inch/hour)	First 1 hour (inch/hour)	2 hours (inch/hour)
2 ft (grass)	0	0.06	0.03
4 ft (grass)	0.5	0.5	0.31
60 ft (grass)	0.25	0.19	0.16
62 ft (grass)	0.38	0.31	0.16
100 ft (grass)	0.88	0.5	0.28
102 ft (grass)	0.63	0.31	0.16
Mean	*0.44*	*0.31*	*0.18*
Std.dev	*0.31*	*0.17*	*0.10*
COV	*0.69*	*0.55*	*0.55*

Location	Wet Condition First 30 min (inch/hour)	First 1 hour (inch/hour)	2 hours (inch/hour)
6 ft (soil)	< 0.01	< 0.01	< 0.01
64 ft (soil)	0.13	0.06	0.03
104 ft (soil)	0.25	0.19	0.13
Mean	*0.19*	*0.13*	*0.08*
Std.dev	*0.08*	*0.09*	*0.07*
COV	*0.45*	*0.74*	*0.88*

Sample Collection and Preparation

A total of 67 samples were collected at the swale entrance (0 ft), 2 ft (0.6 m), 3 ft (0.9 m), 6 ft (1.8 m), 25 ft (7.6 m), 75 ft (22.8 m), and 116 ft (35.3 m) locations during 13 storm events from August 22, 2004 to December 8, 2004. However, not all events were completely sampled. During some events, runoff was insufficient for collecting a runoff sample at the time of sampling at some locations due to the rain and flow ceasing before all samples could be collected. All the samples were collected in 1 litter polyethylene bottles and stored in a refrigerator before analysis.

Descriptions of Storm Events

Weather information during monitoring at the outdoor swale was obtained from a weather station on a University of Alabama building (H.M. Comer) located 1.5 miles (2.4 km) from the site. Table 32 describes weather information for the storm events sampled. Most of the events were small rains, but some had very high rainfall intensities typical of the area. The highest rainfall intensities (3.24 inch/hour (8.2 cm/hour) during 5 min.) were observed on 10/23/2004 and 12/08/2004. During sampling on 12/08/2004, the rainfall intensity increased dramatically, and the flow on the grass swale significantly increased during the sampling period.

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Table 32. Summary of Weather Information for the Sampled Storm Events

	Event-1	Event-2	Event-3	Event-4	Event-5	Event-6	Event-7
Date	8/22/2004	10/09/2004	10/10/2004	10/10/2004	10/11/2004	10/19/2004	10/23/2004
Sampling time	**N/P	10:30 AM	1:00 PM	9:00 PM	4:00 PM	4:00 PM	9:10 PM
Air temperature (Fahrenheit)	73	64	68	68	72	73	67
Preceding dry period (hour)	44.4	0.8	26.0	1.5	19.4	190.5	64.8
Total rain (inch)	0.58	0.05	0.15	0.16	0.11	0.17	0.84
Duration (minute)	80	25	200	110	45	20	115
Average intensity (inch/hour)	0.44	0.12	0.05	0.09	0.15	0.51	0.44
Max. rain fall intensity (inch/hour) in 5 minutes	1.92	0.12	0.12	0.24	0.24	1.08	3.24

	*Event-8	Event-9	Event-10	Event-11	Event-12	Event-13
Date	11/01/2004	11/11/2004	11/21/2004	11/22/2004	12/6/2004	12/8/2004
Sampling time	11:00 AM	12:40 AM	11:00 AM	1:50 PM	12:50 AM	12:50 AM
Air temperature (Fahrenheit)	67	64	60	64	57	59
Preceding dry period (hour)	91.3	168.9	13.5	24.8	5.7	39.4
Total rain (inch)	**N/A	0.23	1.12	2.84	0.32	0.7
Duration (minute)	**N/A	135	495	230	80	85
Average intensity (inch/hour)	**N/A	0.10	0.14	0.74	0.24	0.49
Max. rain fall intensity (inch/hour) in 5minutes	**N/A	0.36	1.08	2.28	1.08	3.24

Rain graphs of the storm events are presented in Appendix K.

* There was no rain detected by the weather station on 11/01/2004. This was likely due to the location difference between the weather station and the swale monitoring site. However, rain was obviously observed during sampling on this date, along with sufficient runoff for sampling.
** N/A = not available

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Analytical Methods

The 67 samples collected from 13 storm events were analyzed for the following constituents:

- Total Solids (Standard Methods 2540B)
- Total Solids after screening with a 106 µm sieve
- Total Suspended Solids (solids retained on a 0.45 µm filter) (Standard Methods 2540D)
- Total Dissolved Solids (solids passing through a 0.45 µm filter) (Standard Methods 2540C)
- Turbidity using a HACH 2100N Turbidimeter
- Particle Size Distribution by Coulter Counter (Beckman® Multi-Sizer III™), composite of several different aperture tube measurements

Results and Discussions

While collecting samples, sediment concentrations obviously decreased visually with increasing swale length during most of the events. Figure 87 shows the runoff samples and sediment captured on glass fiber filters at various swale lengths, collected on October 11, 2004. It was clear that runoff sediments were captured as the stormwater passed through the grass swale. All results are presented in Appendix C. Removal efficiencies for each constituent are presented in Appendix N.

Total Solids and Total Solids (< 106 µm) Variation by Swale Length

Figures 83 and 85 show that total solids and total solids less than 106 µm were very similar to each other for most of the events. This suggests that particle sizes of runoff sediments from the roads and in the grass swales were primary less than 106 µm. However, particles greater than 106 µm may have been present in the road runoff, but were captured at the small pool adjacent to the swale entrance. High sediment reduction rates in total solids and total solids less than 106 µm were observed between the swale entrance and 6 ft (1.8 m). Beyond 6 ft (1.8 m), there was no significant change in sediment concentrations. Total solids and total solids less than 106 µm were not reduced as much as total suspended solids. This suggests that total dissolved solids were the predominant portion of the total solids and total solids less than 106 µm for the samples collected in the grass swale.

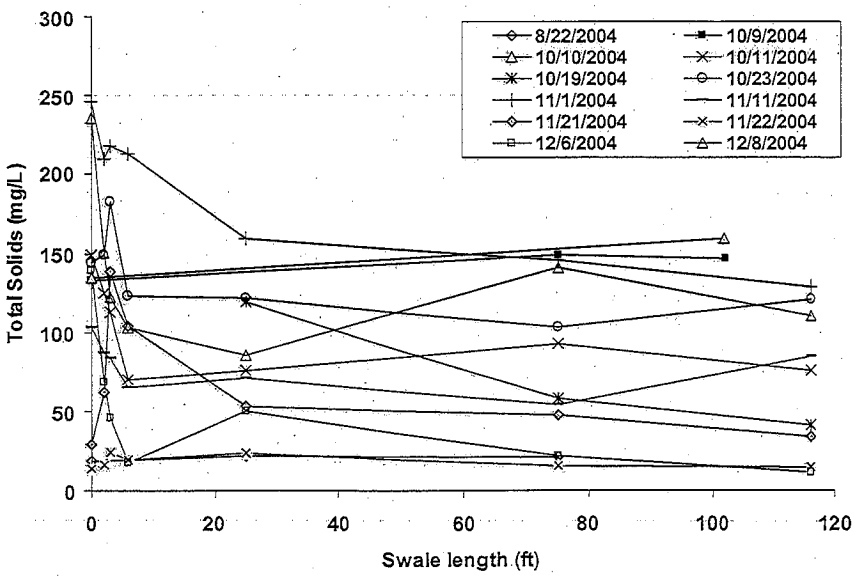

Figure 83. Total solids concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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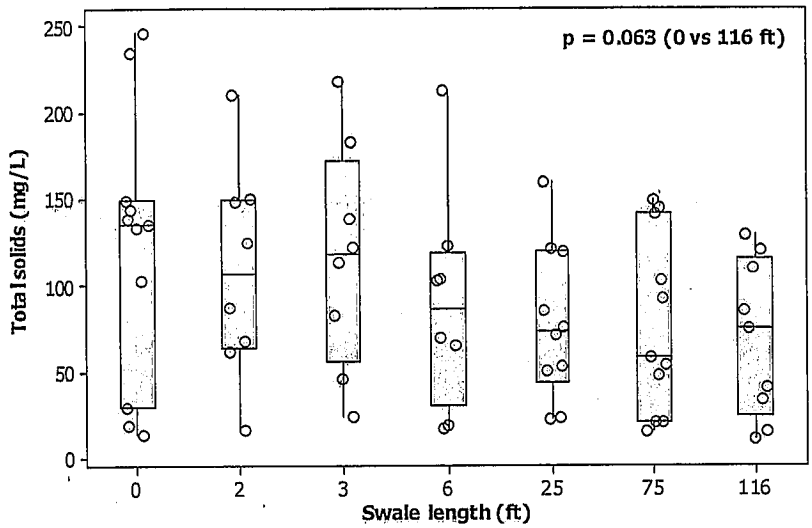

Figure 84. Box-and-whisker plots of total solids concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

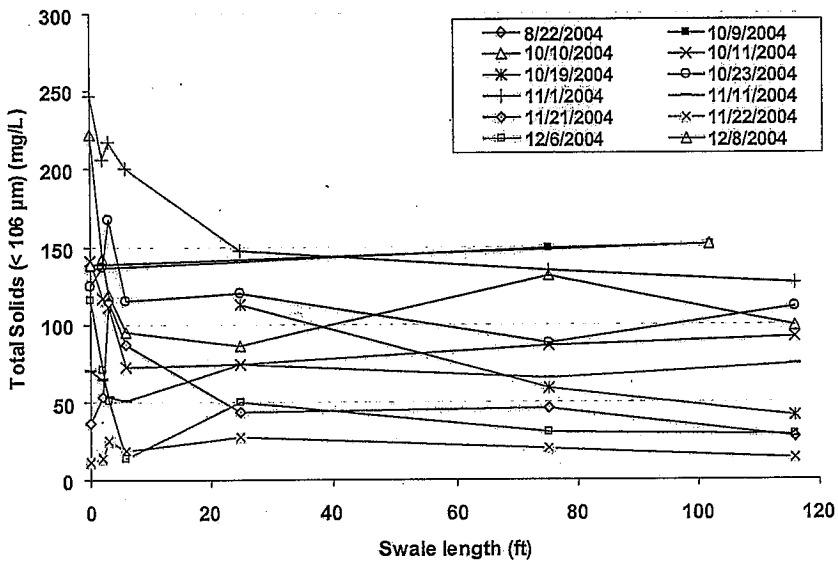

Figure 85. Total solids (< 106 µm) concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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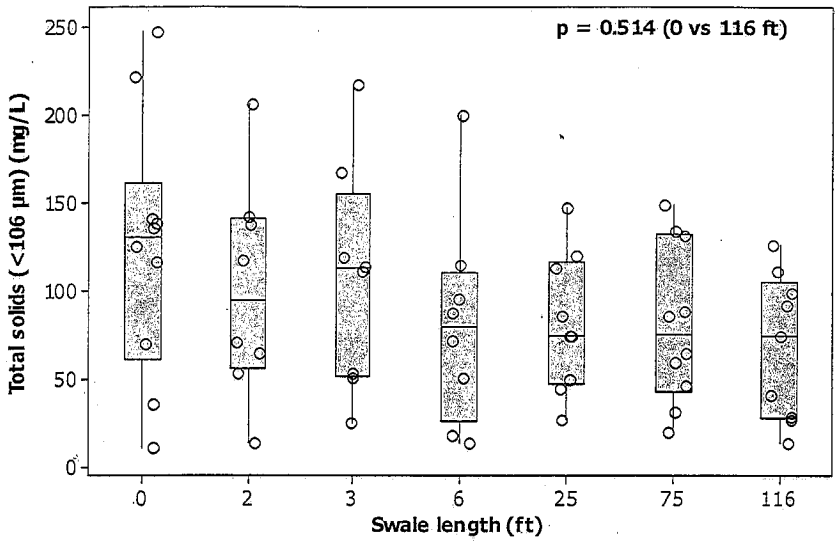

Figure 86. Box-and-whisker plots of total solids (< 106 µm) concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

Total Suspended Solids Concentration Variation by Swale Length

Initial total suspended solids concentrations at the entrance of the swale varied greatly for different rain events, ranging from 4 mg/L to 157 mg/L. Large sediment reductions were normally observed between the swale entrance (0 ft) and 25 ft (7.6 m). Beyond 25 ft (7.6 m), the total suspended solids concentrations were more consistent, with much less sediment reductions in the grass swale. During two events (10/23/2004 and 11/11/2004), total suspended solids concentrations increased between the entrance (0 ft) and 6 ft (1.8 m) instead of decreasing, likely due to scouring of previously deposited sediments at the entrance of the swale. An unusual sediment increase of 51 mg/L between 25 ft (7.6 m) and 75 ft (22.8 m) was observed on 12/08/2004. During this sampling period, the rain intensity and runoff flow rate significantly increased after collecting the upgradient samples. The higher flow rate likely scoured the soil from the swale, resulting in much higher total suspended solids concentrations at 75 ft (23 m) than at 25 ft (7.6 m) during that event, or sediment was more effectively being transported down the swale during the short period of higher flows.

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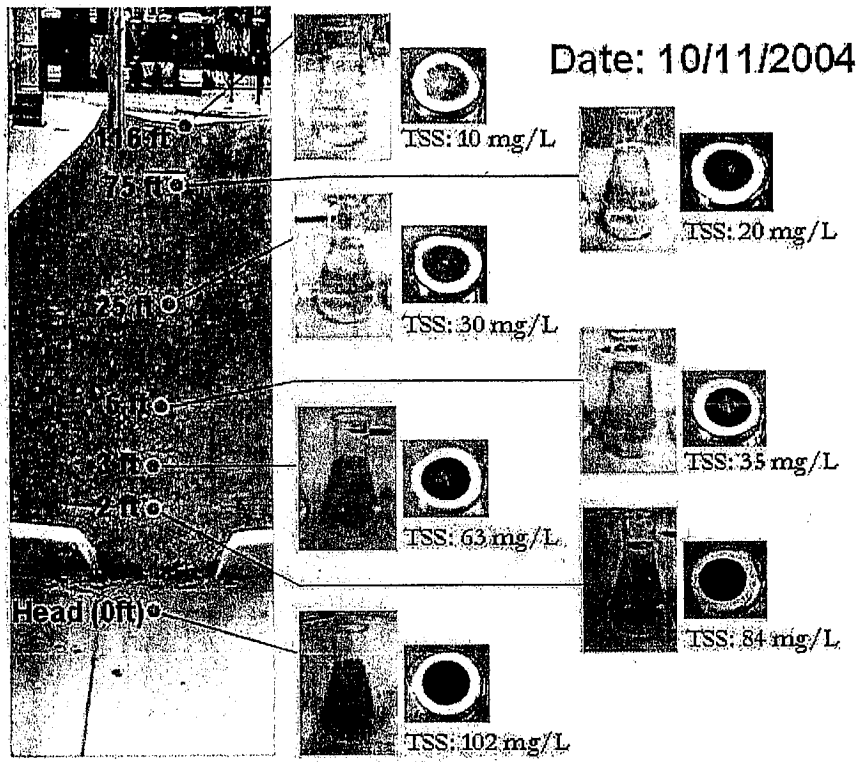

Figure 87. Sampling locations at the outdoor swale monitoring site (Example sediment samples from 10/11/2004).

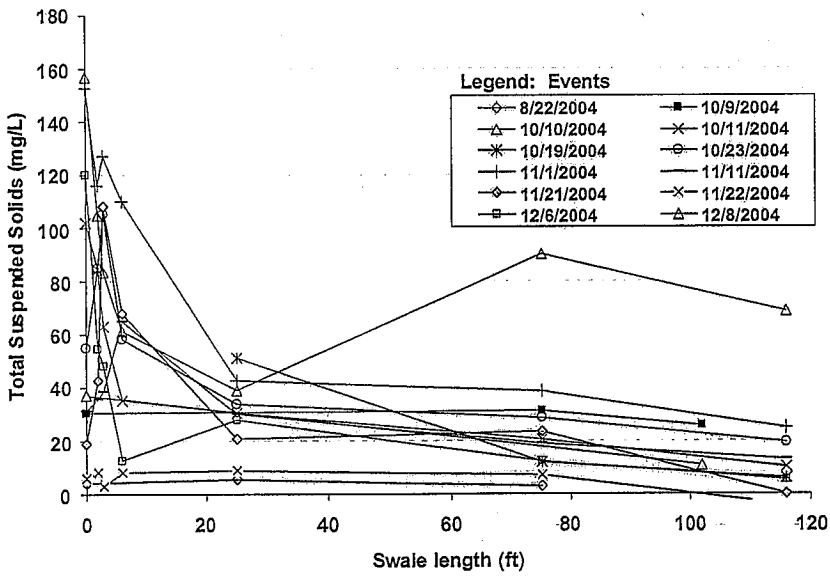

Figure 88. Total suspended solids concentrations vs. swale length, observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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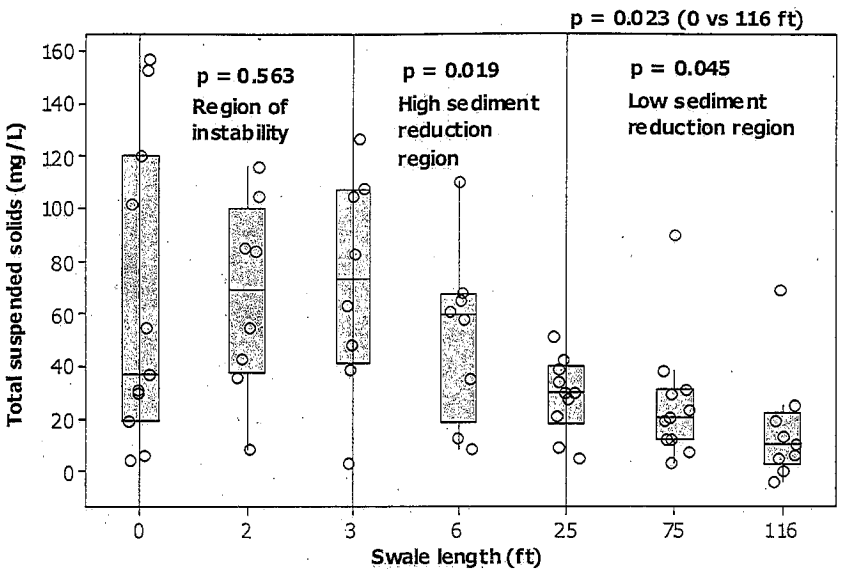

Figure 89. Box-and-whisker plots of total suspended solids concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

Figure 89 indicates that the concentrations were highly variable during the first three feet (0.9 m) of the swale ($p = 0.563$), then significantly decreased between 3 ft (0.9 m) and 25 ft (7.6 m) ($p = 0.019$), and decreased only slightly more to the end of the swale (at 116 ft or 35.3 m) ($p = 0.045$). Thus, the results of total suspended solids show three regions of the swale pertaining to sediment reductions. These regions are:

0 ft to 3 ft (0 m to 0.9 m):	Region of instability
3 ft to 25 ft (0.9 m to 7.6 m):	High sediment reduction region
25 ft to 116 ft (7.6 m to 35.3 m):	Lower sediment reduction region

Total Dissolved Solids Variation by Swale Length

There were no significant changes in total dissolved solids concentrations (particulates < 0.45 μm); total dissolved solids concentrations were neither reduced or increased along the grass swale, except during the rain event occurring on 12/08/2004. On 12/08/2004 an initial total dissolved solids of 69 mg/L at the swale entrance rapidly reduced to 26 mg/L at 6 ft (1.8 m). Then, total dissolved solids concentrations became stable from 6 ft (1.8 m) to 116 ft (35.3 m) with total dissolved solids concentrations of 34 mg/L.

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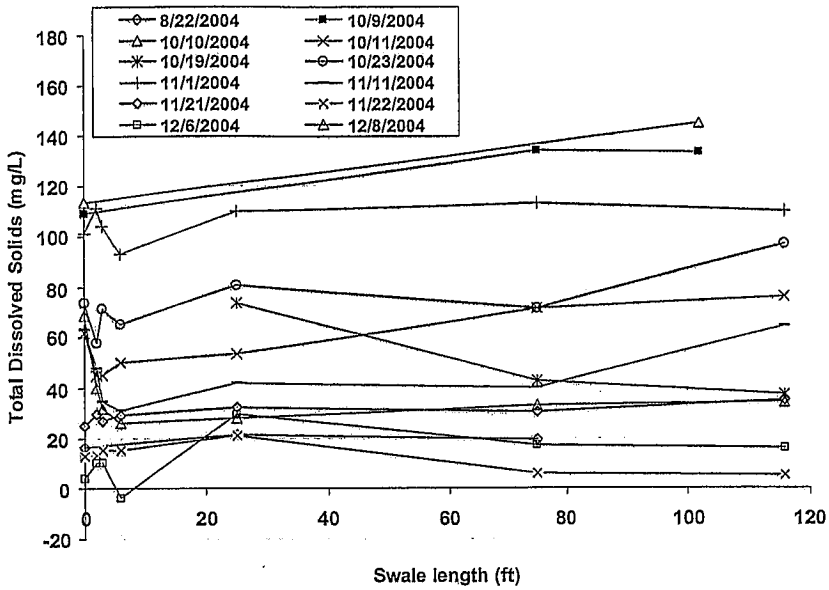

Figure 90. Total dissolved solids concentrations vs. swale length, observed at the outdoor grass swale (Note 1 ft = 0.30 m).

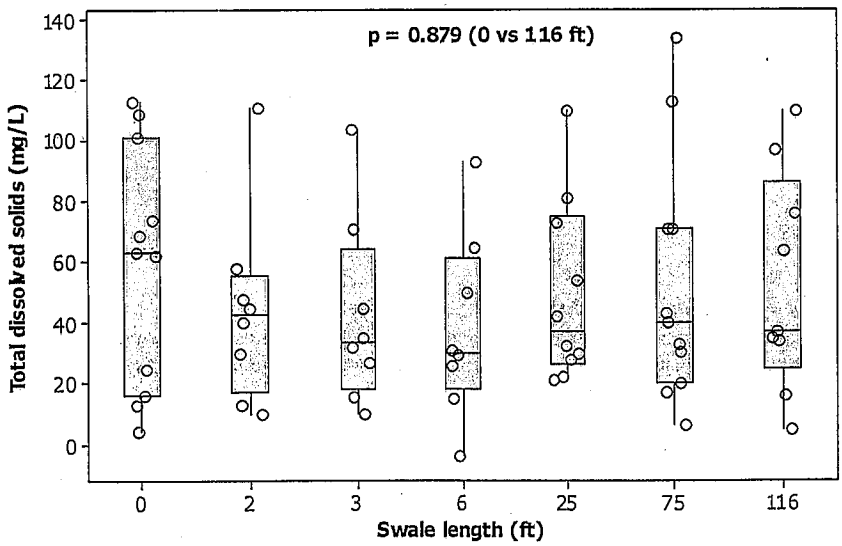

Figure 91. Box-and-whisker plots of total dissolved solids concentrations vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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Turbidity Variation by Swale Length

Significant reductions in turbidity were observed at the outdoor swale. Although initial turbidity values at the entrance ranged from 2 NTU to 137 NTU, all turbidity values (except on 12/08/2004) were reduced to levels below 20 NTU at 116 ft (35.3 m). Increased turbidity at 75 ft (22.8 m) on 12/08/2004 was possibly due to scouring of the soil during a short period of high flows, or due to more efficient transport during a short period of higher flows, as mentioned previously.

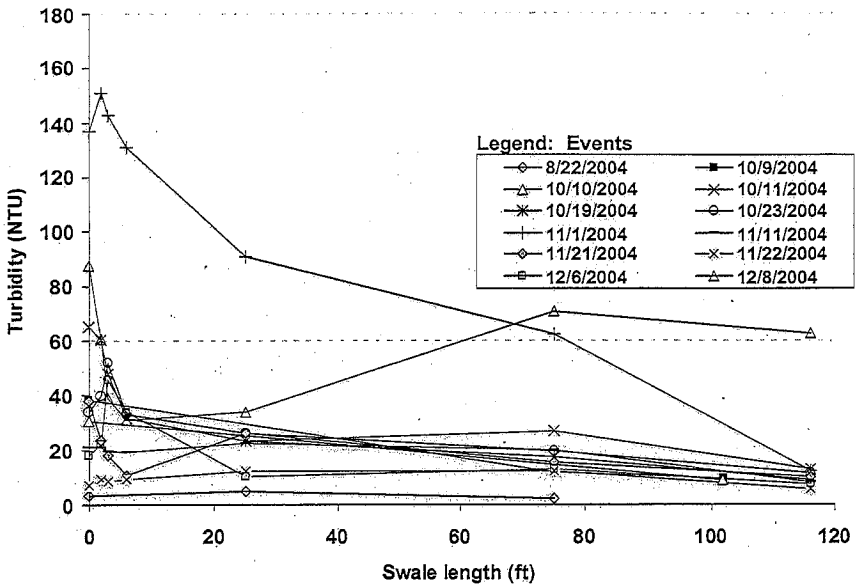

Figure 92. Turbidity vs. swale length, observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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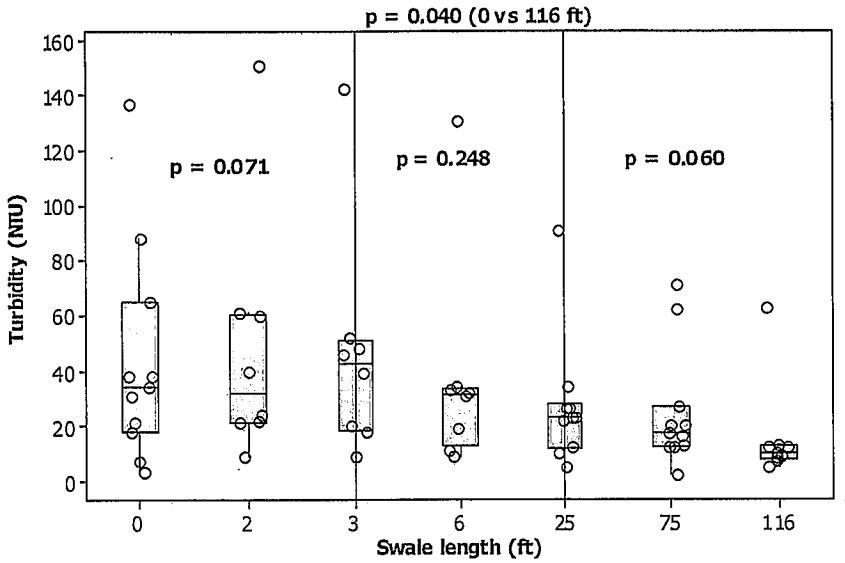

Figure 93. Box-and-whisker plots of turbidity vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

Particle Size Distribution Analyses

Figures 94 and 95 show the median particle sizes of runoff particulates for each swale length location. There was no significant change in median particle sizes between the swale entrance (0 ft) and 6 ft (1.8 m) ($p = 0.248$), between 6 ft (1.8 m) and 25 ft (7.6 m) ($p = 0.149$), and between 25 ft (7.6 m) and 116 ft (35.3 m) ($p = 0.935$).

Although the collective samples show no significant change in median particle sizes, reductions in particle sizes were observed during particular storm events. For example, particle sizes were consistently reduced in the grass swale on 12/06/2004 as shown in Figure 96. Median particle size was reduced from 18.4 μm at the entrance (0 ft or 0 m) to 7.5 μm at 116 ft (35.3 m). Similarly, median particle size was reduced from 10.6 μm at the entrance (0 ft or 0 m) to 2.8 μm at 116 ft (35.3 m) on 11/11/2004 as shown in Figure 97. These observations suggests that grass swales preferentially remove the larger particles, as expected. In addition, particle size distributions were consistently shifted to the left as swale length increased, indicating that smaller particles were also being captured in the grass swales.

Table 33. Summaries of Particle Size Distributions for 12 Storm Events

Date: 10/09/2004					
swale location	10% (μm)	25% (μm)	50% (μm)	75% (μm)	90% (μm)
0 ft (0 m)	1.6	2.5	4.8	9.5	20.6
75 ft (22.8 m)	5.9	19.7	39.2	70.1	105.8
102 ft (31.1 m)	3.6	10.1	26.2	86.1	147.4

Date: 10/10/2004 -100 PM					
swale location	10% (μm)	25% (μm)	50% (μm)	75% (μm)	90% (μm)
0 ft (0 m)	2.2	4.1	9.6	19.6	34.0
102 ft (31.1 m)	2.2	5.4	12.5	25.3	47.7

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Date: 10/10/2004 - 900 PM

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
75 ft (22.8 m)	9.4	18.0	36.6	64.7	92.7
116 ft (35.3 m)	10.5	20.0	38.2	66.2	100.2

Date: 10/11/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	3.4	6.6	11.4	18.1	26.2
2 ft (0.6 m)	3.9	6.9	11.8	19.6	30.4
3 ft (0.9 m)	3.6	7.1	13.4	24.6	47.3
6 ft (1.8 m)	2.8	5.6	11.4	20.5	38.2
25 ft (7.6 m)	2.2	4.6	14.4	47.8	82.9
75 ft (22.8 m)	1.8	3.0	5.8	17.9	38.3
116 ft (35.3 m)	1.7	2.8	8.5	28.2	60.3

Table 33. Summaries of Particle Size Distributions for 12 Storm Events – *Continued*

Date: 10/19/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
25 ft (7.6 m)	6.1	19.9	45.9	75.5	97.7
75 ft (22.8 m)	1.9	6.9	26.5	58.1	84.3
116 ft (35.3 m)	1.4	3.3	33.2	50.0	67.6

Date: 10/23/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	1.8	3.9	9.1	21.6	46.2
2 ft (0.6 m)	3.4	8.9	20.3	39.1	59.5
3 ft (0.9 m)	3.3	7.4	14.7	25.5	44.3
6 ft (1.8 m)	3.0	7.4	17.6	35.3	64.4
25 ft (7.6 m)	1.7	4.5	13.6	38.9	81.3
75 ft (22.8 m)	1.5	4.1	15.4	44.2	75.5
116 ft (35.3 m)	1.1	2.0	5.5	27.9	44.2

Date: 11/01/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	1.7	4.1	10.7	21.0	33.9
2 ft (0.6 m)	1.2	2.3	5.9	14.7	29.0
3 ft (0.9 m)	1.3	2.8	8.6	21.9	38.1
6 ft (1.8 m)	1.2	2.6	8.6	19.8	38.1
25 ft (7.6 m)	1.0	1.6	3.9	24.2	50.5
75 ft (22.8 m)	1.2	2.8	32.5	52.6	74.7
116 ft (35.3 m)	1.2	2.7	18.6	37.6	59.5

Date: 11/11/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	1.8	3.9	10.6	23.6	49.3
2 ft (0.6 m)	2.9	7.5	14.1	26.4	53.8
3 ft (0.9 m)	3.1	8.1	17.5	32.9	70.0
6 ft (1.8 m)	2.7	6.3	17.4	35.9	67.2
25 ft (7.6 m)	1.3	2.9	7.0	14.6	42.3
75 ft (22.8 m)	1.0	1.8	3.8	7.8	17.3
116 ft (35.3 m)	1.0	1.4	2.8	5.8	22.0

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Table 33. Summaries of Particle Size Distributions for 12 Storm Events – *Continued*

Date: 11/21/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	3.2	5.5	9.2	14.9	23.9
2 ft (0.6 m)	3.8	6.9	13.5	29.2	53.4
3 ft (0.9 m)	5.4	9.5	16.6	28.5	46.0
6 ft (1.8 m)	6.2	11.4	20.8	40.6	73.6
25 ft (7.6 m)	2.3	5.6	11.9	23.3	43.0
75 ft (22.8 m)	3.5	7.9	20.7	51.7	82.5
116 ft (35.3 m)	1.9	5.1	10.6	23.0	44.4

Date: 11/22/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	1.7	6.9	13.0	21.5	35.8
2 ft (0.6 m)	4.5	10.9	19.8	38.2	62.9
3 ft (0.9 m)	4.4	9.1	15.9	26.6	46.3
6 ft (1.8 m)	4.1	10.0	20.0	41.3	89.4
25 ft (7.6 m)	2.3	5.6	11.9	23.3	43.0
75 ft (22.8 m)	3.4	7.0	12.8	33.0	54.0
116 ft (35.3 m)	2.2	5.8	12.5	33.6	53.0

Date: 12/06/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	8.9	15.1	28.4	58.9	148.6
2 ft (0.6 m)	7.3	11.3	18.2	32.3	64.4
3 ft (0.9 m)	5.9	9.5	15.7	27.4	44.7
6 ft (1.8 m)	4.6	8.4	14.3	23.8	40.5
25 ft (7.6 m)	2.8	5.4	9.2	17.7	41.3
75 ft (22.8 m)	2.8	5.4	9.2	17.7	41.3
116 ft (35.3 m)	2.6	4.5	7.5	12.0	20.8

Date: 12/08/2004

swale location	10% (µm)	25% (µm)	50% (µm)	75% (µm)	90% (µm)
0 ft (0 m)	8.6	13.4	21.3	34.6	54.1
2 ft (0.6 m)	8.2	12.9	19.1	29.6	55.1
3 ft (0.9 m)	9.9	15.3	22.3	33.3	53.6
6 ft (1.8 m)	7.8	13.0	19.1	28.7	42.1
25 ft (7.6 m)	7.3	11.8	17.3	24.9	38.7
75 ft (22.8 m)	7.0	10.7	15.5	23.9	39.4
116 ft (35.3 m)	6.5	9.8	14.4	24.3	41.9

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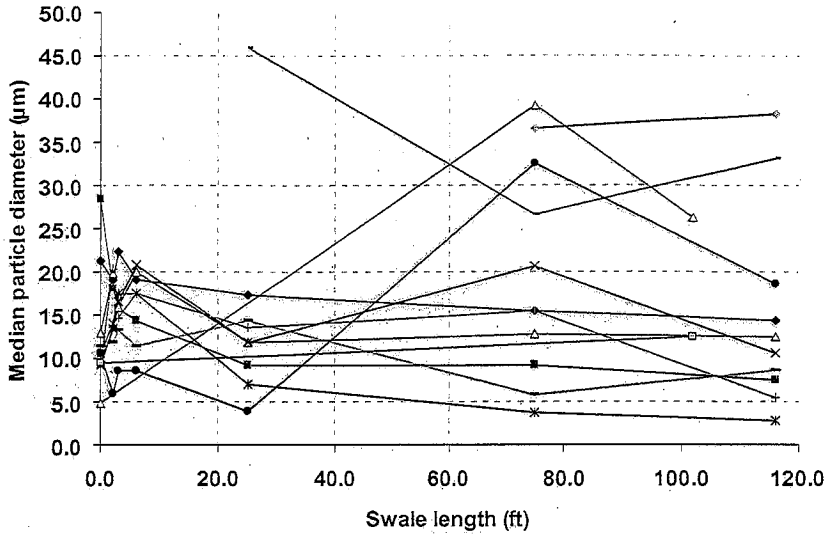

Figure 94. Median particle sizes vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

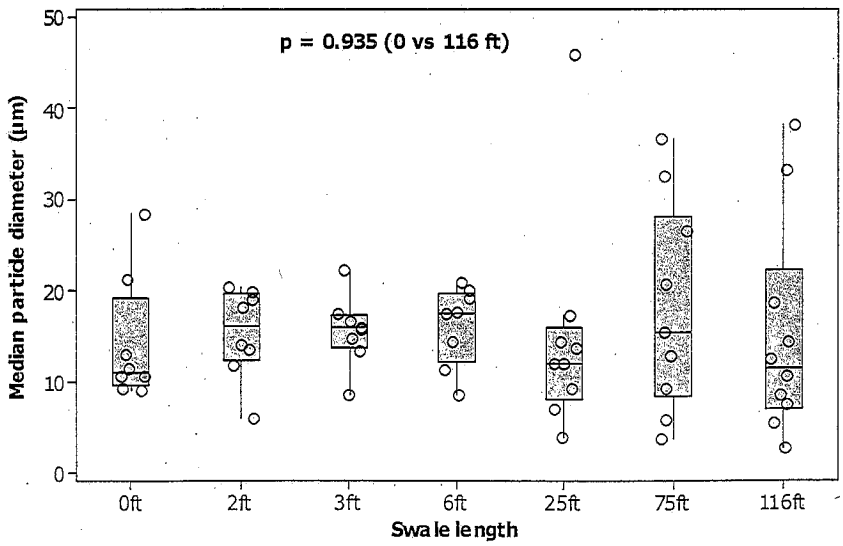

Figure 95. Box-and-whisker plots of median particle diameters vs. swale length observed at the outdoor grass swale (Note 1 ft = 0.30 m).

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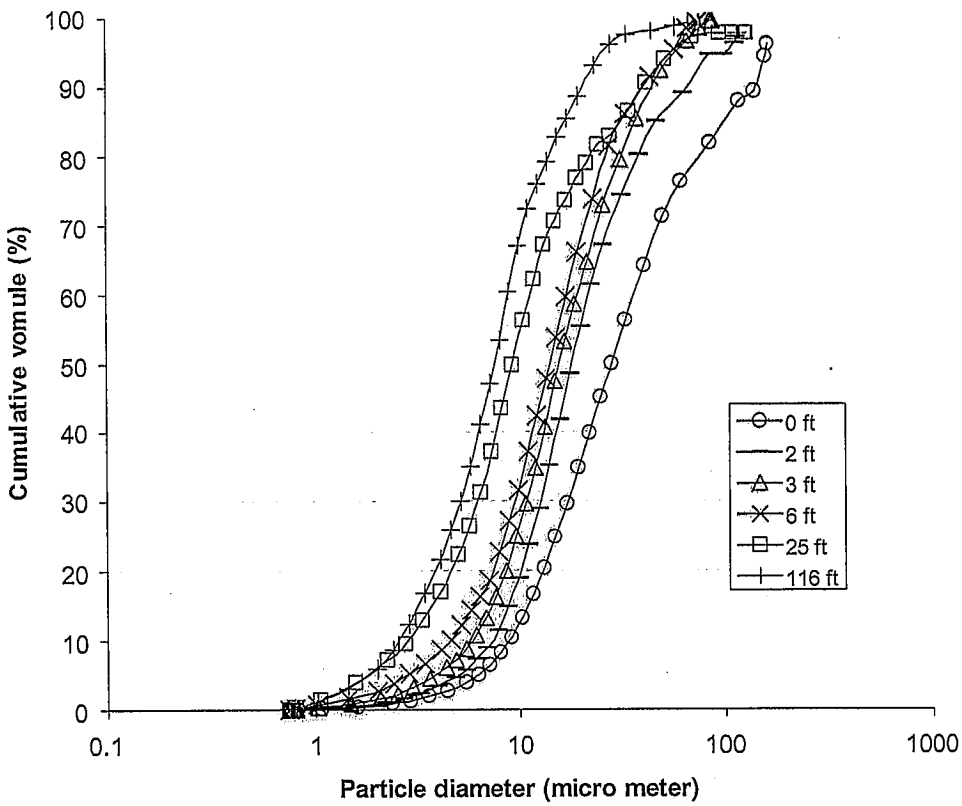

Figure 96. Example particle size distributions for different swale lengths observed on December 6, 2004.

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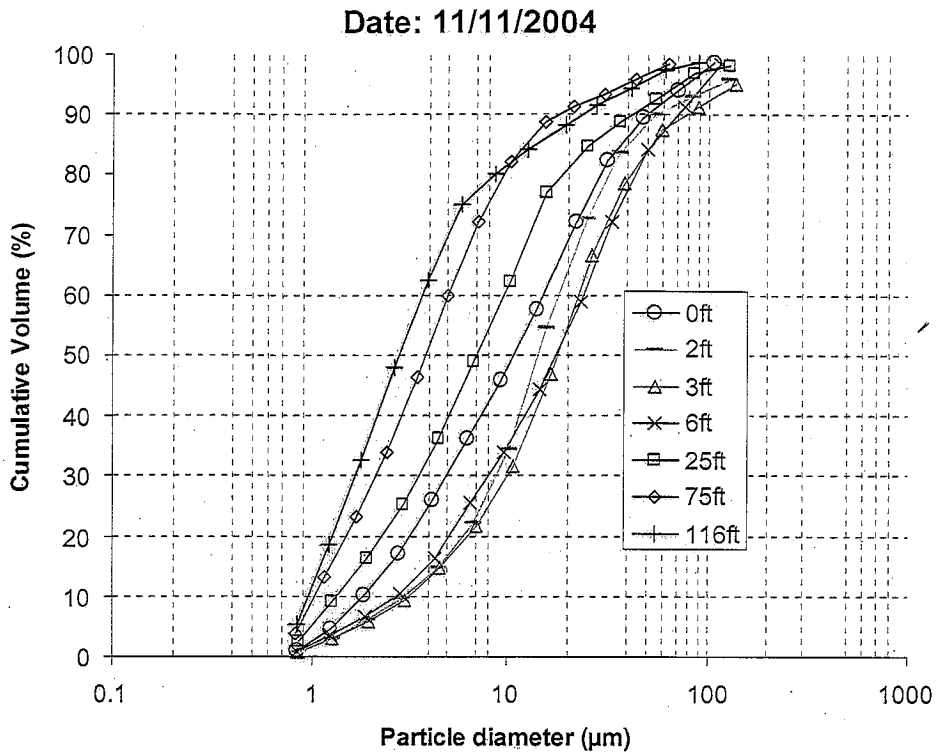

Figure 97. Example particle size distributions for different swale lengths observed on November 11, 2004 (Particle size distributions of all the storm events are presented in Appendix O).

Summary of Findings

Total Solids and Total Solids (< 106 µm)

• Although some storm events (10/11/04, 11/11/04, and 12/08/04) showed sediment reductions, there was no significant changes in total solids concentrations between 0 ft (0 m) and 6 ft (1.8 m) ($p = 0.328$ for total solids and $p = 0.248$ for total solids < 106 µm). There was weak evidence suggesting reductions in total solids and total solids < 106 µm ($p = 0.063$ for total solids and $p = 0.060$ for total solids < 106 µm).

• Total solids and total solids < 106 µm were very similar to each other for most of the events. This suggests that particle sizes of runoff sediments from the roads and in the grass swale were primary less than 106 µm.

• Total dissolved solids were the predominant portion of the total solids and total solids < 106 µm especially beyond 6 ft (1.8 m).

Total Suspended Solids

• Although initial total suspended solids concentrations at the entrance of the swale varied greatly for different rain events, large sediment reductions were normally observed between 3 ft (0.9 m) and 25 ft (7.6 m) ($p = 0.019$). Beyond 25 ft (7.6 m), the total suspended solids concentrations were more consistent, with much less, but significant, sediment reductions in the grass swale ($p = 0.045$).

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• In some storm events (10/23/04, 11/11/04, and 11/21/04), total suspended solids concentrations increased between 0 ft (0 m) and 3 ft (0.9 m) instead of decreasing, likely due to scouring of previously deposited sediments at the entrance of the swale. However, there was no overall significant total suspended solids concentration changes between 0 ft (0 m) and 6 ft (1.8 m) ($p = 0.934$).

• Total suspended solids removals ranging from 56% to 100% were observed, with a mean removal of 80% between 0 ft (0 m) and 116 ft (35.3 m). As an example, a reduction of 90% in total suspended solids was observed (102 mg/L to 10 mg/L) during the rain event occurring on 10/11/2004.

Total Dissolved Solids

• There were no significant changes ($p = 0.879$) in total dissolved solids concentrations (particulates < 0.45 µm), except during the rain event occurring on 12/08/2004.

Turbidity

• Although initial turbidity varied from 2 NTU to 137 NTU, significant reductions in turbidity were observed at the outdoor swale ($p = 0.040$). Overall, median turbidity reduction of 70.5% was observed between the entrance of the swale and 116 ft.

• Turbidity increased between 25 ft (7.6 m) and 75 ft (22.8 m) on 12/08/2004 due to scouring of the top soil during an intermittent period of high flows

Particle Size Distributions

• There was no noticeable change in particle size in the three distinct swale regions; between the swale entrance (0 ft or 0 m) and 6 ft (1.8 m) ($p = 0.248$) due to possible scouring, between 6 ft (1.8 m) and 25 ft (7.6m) ($p = 0.149$), and beyond 25 ft (7.6 m) ($p = 0.935$).

• Particle sizes were consistently reduced on the grass swale during some events. On 12/06/2004, the median particle size was reduced from 18.4 µm at the entrance (0 ft or 0 m) to 7.5 µm at 116 ft (35.3 m), for example.

• Some event showed evidence of scouring of sediment from the swale. The median particle sizes increased from 10.6 µm at 0 ft to 17.4 µm at 6 ft (1.8 m) and then were consistently reduced from 17.4 µm at 6 ft (1.8 m) to 2.8 µm at 116 ft (35.3 m) during the storm event of 11/11/2004. Total suspended solids also increased between 0 ft (0 m) and 6 ft (1.8 m) and decreased consistently from 6 ft (1.8 m) to 116 ft (35.3 m). These suggest that scouring of the sediments between 0 ft (0 m) and 6 ft (1.8 m), which increased total suspended solids, may change particle size because of re-suspension of the deposited particles.

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Chapter 8: Predictive Model

First-Order Decay

During both the indoor experiments and outdoor observations, greater sediment reductions were observed at the beginning of the grass swales, and the concentrations then tended to stabilize after some distance. During the outdoor swale observations, high sediment reductions occurred between 0 ft (0 m) and 25 ft (7.6 m), and lower sediment reductions occurred between 25 ft (7.6 m) to 116 ft (35.3 m) (the location of the drainage inlet). Thus, the concept of first order decay was applied to describe the behavior of the stormwater sediment in grass swales and to statistically identify the significant experimental factors. The following is the equation of first order decay that was used to describe the concentration reductions observed:

(6.1) $$Ln\left(\frac{C_{out}}{C_{in}}\right) = -kt$$

Where:

C_{out} = Sediment concentration at downgradient sampling locations
C_{in} = Initial sediment concentration at the head works
k = First order constant
t = Swale length in feet from the head works

The first order constant (k-constant) is a function of swale length and determines the sediment reduction rate for each experimental condition. Since we are also interested in the effects of the experimental conditions on particles of different size, k-constants for various particle size ranges (listed below) were also computed:

- < 0.45 µm (total dissolved solids)
- 0.45 to 2 µm
- 2 to 5 µm
- 5 to 10 µm
- 10 to 30 µm
- 30 to 60 µm
- 60 to 106 µm
- 106 to 425 µm (total solids minus total solids less than 106 µm)

Also, settling frequency (how many times the particle could conceivably settle to the bottom of the flow depth during the swale length) for each particle size range and for the test length of the grass swales (6 ft (1.8 m) during the second indoor swale tests) was determined using Stoke's law, considering the depths of flow and the flow velocities.

Box and whisker plots of the calculated k-constants for the various particle ranges are shown in Figure 98. This plot shows that no reductions in particles smaller than 0.45 µm in diameter (total dissolved solids) occurred, while the largest particles would be trapped in relatively short swales, depending on flow and depth. Particles larger than 0.45 µm show significant sediment trapping, especially when larger than 30 µm. The largest sediment reductions were observed for the largest particles, in the range between 106 and 425 µm in diameter. The frequencies of settling (the number of times the particle could fall through the flow depth during the length of the swale, considering the flow

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velocity) for these larger particles are much greater than the for the smaller particle sizes. There also were large variations in the k-constant for these larger particles, likely because of the fewer particles found in this large size. Particles from 0.45 to 30 μm showed similar k-constant values (and therefore sediment reduction rates), while the particles from 30 to 106 μm had intermediate values.

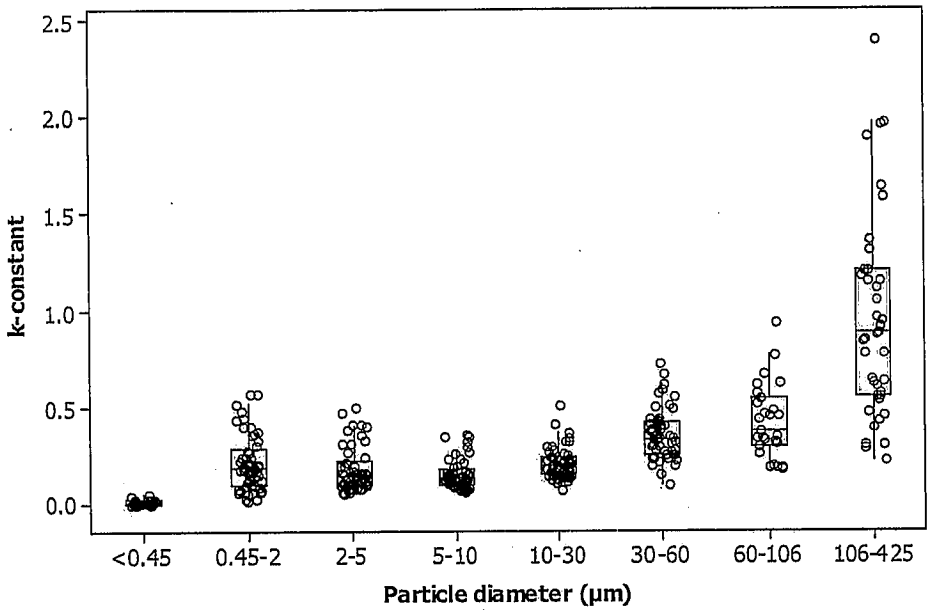

Figure 98. Box-and-whisker plots showing k-constants vs. various particle size ranges (0 to 6 ft).

Settling Frequency

Figure 99 shows percent reductions from the initial sediment concentrations at the head works over the 6 ft (1.8 m) length of the indoor experimental swales. The three grass types are represented by different symbols. The statistical analyses using the data from the second set of indoor tests showed that the percent reductions of sediment in the synthetic turf lined swales for various particle size ranges were significantly less than for the Zoysia and Bluegrass lined swales. This is also illustrated in Figure 99, where the synthetic turf data points are generally all much lower than for the other grasses for the same settling frequencies. However, the differences in sediment reductions between the Zoysia and Bluegrass planted swales were found to be insignificant. Since the synthetic turf lined swale was not representative of grass-lined swales, the data collected during the synthetic turf lined swale tests were not used to develop the final sediment trapping model described below. The sediment transport observations obtained with the Zoysia and Bluegrass swales were combined.

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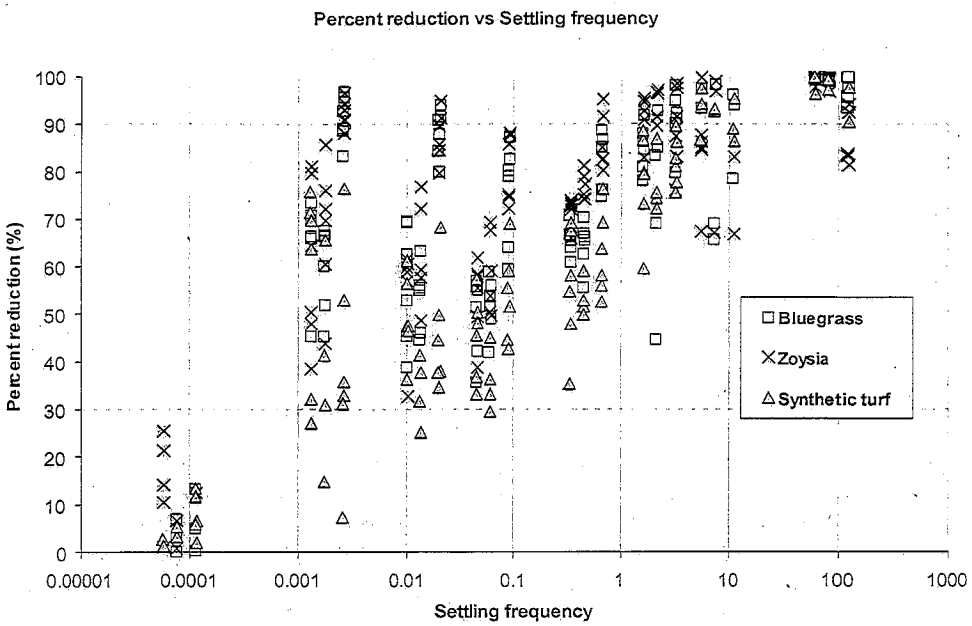

Figure 99. Percent sediment reductions vs. settling frequencies for the different grass types (results of the second indoor experiments).

Figure 99 also contains vertical clusters of observations. Each of these clusters of data represents a narrow particle size range. Particle less than 0.45 µm (total dissolved solids) shows very low sediment reductions (0 to 25% reductions) for all flow conditions. Large particles ranging from 106 to 425 µm had the highest reductions (80 to 100% reductions) for all flow conditions.

The effects of flow rate were found to be significant. This is illustrated on Figure 100. The sediment reductions during the 10 GPM (0.038 m^3/min) tests were much higher than during the 15 GPM (0.064 m^3/min) and 20 GPM (0.076 m^3/min) tests for the particles ranging from 0.45 to 30 µm. However, there were no significant differences found in sediment reductions between the 15 GPM (0.064 m^3/min) and 20 GPM tests (0.076 m^3/min).

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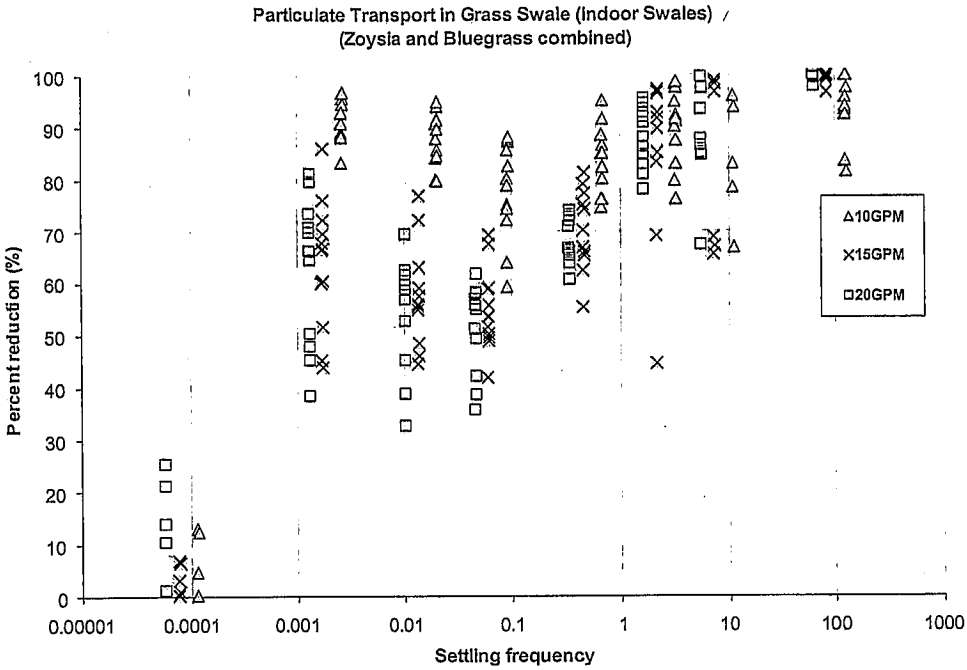

Figure 100. Percent sediment reductions vs. settling frequencies for the different flow rates (Zoysia and Bluegrass data combined).

The relationship between flow depth and grass height is shown to be very promising when explaining the variation in settling frequency and sediment retention, as shown on Figure 101. This factor considers the opportunities of the runoff water and entrained sediment to contact the grass plant. When the water is flowing within the height of the grass, the settled sediment is much better protected from scour, as the water velocity is quite low, and associated Manning's n, is very large (Kirby 2003). In addition, the grass may act like inclined tube or plate settlers, effectively increasing the settling area. To determine the effect of the flow depth to grass height ratio, this ratio was computed for each experimental condition. The percent reduction-settling frequency plots were then separated into three distinct flow depth to grass height ratio categories: 0 to 1.0, 1.0 to 1.5, and 1.5 to 4. A ratio less than 1.0 means that the grass height is higher than the flow depth. These separate categories are seen to have much reduced variabilities in reductions of sediment for each settling frequency category.

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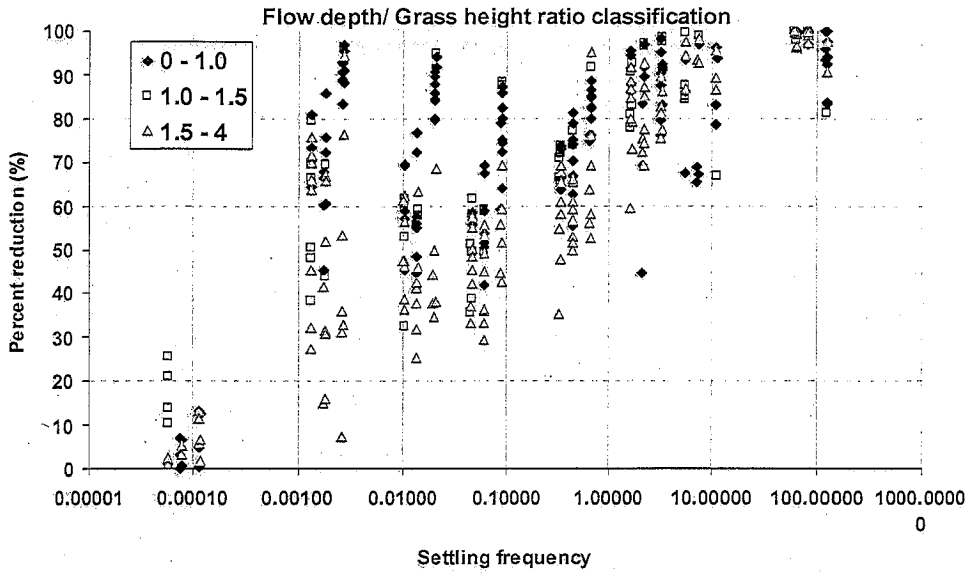

Figure 101. Percent sediment reductions vs. settling frequencies for the different flow depth to grass height ratios (Zoysia and Bluegrass data combined).

A sensitivity analysis of shear stress and slope was also conducted to determine their relative significance on sediment retention. When plotted, these factors did not provide any further resolution of the observed variance, such as indicated in Figure 102. Related plots are presented in Appendix Q. It was therefore concluded that shear stress and slope were not as important as the flow depth and grass height when describing sediment retention in grass swales.

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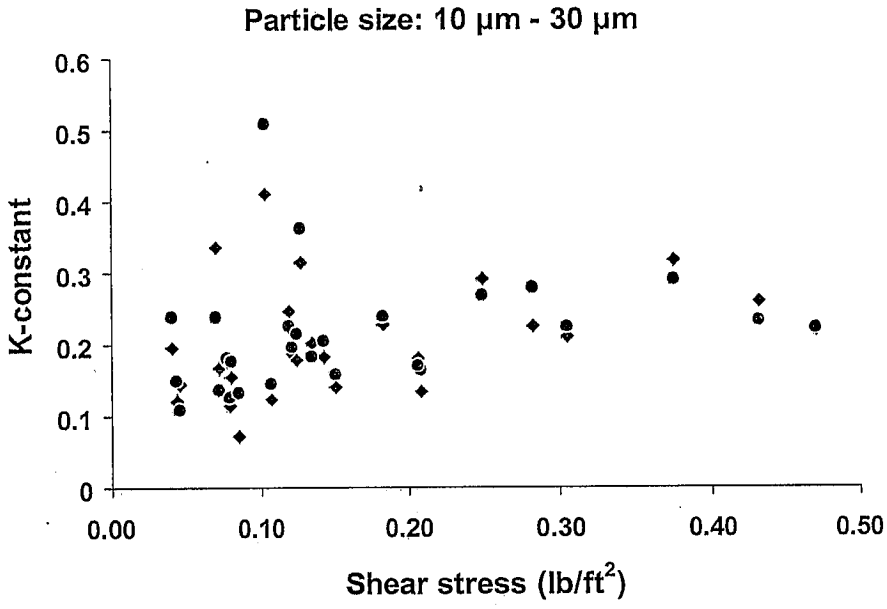

Figure 102. Example of k-constants vs. shear stress.

Predictive Model

Data obtained from the Zoysia and Bluegrass tests were used to create a sediment reduction predictive model. Third-order polynomial regression equations were fitted to the percent reduction-settling frequency graphs for the three different flow depth to grass ratio categories. Obviously, assuming that if the settling frequency is ≥ 1 would result in complete capture and settling frequencies < 1 would result in complete transport of the associated particle is overly simplified. The polynomial regression model was therefore used to fit the data since there seemed to be three distinct performance regions across the range of settling frequencies: very small (dissolved) particles, very large (> 250 µm) particles, and intermediate-sized particles.

The following figures show the percent reductions against settling frequencies, the regression lines, and the 95% confidence intervals for the means. Also shown are the residual analyses indicating that the equations were properly determined, although the residuals are smaller for the larger particles as they approach the 100% retention upper limit, a physical barrier to performance.

As indicated previously, the percent reductions of dissolved solids (indicated by the clusters of data points at the lowest settling frequency) are very low compared to the larger particles. These data were therefore not included in the regressions as they would have distorted the results for the sediment retention predictions. Large particles of 250 and 425 µm in diameter (associated with 100 settling frequencies) had the largest percent reductions for all three flow to grass height ratio categories. When the flow depth to grass height ratios are less than 1, indicating shallow flow, the percent reductions are high and fairly consistent for the different settling frequencies, except for the dissolved solids which are poorly controlled and the large particles that are much better controlled. As the ratio of flow depth and grass height increases to greater than 1, the percent retention of the small particles in the swales decrease, especially for particles whose settling frequencies are between 0.001 and 1.

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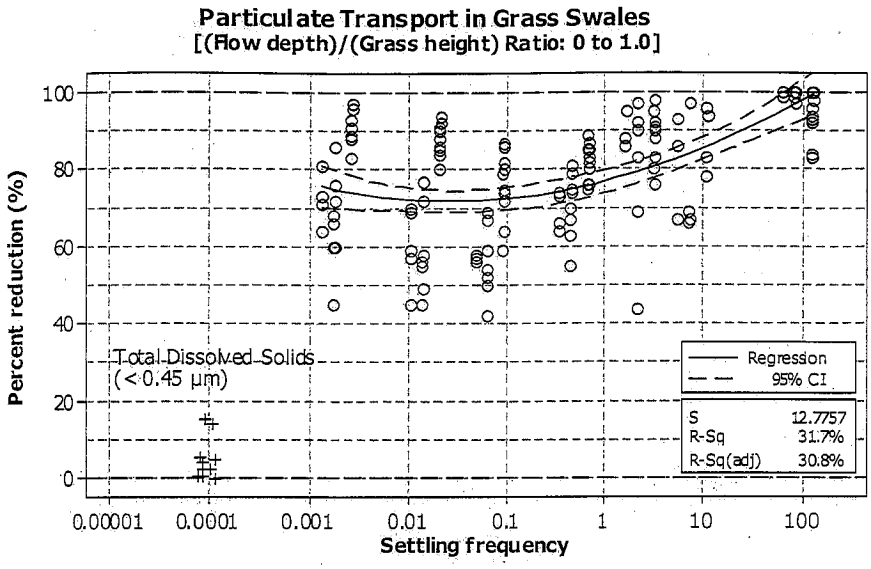

Figure 103. Polynomial regression line and observed percent reductions vs. settling frequency for the (flow depth)/(grass height) ratio between 0 to 1.0.

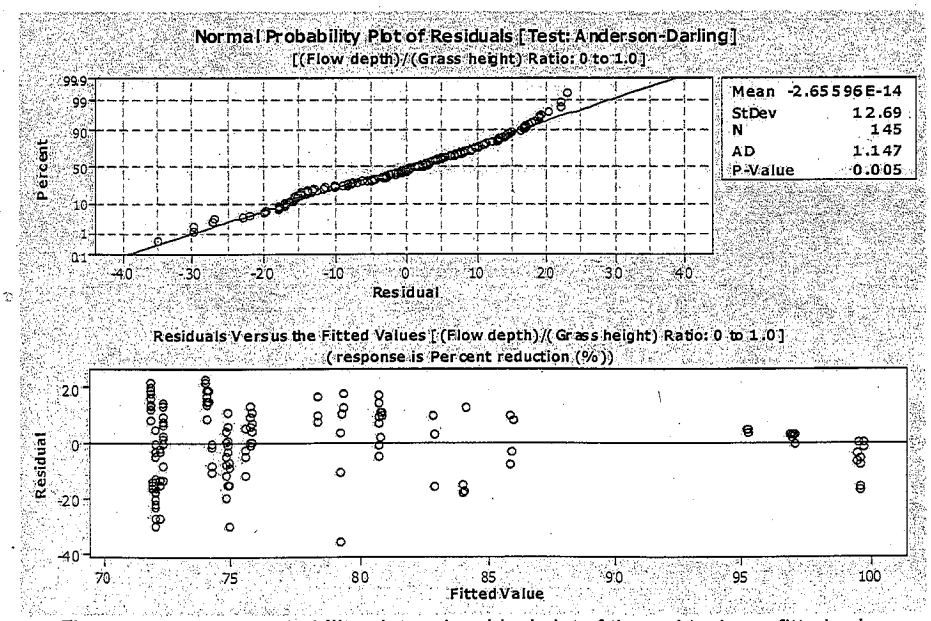

Figure 104. Normal probability plot and residual plot of the residuals vs. fitted values for the (flow depth)/(grass height) ratio between 0 to 1.0.

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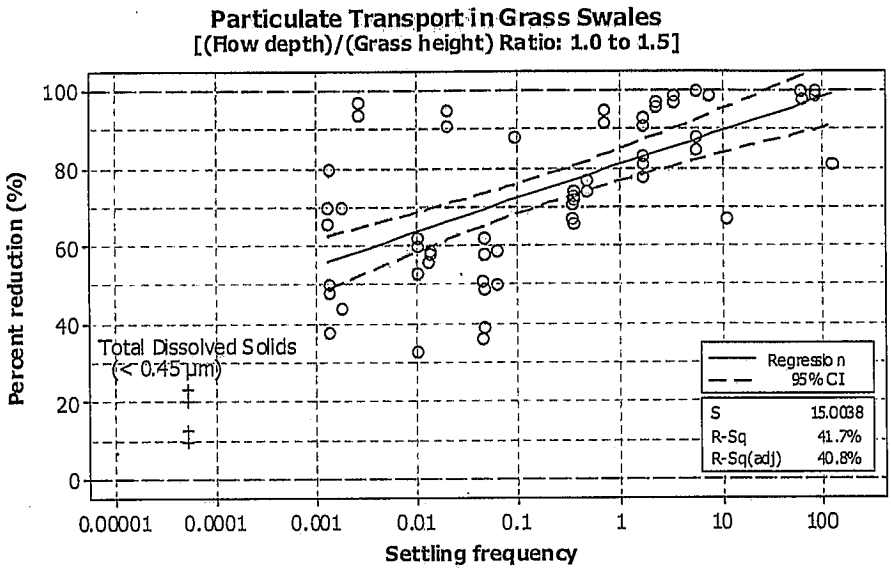

Figure 105. Polynomial regression line and observed percent reductions vs. settling frequency for the (flow depth)/(grass height) ratio between 1.0 to 1.5.

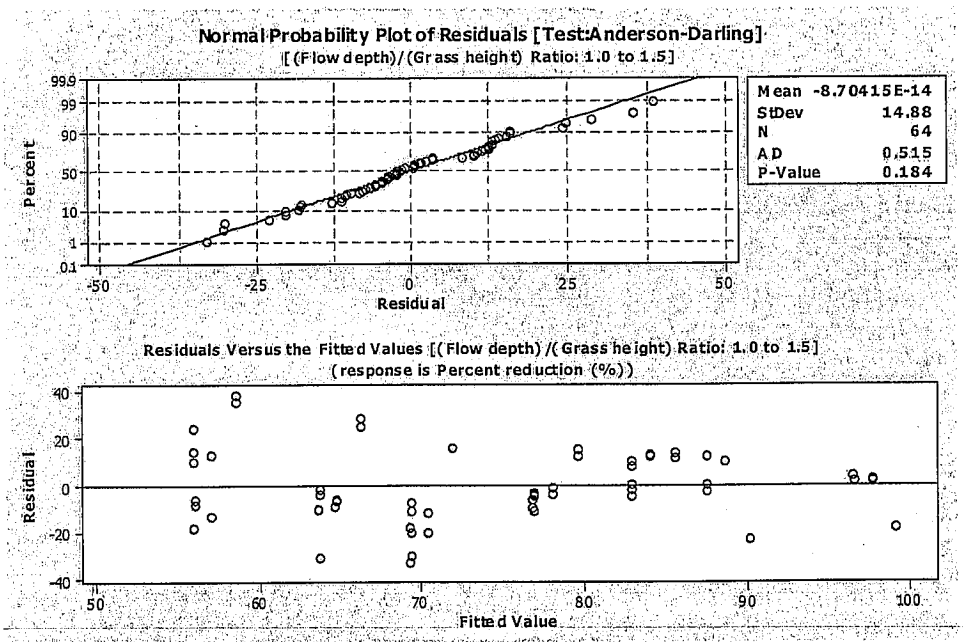

Figure 106. Normal probability plot and residual plot of the residuals vs. fitted values for the (flow depth)/(grass height) ratio between 1.0 to 1.5.

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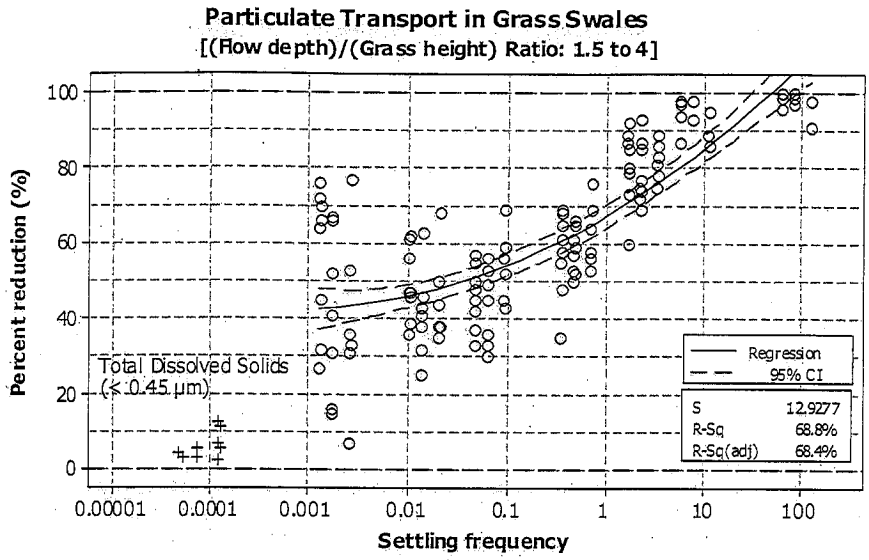

Figure 107. Polynomial regression line and observed percent reductions vs. settling frequency for the (flow depth)/(grass height) ratio between 1.5 to 4.0.

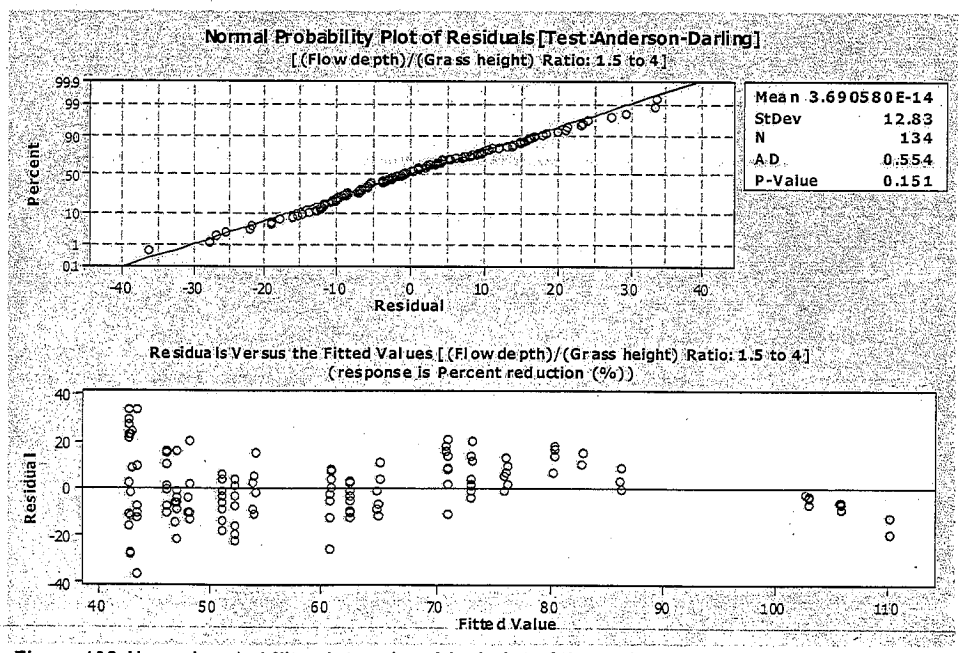

Figure 108. Normal probability plot and residual plot of the residuals vs. fitted values for the (flow depth)/(grass height) ratio between 1.5 to 4.0.

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The following lists the equations and the ANOVA analyses for the polynomial regression lines for each flow depth to grass height ratio category:

Flow to Grass Height Ratio: 0 to 1.0

(6.12) $$Y = 2.101 * \log(X)^2 + 6.498 * \log(X) + 76.82$$

Where:

Y = Percent reduction

X = Settling frequency

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	10765.9	5382.93	32.98	< 0.001
Error	142	23177.0	163.22		
Total	144	33942.8			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	7728.35	42.16	< 0.001
Quadratic	1	3037.51	18.61	< 0.001

Flow to Grass Height Ratio: 1.0 to 1.5

(6.13) $$Y = 8.692 * \log(X) + 80.94$$

Where:

Y = Percent reduction

X = Settling frequency

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	9986.4	9986.44	44.36	< 0.001
Error	62	13957.0	225.11		
Total	63	23943.5			

Flow to Grass Height Ratio: 1.5 to 4.0

(6.14) $$Y = 2.382 * \log(X)^2 + 15.47 * \log(X) + 67.46$$

Where:

Y = Percent reduction

X = Settling frequency

Analysis of Variance

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Source	DF	SS	MS	F	P
Regression	2	48358.8	24179.4	144.68	< 0.001
Error	131	21893.5	167.1		
Total	133	70252.3			

Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	45055.2	236.03	< 0.001
Quadratic	1	3303.5	19.77	< 0.001

As indicated in the above ANOVA tests, the regression equations are all highly significant ($p < 0.001$). Sequential analysis of variance tests were also performed to determine the significance of the terms of the regression equations. All the linear, quadratic, and cubic terms of all the ratios were found to be significant since all probabilities were less than 0.001.

Model Application to Outdoor Swale Performance Observations

The data obtained during the outdoor swale observations were examined to verify the suitability of the regression equations obtained from the second indoor controlled experiments to larger swales during actual rains. Initially, the k-constants were computed using data collected at 0 ft (0 m) and 116 ft (35.3 m). However, the regression lines from these computed k-constants had very poor correlations with the data points. The data were further examined to distinguish separate performance zones along the swale. When examining the total suspended solids data obtained for the outdoor swale, there seemed to be three distinct regions for sediment reduction behavior. These were found to be located at 0 to 3 ft (0 to 0.9 m), 3 to 25 ft (0.9 to 7.6 m), and 25 to 116 ft (7.6 to 35.3 m). Although there were some high sediment reductions observed between 0 ft (0 m) and 3 ft (0.9 m) for some events, large increases in sediment concentrations were also observed. This was likely due to scouring occurring at the upper end of the swale, causing some re-suspension of previously deposited sediments, and possibly eroding of the swale lining soil. As noted before, there was a noticeable mound of large sediment close to the upper end of the swale. This material was likely scoured during some events. Further analyses are needed to confirm sediment transport at the upper end of the swale. Thus, it is the region of unknown behavior, or a buffer zone/transition. The region between 3 ft (0.9 m) and 25 ft (7.6 m) showed the highest and most consistent sediment reductions. Data from this range were therefore evaluated and are presented in Figure 109. Sediment reductions for other swale regions were presented in Appendix R.

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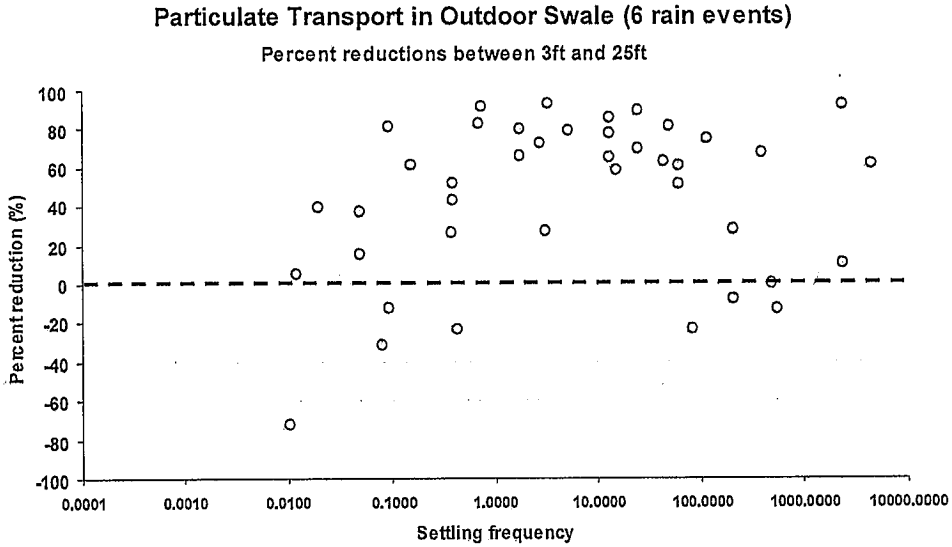

Figure 109. Percent reductions vs. settling frequencies observed at the outdoor swale between 3 ft (0.9 m) and 25 ft (7.6 m) (data from twelve storm events).

Figure 109 indicates a wide variation in sediment reductions for the different settling frequencies. There are many low reduction rates noted. It was determined that these negative and low percent reductions occurred during events that had very low initial sediment concentrations. Appendix P shows sediment concentrations between 3 ft (0.9 m) and 25 ft (7.6 m) for each particle size range. These figures clearly show that higher initial sediment concentrations correspond to higher sediment reduction rates than lower initial sediment concentrations (except for dissolved solids). Also, looking at each particle range, there are "irreducible" concentrations due to very low initial concentrations. "Irreducible" concentrations for each particle size range are shown on Table 34.

Table 34. Approximate "Irreducible" Concentrations Determined for the Different Particle Size Ranges (using data obtained from the outdoor swale observations)

Particle size range	Irreducible concentration
< 0.45 µm (TDS)	N/A
0.45 to 2 µm	7 mg/L
2 to 5 µm	5 mg/L
5 to 10 µm	5 mg/L
10 to 30 µm	10 mg/L
30 to 60 µm	5 mg/L
60 to 106 µm	5 mg/L
106 to 425 µm	10 mg/L
> 0.45 µm (TSS)	20 mg/L

Note: N/A = not available

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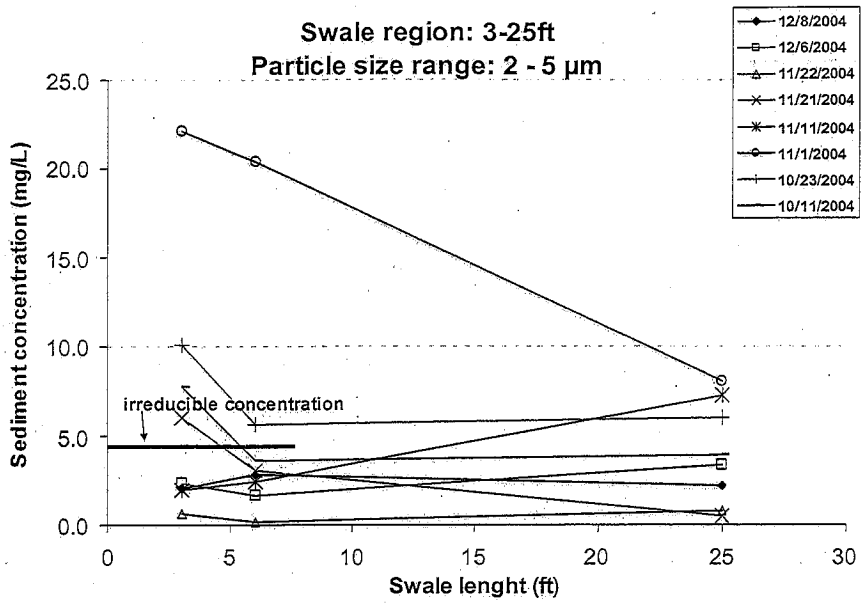

Figure 110. Example of the 'irreducible' sediment concentrations.

Negative and very low percent reductions were generated during events having initial concentrations close to, or less, than the irreducible concentrations. Therefore, these data were eliminated from the sediment reduction calculations for the outdoor swale tests. Figure 111 shows the sediment reductions and settling frequencies for the outdoor swale observations after eliminating the observations that had initial concentrations below the "irreducible" concentrations.

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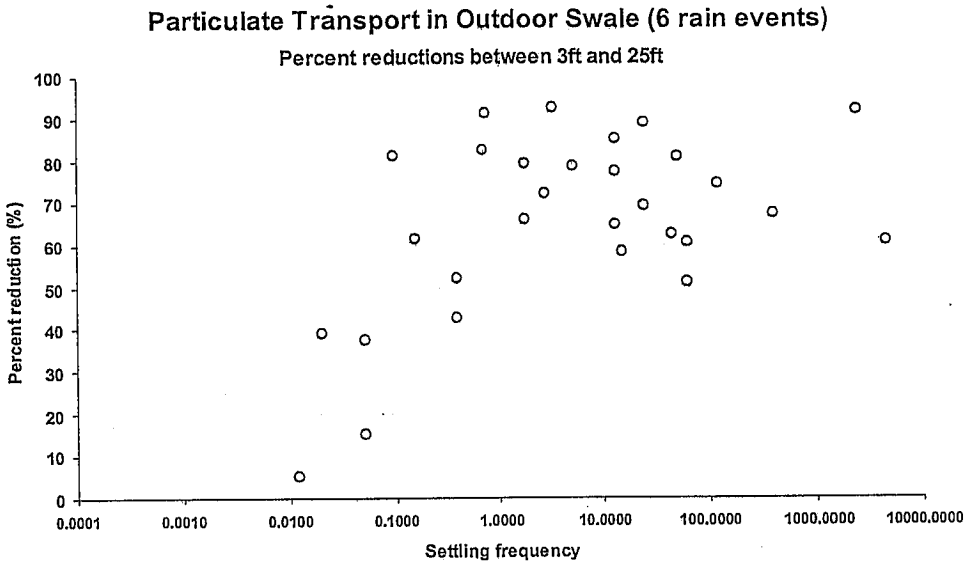

Figure 111. Percent reductions vs. settling frequency observed at the outdoor swale between 3 ft (0.9 m) and 25 ft (7.6 m) (data from six storm events), after eliminating the observations that had initial concentrations below the "irreducible" concentrations.

Settling frequencies above 1.0 are surprisingly consistent, with about 75% removals, while the percentage removals drop dramatically for smaller settling frequencies (down to about 0% for 0.01 settling frequencies).

Descriptions of Events Having Outdoor Swale Observations

Tables 35 through 37 summarize information for the eight rain events that had suitable data for determining sediment reductions using the outdoor swales.

Table 35. Storm Events Which Had Suitable Data for the Different Particle Size Ranges

Particle size	Event							
< 0.45 µm	12/8/04	12/6/04	11/22/04	11/21/04	11/11/04	11/1/04	10/23/04	10/11/04
0.45 to 2 µm	11/1/04							
2 to 5 µm	11/21/04	11/1/04	10/23/04	10/11/04				
5 to 10 µm	12/8/04	12/6/04	11/21/04	11/1/04	10/23/04	10/11/04		
10 to 30 µm	12/8/04	12/6/04	11/21/04	11/1/04	10/23/04	10/11/04		
30 to 60 µm	12/8/04	12/6/04	11/21/04	11/1/04	10/23/04	10/11/04		
60 to 106 µm	12/8/04	11/21/04	10/23/04	10/11/04				
106 to 425 µm	11/21/04	11/11/04	10/23/04					

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Table 36. Weather Information of the Storm Events Which Had Suitable Data for Producing the Percent Reductions between 3 ft (0.9 m) and 25 ft (7.6 m)

	10/11/2004	10/23/2004	*11/1/2004	11/11/2004
Air temperature (Fahrenheit)	72	67	67	64
Preceding dry period (hour)	19.4	64.8	91.3	168.9
Total rain (inch)	0.11	0.84	N/A	0.23
Duration (minute)	45	115	N/A	135
Average intensity (inch/hour)	0.15	0.44	N/A	0.1
Max. rain fall intensity (inch/hour) in 5 minutes	0.24	3.24	N/A	0.36

	11/21/2004	11/22/2004	12/6/2004	12/8/2004
Air temperature (Fahrenheit)	60	64	57	59
Preceding dry period (hour)	13.5	24.8	5.7	39.4
Total rain (inch)	1.12	2.84	0.32	0.7
Duration (minute)	495	230	80	85
Average intensity (inch/hour)	0.14	0.74	0.24	0.49
Max. rain fall intensity (inch/hour) in 5 minutes	1.08	2.28	1.08	3.24

* Rain observed at the site, but not recorded at the rain gage on the campus
Note: N/A = not available

Table 37. Initial Sediment and Turbidity Concentrations for Storm Events Having Suitable Data of Sediment Trapping between 3 ft (0.9 m) and 25 ft (7.6 m)

Date	Total solids (mg/L)	Total solids < 106 µm (mg/L)	Total suspended solids (mg/L)	Total dissolved solids (mg/L)	Turbidity (NTU)
10/11/2004	149	141	102	62	65
10/23/2004	144	125	55	74	34
11/1/2004	246	247	153	101	137
11/11/2004	103	70	31	63	21
11/21/2004	29	36	18	24	38
11/22/2004	14	11	6	13	7
12/6/2004	139	116	120	4	18
12/8/2004	235	222	157	69	88

During sampling, flow depth and velocity were determined for most storm events. However, only the flow depths of the six storm events from 11/01/2004 to 12/08/2004 were determined. Despite the effort, it was almost impossible to observe flow velocities during the storm events because there was no equipment that could observe flow velocities of a very shallow flow disturbed by a thick vegetation. Thus, velocities were estimated by Manning's equation using the observed flow depths and channel slopes. Table 38 summarizes the observed flow depths and computed flow velocities for the six storm events.

Manning's equation:

$$V = 1.49\frac{R^{2/3}}{n} * S^{1/2} \quad (6.15)$$

Where:

V = flow velocity (ft/s)
R = Hydraulic radius ~ Flow depth (ft)
S = Channel slope (fraction)
n = Manning's n (Kirby 2003 VR-n curves)

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Table 38. Observed Flow Depths and Computed Flow Velocities during the Six Storm Events from 11/01/2004 to 12/08/2004 (Note 1 inch = 2.54 cm)

		11/1/2004		11/11/2004		11/21/2004	
Swale length	Slope	Flow depth (inch)	Flow velocity (inch/s)	Flow depth (inch)	Flow velocity (inch/s)	Flow depth (inch)	Flow velocity (inch/s)
0 ft to 6 ft (0 m to 1.8 m)	7%	0.50	0.27	0.53	0.28	0.34	0.21
6 ft to 75 ft (1.8 m to 22.8 m)	3%	1.17	0.32	0.50	0.18	0.50	0.18
75 ft to 116 ft (22.8 m to 35.3 m)	1%	1.25	0.23	1.00	0.20	1.25	0.23

		11/22/2004		12/6/2004		12/8/2004	
Swale length	Slope	Flow depth (inch)	Flow velocity (inch/s)	Flow depth (inch)	Flow velocity (inch/s)	Flow depth (inch)	Flow velocity (inch/s)
0 ft to 6 ft (0 m to 1.8 m)	7%	1.13	0.47	1.39	0.54	0.75	0.36
6 ft to 75 ft (1.8 m to 22.8 m)	3%	1.25	0.33	1.35	0.35	1.80	0.42
75 ft to 116 ft (22.8 m to 35.3 m)	1%	1.83	0.30	1.73	0.28	2.88	0.40

The calculated flow velocities are all very small.

Comparing Second Indoor Swale and Outdoor Swale Observations

Figure 112 is a comparison of the sediment reductions obtained from the second set of indoor swale experiments and the sediment reductions obtained from the outdoor swale observations. Only data for the experiments having flow depths to grass height ratios of less than 1 are used, as most of the events at the outdoor swale had very shallow flows.

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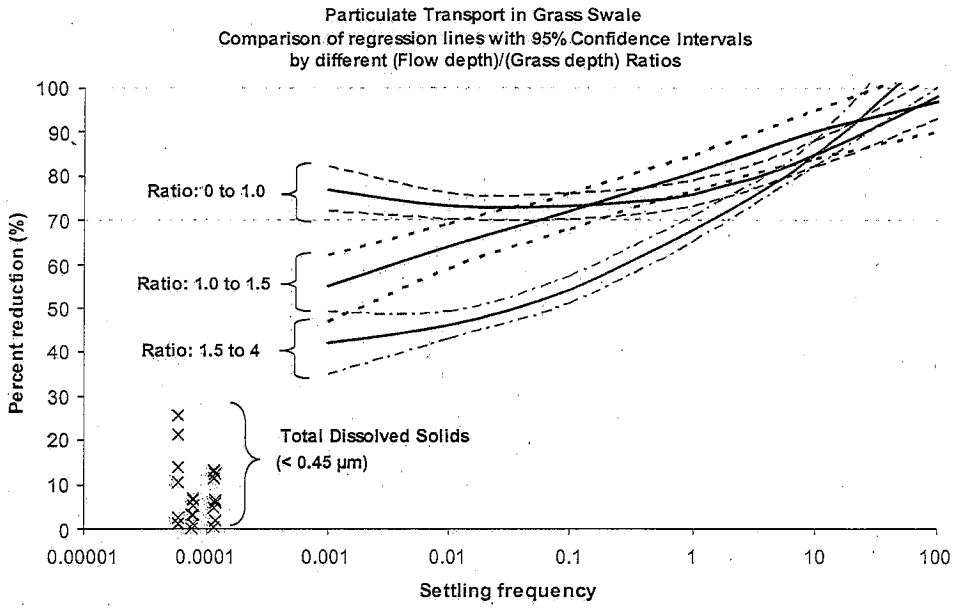

Figure 112. Comparison of regression lines with 95% confidence intervals for different (flow depth)/(grass height) ratios.

The sediment reduction confidence intervals associated with settling frequencies between 0.2 and 40 overlap. The sediment reductions at the outdoor swale for other settling frequencies were significantly lower than for the indoor swale experiments, as shown on Figure 113. It is assumed that the high total suspended solids concentrations during the indoor swale experiments (average of 500 mg/L range of 200 to 1,000 mg/L) resulted in higher percentage removals, compared to the lower concentrations (average of 60 mg/L, range of 10 to 160 mg/L) observed at the outdoor swales. This is commonly observed for all stormwater control practices: high influent concentrations result in larger percentage removals than lower influent concentrations. This is especially evident when the influent concentrations are close to the irreducible concentrations. Therefore, the important factors for these predictive equations are the settling frequency, flow height to grass height ratio, and the influent concentration.

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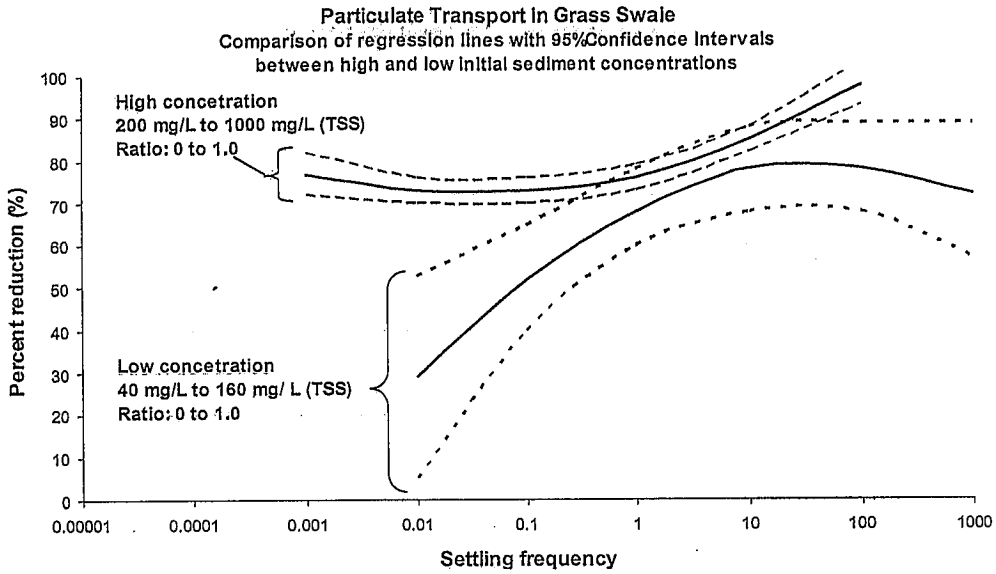

Figure 113. Regression lines with 95% confidence intervals for the low and high initial sediment concentrations (high concentrations from the second indoor experiment, average of 500 mg/L, range of 200 to 1,000 mg/L; low concentrations from the outdoor swale observations, average of 60 mg/L, range of 10 to 160 mg/L).

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Section 3: Appendices

This report section contains the detailed data obtained during the controlled indoor swale tests and the full-scale outdoor swale tests.

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Appendix A: Raw Data – Initial Indoor Experiments

Table A1

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Centipede	5%	1 min	0 ft	60	251
15 GPM (High flow)	Centipede	5%	3 min	0 ft	159	252
15 GPM (High flow)	Centipede	5%	6 min	0 ft	28	280
15 GPM (High flow)	Centipede	5%	1 min	2 ft	107	288
15 GPM (High flow)	Centipede	5%	3 min	2 ft	137	288
15 GPM (High flow)	Centipede	5%	6 min	2 ft	162	284
15 GPM (High flow)	Centipede	5%	1 min	6 ft	141	275
15 GPM (High flow)	Centipede	5%	3 min	6 ft	111	260
15 GPM (High flow)	Centipede	5%	6 min	6 ft	124	268

Table A2

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Centipede	5%	1 min	0 ft	112	270
8 GPM (Low flow)	Centipede	5%	5 min	0 ft	137	265
8 GPM (Low flow)	Centipede	5%	10 min	0 ft	148	232
8 GPM (Low flow)	Centipede	5%	1 min	2 ft	139	244
8 GPM (Low flow)	Centipede	5%	5 min	2 ft	120	281
8 GPM (Low flow)	Centipede	5%	10 min	2 ft	179	274
8 GPM (Low flow)	Centipede	5%	1 min	6 ft	48	200
8 GPM (Low flow)	Centipede	5%	5 min	6 ft	112	198
8 GPM (Low flow)	Centipede	5%	10 min	6 ft	99	182

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Table A3

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Zoysia	5%	1 min	0 ft	143	258
15 GPM (High flow)	Zoysia	5%	3 min	0 ft	105	239
15 GPM (High flow)	Zoysia	5%	6 min	0 ft	86	211
15 GPM (High flow)	Zoysia	5%	1 min	2 ft	158	254
15 GPM (High flow)	Zoysia	5%	3 min	2 ft	146	195
15 GPM (High flow)	Zoysia	5%	6 min	2 ft	197	299
15 GPM (High flow)	Zoysia	5%	1 min	6 ft	174	254
15 GPM (High flow)	Zoysia	5%	3 min	6 ft	146	255
15 GPM (High flow)	Zoysia	5%	6 min	6 ft	181	280

Table A4

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Zoysia	5%	1 min	0 ft	187	276
8 GPM (Low flow)	Zoysia	5%	5 min	0 ft	103	224
8 GPM (Low flow)	Zoysia	5%	10 min	0 ft	76	256
8 GPM (Low flow)	Zoysia	5%	1 min	2 ft	130	255
8 GPM (Low flow)	Zoysia	5%	5 min	2 ft	167	242
8 GPM (Low flow)	Zoysia	5%	10 min	2 ft	141	228
8 GPM (Low flow)	Zoysia	5%	1 min	6 ft	127	244
8 GPM (Low flow)	Zoysia	5%	5 min	6 ft	152	220
8 GPM (Low flow)	Zoysia	5%	10 min	6 ft	116	210

Table A5

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Bluegrass	5%	1 min	0 ft	81	286
15 GPM (High flow)	Bluegrass	5%	3 min	0 ft	149	265
15 GPM (High flow)	Bluegrass	5%	6 min	0 ft	81	280
15 GPM (High flow)	Bluegrass	5%	1 min	2 ft	26	273
15 GPM (High flow)	Bluegrass	5%	3 min	2 ft	109	275
15 GPM (High flow)	Bluegrass	5%	6 min	2 ft	124	245
15 GPM (High flow)	Bluegrass	5%	1 min	6 ft	119	240
15 GPM (High flow)	Bluegrass	5%	3 min	6 ft	95	236
15 GPM (High flow)	Bluegrass	5%	6 min	6 ft	126	242

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Table A6

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Bluegrass	5%	1 min	0 ft	140	241
8 GPM (Low flow)	Bluegrass	5%	5 min	0 ft	10	254
8 GPM (Low flow)	Bluegrass	5%	10 min	0 ft	151	249
8 GPM (Low flow)	Bluegrass	5%	1 min	2 ft	152	255
8 GPM (Low flow)	Bluegrass	5%	5 min	2 ft	20	236
8 GPM (Low flow)	Bluegrass	5%	10 min	2 ft	124	280
8 GPM (Low flow)	Bluegrass	5%	1 min	6 ft	46	247
8 GPM (Low flow)	Bluegrass	5%	5 min	6 ft	17	225
8 GPM (Low flow)	Bluegrass	5%	10 min	6 ft	64	244

Table A7

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Bluegrass	1%	1 min	0 ft	44	241
15 GPM (High flow)	Bluegrass	1%	3 min	0 ft	51	263
15 GPM (High flow)	Bluegrass	1%	6 min	0 ft	14	234
15 GPM (High flow)	Bluegrass	1%	1 min	2 ft	32	265
15 GPM (High flow)	Bluegrass	1%	3 min	2 ft	14	236
15 GPM (High flow)	Bluegrass	1%	6 min	2 ft	115	235
15 GPM (High flow)	Bluegrass	1%	1 min	6 ft	37	270
15 GPM (High flow)	Bluegrass	1%	3 min	6 ft	50	245
15 GPM (High flow)	Bluegrass	1%	6 min	6 ft	46	238

Table A8

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Bluegrass	1%	1 min	0 ft	15	242
8 GPM (Low flow)	Bluegrass	1%	5 min	0 ft	141	246
8 GPM (Low flow)	Bluegrass	1%	10 min	0 ft	18	224
8 GPM (Low flow)	Bluegrass	1%	1 min	2 ft	51	231
8 GPM (Low flow)	Bluegrass	1%	5 min	2 ft	106	198
8 GPM (Low flow)	Bluegrass	1%	10 min	2 ft	32	199
8 GPM (Low flow)	Bluegrass	1%	1 min	6 ft	49	196
8 GPM (Low flow)	Bluegrass	1%	5 min	6 ft	46	194
8 GPM (Low flow)	Bluegrass	1%	10 min	6 ft	62	167

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Table A9

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Zoysia	1%	1 min	0 ft	18	243
15 GPM (High flow)	Zoysia	1%	3 min	0 ft	99	243
15 GPM (High flow)	Zoysia	1%	6 min	0 ft	71	210
15 GPM (High flow)	Zoysia	1%	1 min	2 ft	35	257
15 GPM (High flow)	Zoysia	1%	3 min	2 ft	48	247
15 GPM (High flow)	Zoysia	1%	6 min	2 ft	21	219
15 GPM (High flow)	Zoysia	1%	1 min	6 ft	77	223
15 GPM (High flow)	Zoysia	1%	3 min	6 ft	47	213
15 GPM (High flow)	Zoysia	1%	6 min	6 ft	78	244

Table A10

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Zoysia	1%	1 min	0 ft	63	248
8 GPM (Low flow)	Zoysia	1%	5 min	0 ft	100	222
8 GPM (Low flow)	Zoysia	1%	10 min	0 ft	20	217
8 GPM (Low flow)	Zoysia	1%	1 min	2 ft	52	230
8 GPM (Low flow)	Zoysia	1%	5 min	2 ft	76	252
8 GPM (Low flow)	Zoysia	1%	10 min	2 ft	98	247
8 GPM (Low flow)	Zoysia	1%	1 min	6 ft	84	179
8 GPM (Low flow)	Zoysia	1%	5 min	6 ft	84	170
8 GPM (Low flow)	Zoysia	1%	10 min	6 ft	133	164

Table A11

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
15 GPM (High flow)	Centipede	1%	1 min	0 ft	87	273
15 GPM (High flow)	Centipede	1%	3 min	0 ft	114	322
15 GPM (High flow)	Centipede	1%	6 min	0 ft	128	293
15 GPM (High flow)	Centipede	1%	1 min	2 ft	154	269
15 GPM (High flow)	Centipede	1%	3 min	2 ft	131	268
15 GPM (High flow)	Centipede	1%	6 min	2 ft	85	293
15 GPM (High flow)	Centipede	1%	1 min	6 ft	153	246
15 GPM (High flow)	Centipede	1%	3 min	6 ft	108	238
15 GPM (High flow)	Centipede	1%	6 min	6 ft	141	244

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Table A12

Flow rate	Grass type	Slope	Sampling time	Swale length	Turbidity (NTU)	Total solids (mg/L)
8 GPM (Low flow)	Centipede	1%	1 min	0 ft	79	276
8 GPM (Low flow)	Centipede	1%	5 min	0 ft	41	283
8 GPM (Low flow)	Centipede	1%	10 min	0 ft	19	243
8 GPM (Low flow)	Centipede	1%	1 min	2 ft	42	279
8 GPM (Low flow)	Centipede	1%	5 min	2 ft	90	278
8 GPM (Low flow)	Centipede	1%	10 min	2 ft	23	278
8 GPM (Low flow)	Centipede	1%	1 min	6 ft	105	189
8 GPM (Low flow)	Centipede	1%	5 min	6 ft	63	190
8 GPM (Low flow)	Centipede	1%	10 min	6 ft	89	199

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Appendix B: Raw Data – Second Indoor Experiments

Table B1

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	1%	10 GPM	0 ft	A	387.2	341.8	236.7	121.1	111.0
Synthetic turf	1%	10 GPM	0 ft	B	394.0	342.4	236.0	120.0	120.0
Synthetic turf	1%	10 GPM	2 ft	A	264.9	278.7	153.1	99.1	109.0
Synthetic turf	1%	10 GPM	2 ft	B	265.9	270.3	158.7	105.4	113.0
Synthetic turf	1%	10 GPM	3 ft	A	254.0	254.3	134.8	116.9	107.0
Synthetic turf	1%	10 GPM	3 ft	B	244.8	250.0	140.9	120.4	102.0
Synthetic turf	1%	10 GPM	6 ft	A	221.5	222.0	99.0	126.7	101.0
Synthetic turf	1%	10 GPM	6 ft	B	220.6	186.5	95.8	121.9	102.0

Table B2

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	1%	15 GPM	0 ft	A	504.1	430.0	389.6	130.2	75.6
Synthetic turf	1%	15 GPM	0 ft	B	509.4	435.2	374.5	126.5	62.6
Synthetic turf	1%	15 GPM	2 ft	A	340.2	342.9	227.5	129.4	58.0
Synthetic turf	1%	15 GPM	2 ft	B	345.6	333.7	225.8	124.7	61.0
Synthetic turf	1%	15 GPM	3 ft	A	300.9	301.8	171.0	125.0	46.4
Synthetic turf	1%	15 GPM	3 ft	B	292.8	298.1	168.6	127.6	39.9
Synthetic turf	1%	15 GPM	6 ft	A	284.7	286.0	157.4	125.7	53.9
Synthetic turf	1%	15 GPM	6 ft	B	281.0	278.1	155.9	117.6	50.7

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Table B3

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	1%	20 GPM	0 ft	A	554.6	397.2	362.5	126.9	54.7
Synthetic turf	1%	20 GPM	0 ft	B	552.9	391.8	358.0	130.0	56.6
Synthetic turf	1%	20 GPM	2 ft	A	334.3	337.1	193.9	114.1	52.2
Synthetic turf	1%	20 GPM	2 ft	B	330.2	331.0	189.1	123.8	47.8
Synthetic turf	1%	20 GPM	3 ft	A	272.2	302.0	149.0	131.4	45.5
Synthetic turf	1%	20 GPM	3 ft	B	279.2	305.1	150.5	129.7	40.2
Synthetic turf	1%	20 GPM	6 ft	A	259.4	269.7	124.5	137.7	41.0
Synthetic turf	1%	20 GPM	6 ft	B	257.7	255.7	127.1	149.0	32.6

Table B4

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	3%	10 GPM	0 ft	A	360.6	391.5	239.4	133.3	40.5
Synthetic turf	3%	10 GPM	0 ft	B	389.8	363.3	242.9	134.9	39.0
Synthetic turf	3%	10 GPM	2 ft	A	268.9	278.8	163.3	110.2	45.2
Synthetic turf	3%	10 GPM	2 ft	B	282.0	282.2	166.4	135.4	45.3
Synthetic turf	3%	10 GPM	3 ft	A	256.8	0.0	137.5	125.0	41.6
Synthetic turf	3%	10 GPM	3 ft	B	263.4	290.5	148.1	120.8	37.3
Synthetic turf	3%	10 GPM	6 ft	A	218.5	227.1	100.0	117.8	32.4
Synthetic turf	3%	10 GPM	6 ft	B	224.7	225.6	98.8	120.5	36.4

Table B5

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	3%	15 GPM	0 ft	A	595.0	435.0	441.0	128.6	66.6
Synthetic turf	3%	15 GPM	0 ft	B	564.0	432.6	463.0	135.2	75.7
Synthetic turf	3%	15 GPM	2 ft	A	370.8	364.4	231.7	136.6	59.6
Synthetic turf	3%	15 GPM	2 ft	B	368.0	360.6	231.1	135.0	62.5
Synthetic turf	3%	15 GPM	3 ft	A	322.9	329.1	208.9	136.6	60.2
Synthetic turf	3%	15 GPM	3 ft	B	340.0	323.0	207.8	140.8	54.7
Synthetic turf	3%	15 GPM	6 ft	A	296.0	295.4	172.4	126.7	51.3
Synthetic turf	3%	15 GPM	6 ft	B	288.1	288.5	168.3	138.6	54.9

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Table B6

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	3%	20 GPM	0 ft	A	594.3	441.5	472.3	116.8	59.1
Synthetic turf	3%	20 GPM	0 ft	B	601.0	435.7	469.7	118.2	61.2
Synthetic turf	3%	20 GPM	2 ft	A	344.3	348.9	228.6	114.8	54.6
Synthetic turf	3%	20 GPM	2 ft	B	349.0	345.5	180.0	114.0	57.9
Synthetic turf	3%	20 GPM	3 ft	A	334.3	325.7	211.1	131.3	54.8
Synthetic turf	3%	20 GPM	3 ft	B	340.4	333.0	206.1	131.2	50.4
Synthetic turf	3%	20 GPM	6 ft	A	263.9	269.1	132.4	122.2	35.6
Synthetic turf	3%	20 GPM	6 ft	B	257.6	273.2	138.9	117.6	37.7

Table B7

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	5%	10 GPM	0 ft	A	506.3	360.2	193.0	123.0	38.6
Synthetic turf	5%	10 GPM	0 ft	B	494.0	357.4	345.5	114.1	40.1
Synthetic turf	5%	10 GPM	2 ft	A	282.0	265.3	144.9	118.4	45.1
Synthetic turf	5%	10 GPM	2 ft	B	280.6	253.8	145.9	116.5	39.6
Synthetic turf	5%	10 GPM	3 ft	A	266.3	276.6	124.2	125.3	41.2
Synthetic turf	5%	10 GPM	3 ft	B	271.1	282.2	133.3	113.8	39.1
Synthetic turf	5%	10 GPM	6 ft	A	221.5	217.0	166.0	121.7	28.5
Synthetic turf	5%	10 GPM	6 ft	B	237.0	219.8	108.2	122.4	33.1

Table B8

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	5%	15 GPM	0 ft	A	566.0	428.6	440.6	125.5	68.2
Synthetic turf	5%	15 GPM	0 ft	B	566.3	436.5	452.9	114.7	67.6
Synthetic turf	5%	15 GPM	2 ft	A	359.0	340.4	229.1	136.9	50.2
Synthetic turf	5%	15 GPM	2 ft	B	351.8	351.0	218.3	129.8	54.1
Synthetic turf	5%	15 GPM	3 ft	A	332.3	314.0	202.8	143.5	63.1
Synthetic turf	5%	15 GPM	3 ft	B	312.6	326.5	196.2	137.1	59.5
Synthetic turf	5%	15 GPM	6 ft	A	288.5	290.0	157.7	120.0	52.3
Synthetic turf	5%	15 GPM	6 ft	B	287.6	287.0	161.9	120.0	43.6

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Table B9

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Synthetic turf	5%	20 GPM	0 ft	A	543.5	438.4	325.8	133.0	60.7
Synthetic turf	5%	20 GPM	0 ft	B	537.8	440.0	341.4	128.3	65.6
Synthetic turf	5%	20 GPM	2 ft	A	359.4	336.4	197.9	126.8	47.8
Synthetic turf	5%	20 GPM	2 ft	B	350.5	343.8	198.0	150.0	40.8
Synthetic turf	5%	20 GPM	3 ft	A	313.1	308.4	172.3	137.6	51.9
Synthetic turf	5%	20 GPM	3 ft	B	303.0	314.0	177.2	130.7	51.1
Synthetic turf	5%	20 GPM	6 ft	A	260.0	250.5	112.6	135.8	40.5
Synthetic turf	5%	20 GPM	6 ft	B	262.5	256.6	118.6	129.9	39.2

Table B10

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	1%	10 GPM	0 ft	A	432.1	353.9	251.0	126.0	40.1
Zoysia	1%	10 GPM	0 ft	B	424.5	354.1	229.7	122.8	45.0
Zoysia	1%	10 GPM	2 ft	A	236.1	215.6	89.5	135.8	24.0
Zoysia	1%	10 GPM	2 ft	B	231.8	220.6	91.9	135.4	26.0
Zoysia	1%	10 GPM	3 ft	A	192.7	180.6	63.0	126.9	18.0
Zoysia	1%	10 GPM	3 ft	B	183.7	184.2	54.4	127.2	18.1
Zoysia	1%	10 GPM	6 ft	A	175.5	155.6	30.2	135.4	14.8
Zoysia	1%	10 GPM	6 ft	B	173.7	153.6	34.3	140.4	15.9

Table B11

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	1%	15 GPM	0 ft	A	604.8	453.5	471.4	117.3	80.1
Zoysia	1%	15 GPM	0 ft	B	594.3	455.4	475.5	123.5	68.0
Zoysia	1%	15 GPM	2 ft	A	323.5	316.8	194.2	120.2	53.9
Zoysia	1%	15 GPM	2 ft	B	318.3	314.7	195.8	119.8	54.1
Zoysia	1%	15 GPM	3 ft	A	290.7	283.8	164.0	117.0	47.0
Zoysia	1%	15 GPM	3 ft	B	287.6	283.7	158.2	120.4	50.6
Zoysia	1%	15 GPM	6 ft	A	222.2	222.1	105.0	141.0	38.4
Zoysia	1%	15 GPM	6 ft	B	221.5	219.2	105.0	139.6	36.6

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Table B12

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	1%	20 GPM	0 ft	A	619.6	444.9	486.9	142.4	64.7
Zoysia	1%	20 GPM	0 ft	B	627.1	453.7	474.3	135.8	63.0
Zoysia	1%	20 GPM	2 ft	A	296.0	311.9	172.2	113.4	44.4
Zoysia	1%	20 GPM	2 ft	B	293.9	302.9	169.1	111.7	50.3
Zoysia	1%	20 GPM	3 ft	A	280.9	288.8	153.1	120.4	40.2
Zoysia	1%	20 GPM	3 ft	B	278.4	281.4	152.0	112.0	45.4
Zoysia	1%	20 GPM	6 ft	A	228.2	238.1	94.8	135.4	32.6
Zoysia	1%	20 GPM	6 ft	B	224.5	244.2	94.9	137.4	28.8

Table B13

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	3%	10 GPM	0 ft	A	513.9	358.8	288.5	126.0	38.6
Zoysia	3%	10 GPM	0 ft	B	518.8	363.3	361.5	139.4	38.8
Zoysia	3%	10 GPM	2 ft	A	164.4	170.7	38.1	141.2	16.7
Zoysia	3%	10 GPM	2 ft	B	168.7	171.9	34.7	138.6	15.6
Zoysia	3%	10 GPM	3 ft	A	211.2	189.8	73.7	128.3	22.9
Zoysia	3%	10 GPM	3 ft	B	206.9	191.6	76.8	126.3	25.0
Zoysia	3%	10 GPM	6 ft	A	233.3	221.2	105.3	130.5	26.9
Zoysia	3%	10 GPM	6 ft	B	238.3	218.8	100.0	122.6	26.1

Table B14

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	3%	15 GPM	0 ft	A	695.0	518.8	587.5	129.2	74.6
Zoysia	3%	15 GPM	0 ft	B	727.3	520.6	586.0	129.0	74.3
Zoysia	3%	15 GPM	2 ft	A	373.2	357.0	256.1	140.8	59.6
Zoysia	3%	15 GPM	2 ft	B	376.9	366.7	251.0	130.4	74.8
Zoysia	3%	15 GPM	3 ft	A	297.9	311.0	179.4	137.1	56.7
Zoysia	3%	15 GPM	3 ft	B	312.5	303.1	185.4	131.1	54.9
Zoysia	3%	15 GPM	6 ft	A	243.6	240.6	119.2	130.8	40.1
Zoysia	3%	15 GPM	6 ft	B	235.0	235.2	113.5	126.0	47.8

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Table B15

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	3%	20 GPM	0 ft	A	708.4	514.1	570.1	130.9	78.3
Zoysia	3%	20 GPM	0 ft	B	673.7	501.0	575.0	144.8	66.5
Zoysia	3%	20 GPM	2 ft	A	335.0	351.0	201.1	118.1	54.5
Zoysia	3%	20 GPM	2 ft	B	328.0	338.4	200.0	113.9	51.6
Zoysia	3%	20 GPM	3 ft	A	287.5	300.0	163.7	121.6	55.1
Zoysia	3%	20 GPM	3 ft	B	296.0	304.1	164.6	114.6	47.1
Zoysia	3%	20 GPM	6 ft	A	235.8	231.7	110.9	131.8	45.2
Zoysia	3%	20 GPM	6 ft	B	232.7	235.6	109.4	127.4	44.4

Table B16

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	5%	10 GPM	0 ft	A	421.4	321.4	231.8	122.4	39.0
Zoysia	5%	10 GPM	0 ft	B	423.5	330.2	261.0	123.0	44.8
Zoysia	5%	10 GPM	2 ft	A	333.3	281.0	174.0	137.5	34.1
Zoysia	5%	10 GPM	2 ft	B	337.7	276.2	176.5	141.8	33.4
Zoysia	5%	10 GPM	3 ft	A	276.0	236.2	110.4	155.7	39.5
Zoysia	5%	10 GPM	3 ft	B	266.7	235.8	111.2	144.9	29.9
Zoysia	5%	10 GPM	6 ft	A	204.0	186.9	54.2	151.0	22.9
Zoysia	5%	10 GPM	6 ft	B	210.3	194.6	54.1	152.0	22.0

Table B17

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	5%	15 GPM	0 ft	A	712.7	503.9	594.3	135.2	74.3
Zoysia	5%	15 GPM	0 ft	B	716.3	508.4	600.0	129.5	75.9
Zoysia	5%	15 GPM	2 ft	A	360.0	350.0	234.3	136.4	60.6
Zoysia	5%	15 GPM	2 ft	B	363.0	350.5	240.7	136.1	65.2
Zoysia	5%	15 GPM	3 ft	A	283.7	282.4	160.0	131.4	46.0
Zoysia	5%	15 GPM	3 ft	B	286.1	286.1	160.0	124.0	47.8
Zoysia	5%	15 GPM	6 ft	A	217.3	223.7	92.2	130.1	36.5
Zoysia	5%	15 GPM	6 ft	B	218.4	216.3	95.2	130.5	31.9

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Table B18

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Zoysia	5%	20 GPM	0 ft	A	953.5	524.0	608.1	129.3	77.1
Zoysia	5%	20 GPM	0 ft	B	940.0	531.1	793.8	133.0	64.0
Zoysia	5%	20 GPM	2 ft	A	409.9	368.1	287.0	141.7	57.1
Zoysia	5%	20 GPM	2 ft	B	419.2	371.8	286.3	140.0	50.3
Zoysia	5%	20 GPM	3 ft	A	306.1	293.7	162.2	133.7	51.0
Zoysia	5%	20 GPM	3 ft	B	298.0	292.0	155.2	126.0	44.4
Zoysia	5%	20 GPM	6 ft	A	238.0	232.3	101.0	125.0	43.7
Zoysia	5%	20 GPM	6 ft	B	233.0	240.0	103.0	132.3	38.1

Table B19

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	1%	10 GPM	0 ft	A	455.3	347.7	267.3	124.5	32.5
Bluegrass	1%	10 GPM	0 ft	B	486.0	355.3	273.7	116.8	32.1
Bluegrass	1%	10 GPM	2 ft	A	191.7	192.9	68.0	122.0	18.0
Bluegrass	1%	10 GPM	2 ft	B	192.7	188.4	67.6	120.4	18.5
Bluegrass	1%	10 GPM	3 ft	A	207.1	202.9	64.3	137.8	22.6
Bluegrass	1%	10 GPM	3 ft	B	207.9	199.1	63.9	136.1	19.3
Bluegrass	1%	10 GPM	6 ft	A	177.3	172.3	39.4	136.5	15.4
Bluegrass	1%	10 GPM	6 ft	B	172.9	186.1	40.6	132.7	15.1

Table B20

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	1%	15 GPM	0 ft	A	819.4	493.9	690.5	118.9	78.2
Bluegrass	1%	15 GPM	0 ft	B	823.2	495.0	696.1	123.3	78.7
Bluegrass	1%	15 GPM	2 ft	A	384.6	375.2	263.5	129.8	61.1
Bluegrass	1%	15 GPM	2 ft	B	390.0	371.8	265.3	126.3	66.6
Bluegrass	1%	15 GPM	3 ft	A	350.0	334.7	225.5	132.7	68.8
Bluegrass	1%	15 GPM	3 ft	B	346.2	333.7	227.2	130.1	63.5
Bluegrass	1%	15 GPM	6 ft	A	263.9	263.4	136.7	133.7	54.8
Bluegrass	1%	15 GPM	6 ft	B	261.8	262.1	133.0	132.1	48.1

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Table B21

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	1%	20 GPM	0 ft	A	910.8	485.0	776.2	137.6	62.4
Bluegrass	1%	20 GPM	0 ft	B	894.3	502.1	771.4	131.4	57.6
Bluegrass	1%	20 GPM	2 ft	A	376.4	370.6	266.0	129.1	44.2
Bluegrass	1%	20 GPM	2 ft	B	374.3	362.9	245.2	126.0	48.5
Bluegrass	1%	20 GPM	3 ft	A	329.5	331.3	200.0	142.2	53.3
Bluegrass	1%	20 GPM	3 ft	B	318.6	331.0	198.9	138.9	45.4
Bluegrass	1%	20 GPM	6 ft	A	275.3	268.9	142.3	129.8	41.9
Bluegrass	1%	20 GPM	6 ft	B	272.9	270.0	144.7	131.1	42.4

Table B22

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	3%	10 GPM	0 ft	A	598.0	376.0	330.9	125.8	38.7
Bluegrass	3%	10 GPM	0 ft	B	600.0	366.7	336.3	117.6	33.6
Bluegrass	3%	10 GPM	2 ft	A	225.7	226.3	172.9	125.0	27.0
Bluegrass	3%	10 GPM	2 ft	B	230.8	225.8	89.7	140.2	26.9
Bluegrass	3%	10 GPM	3 ft	A	194.1	202.0	77.8	131.5	24.6
Bluegrass	3%	10 GPM	3 ft	B	199.1	195.9	76.0	123.0	23.7
Bluegrass	3%	10 GPM	6 ft	A	162.0	173.7	38.5	124.0	16.4
Bluegrass	3%	10 GPM	6 ft	B	161.0	165.7	38.9	126.9	16.4

Table B23

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	3%	15 GPM	0 ft	A	867.7	509.0	718.6	130.4	76.8
Bluegrass	3%	15 GPM	0 ft	B	847.6	503.2	704.6	133.0	74.8
Bluegrass	3%	15 GPM	2 ft	A	488.6	462.2	362.4	131.7	72.9
Bluegrass	3%	15 GPM	2 ft	B	479.6	467.3	358.8	135.3	71.5
Bluegrass	3%	15 GPM	3 ft	A	378.1	364.0	255.8	129.8	66.8
Bluegrass	3%	15 GPM	3 ft	B	374.5	368.7	252.4	130.1	64.3
Bluegrass	3%	15 GPM	6 ft	A	275.8	279.4	151.0	128.4	47.9
Bluegrass	3%	15 GPM	6 ft	B	278.4	272.4	149.5	127.8	46.5

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Table B24

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	3%	20 GPM	0 ft	A	1142.7	483.3	1021.6	122.5	56.2
Bluegrass	3%	20 GPM	0 ft	B	1076.6	490.3	911.5	129.2	56.5
Bluegrass	3%	20 GPM	2 ft	A	432.1	399.1	307.9	132.7	55.5
Bluegrass	3%	20 GPM	2 ft	B	427.7	389.6	301.0	133.0	55.7
Bluegrass	3%	20 GPM	3 ft	A	351.0	350.0	257.0	131.0	49.2
Bluegrass	3%	20 GPM	3 ft	B	345.4	350.5	230.8	128.0	48.1
Bluegrass	3%	20 GPM	6 ft	A	253.0	263.5	129.0	134.0	35.6
Bluegrass	3%	20 GPM	6 ft	B	251.6	260.2	131.5	130.6	38.3

Table B25

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	5%	10 GPM	0 ft	A	544.0	352.3	263.6	133.3	35.9
Bluegrass	5%	10 GPM	0 ft	B	538.6	344.2	320.8	126.7	35.6
Bluegrass	5%	10 GPM	2 ft	A	250.5	239.8	114.0	129.0	34.3
Bluegrass	5%	10 GPM	2 ft	B	252.9	235.2	117.1	125.7	37.5
Bluegrass	5%	10 GPM	3 ft	A	185.9	213.7	78.3	122.6	31.1
Bluegrass	5%	10 GPM	3 ft	B	201.0	209.0	83.8	116.2	26.3
Bluegrass	5%	10 GPM	6 ft	A	189.7	175.3	41.6	129.7	15.4
Bluegrass	5%	10 GPM	6 ft	B	191.9	171.0	45.5	124.2	14.8

Table B26

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	5%	15 GPM	0 ft	A	978.4	507.1	872.6	140.0	76.8
Bluegrass	5%	15 GPM	0 ft	B	988.0	521.2	857.4	133.3	81.8
Bluegrass	5%	15 GPM	2 ft	A	447.1	444.4	329.2	128.1	74.3
Bluegrass	5%	15 GPM	2 ft	B	455.4	400.0	324.0	139.6	75.1
Bluegrass	5%	15 GPM	3 ft	A	441.2	426.7	314.4	134.0	64.9
Bluegrass	5%	15 GPM	3 ft	B	444.0	425.7	303.9	134.0	66.7
Bluegrass	5%	15 GPM	6 ft	A	288.1	281.3	160.4	128.7	49.5
Bluegrass	5%	15 GPM	6 ft	B	285.7	277.2	152.1	136.5	55.0

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Table B27

Grass type	Slope	Flow rate	Swale length	Duplicate	Total solids (mg/L)	Total solids (<106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
Bluegrass	5%	20 GPM	0 ft	A	1100.0	501.0	974.7	118.9	72.9
Bluegrass	5%	20 GPM	0 ft	B	1109.4	500.9	1009.3	119.4	71.2
Bluegrass	5%	20 GPM	2 ft	A	388.0	376.3	265.4	136.5	60.7
Bluegrass	5%	20 GPM	2 ft	B	384.8	371.1	263.0	129.0	57.5
Bluegrass	5%	20 GPM	3 ft	A	337.9	356.9	193.6	138.3	55.8
Bluegrass	5%	20 GPM	3 ft	B	340.7	365.7	191.9	133.3	54.1
Bluegrass	5%	20 GPM	6 ft	A	256.1	271.1	114.6	137.5	40.7
Bluegrass	5%	20 GPM	6 ft	B	259.6	272.0	109.4	137.5	41.5

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Appendix C: Raw Data – Outdoor Swale Observations

Table C1

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
8/22/2004	0	19	N/A	4	16	3
8/22/2004	25	22	N/A	5	22	5
8/22/2004	75	21	N/A	3	20	2

Note: N/A = not available

Table C2

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
10/9/2004	0	133	136	30	109	38
10/9/2004	75	149	149	31	134	12
10/9/2004	102	147	151	25	133	9

Table C3

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
10/10/2004	0	135	138	37	113	31
10/10/2004	101.9	159	151	11	145	9

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Table C4

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
10/11/2004	0	149	141	102	62	65
10/11/2004	2	125	117	84	45	60
10/11/2004	3	113	111	63	45	48
10/11/2004	6	70	72	35	50	32
10/11/2004	25	76	74	30	54	23
10/11/2004	75	92	86	20	71	27
10/11/2004	116	75	92	10	76	13

Table C5

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
10/19/2004	25	119	113	51	73	23
10/19/2004	75	58	59	12	43	17
10/19/2004	116	41	41	6	37	9

Table C6

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
10/23/2004	0	144	125	55	74	34
10/23/2004	2	148	137	85	58	40
10/23/2004	3	183	167	105	71	52
10/23/2004	6	123	115	58	65	33
10/23/2004	25	121	120	34	81	26
10/23/2004	75	103	88	29	71	20
10/23/2004	116	120	111	19	97	12

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Table C7

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
11/1/2004	0	246	247	153	101	137
11/1/2004	2	210	206	116	111	151
11/1/2004	3	218	217	127	104	143
11/1/2004	6	213	200	110	93	131
11/1/2004	25	160	147	42	110	91
11/1/2004	75	145	134	38	113	62
11/1/2004	116	129	126	25	110	12

Table C8

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
11/11/2004	0	103	70	31	63	21
11/11/2004	2	87	65	36	48	21
11/11/2004	3	83	53	39	35	20
11/11/2004	6	65	51	65	31	19
11/11/2004	25	71	74	30	42	22
11/11/2004	75	54	65	19	40	20
11/11/2004	116	85	74	13	64	8

Table C9

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
11/21/2004	0	29	36	18.8	24.8	38
11/21/2004	2	62	53	42.6	29.7	24
11/21/2004	3	139	114	108.0	27.0	18
11/21/2004	6	104	87	67.7	29.3	11
11/21/2004	25	53	44	20.6	32.4	26
11/21/2004	75	48	46	23.2	30.3	16
11/21/2004	116	34	27	0.0	35.0	10

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Table C10

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
11/22/2004	0	14	11	6.0	13.0	7
11/22/2004	2	16	14	8.1	13.1	9
11/22/2004	3	24	25	3.1	15.3	9
11/22/2004	6	19	18	8.1	15.2	9
11/22/2004	25	23	27	9.0	21.0	12
11/22/2004	75	15	20	7.1	6.1	12
11/22/2004	116	15	14	-4.0	5.0	5

Table C11

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
12/6/2004	0	139	116	120.0	4.0	18
12/6/2004	2	68	71	54.5	10.1	22
12/6/2004	3	46	51	48.0	10.0	46
12/6/2004	6	17	14	12.7	-3.9	34
12/6/2004	25	50	50	27.7	29.7	10
12/6/2004	75	21	31	12.1	17.2	13
12/6/2004	116	11	29	5	16	7

Table C12

Sampling date	Swale length (ft)	Total solids (mg/L)	Total solids (< 106 µm) (mg/L)	TSS (mg/L)	TDS (mg/L)	Turbidity (NTU)
12/8/2004	0	235	222	157	69	88
12/8/2004	2	150	142	105	40	61
12/8/2004	3	122	119	83	32	39
12/8/2004	6	103	95	61	26	31
12/8/2004	25	85	86	39	28	34
12/8/2004	75	141	131	90	33	71
12/8/2004	116	110	99	69	34	63

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Appendix D: Initial Experiments – Box-and-Whisker Plots of Total Solids and Turbidity by Experimental Variables

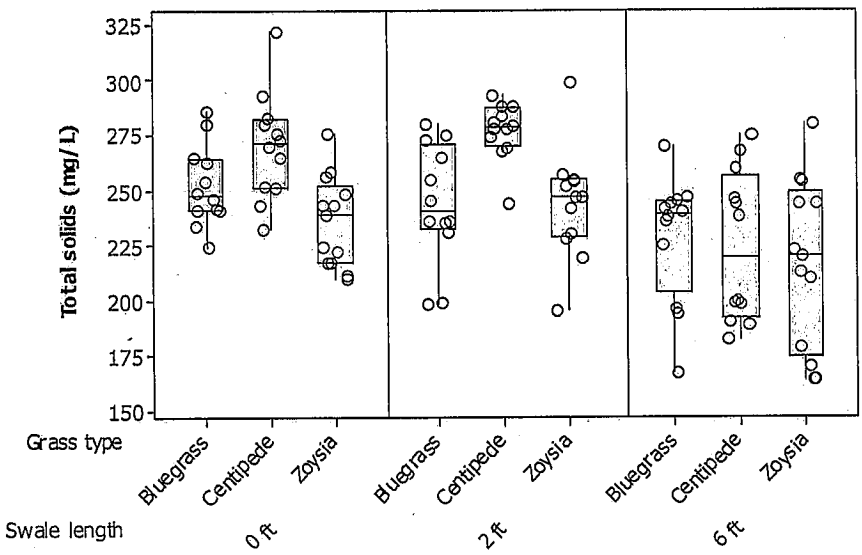

Figure D1

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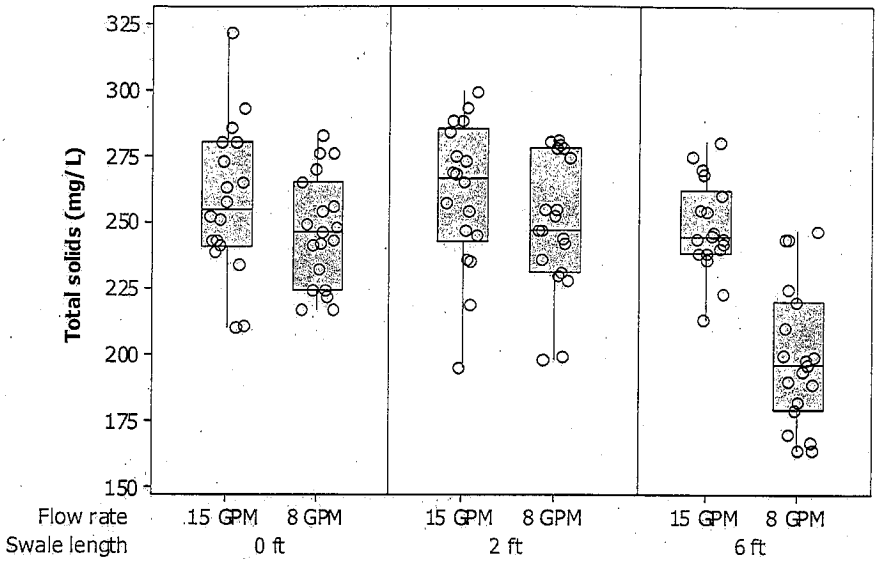
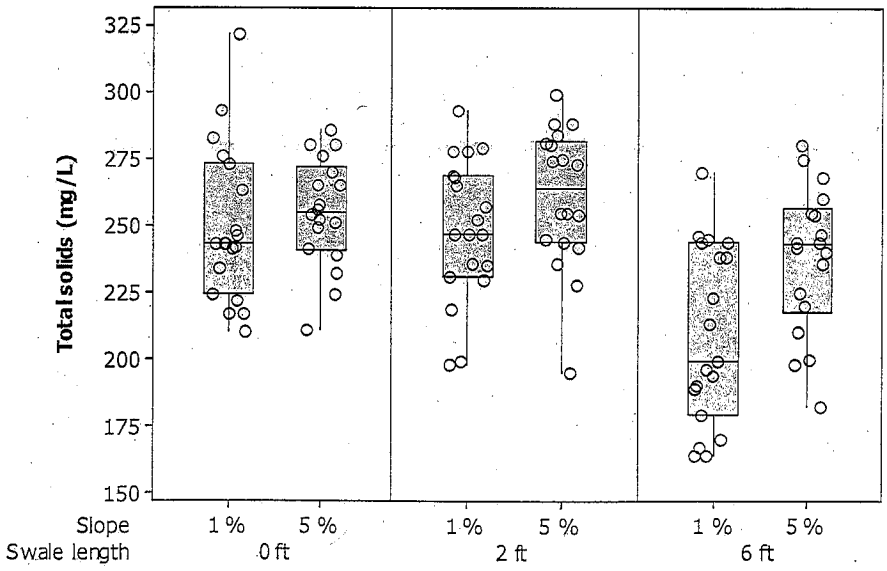


Figure D2



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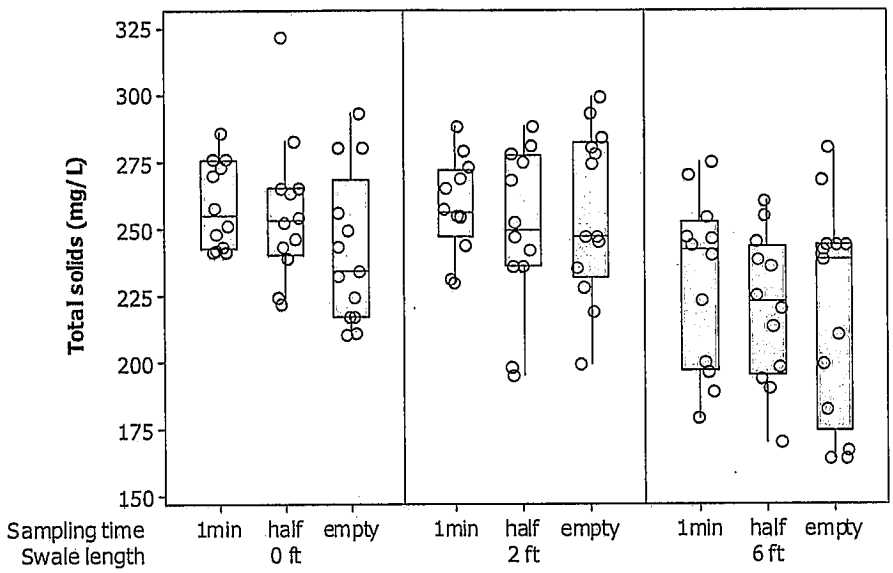
A007711



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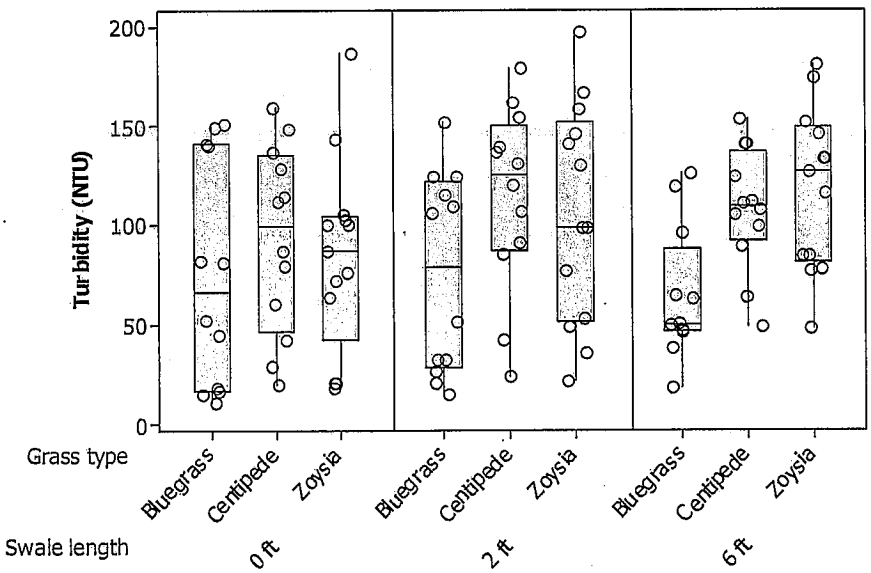

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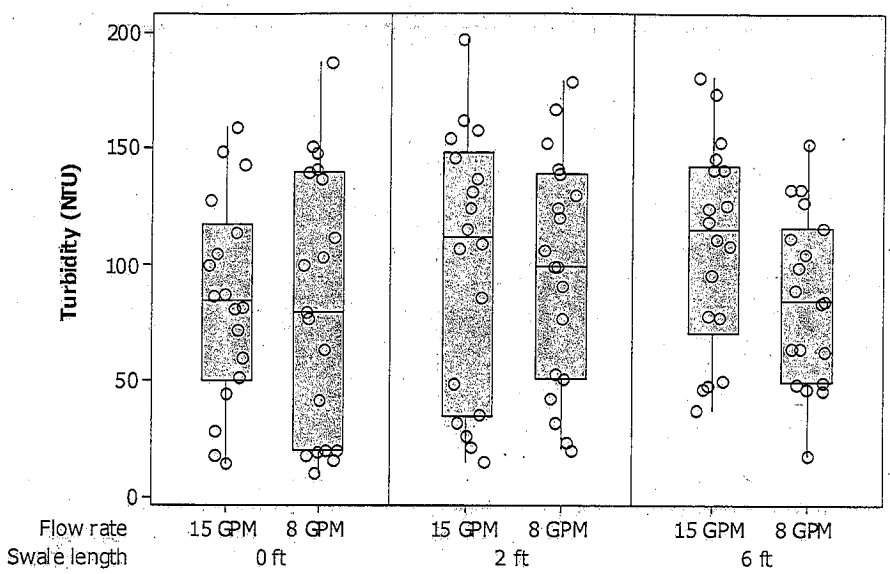
A007712



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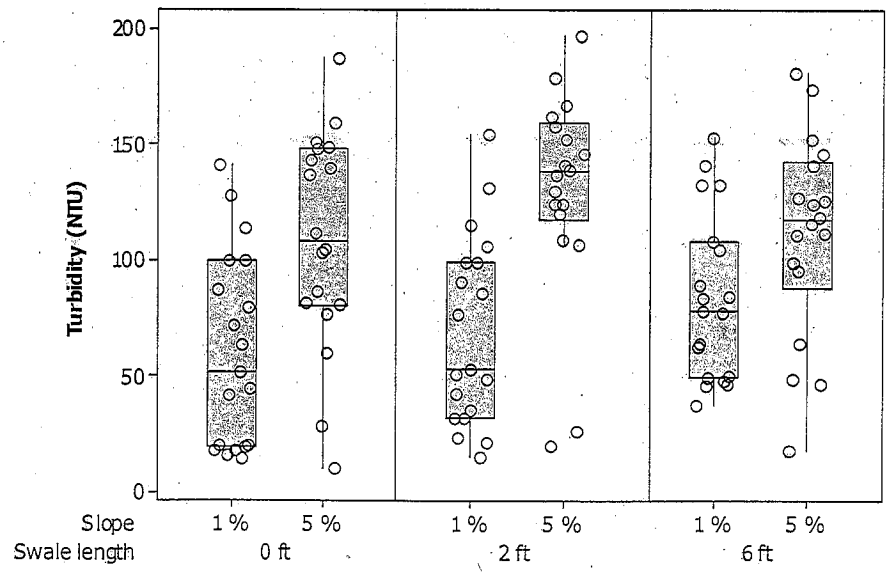

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A007713

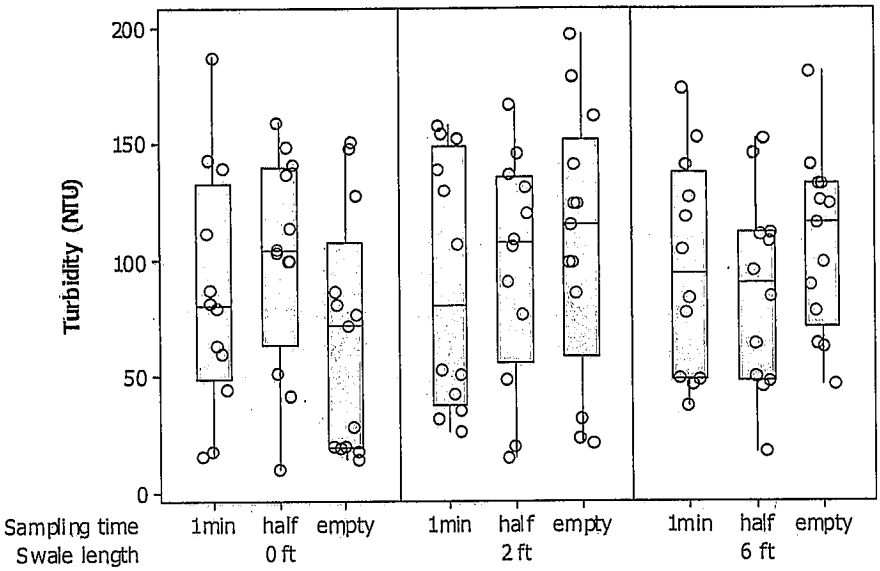


Figure D8

A007714

Appendix E: Initial Experiments – Line Plots for Total Solids and Turbidity

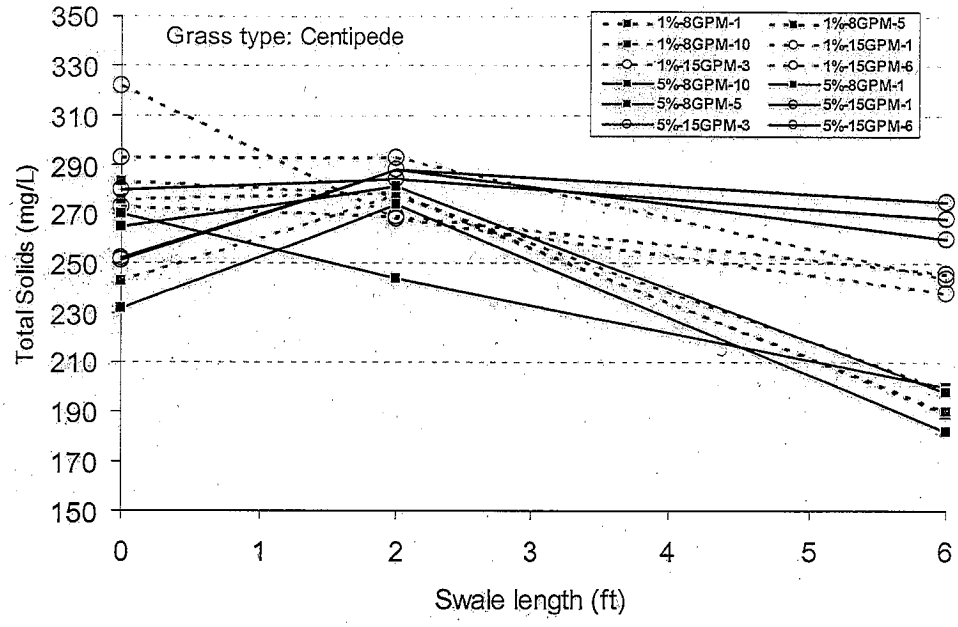


Figure E1

A007715

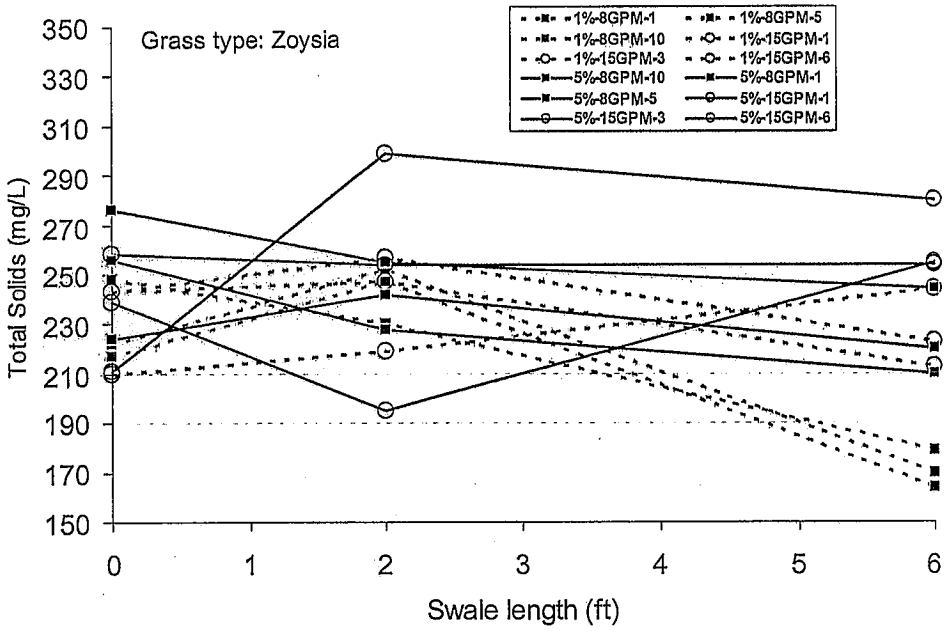


Figure E2

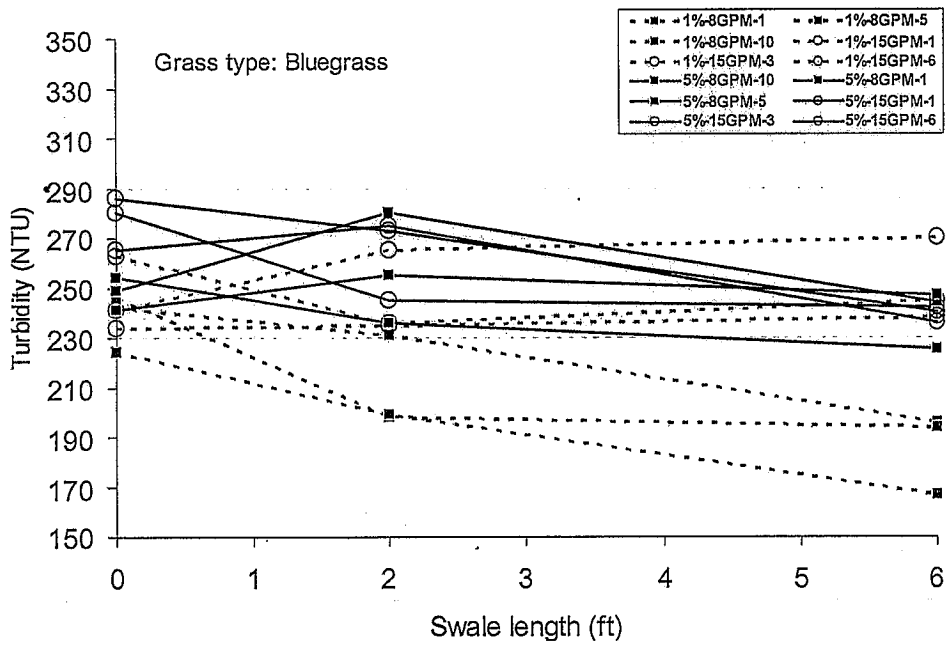
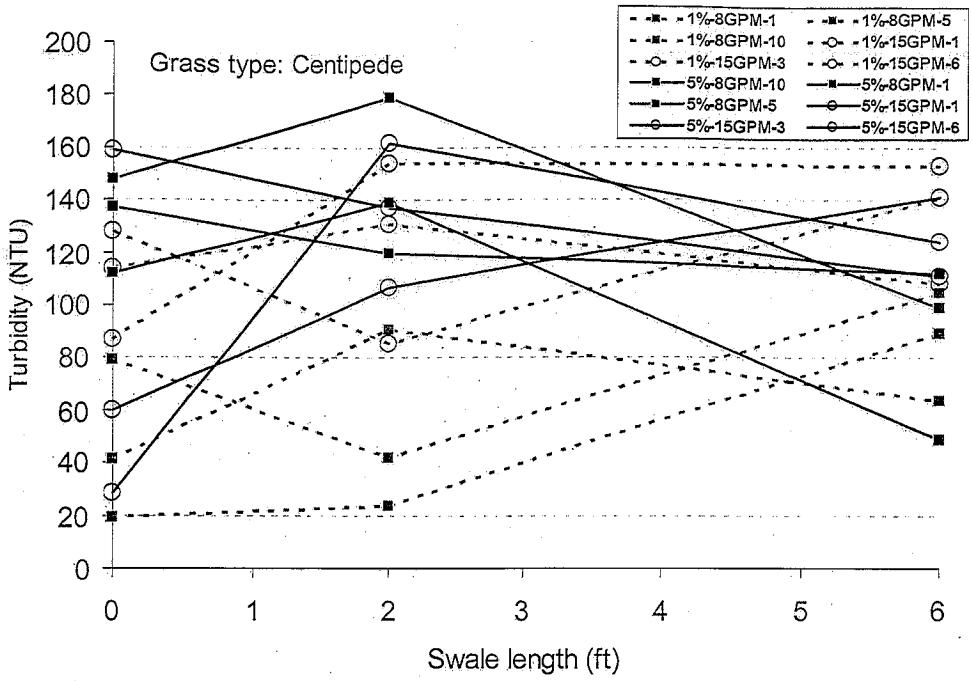


Figure E3

A007716



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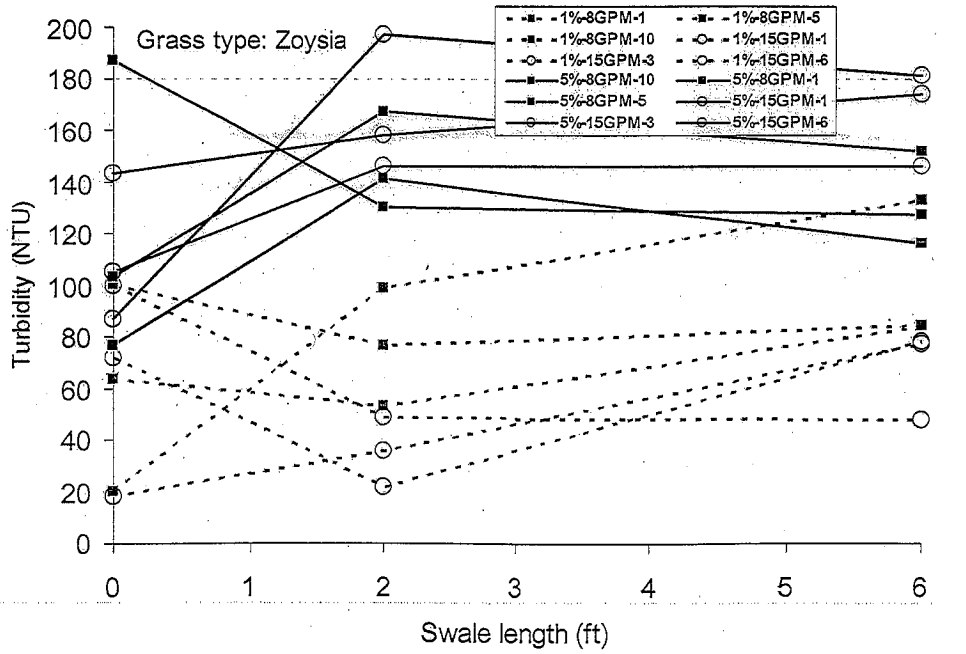

Figure E5

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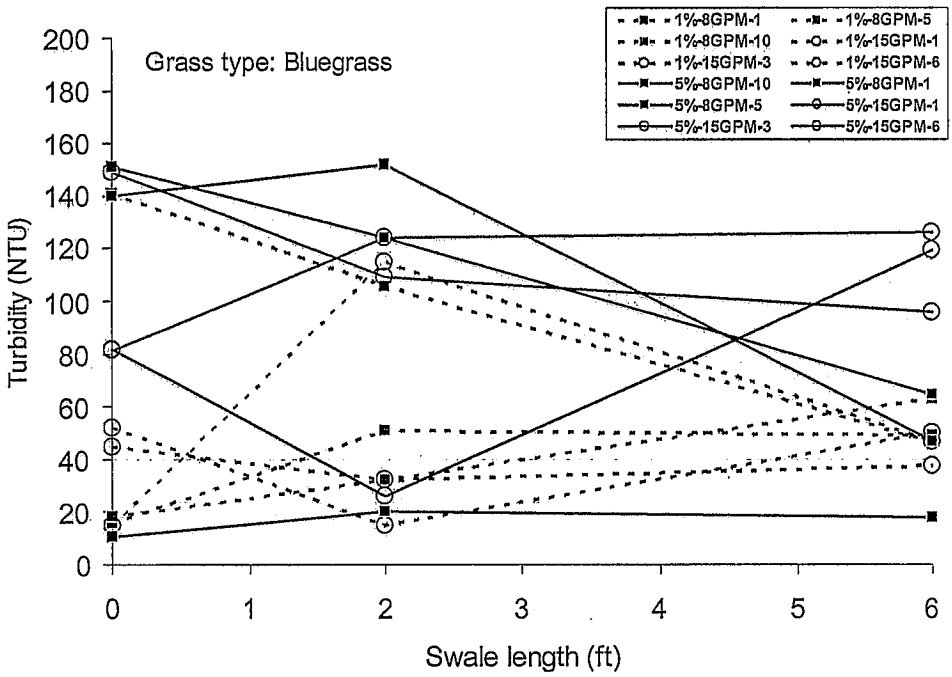


Figure E6

A007718

Appendix F: Initial Experiments – Particle Size Distributions (Coulter Counter Beckman® Multi-Sizer III) for each Experimental Condition

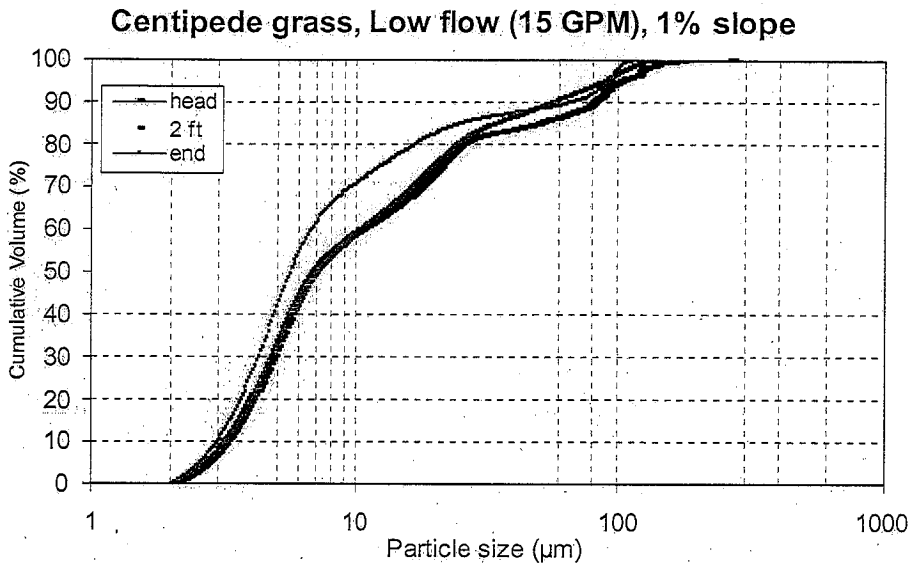


Figure F1

A007719

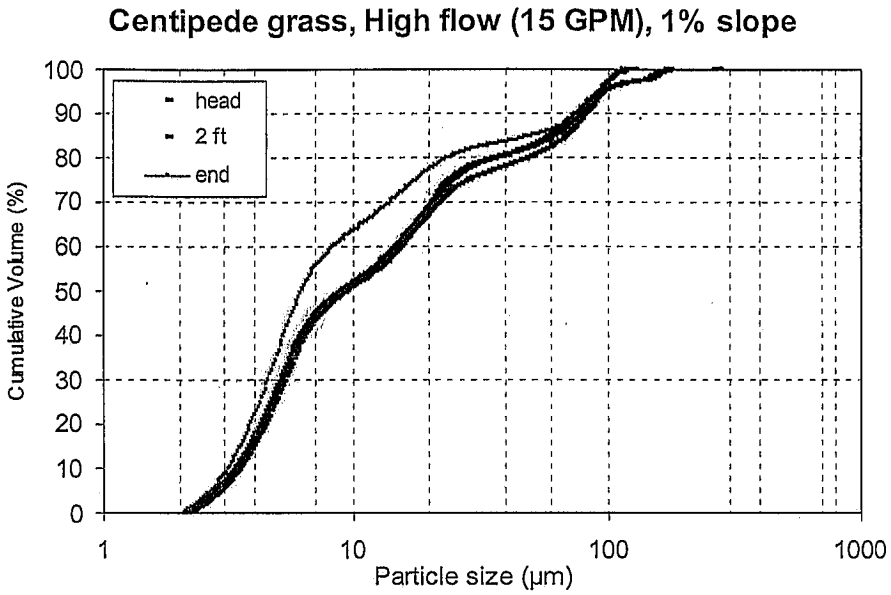


Figure F2

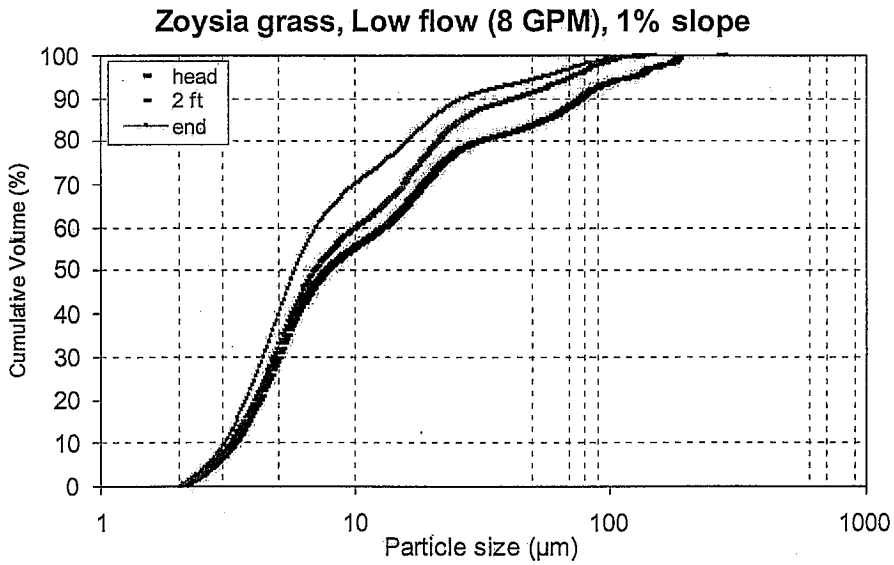


Figure F3

A007720

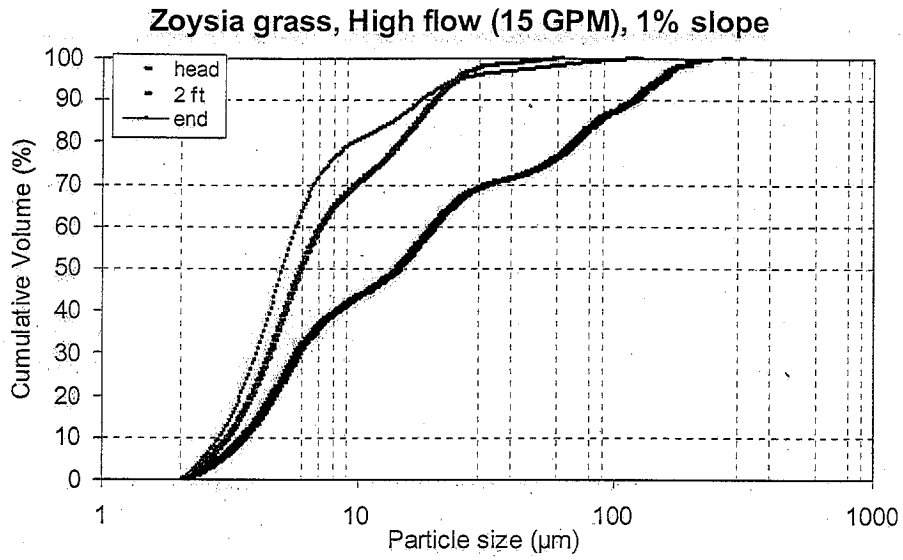


Figure F4

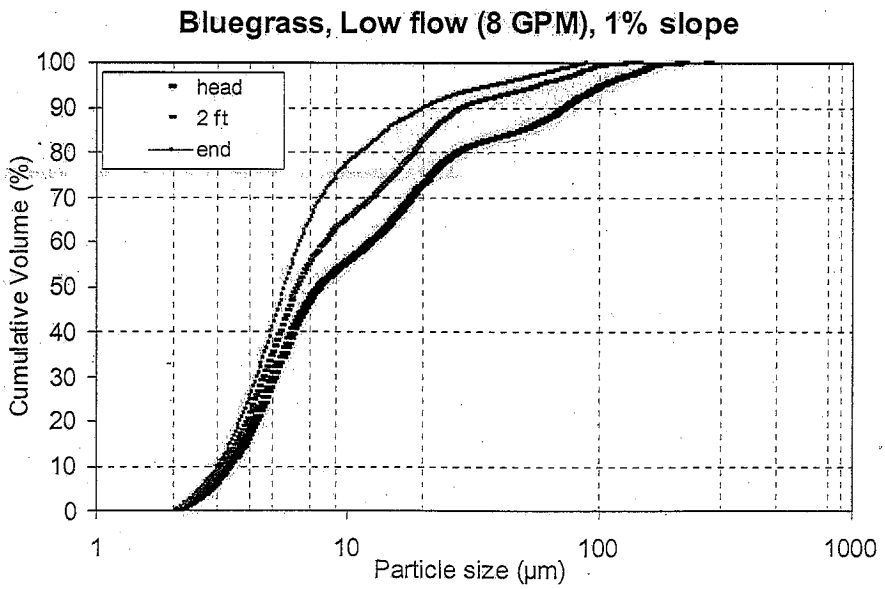


Figure F5

A007721

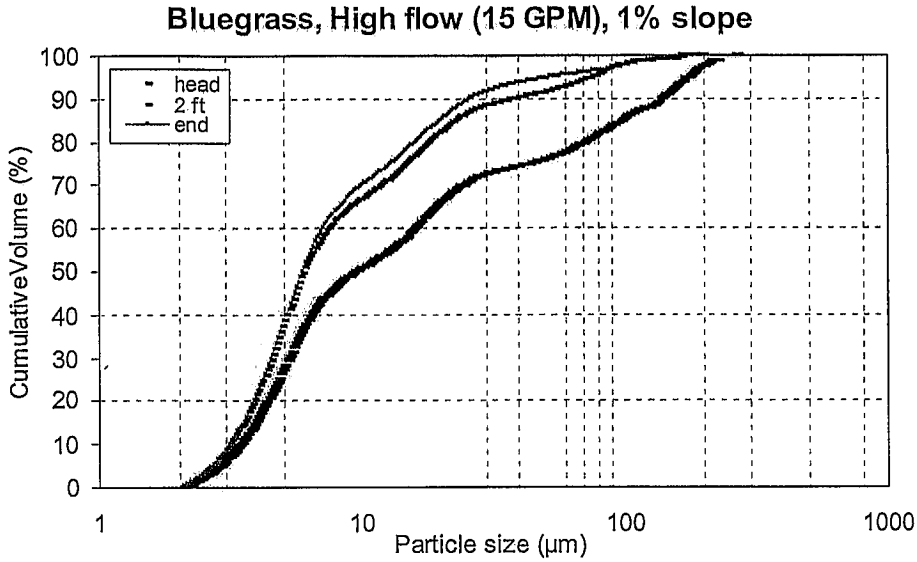
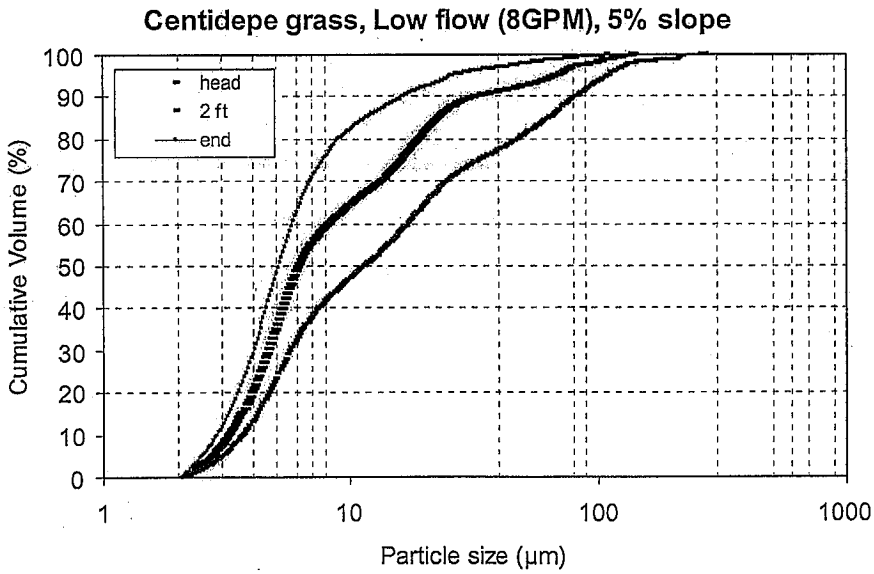


Figure F6



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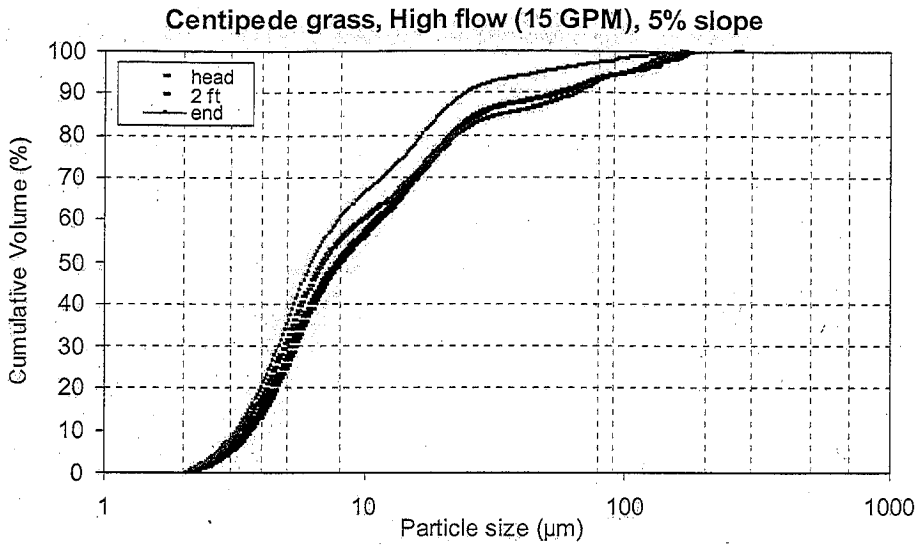

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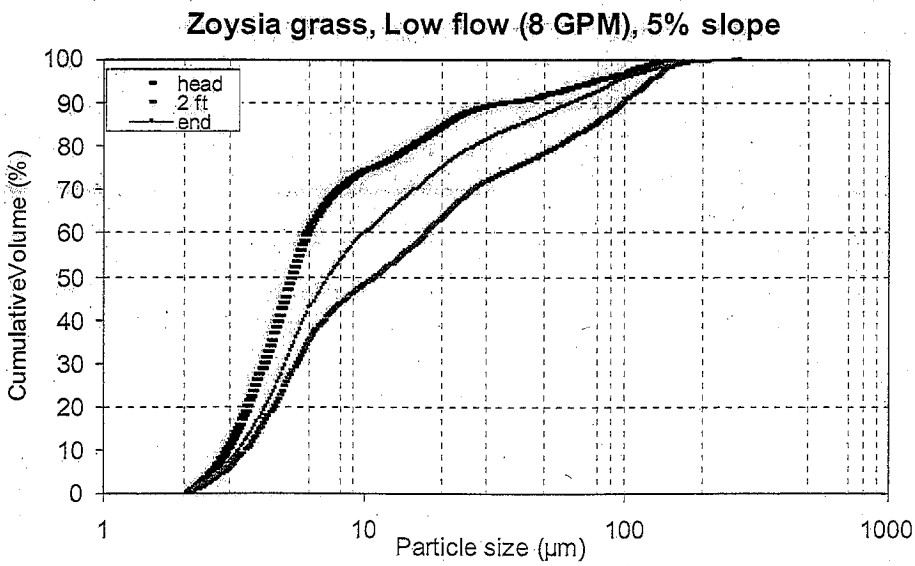

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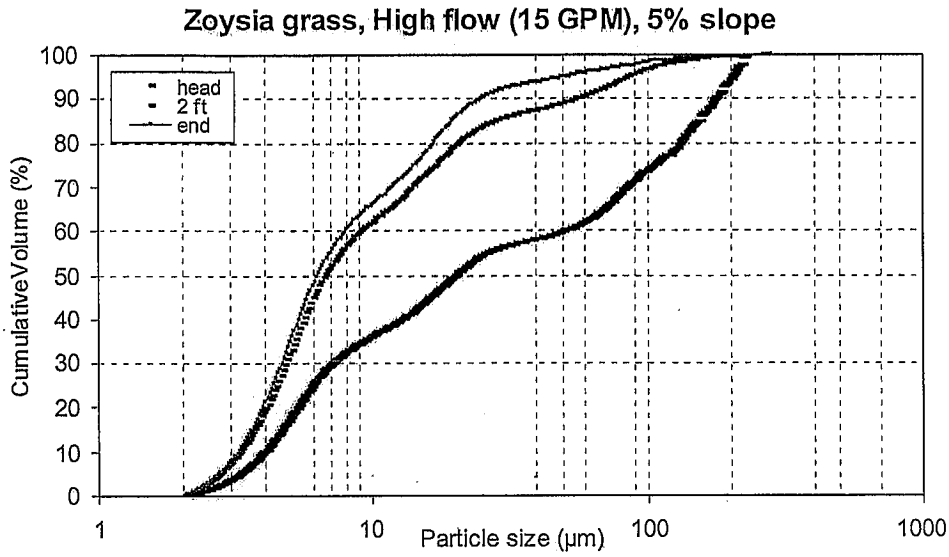

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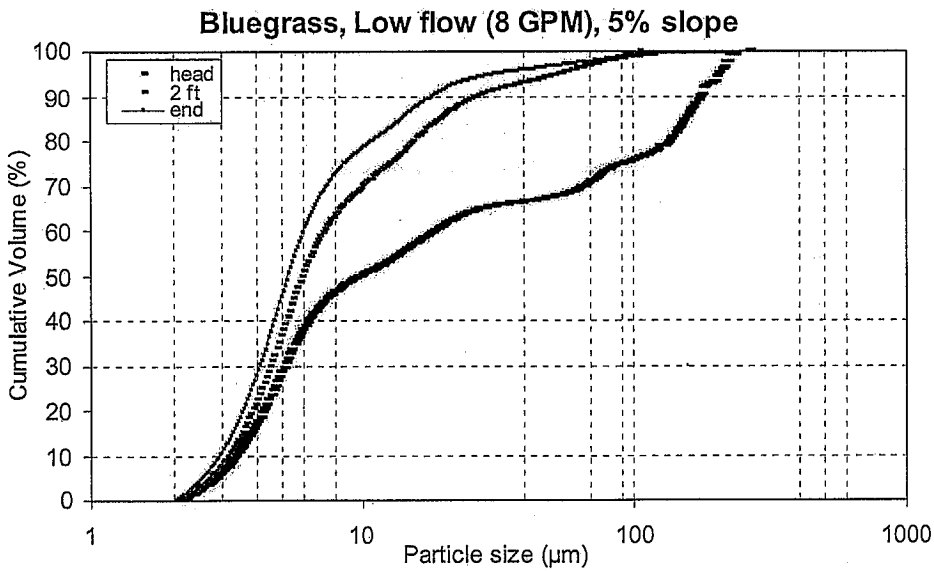

Figure F11

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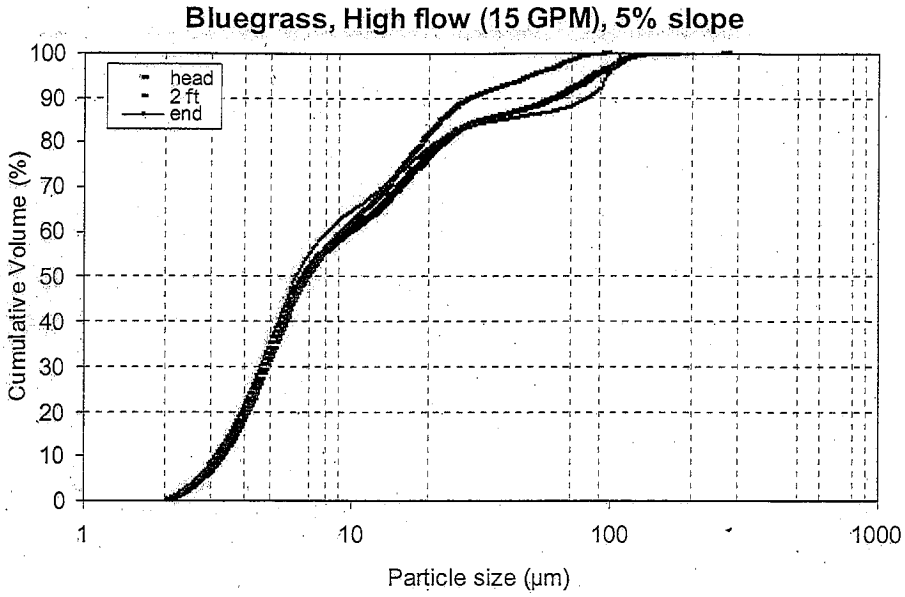


Figure F12

A007725

Appendix G: Second Experiments – Box-and-Whisker Plots of Constituents by Experimental Variables

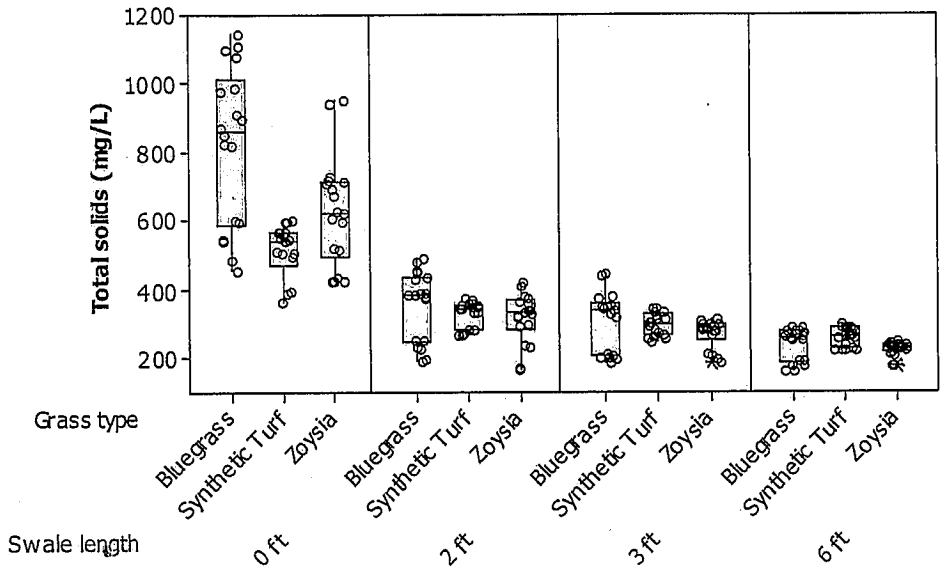
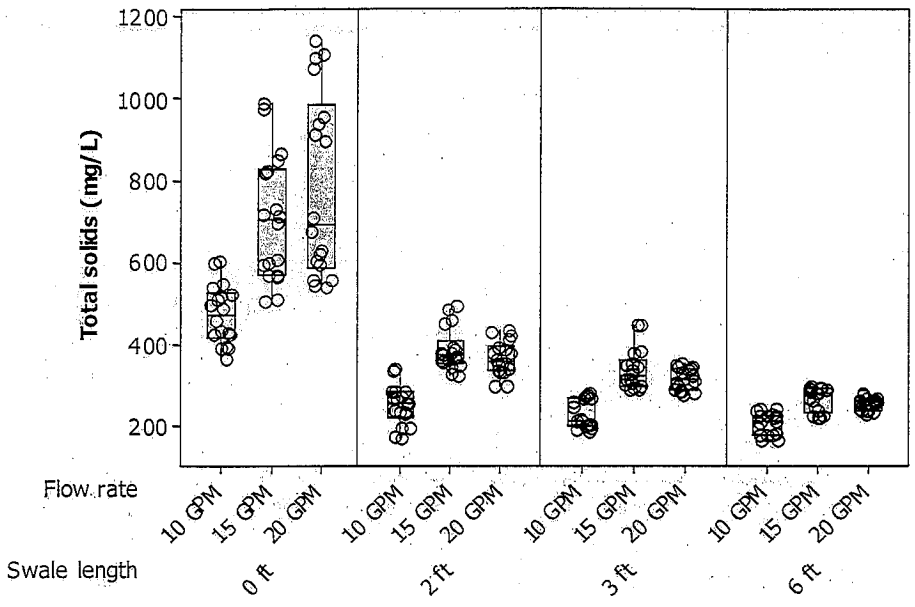


Figure G1

A007726



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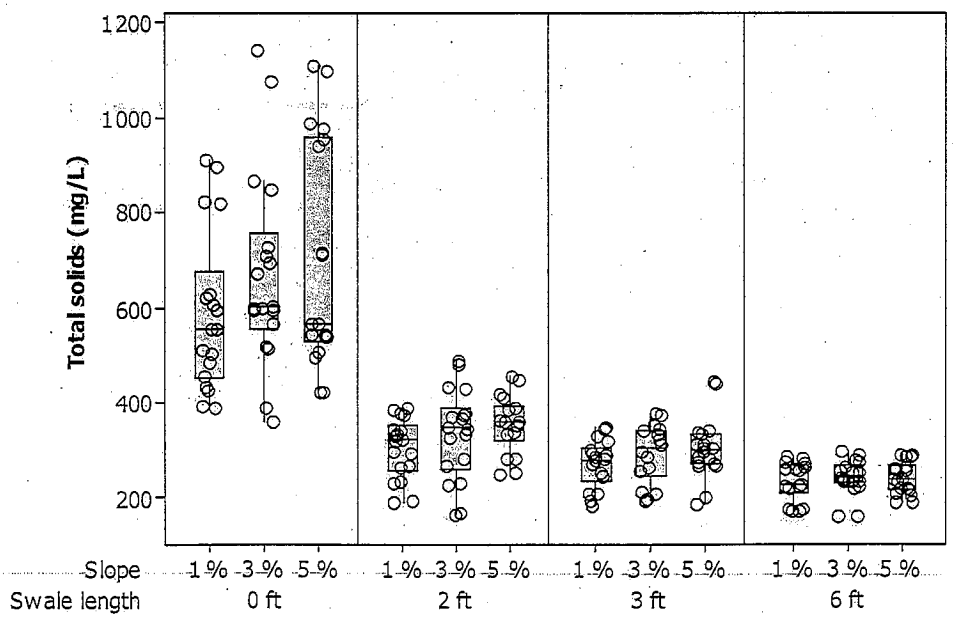

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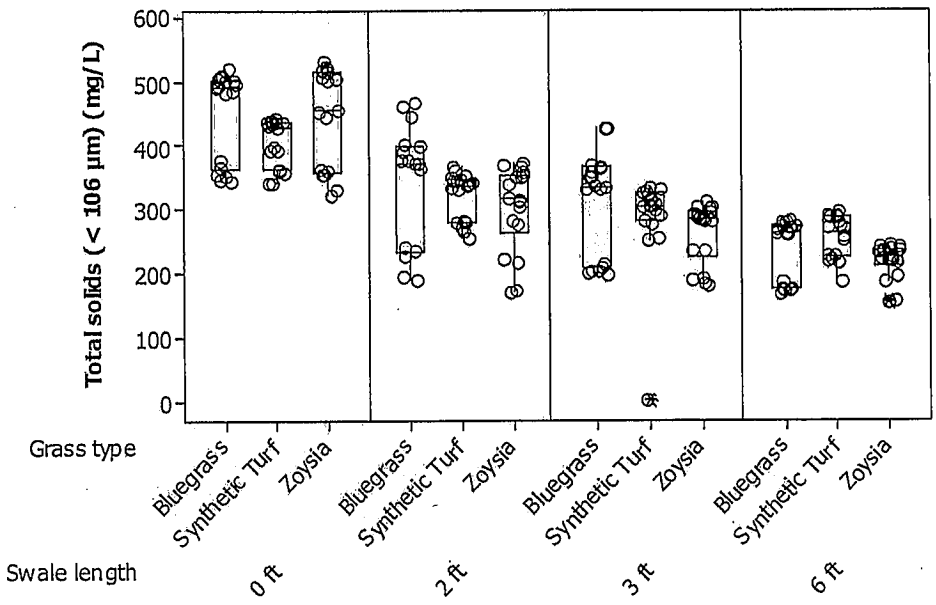
A807727



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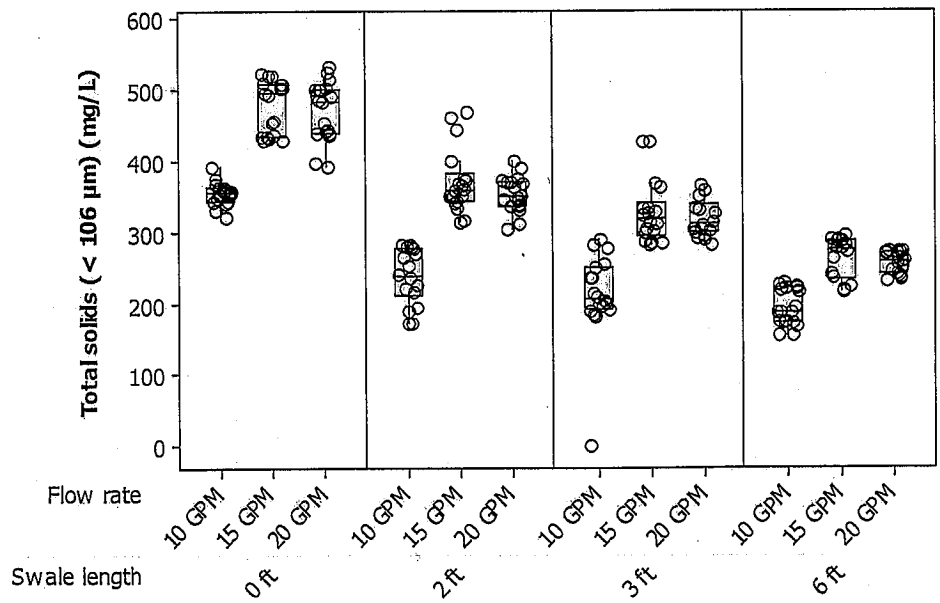

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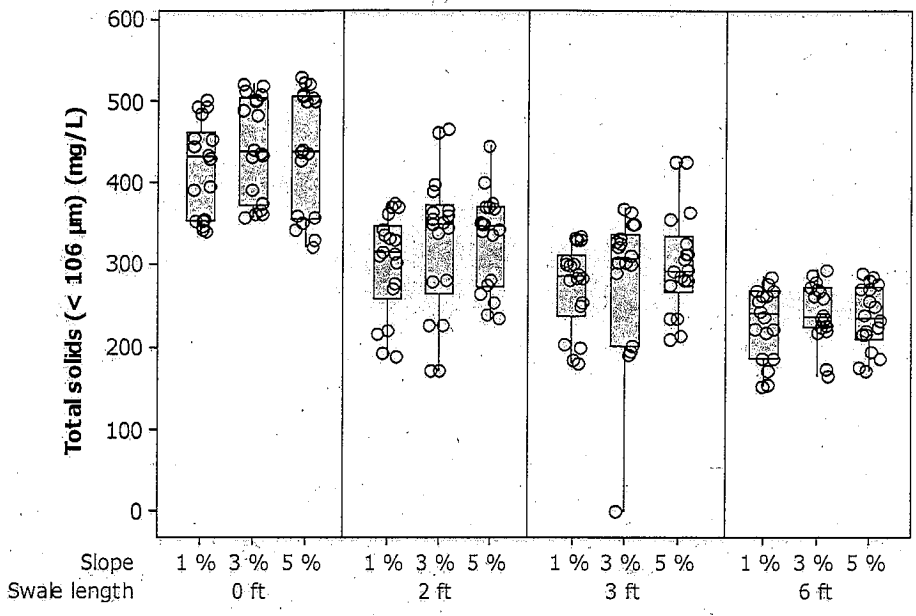

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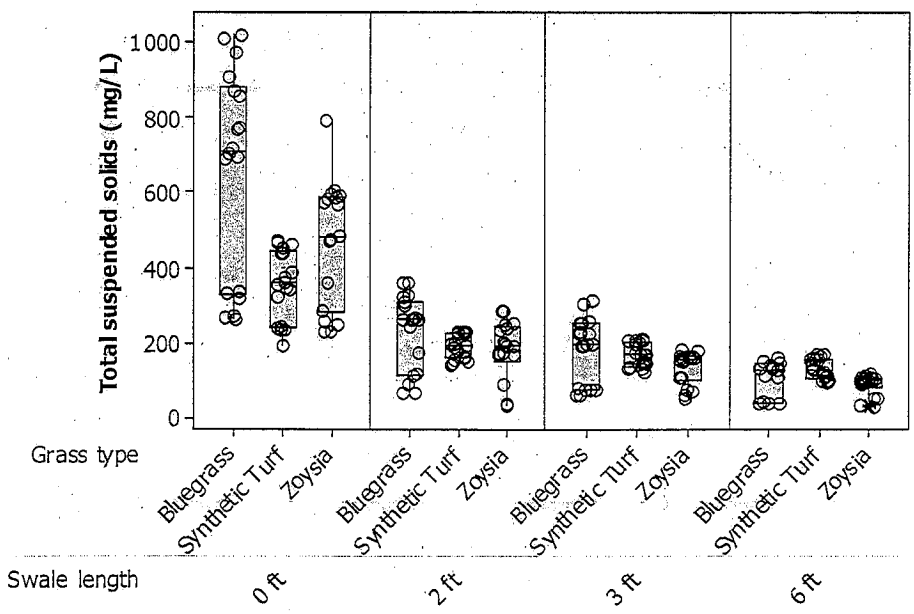

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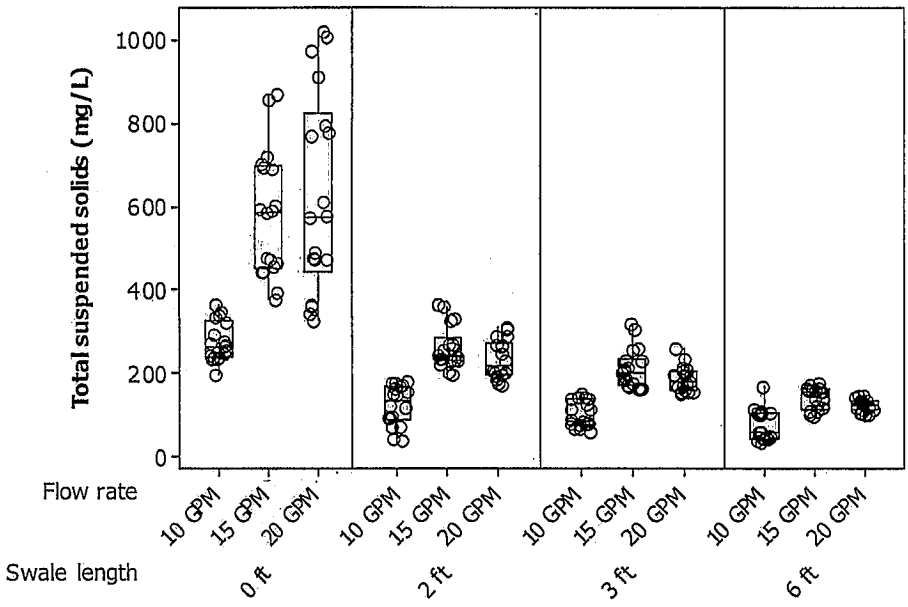

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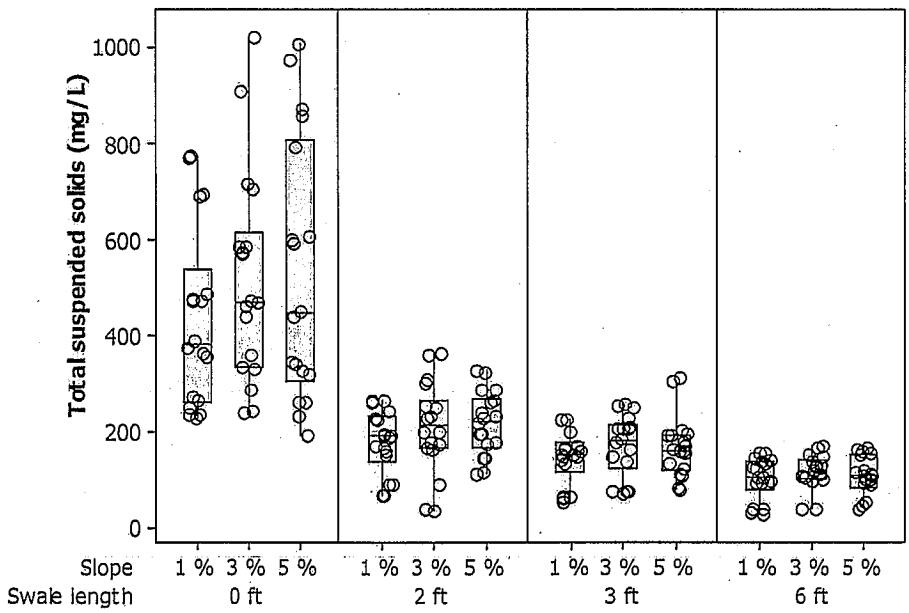


Figure G9

A007730

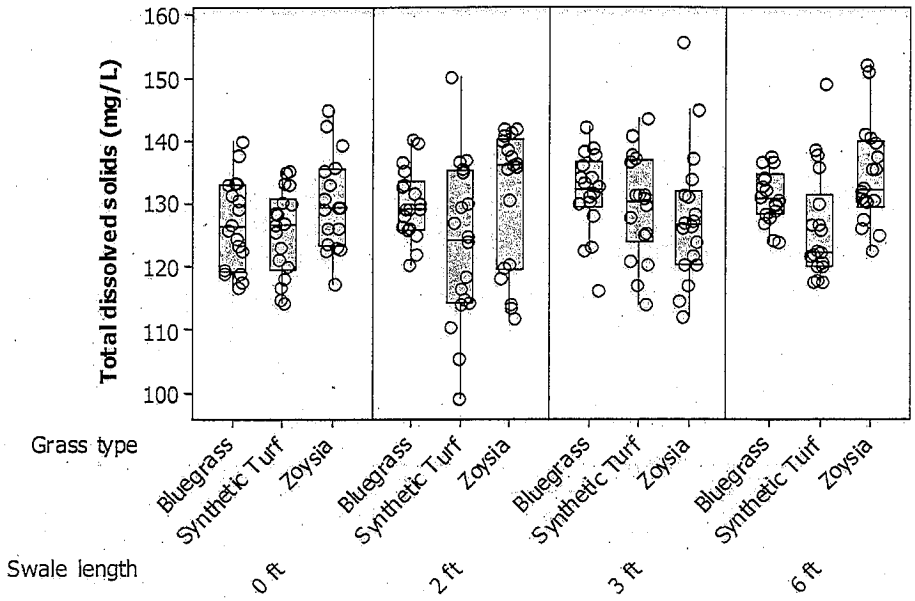


Figure G10

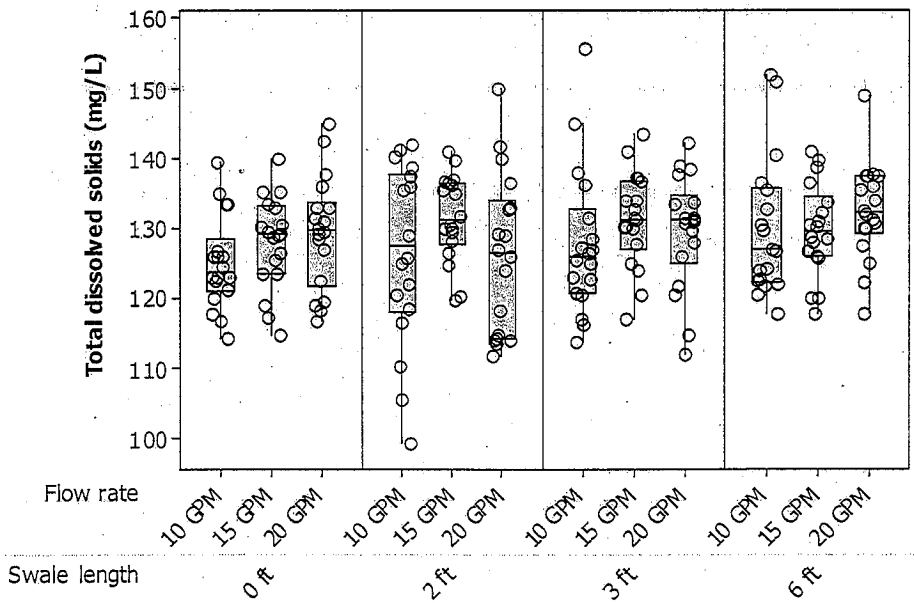
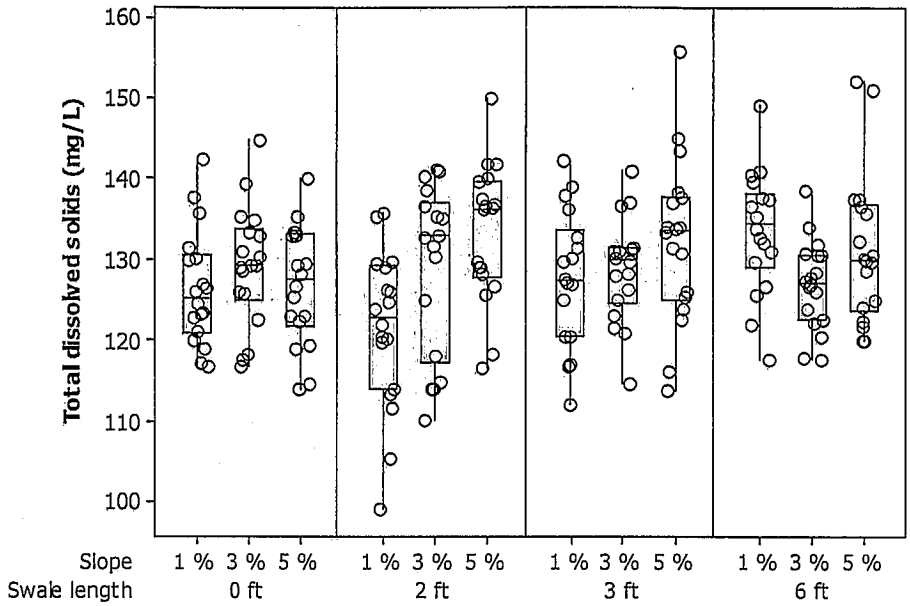


Figure G11

A007731



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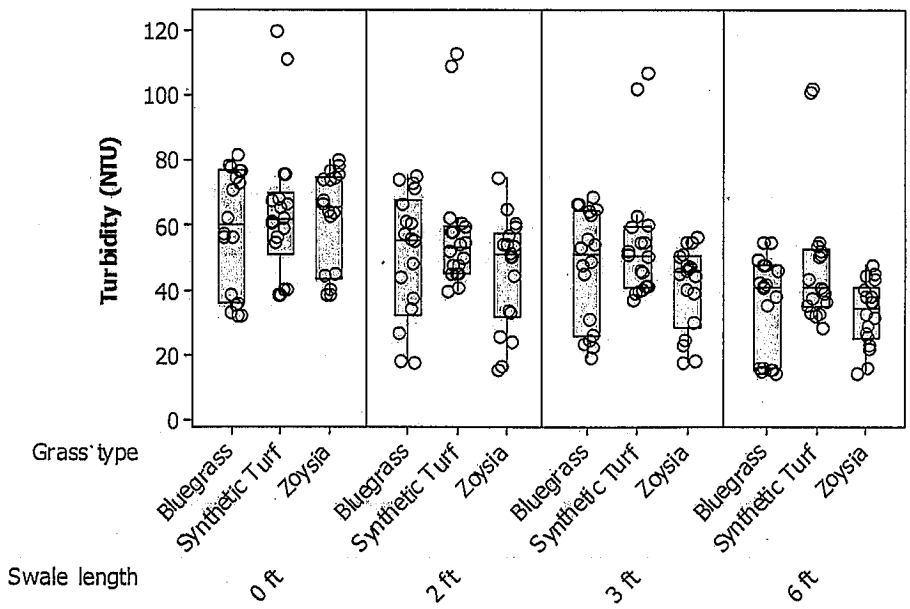

Figure G13

A007732

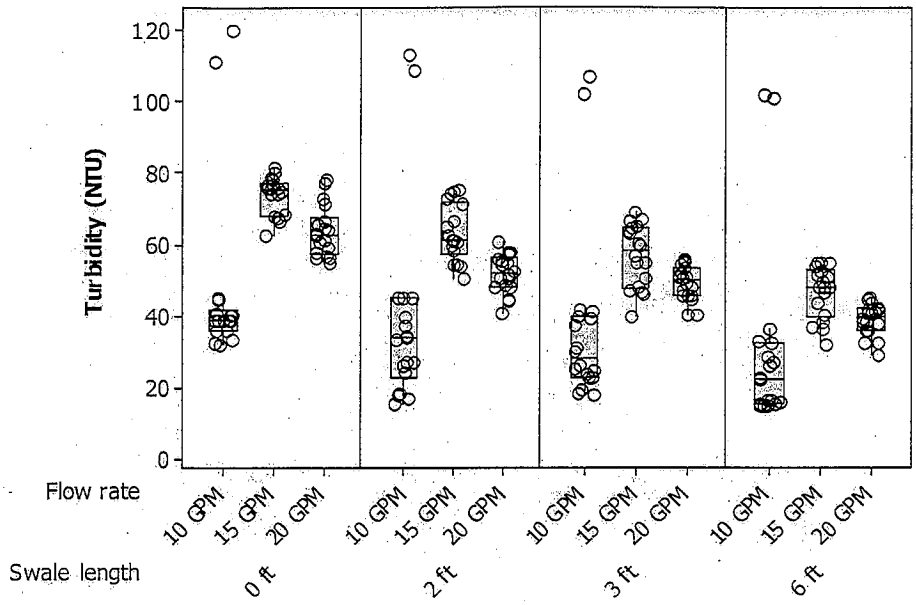

Figure G14

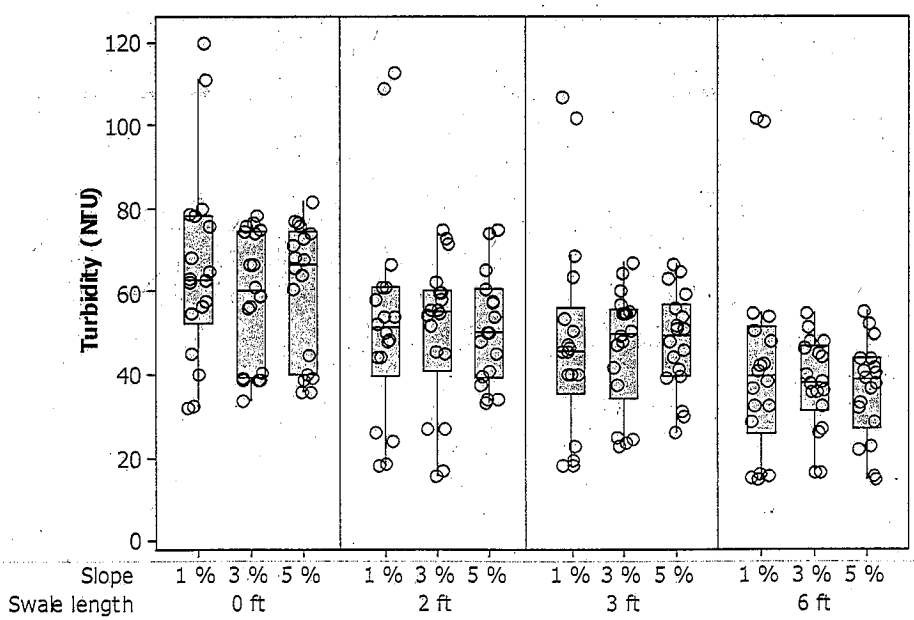

Figure G15

A007733

Appendix H: Second Experiments –Statistical Summaries of Particle Size Distributions for each Experiment

Table H1

Synthetic turf, 1% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	2.1	4.7	12.9	24.4	35.9
2 ft (0.6 m)	2.3	4.1	10.2	19.4	29.1
3 ft (0.9 m)	2	3.7	9.1	18.8	28
6 ft (1.8 m)	1.7	2.9	6.6	14.3	27.5

Table H2

Synthetic turf, 1% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.1	7.2	15.5	25.9	35.5
2 ft (0.6 m)	2.9	6.2	13.3	22.1	32.5
3 ft (0.9 m)	3.7	6.8	12.8	21.1	30.3
6 ft (1.8 m)	2.5	4.9	10.4	18.7	27.3

Table H3

Synthetic turf, 1% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	2.8	5.9	12.6	22.8	37.1
2 ft (0.6 m)	2.7	6.1	14.2	24.5	36.2
3 ft (0.9 m)	2.5	5.4	12.1	20.8	29.6
6 ft (1.8 m)	2.5	5.1	10.8	18.8	27.7

Table H4

Synthetic turf, 3% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.3	6.6	13.7	23.9	36.6
2 ft (0.6 m)	2.9	5.8	11.8	19.6	28.4
3 ft (0.9 m)	2.9	5.9	13.1	22.5	33.3
6 ft (1.8 m)	2.4	4.5	9.6	17.1	27

A007734

Table H5

Synthetic turf, 3% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.2	6.8	14.2	24.1	36.8
2 ft (0.6 m)	3	6.1	12.9	22.4	32.8
3 ft (0.9 m)	2.9	6.1	13.1	21.4	29.5
6 ft (1.8 m)	2.7	5.4	10.7	19	27

Table H6

Synthetic turf, 3% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.1	7.4	16.7	29.9	43.8
2 ft (0.6 m)	2.7	5.8	12.6	21.3	30.4
3 ft (0.9 m)	7	10.7	16.4	24.2	33.2
6 ft (1.8 m)	2.4	4.7	9.8	17.4	25.9

Table H7

Synthetic turf, 5% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.2	6.9	15.5	30.9	44.2
2 ft (0.6 m)	2.9	6.5	14.6	24.6	35.8
3 ft (0.9 m)	2.8	5.7	12.1	20.4	30.5
6 ft (1.8 m)	2.5	4.6	10.2	18.7	30.3

Table H8

Synthetic turf, 5% slope, 5 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.1	6.6	14	23.7	33.1
2 ft (0.6 m)	3.1	6.6	13.6	23	33.9
3 ft (0.9 m)	2.1	4.9	12.7	24.6	105.5
6 ft (1.8 m)	2.6	5.1	10.7	18.9	29.2

Table H9

Synthetic turf, 5% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.3	7.1	14.7	23.8	34
2 ft (0.6 m)	3.2	6.5	13.6	23	33.3
3 ft (0.9 m)	2.8	5.9	12.4	21.4	32.5
6 ft (1.8 m)	2.8	5.2	10.9	19.6	29.2

A007735

Table H10

Bluegrass, 1% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3	5.8	11.3	19.8	29.9
2 ft (0.6 m)	4.2	7.3	12.2	19.7	30.8
3 ft (0.9 m)	4.2	7.1	11.6	18.7	27.6
6 ft (1.8 m)	4.8	8.2	12.9	19.1	26.9

Table H11

Bluegrass, 1% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.1	6.9	14.7	26	36.8
2 ft (0.6 m)	3	6.1	12.3	20.6	30.3
3 ft (0.9 m)	2.7	5.7	11.2	19	27.8
6 ft (1.8 m)	2.7	5.4	11.1	19	27.3

Table H12

Bluegrass, 1% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.1	6.4	12.8	21.1	30.4
2 ft (0.6 m)	3.2	6.6	13.3	23.2	35.6
3 ft (0.9 m)	3.3	6.6	14.1	24.2	37.3
6 ft (1.8 m)	2.7	5.3	10.4	18.4	26.7

Table H13

Bluegrass, 3% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.9	7.9	16.7	29.2	43.6
2 ft (0.6 m)	2.3	4.5	9.2	18.5	31.5
3 ft (0.9 m)	3.2	6.1	11.9	21.6	38.6
6 ft (1.8 m)	4.5	7.3	11.1	16.3	27.5

Table H14

Bluegrass, 3% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	2.7	5.7	13.3	22.4	31.8
2 ft (0.6 m)	3.5	8.1	18.4	32.6	50.2
3 ft (0.9 m)	2.8	5.6	11.8	19.8	28.8
6 ft (1.8 m)	2.3	4.3	9.4	18.5	29

A007736

Table H15

Bluegrass, 3% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.6	7.7	15.6	25	35
2 ft (0.6 m)	3.4	6.8	14.5	24.2	33.9
3 ft (0.9 m)	3.6	6.8	12.6	21.4	32.5
6 ft (1.8 m)	3.2	5.8	11.1	19.6	29.6

Table H16

Bluegrass, 5% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.2	7	15.6	27.8	38.3
2 ft (0.6 m)	3.7	7.4	14.3	24.4	37.7
3 ft (0.9 m)	4.2	7.2	12.5	21.4	34.5
6 ft (1.8 m)	4.7	8	13.2	21.8	38.2

Table H17

Bluegrass, 5% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.2	7	15	25	36.5
2 ft (0.6 m)	3.4	7.6	16.3	27.2	38.7
3 ft (0.9 m)	3.8	7.6	15.4	26.8	39.5
6 ft (1.8 m)	3.2	6.3	12.8	22.4	32.8

Table H18

Bluegrass, 5% slope, 20GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3	6.1	12.7	22.1	32.6
2 ft (0.6 m)	3.6	7	14.3	23.4	32.2
3 ft (0.9 m)	3.4	6.8	14.5	25.8	38.3
6 ft (1.8 m)	3.3	6	10.2	17.2	23.3

Table H19

Zoysia, 1% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.5	7.6	16.6	27.3	38.3
2 ft (0.6 m)	3.4	6.1	11.1	18.8	28.5
3 ft (0.9 m)	3.9	6.9	12.5	20.9	39
6 ft (1.8 m)	4.1	6.8	11.9	18.6	29.9

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Table H20

Zoysia, 1% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.5	7.6	16.9	29.4	41.8
2 ft (0.6 m)	2.7	5.4	10.9	19	28.2
3 ft (0.9 m)	3.1	5.6	9.9	16.4	24.2
6 ft (1.8 m)	3.6	7.9	16.3	27.3	37.5

Table H21

Zoysia, 1% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.6	7.9	16.3	27.3	37.5
2 ft (0.6 m)	2.7	5.5	11.8	22.1	33.6
3 ft (0.9 m)	2.7	5.4	11.4	19.3	28.2
6 ft (1.8 m)	3.1	5.7	11.2	19.2	30.5

Table H22

Zoysia, 3% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	4.2	8.1	15.8	27.9	61.1
2 ft (0.6 m)	4.4	7.3	12.3	28.3	65.8
3 ft (0.9 m)	4	7.5	14.4	31.7	98.3
6 ft (1.8 m)	5.5	9	15.1	25.8	61.5

Table H23

Zoysia, 3% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.4	7.7	16.5	27.3	37.3
2 ft (0.6 m)	3.3	6.6	12.9	21.6	31.9
3 ft (0.9 m)	2.8	5.5	11.1	18.6	27
6 ft (1.8 m)	2.7	4.8	9.1	15.4	23.4

Table H24

Zoysia, 3% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.4	7.7	16.8	28.5	43.3
2 ft (0.6 m)	3.3	6.9	14	23.8	33.9
3 ft (0.9 m)	3.1	6.2	12.7	22	30.9
6 ft (1.8 m)	2.9	5.4	10.3	17.8	26.8

A007738

Table H25

Zoysia, 5% slope, 10 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	2.5	5.9	12.7	22.4	37.9
2 ft (0.6 m)	2.2	3.9	12.2	26.7	58.3
3 ft (0.9 m)	6.8	11.5	20.8	50.4	91.8
6 ft (1.8 m)	3.5	6.9	13.5	27.5	147.4

Table H26

Zoysia, 5% slope, 15 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.2	6.9	15.3	25.5	35.5
2 ft (0.6 m)	3.6	7.4	14.7	23.7	32.1
3 ft (0.9 m)	3.3	6.6	13.2	22.8	33
6 ft (1.8 m)	3.2	5.8	10.8	17.3	26.8

Table H27

Zoysia, 5% slope, 20 GPM

	10%	25%	50%	75%	90%
0 ft (0 m)	3.4	8.4	18.4	32.6	43.1
2 ft (0.6 m)	3.5	8	17.2	27.6	39.2
3 ft (0.9 m)	3.2	6.3	12.6	21.6	30.6
6 ft (1.8 m)	2.8	5.2	10.1	17.9	28.1

A007739

Appendix I: Second Experiments – Particle Size Distributions for each Experimental Condition

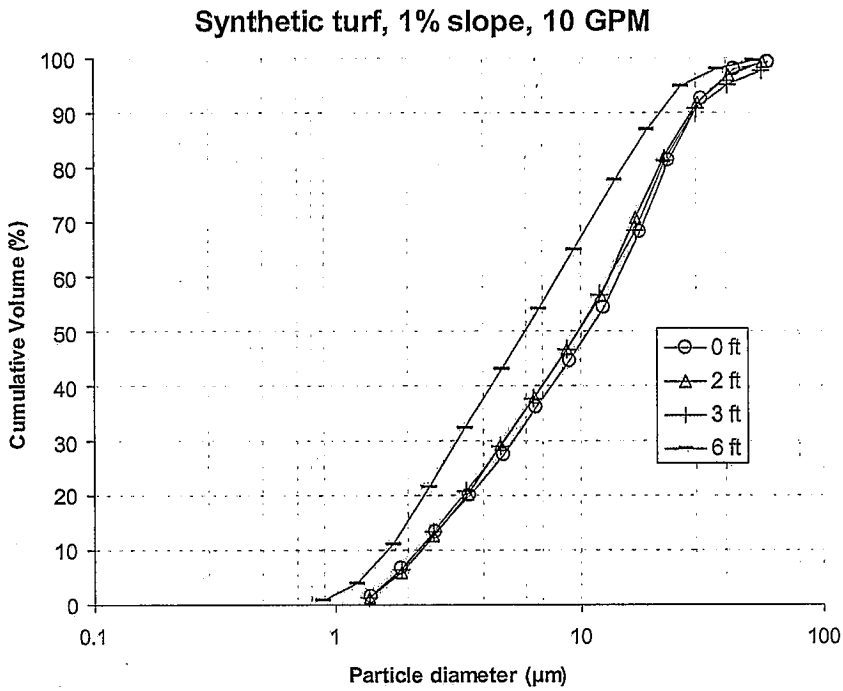


Figure I1

A007740

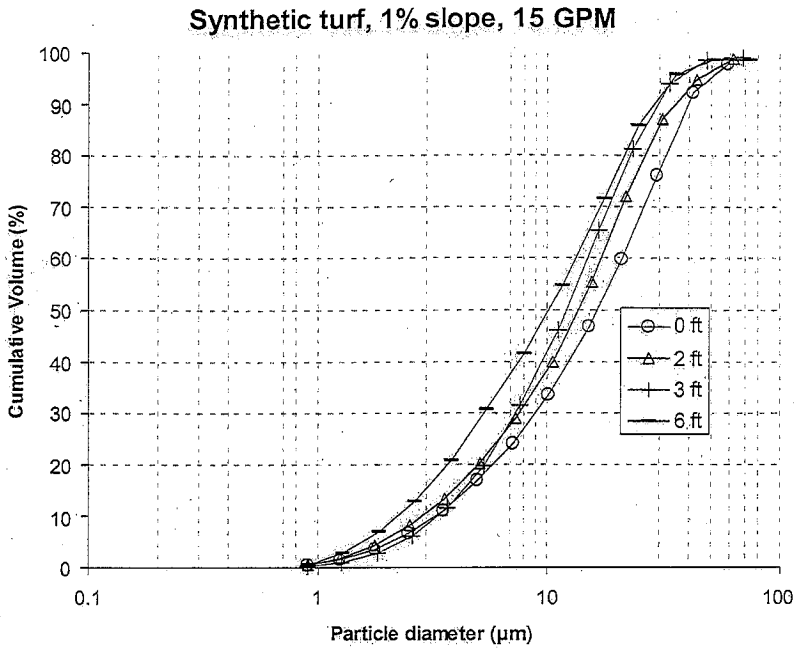


Figure I2

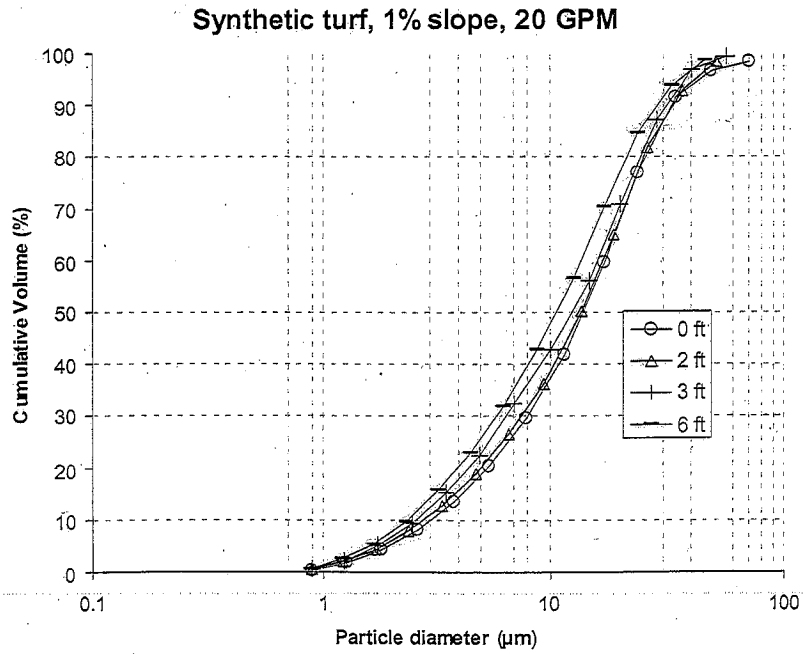


Fig.I3

A007741

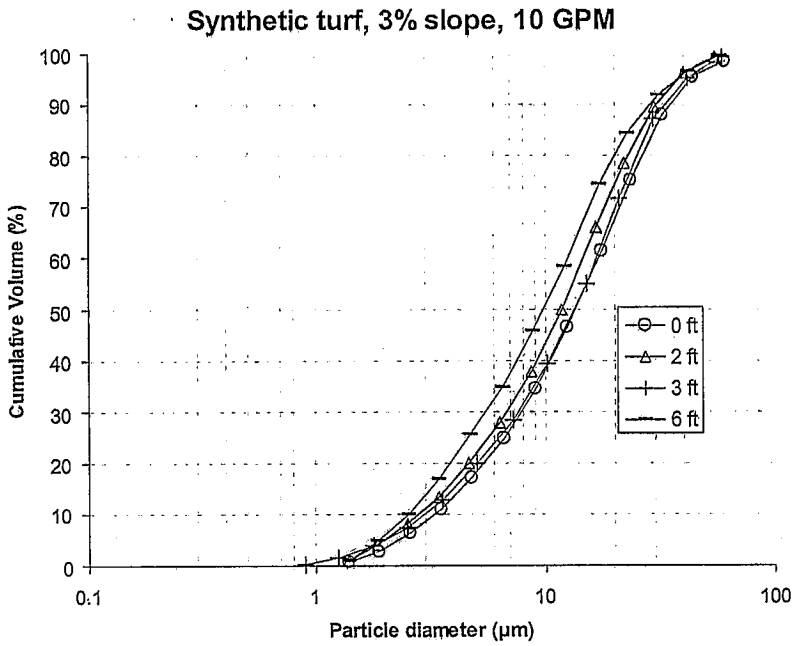


Figure I4

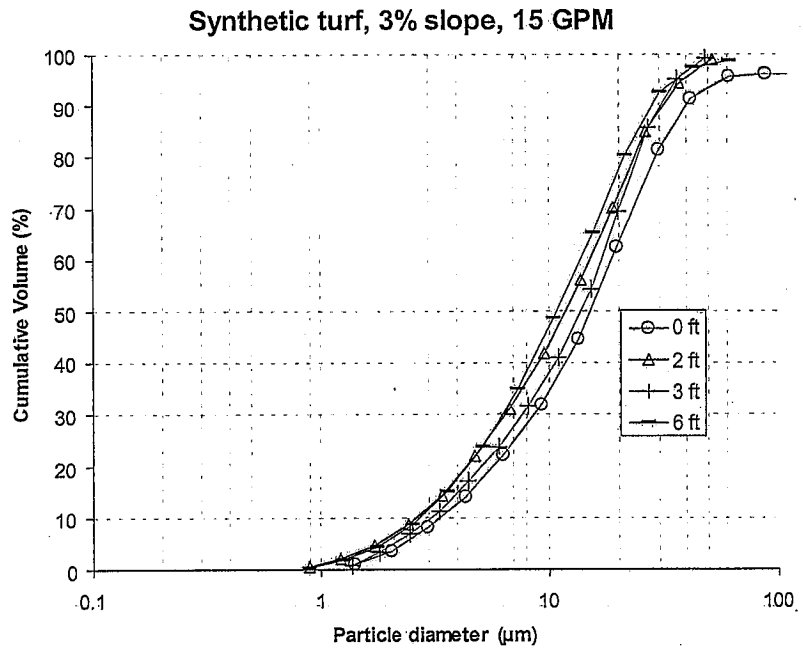
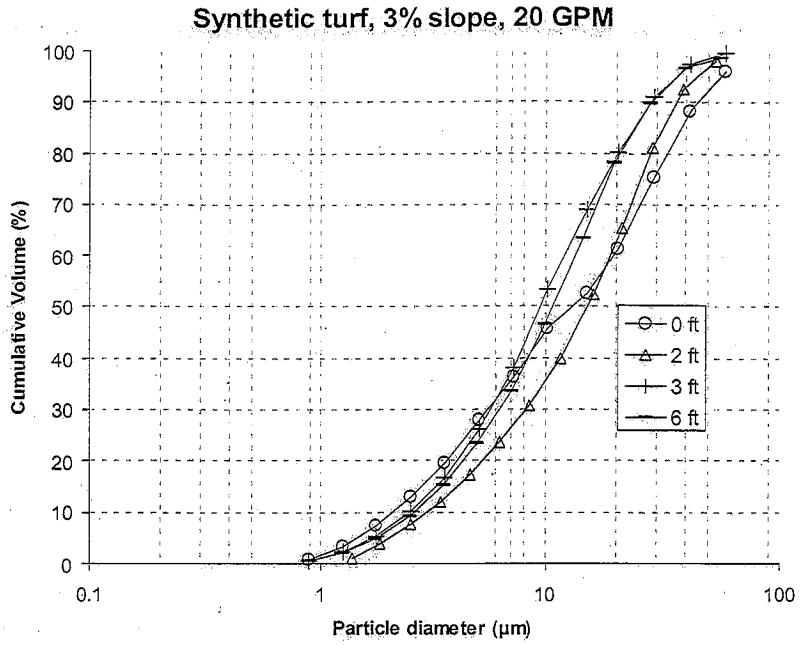


Figure I5

A007742



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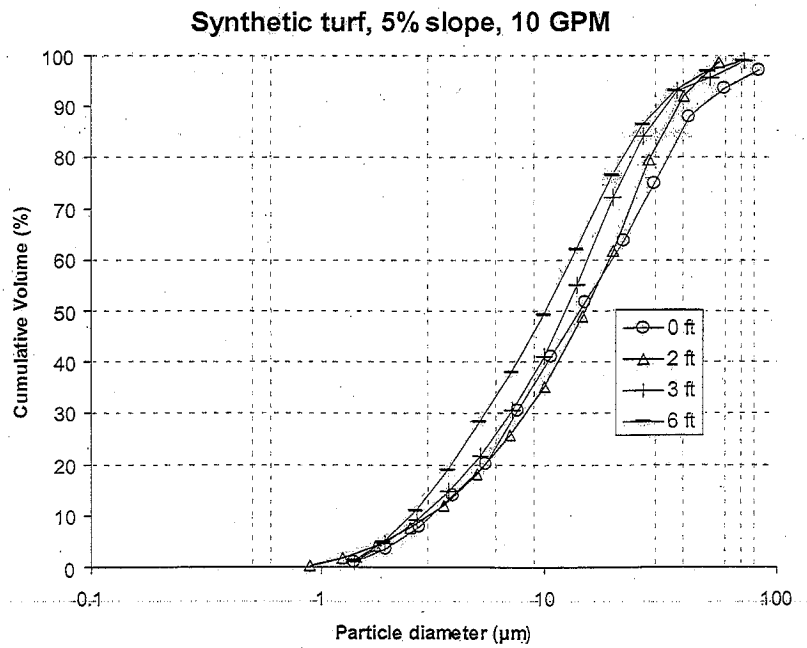
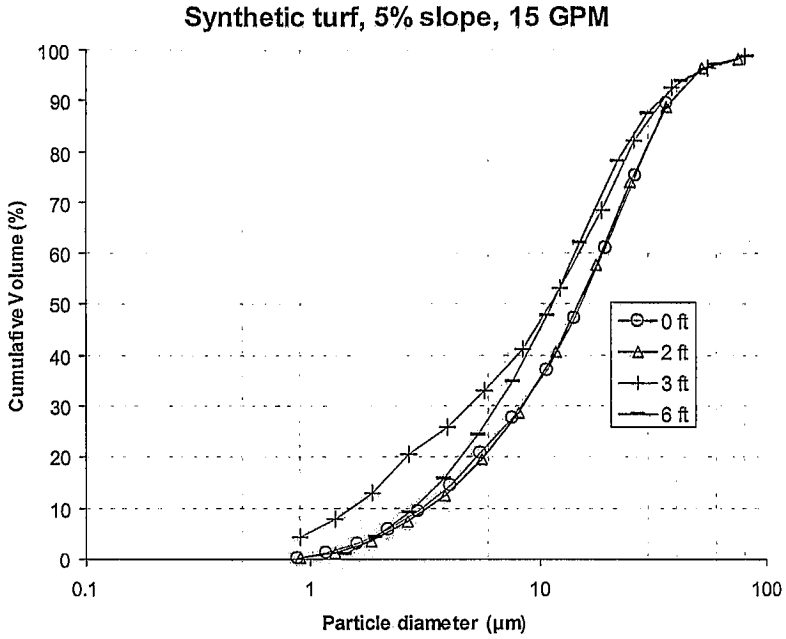


Figure I7

A007743



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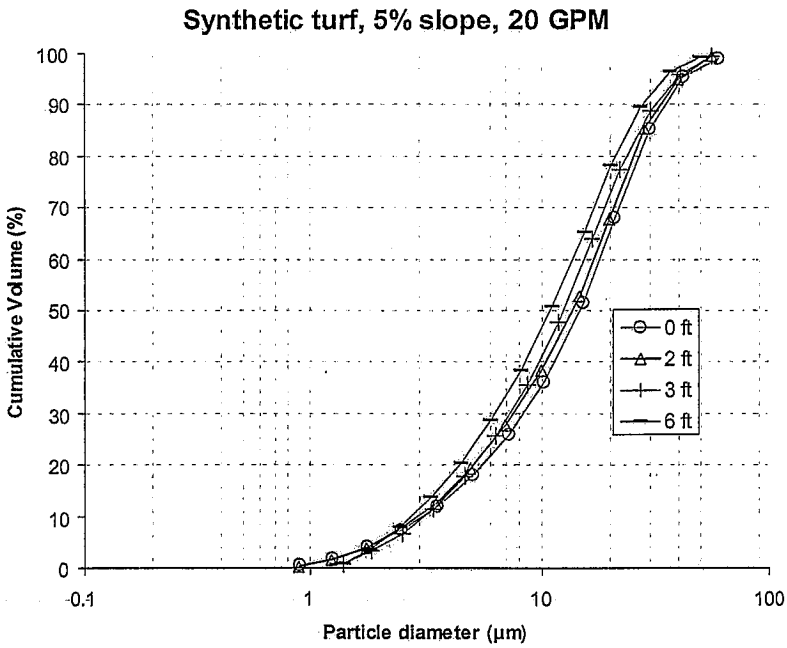


Figure I9

A0077414

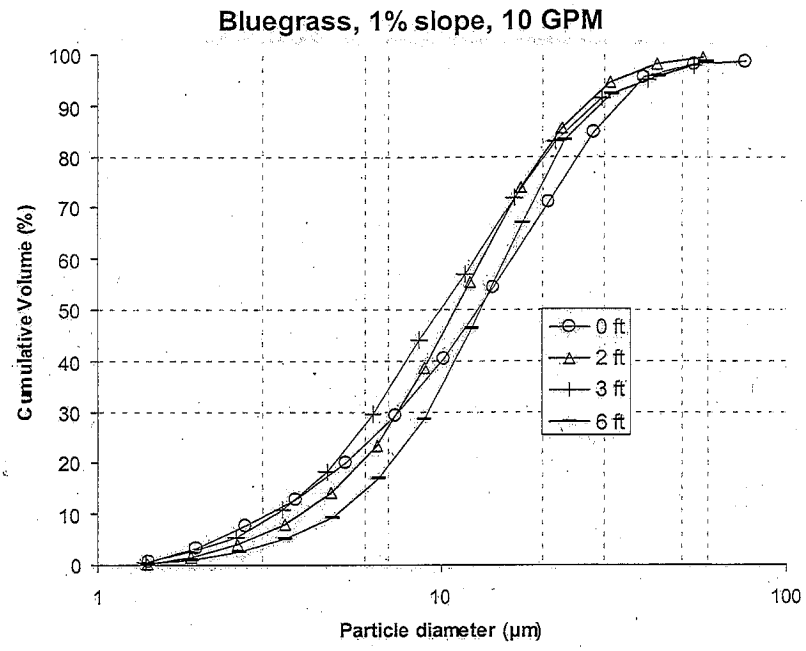


Figure I10

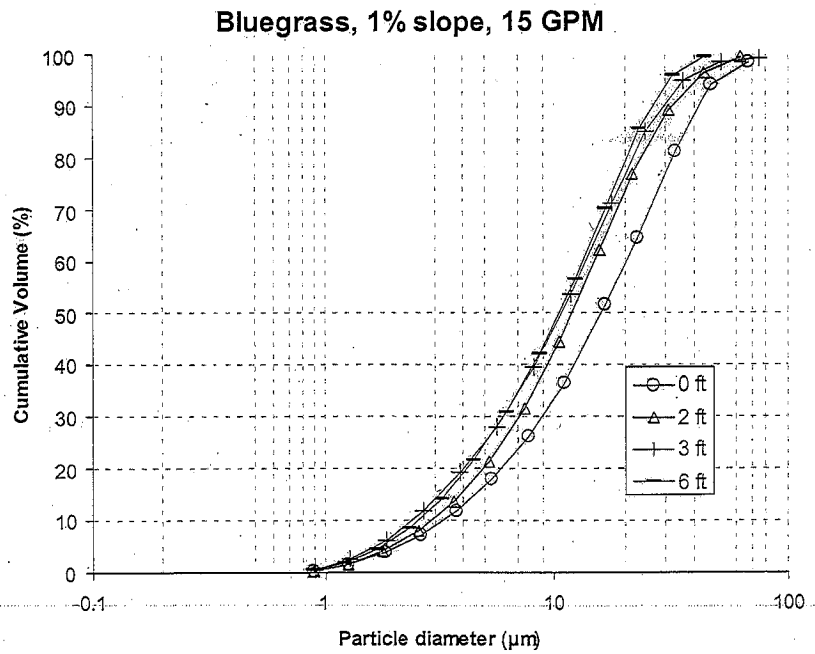


Figure I11

A007745

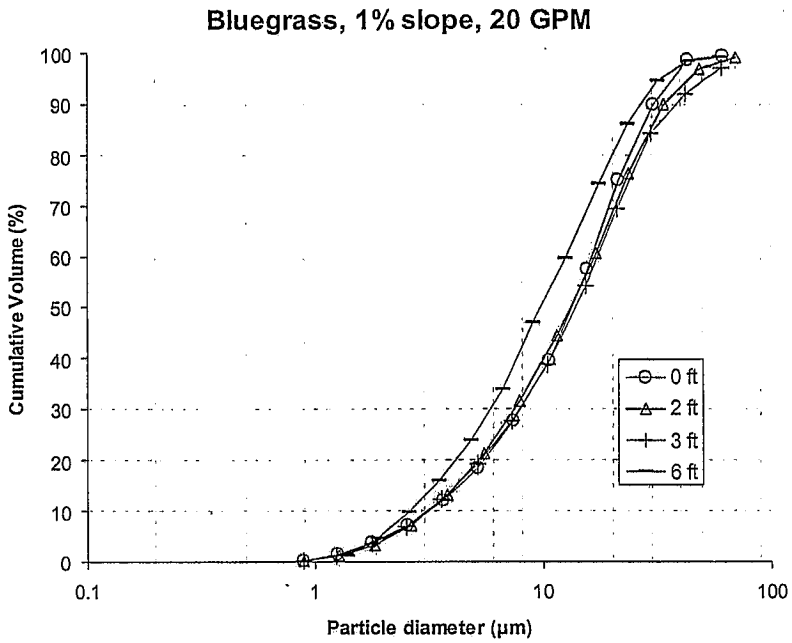


Figure I12

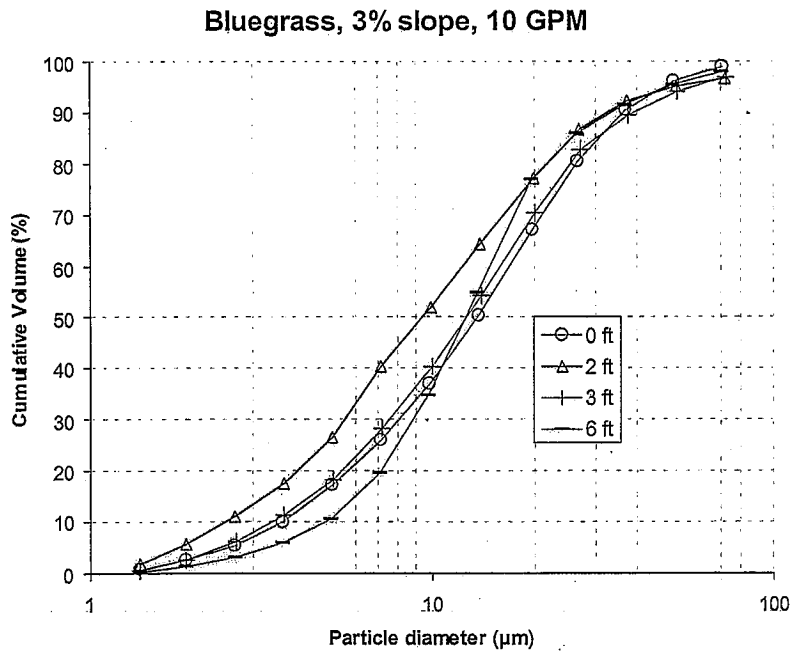


Figure I13

A007746

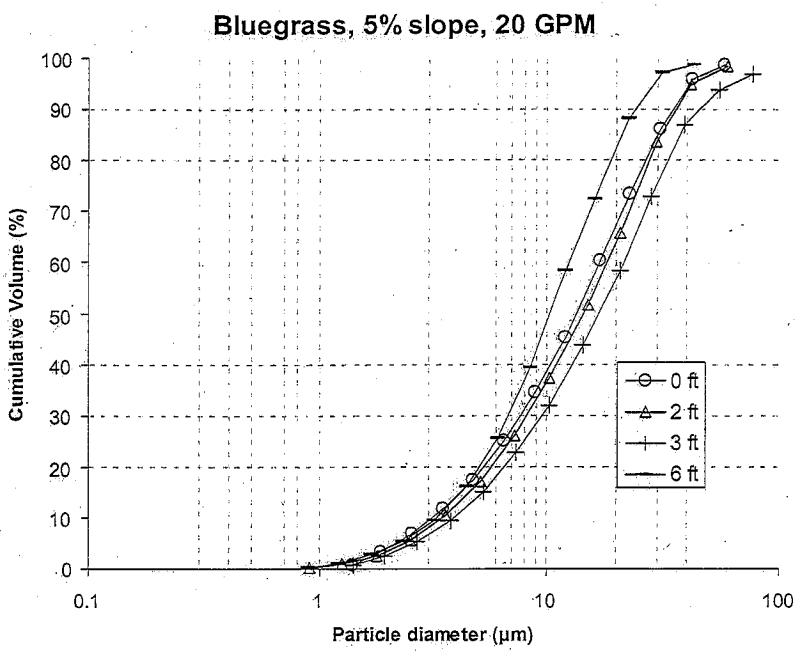


Figure I14

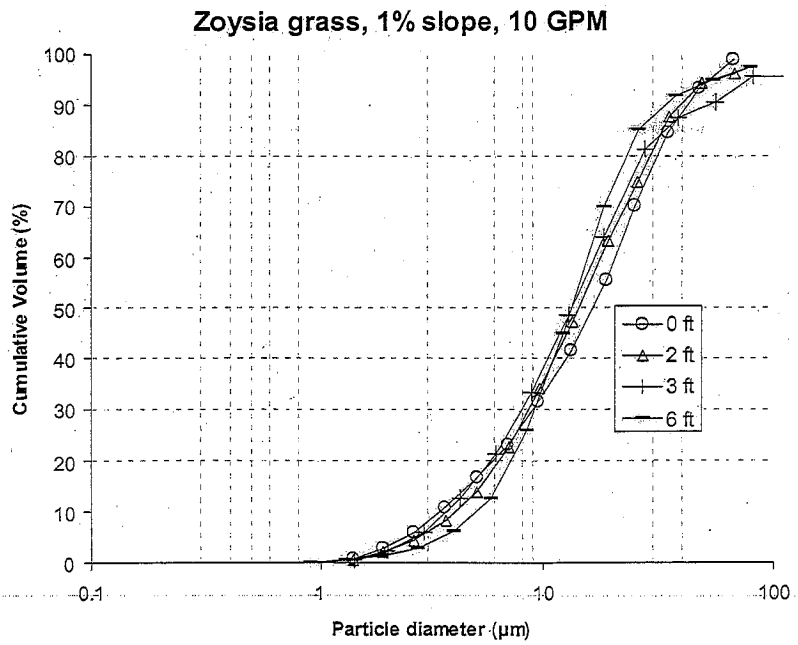


Figure I15

A007747

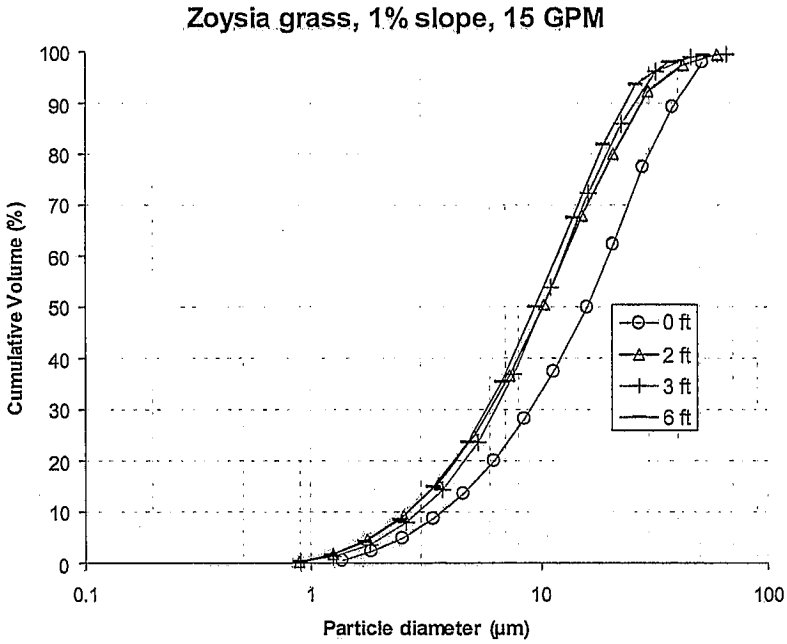


Figure I16

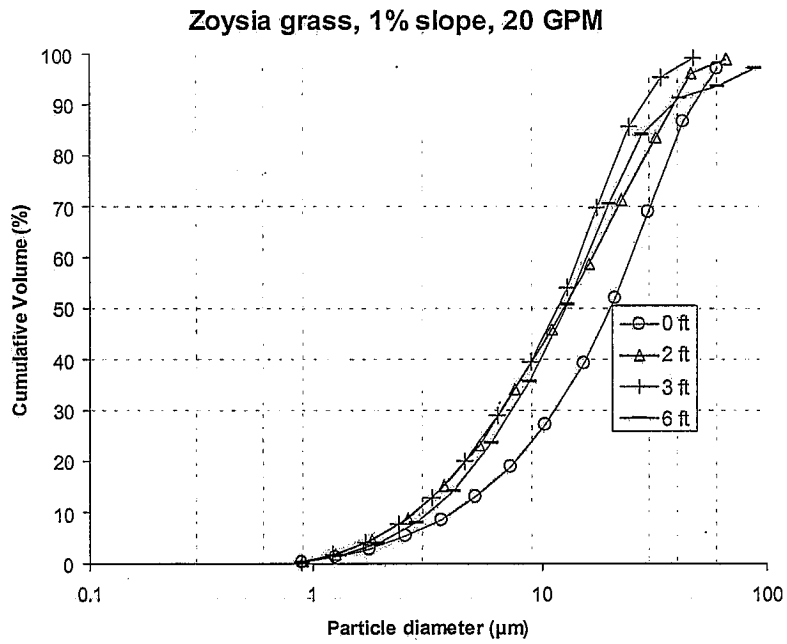


Figure I17

A007748

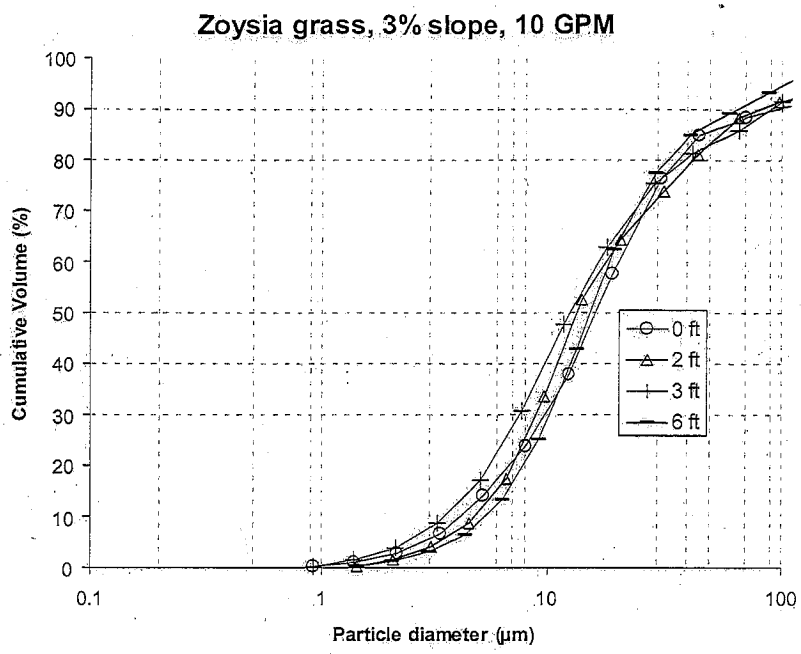


Figure I18

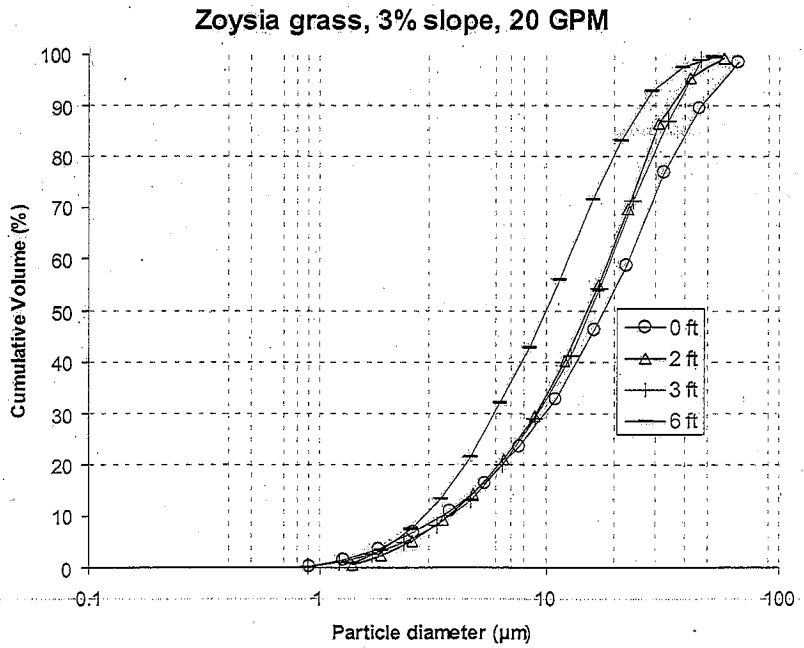


Figure I19

A007749

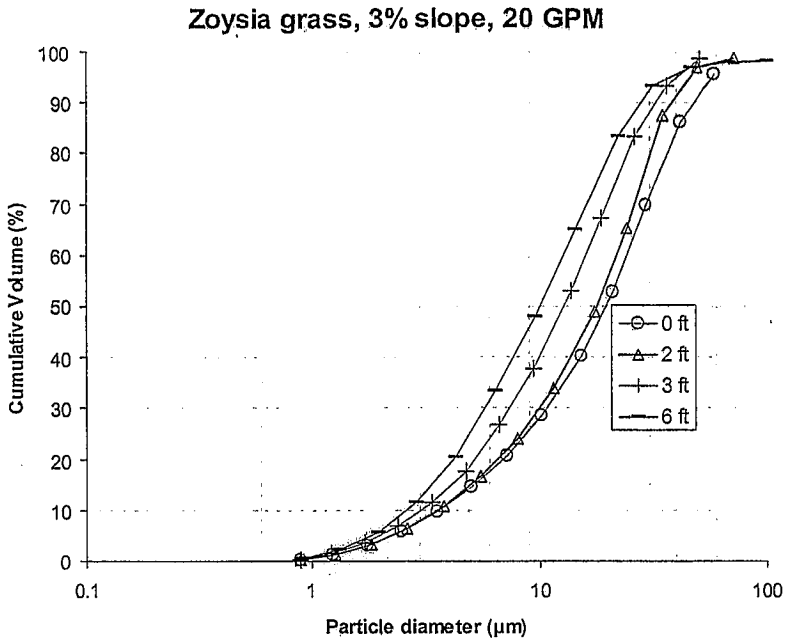


Figure I20

A007750

Appendix J: Second Experiments – Performance of USGS/Dekaport Cone Sample Splitter (Rickly Hydrological Company)

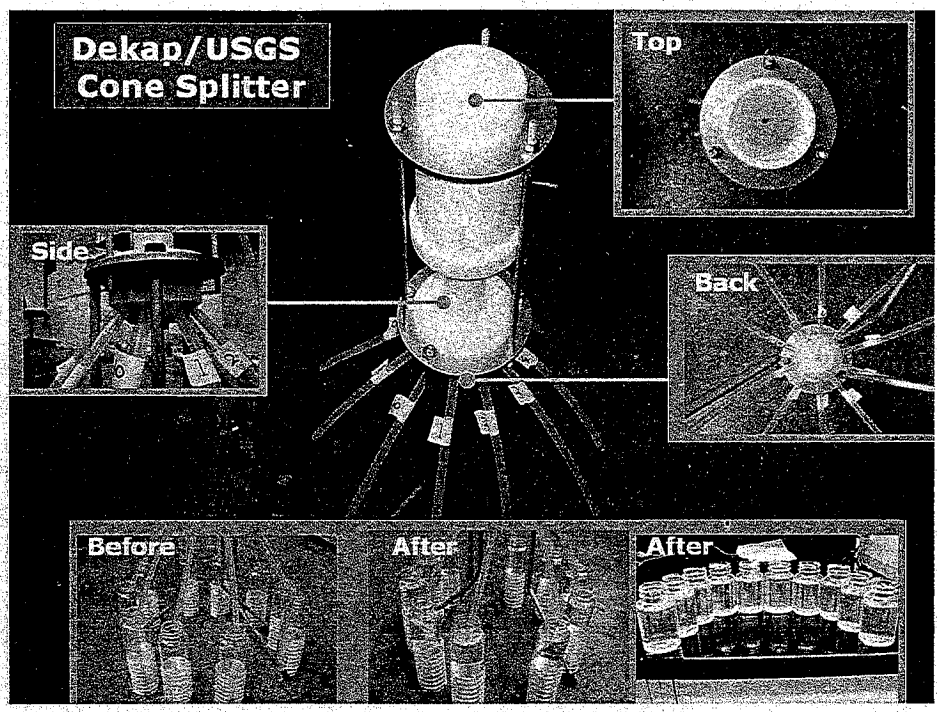


Figure J1

The USGS (US Geological Survey)/Dekaport Cone Sample Splitter is a device that divides a water sample into ten identical sub-samples. It was utilized in the second experiments and outdoor observations for analyzing the six different analytical parameters and for producing duplicates. To ensure identical sediment characteristics of the sub-samples, the performance of the sample splitter was tested by using the same mix of the test sediments that were used in the second experiments. In addition to the mix of the test sediments, SIL-CO-SIL®250 and Sieved Sand (90 to 250 μm) were also tested separately to compare the variability of the three different sediment constituents. Two separate runs were conducted for each sediment mixture.

Known amounts of the sediments were measured (approximately 0.5 g) and mixed with one litter of water so that sediment concentration would be approximately 500 mg/L. Then, the test solution was poured into the top of the USGS/Dekaport Cone Sample Splitter to produce ten identical sub-samples. Total solids analyses were conducted on all of the sub-samples for the three sediment constituents.

The following tables show the sediment constituents and amounts of the sediments used for testing the performance of the sample splitter.

A007751

Table J1. Sediment Constituent: Mixture of Sediments

Sediments	Contribution	First run (g)	Second run (g)
SIL-CO-SIL®106	15%	0.0752	0.0752
SIL-CO-SIL®250	50%	0.2408	0.2408
Sieved Sand (90 to250 μm)	25%	0.1225	0.1225
Sieved Sand (300 to 425μm)	10%	0.0532	0.0532
Total	*100%*	*0.4917*	*0.4917*

Table J2. Sediment Constituent: SIL-CO-SIL®250

	First run	Second run
SIL-CO-SIL®250	0.5004 (g)	0.5002 (g)

Table J3. Sediment Constituent: Sieved Sand (90 to 250 μm)

	First run	Second run
Sieved Sand (90 to 250 μm)	0.5003 (g)	0.5006 (g)

The test results shown below shows that the averaged total solids concentration for each sediment constituent was approximately 560 mg/L due to the presence of dissolved solids in the tap water adding additional solids to the mixture.

As result, we found that the USGS/Dekaport Cone Sample Splitter was very efficient in splitting a sample equally into sub-samples. Very little variability was determined between the sub-samples for both sample volumes and sediments. The coefficient of variations (COV) of all the sub-sample sets for the three different sediment constituents were found to be below 0.10 which shows that the sediment concentrations between the different sub-samples were very similar. Although COVs for the three sediment constituents were found to be quite small, it was determined that larger particles had slightly greater variability than smaller particles when comparing the COVs of SIL-CO-SIL®250 and sieved Sand (90 to 250 μm). The following tables and graphs show the performance of the USGS/Dekaport Cone Sample Splitter for the different sediment constituents and for volume.

A007752

Table J4 Test Results: SIL-CO-SIL®250

Tube ID	First run Total solids (mg/L)	Second run Total solids (mg/L)	*Avg.*	*Std. Dev*	*COV*
1	573.1	563.2	*568.1*	*7.0*	*0.012*
2	556.0	559.8	*557.9*	*2.7*	*0.005*
3	563.7	547.6	*555.6*	*11.4*	*0.021*
4	553.5	558.8	*556.1*	*3.8*	*0.007*
5	558.2	560.6	*559.4*	*1.7*	*0.003*
6	564.3	565.3	*564.8*	*0.7*	*0.001*
7	577.4	523.1	*550.2*	*38.4*	*0.070*
8	565.3	571.9	*568.6*	*4.7*	*0.008*
9	563.6	559.0	*561.3*	*3.3*	*0.006*
10	574.5	570.4	*572.4*	*2.9*	*0.005*
Avg.	*564.95*	*557.96*			
Std. Dev	*7.98*	*14.01*			
COV	*0.014*	*0.025*			

Table J5 Test Results: Mix Sediments

Tube ID	First run Total solids (mg/L)	Second run Total solids (mg/L)	*Avg.*	*Std. Dev*	*COV*
1	547.4	561.9	*554.6*	*10.2*	*0.018*
2	549.5	572.6	*561.1*	*16.4*	*0.029*
3	560.6	556.0	*558.3*	*3.2*	*0.006*
4	550.0	561.5	*555.8*	*8.2*	*0.015*
5	565.0	552.0	*558.5*	*9.2*	*0.016*
6	576.2	563.4	*569.8*	*9.1*	*0.016*
7	573.8	572.9	*573.4*	*0.7*	*0.001*
8	556.8	587.5	*572.2*	*21.7*	*0.038*
9	560.0	561.0	*560.5*	*0.7*	*0.001*
10	563.3	572.4	*567.9*	*6.5*	*0.011*
Avg.	*560.26*	*566.12*			
Std. Dev	*9.83*	*10.33*			
COV	*0.018*	*0.018*			

A007753

Table J6 Test Results: Sieved Sand (90 to 250 μm)

Tube ID	First run Total solids (mg/L)	Second run Total solids (mg/L)	*Avg.*	*Std. Dev*	*COV*
1	573.7	554.7	*564.2*	*13.4*	*0.024*
2	578.4	536.9	*557.7*	*29.4*	*0.053*
3	558.8	575.7	*567.3*	*12.0*	*0.021*
4	565.0	565.0	*565.0*	*0.0*	*0*
5	586.7	576.5	*581.6*	*7.2*	*0.012*
6	598.0	627.6	*612.8*	*20.9*	*0.034*
7	587.9	602.8	*595.3*	*10.6*	*0.018*
8	576.3	592.7	*584.5*	*11.6*	*0.02*
9	581.0	563.0	*572.0*	*12.7*	*0.022*
10	569.7	537.4	*553.5*	*22.9*	*0.041*
Avg.	*577.55*	*573.24*			
Std. Dev	*11.58*	*28.57*			
COV	*0.02*	*0.05*			

Table J7 Volumetric Test

Tube ID	First run (mL)	Second run (mL)	Third run (mL)	Fourth run (mL)	Fifth run (mL)	Sixth run (mL)	*Avg.*	*Std.Dev*	*COV*
1	97	97	97	97	97	97	*97.0*	*0*	*0*
2	95	95	96	96	95	95	*95.3*	*0.52*	*0.005*
3	109	109	108	108	109	109	*108.7*	*0.52*	*0.005*
4	104	103	103	103	104	104	*103.5*	*0.55*	*0.005*
5	101	99	100	99	100	100	*99.8*	*0.75*	*0.008*
6	101	99	99	100	101	101	*100.2*	*0.98*	*0.010*
7	107	107	107	108	107	107	*107.2*	*0.41*	*0.004*
8	97	95	96	94	95	96	*95.5*	*1.05*	*0.011*
9	101	100	100	101	100	100	*100.3*	*0.52*	*0.005*
10	99	98	97	98	98	98	*98.0*	*0.63*	*0.006*
Avg.	*101.1*	*100.2*	*100.3*	*100.4*	*100.6*	*100.7*			
Std.Dev	*4.48*	*4.76*	*4.37*	*4.74*	*4.79*	*4.67*			
COV	*0.04*	*0.05*	*0.04*	*0.05*	*0.05*	*0.05*			

A007754

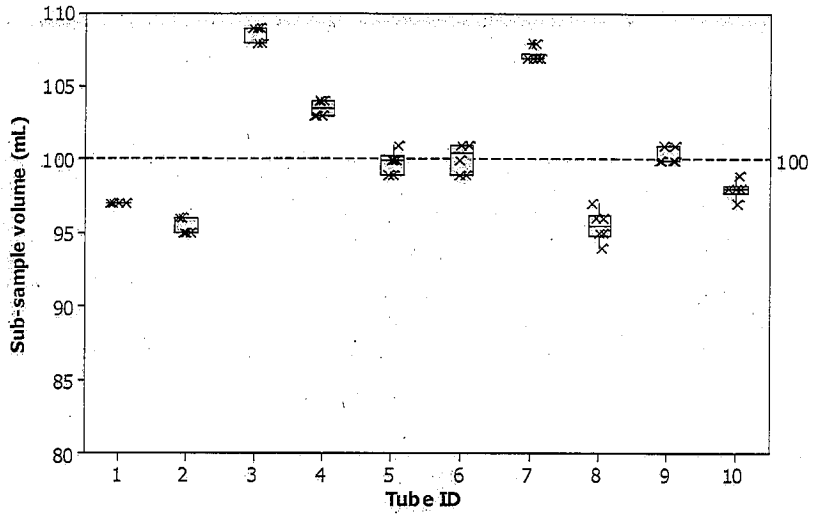


Figure J2 Box and whisker plot showing the volumes of the sub-samples

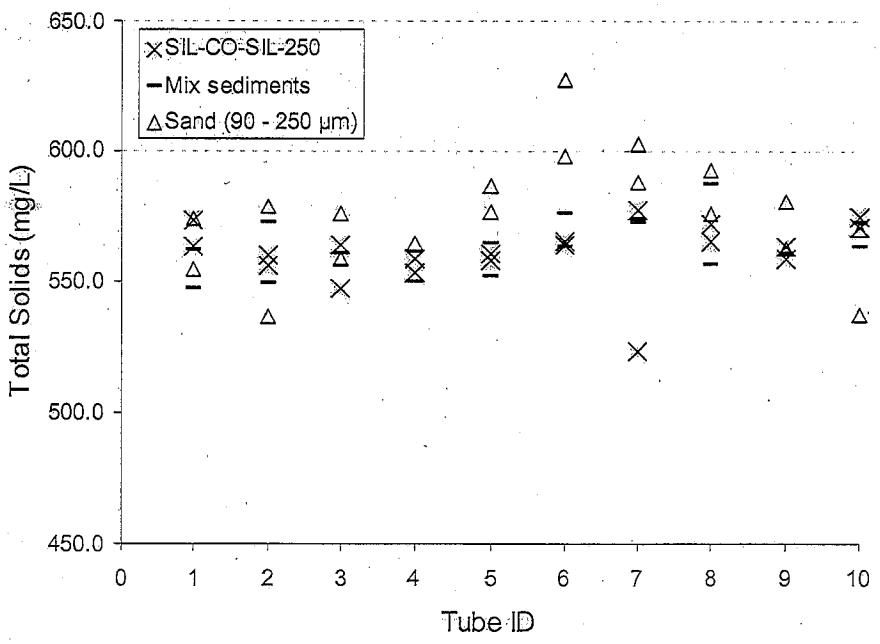


Figure J3 Scatter plot showing sediment concentrations of the sub-samples for each sediment constituent

A007755

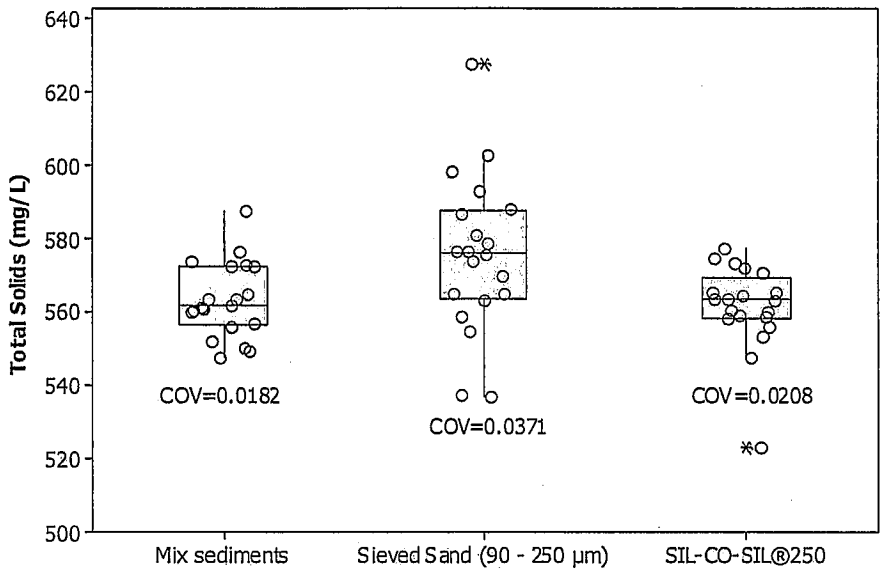


Figure J4. Box and whisker plots of total solids content of the subsamples of the different sediment test mixtures.

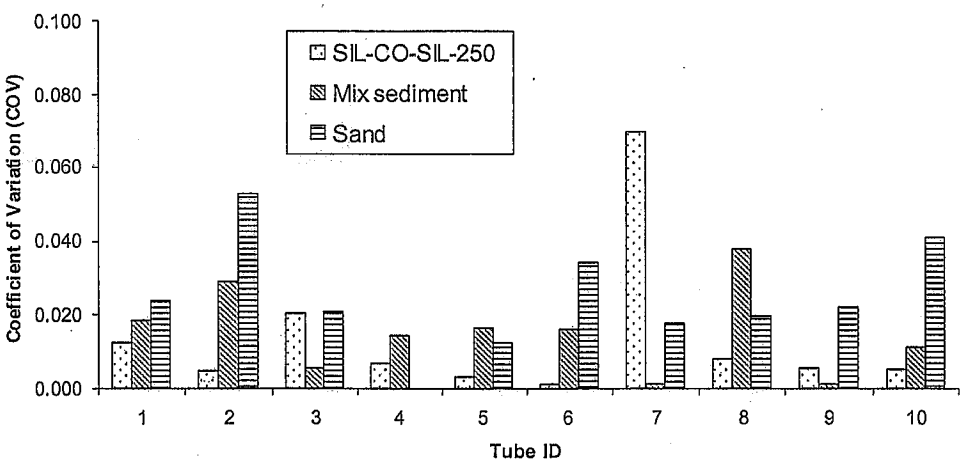


Figure J5. Bar chart of COVs obtained from the three different sediment test mixtures.

A007756

Appendix K: Outdoor Swale - Rain Information of Monitored Storm Events

The rainfall data shown in this appendix was obtained from a weather station located 1.5 mile (2.4 km) away from the outdoor swale test site, at the University of Alabama campus.

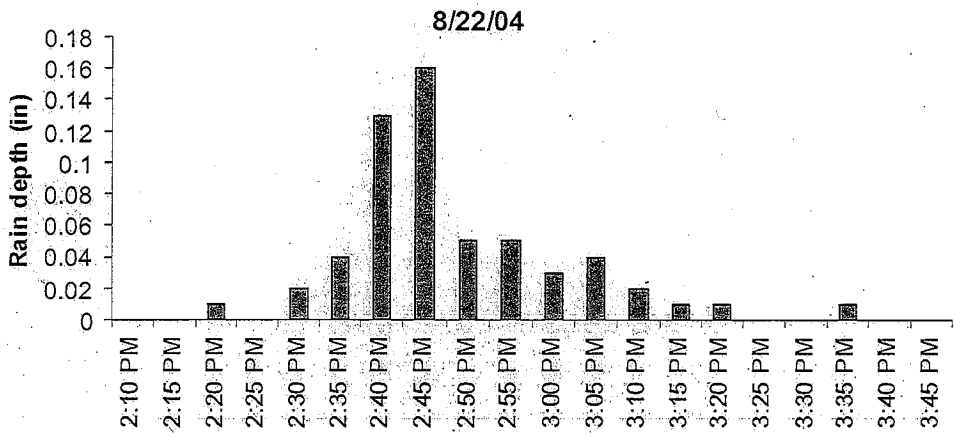


Figure K1

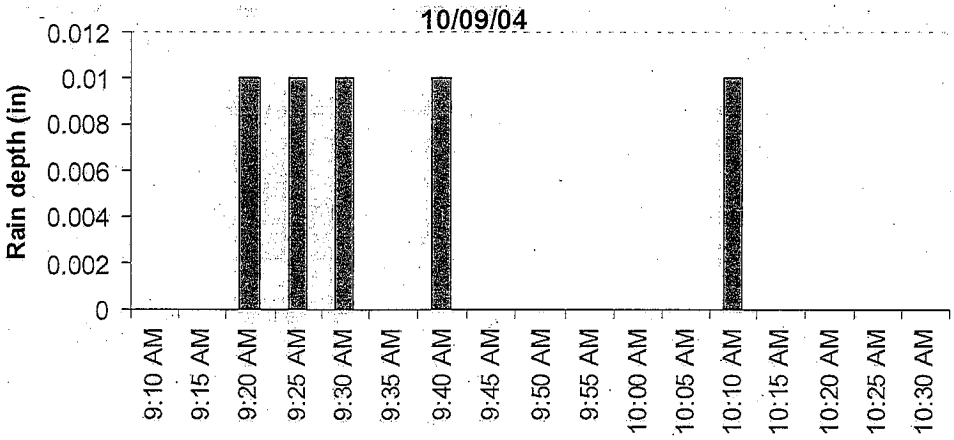
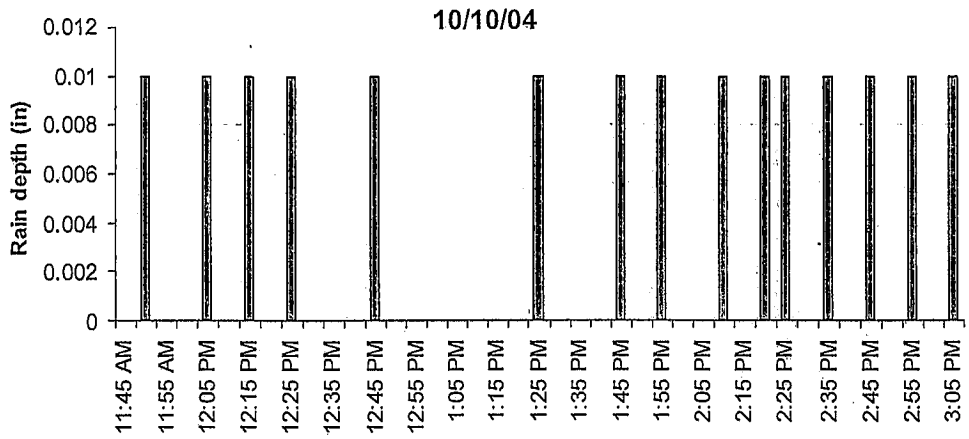


Figure K2

A007757



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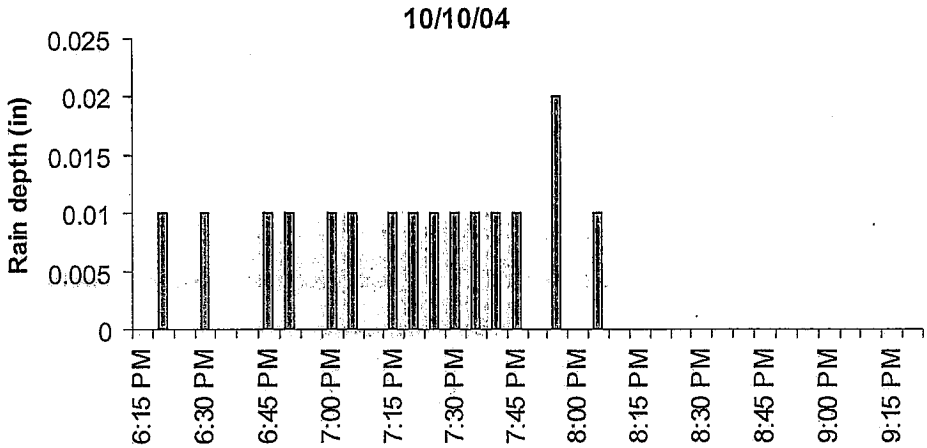


Figure K4

A007758

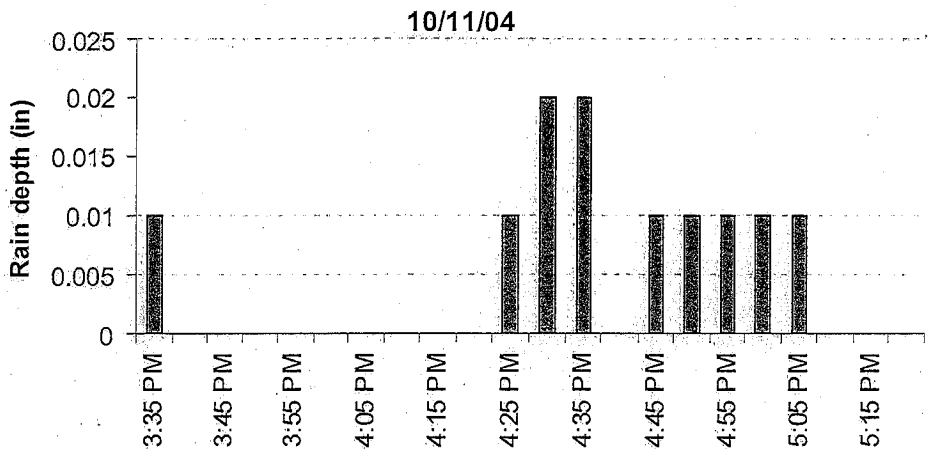


Figure K5

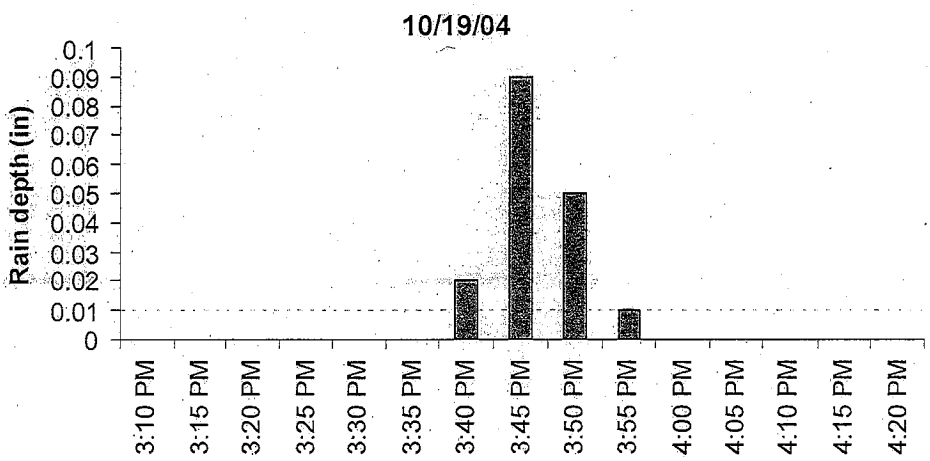


Figure K6

A007759

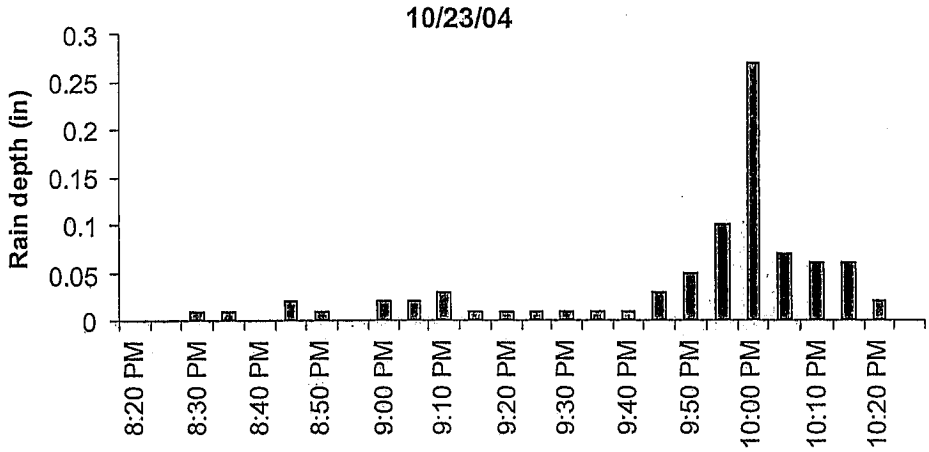
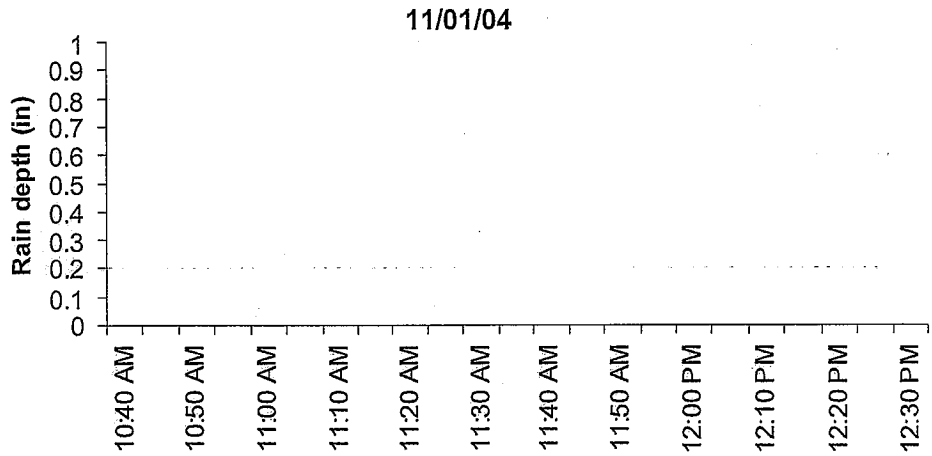


Fig.K7



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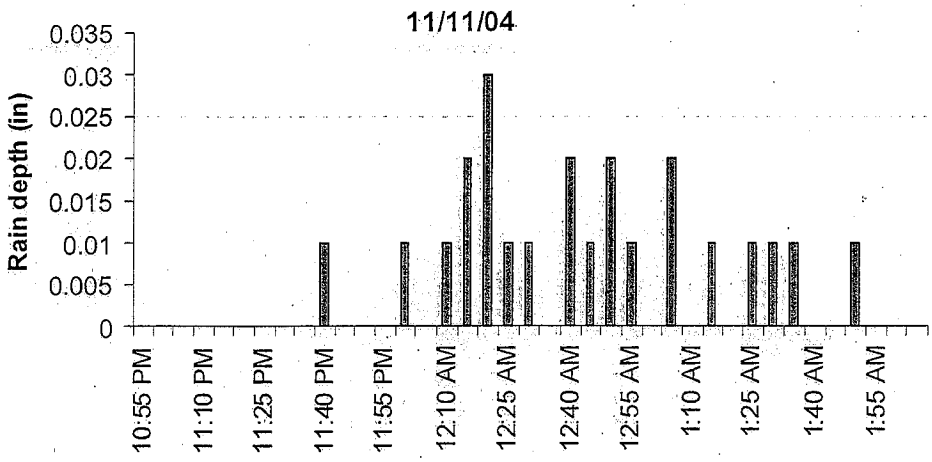
A007760



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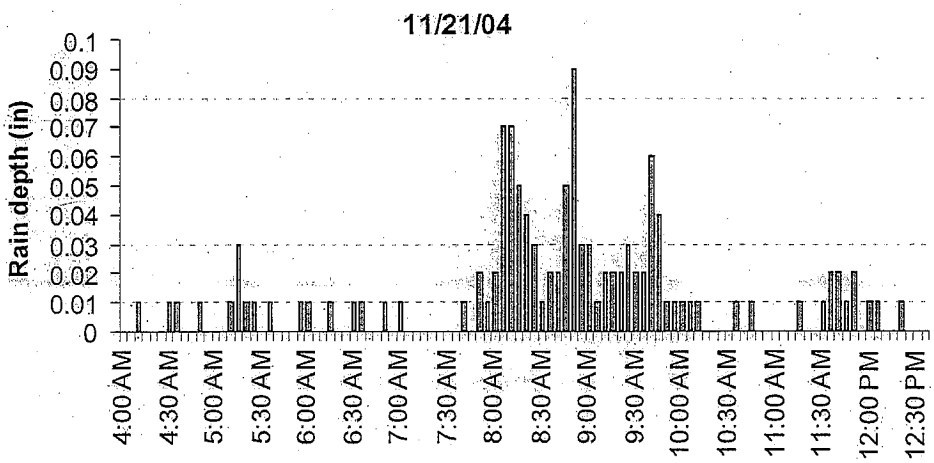


Figure K10

A007761

11/22/04

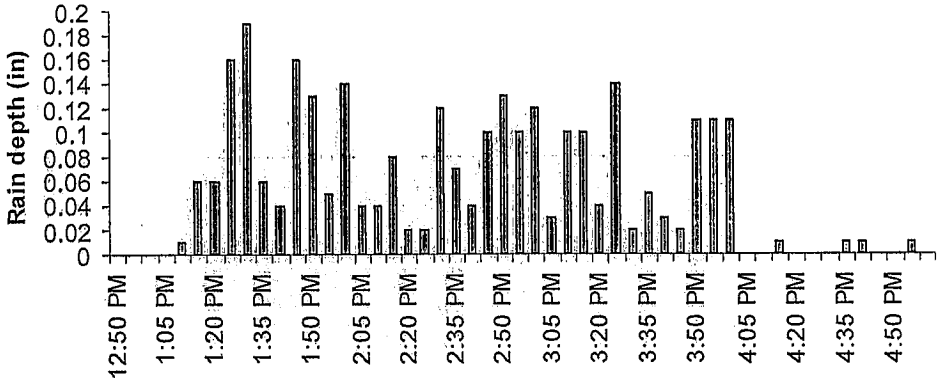
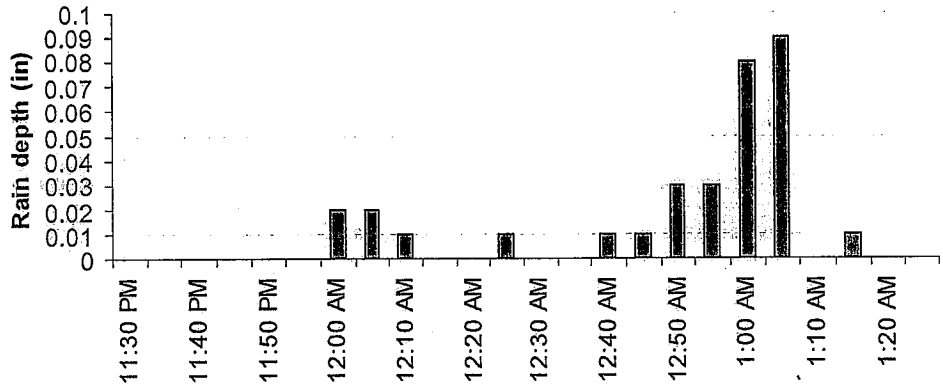


Figure K11

12/06/04



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A007762

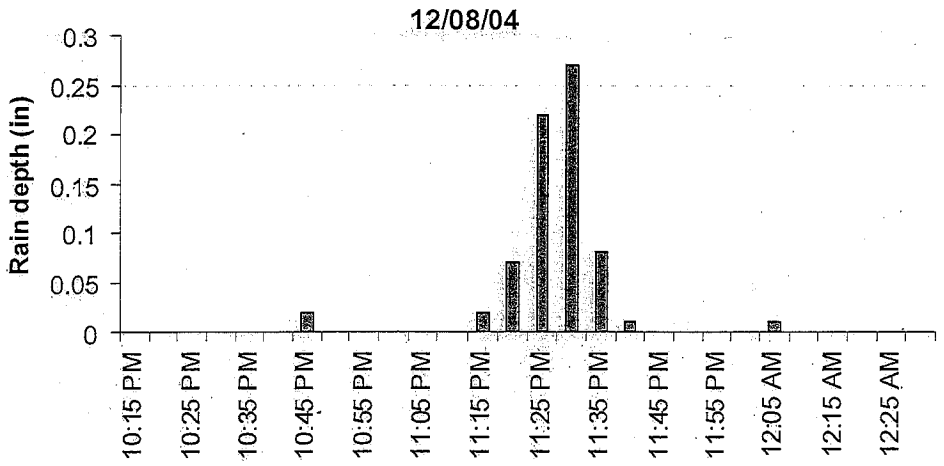
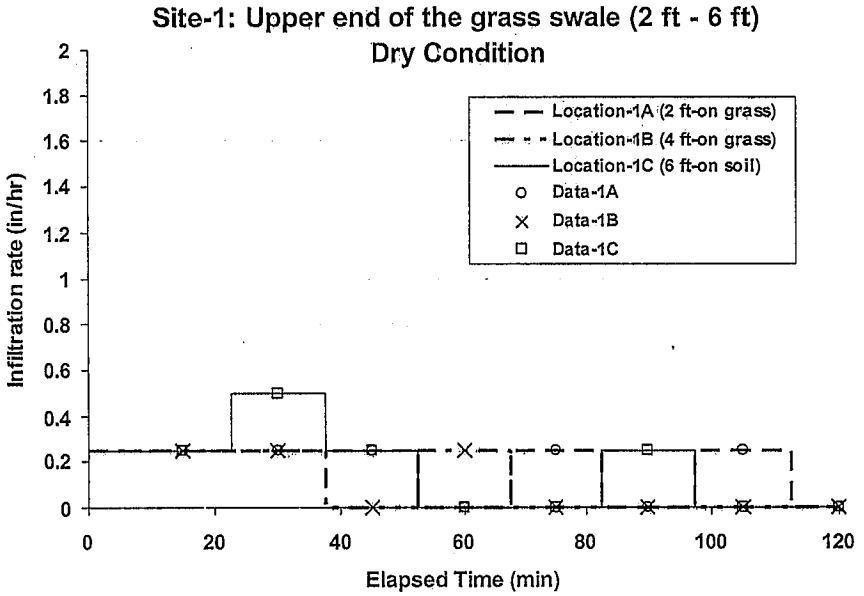


Figure K13

A007763

Appendix L: Infiltration Rates of Soils at the Outdoor Grass Swale Site



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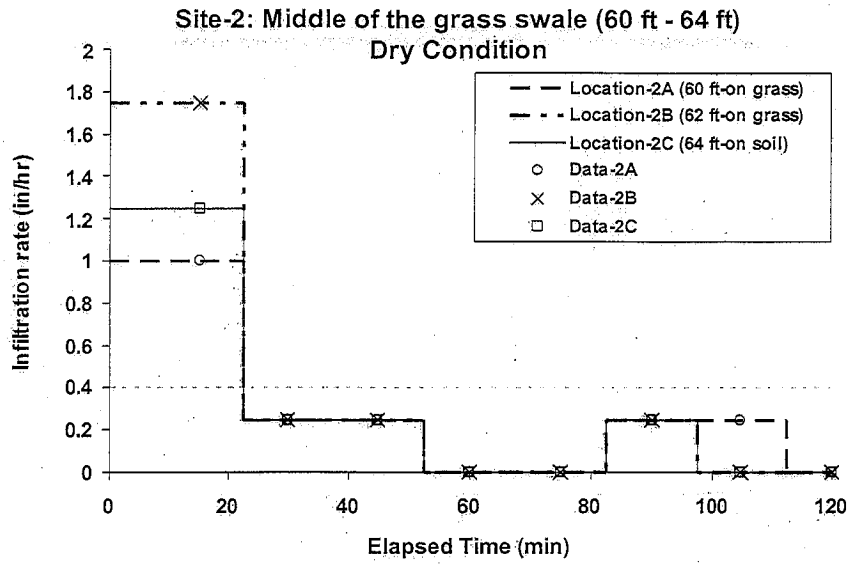
A007764



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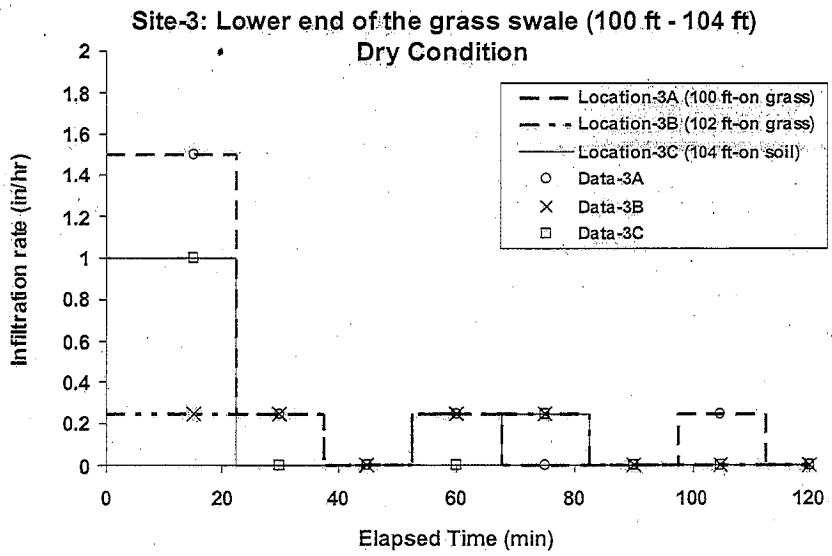

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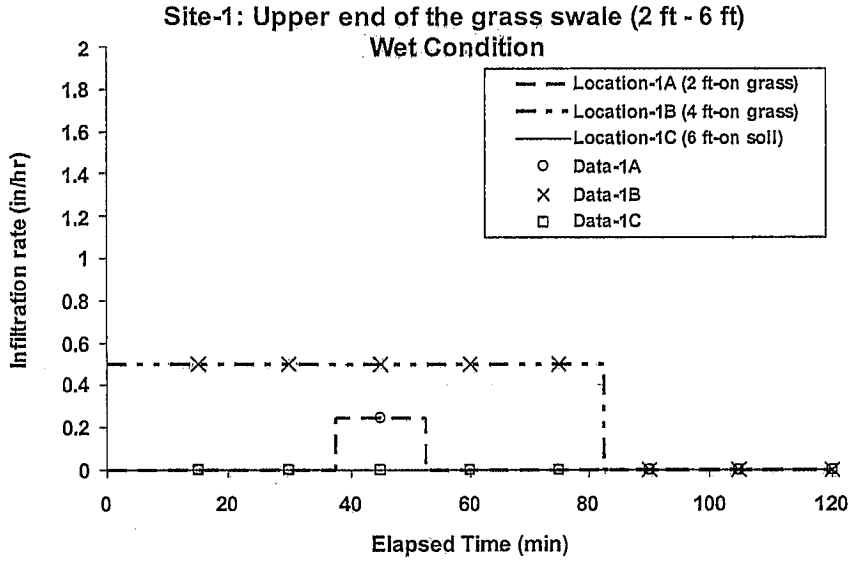
A007765



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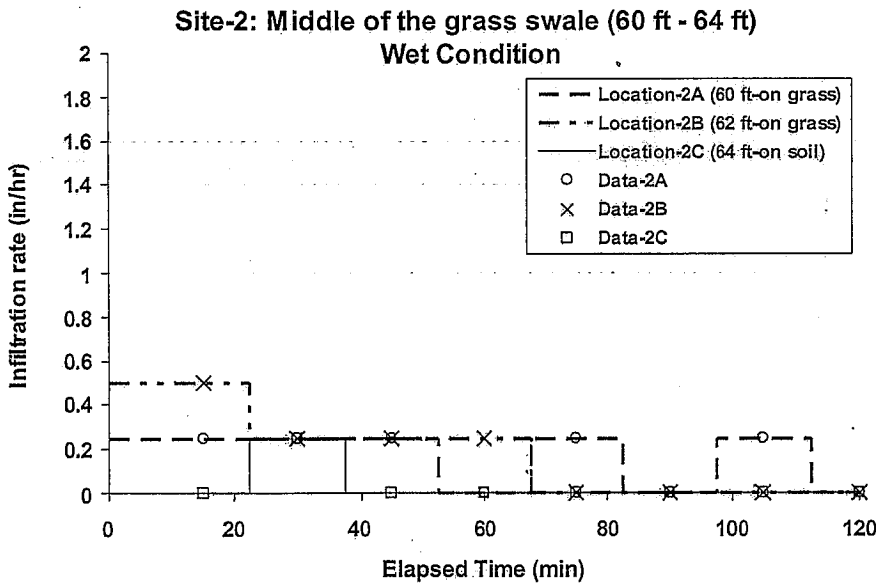


Figure L5

A007766

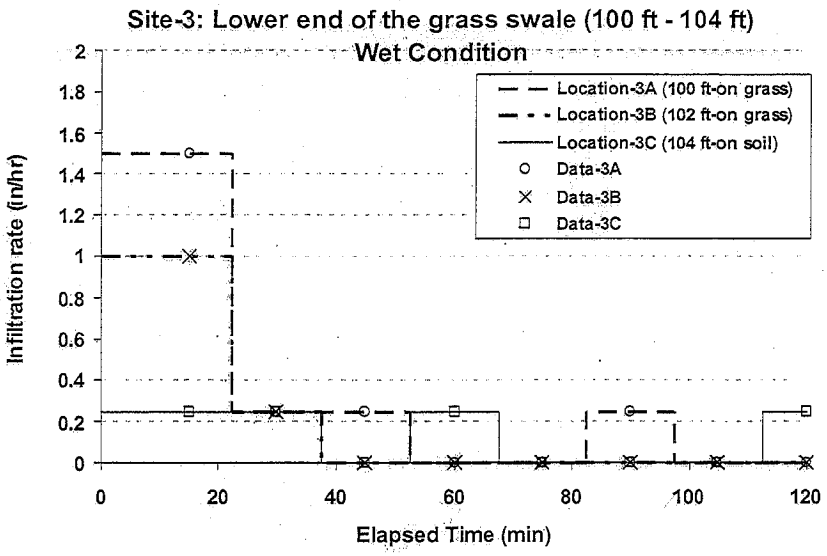
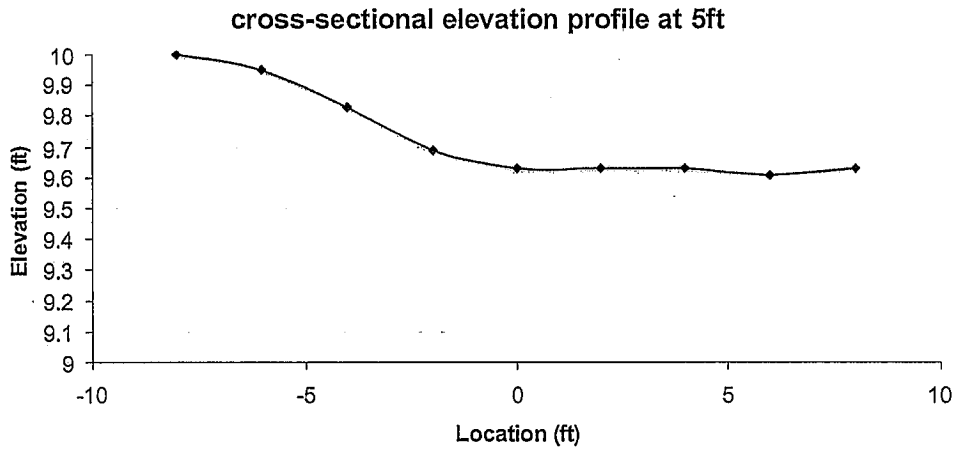


Figure L6

A007767

Appendix M: Cross-Sectional Elevation Profiles of the Outdoor Grass Swale



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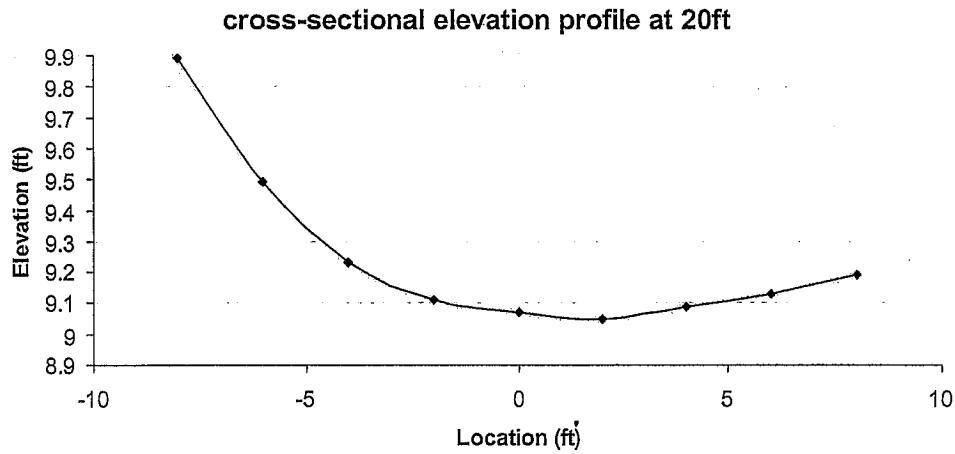

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A007768

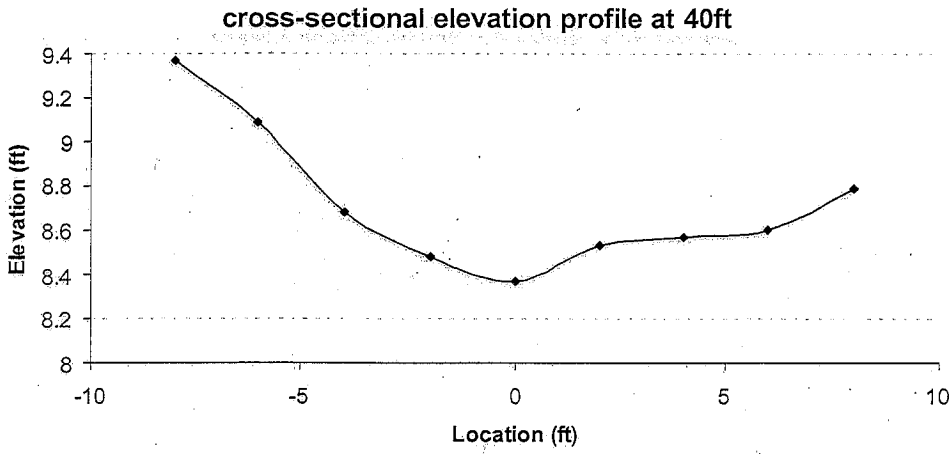


Figure M3

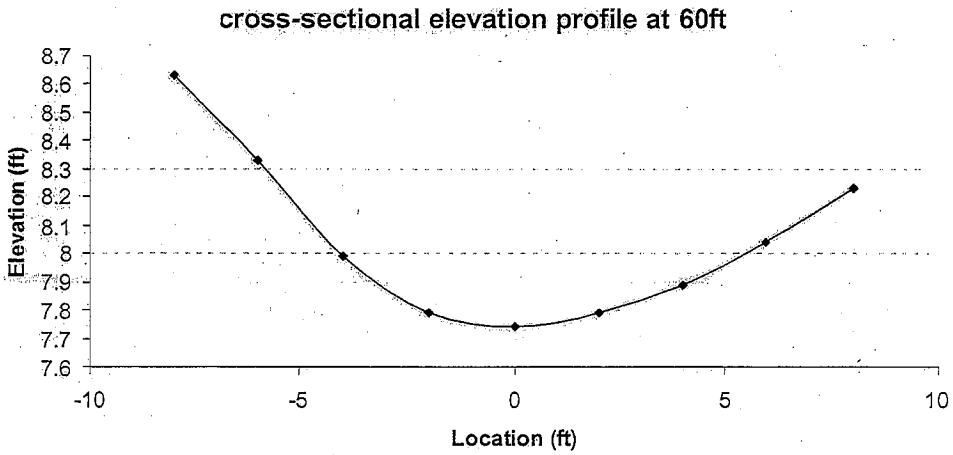
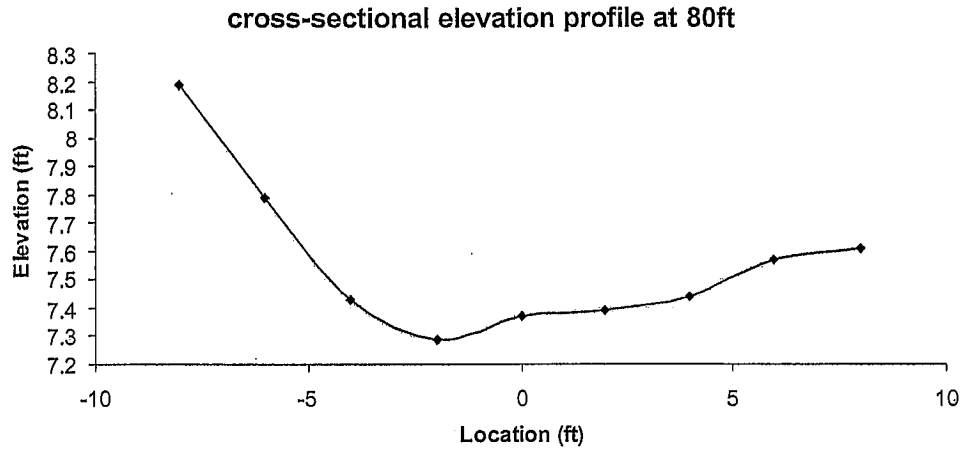


Figure M4

A007769



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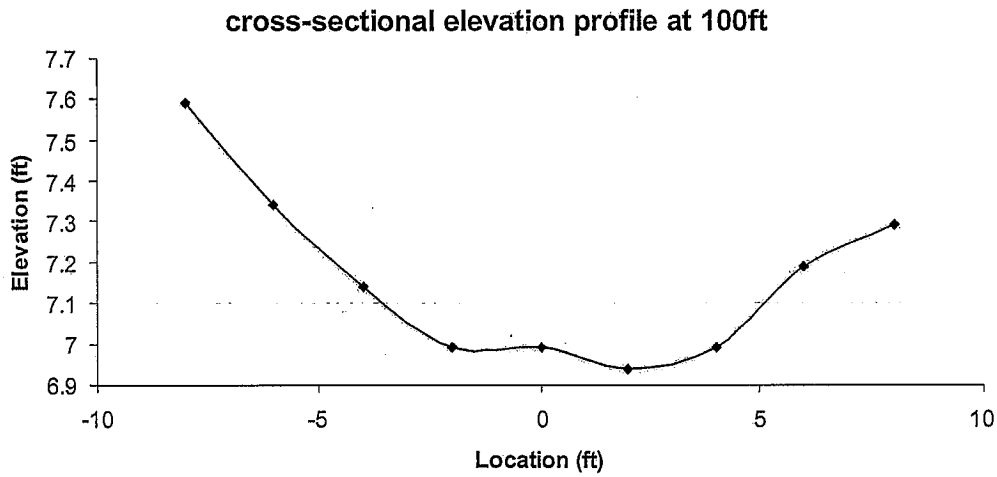


Figure M6

A007770

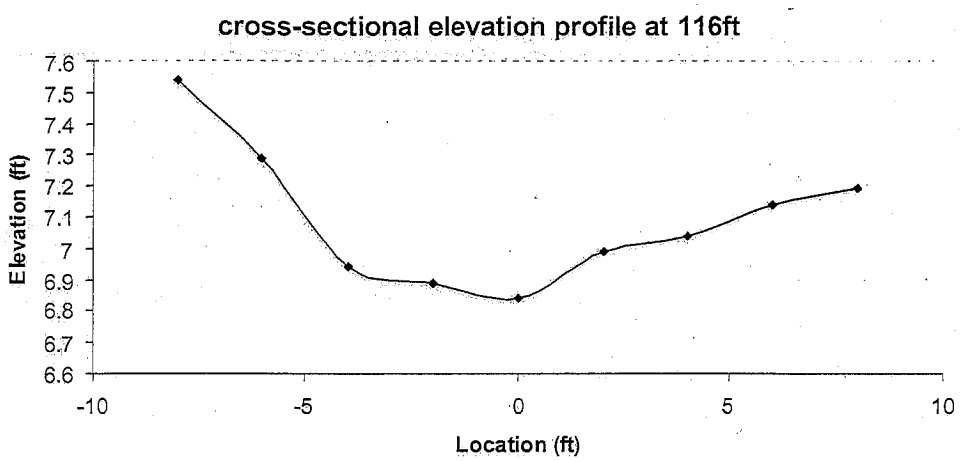


Figure M7

A007771

Appendix N: Outdoor Swale – Removal Efficiencies Observed for the Different Constituents

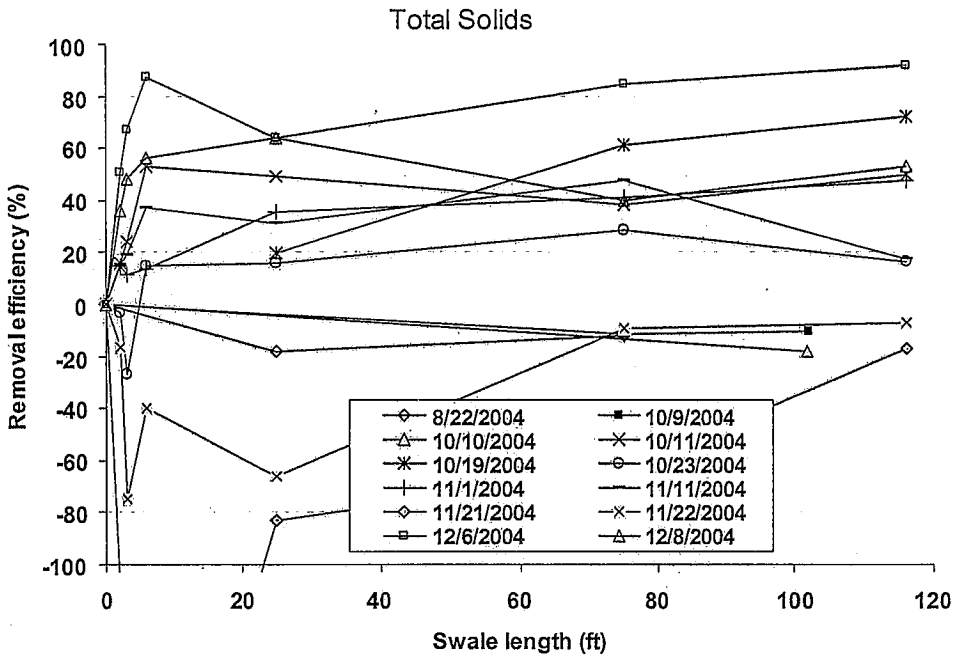
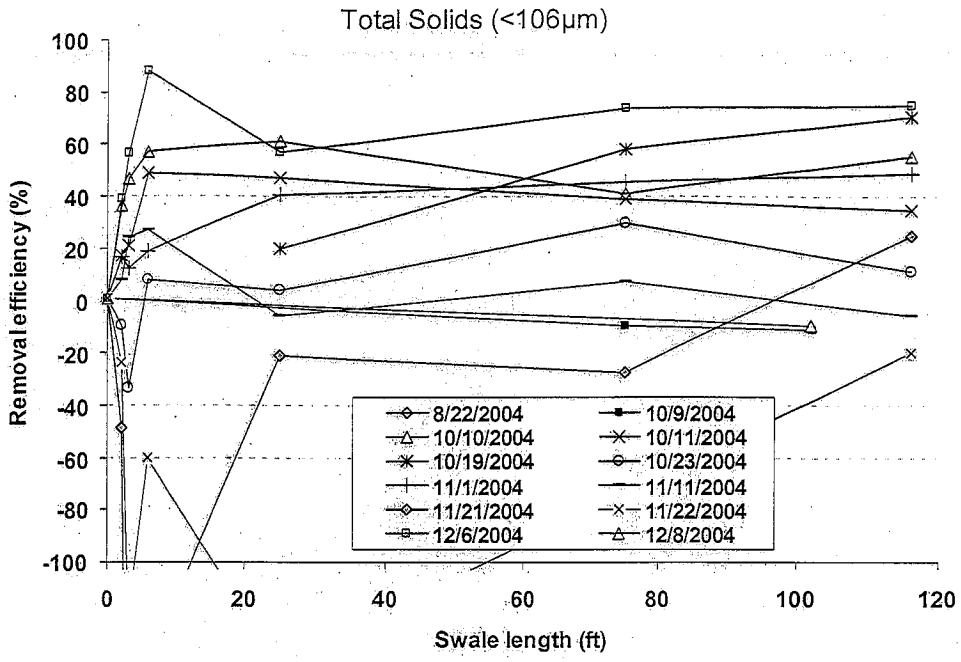


Figure N1

A007772



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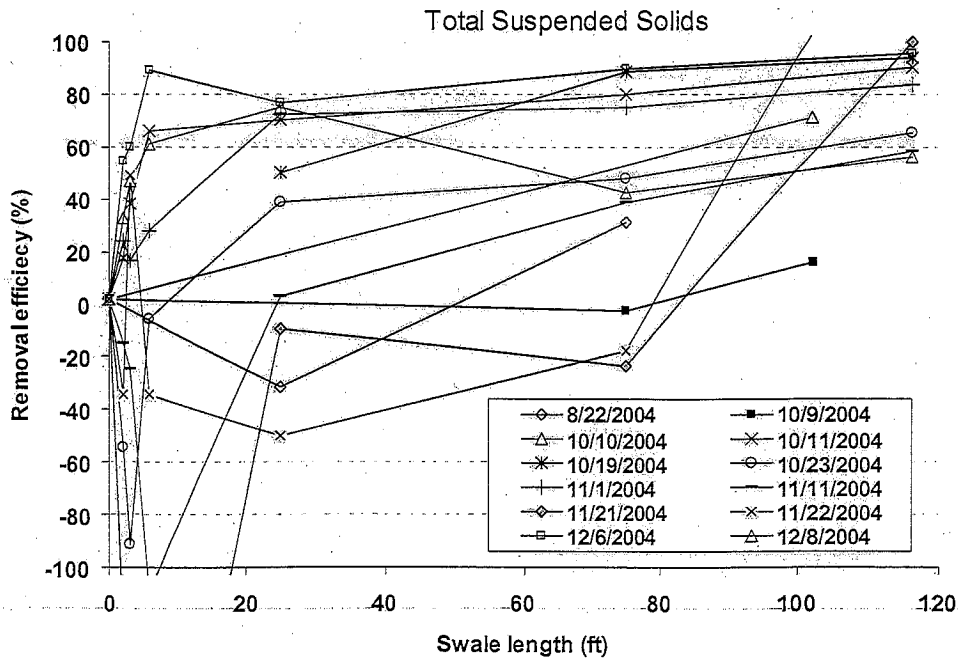


Figure N3

A007773

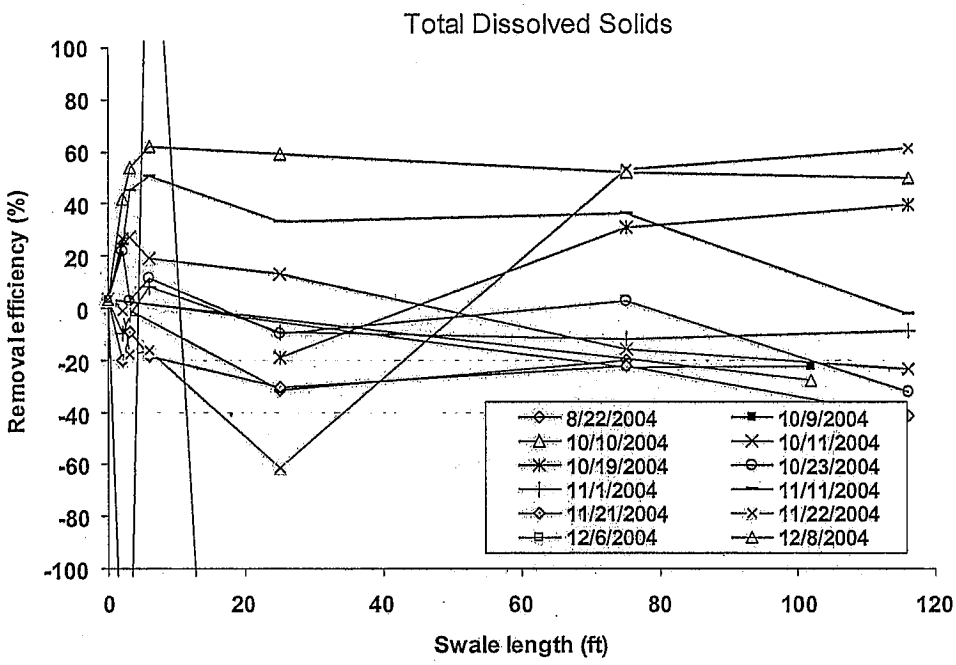


Figure N4

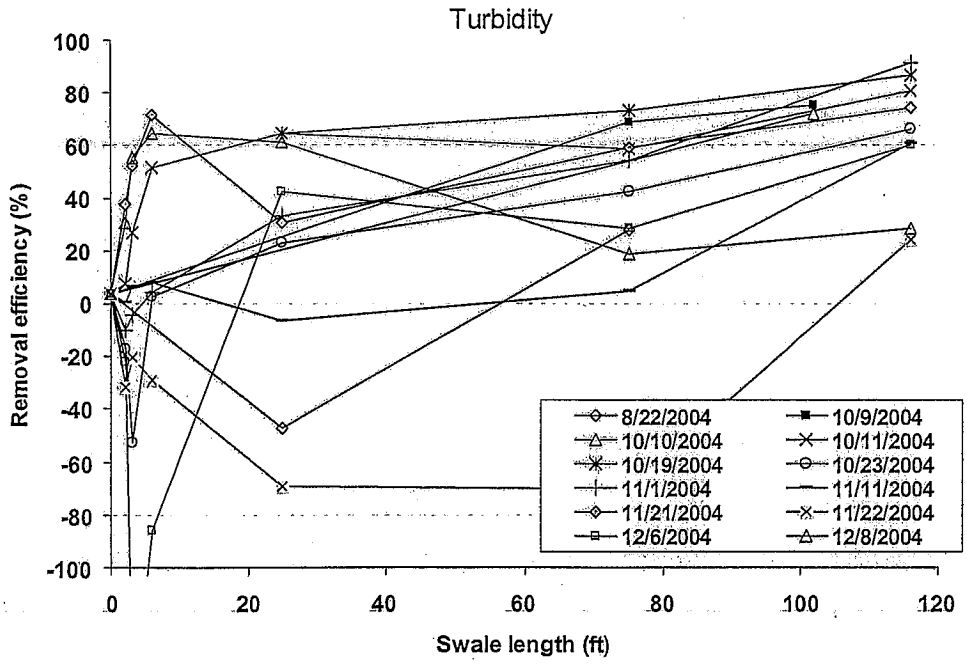


Figure N5

AD07774

Appendix O: Outdoor Swale –Particle Size Distributions for each Sample

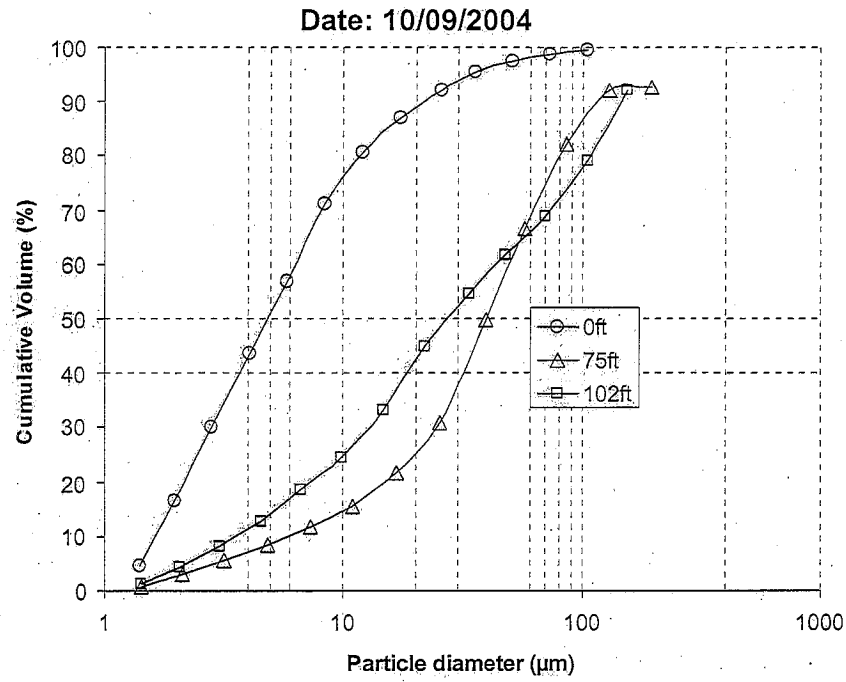
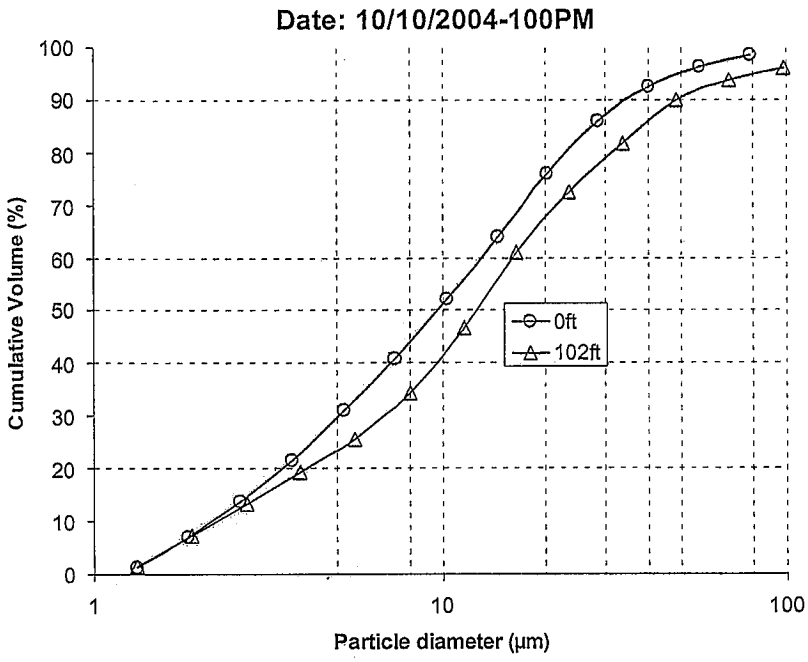


Figure O1

A007775



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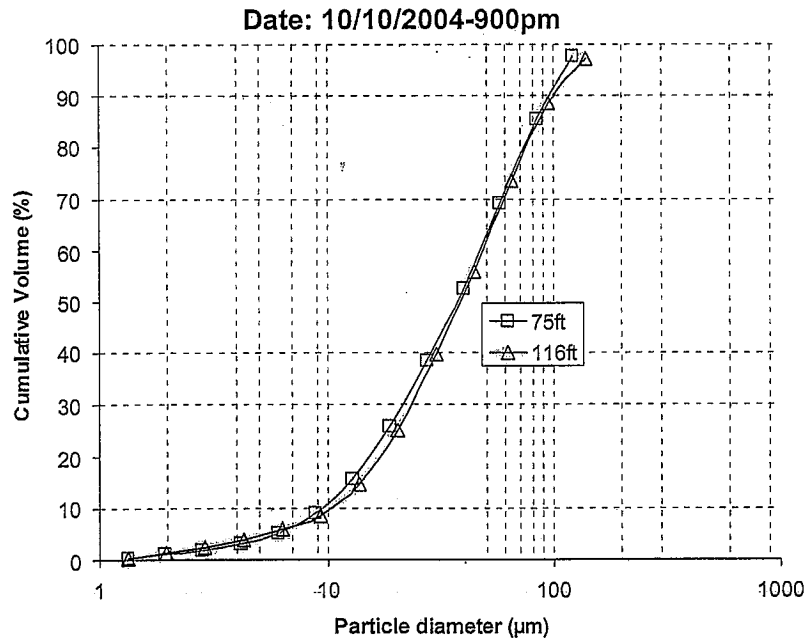


Figure O3

A007776

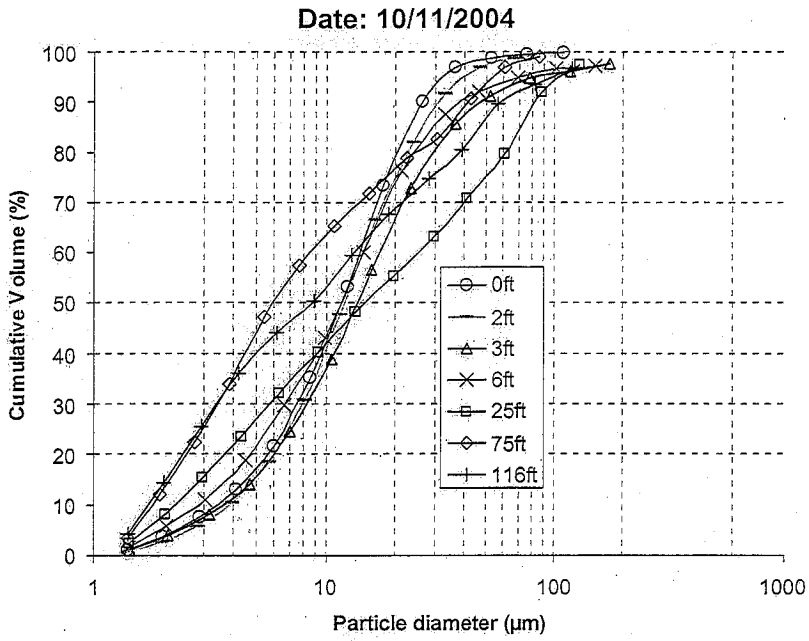


Figure O4

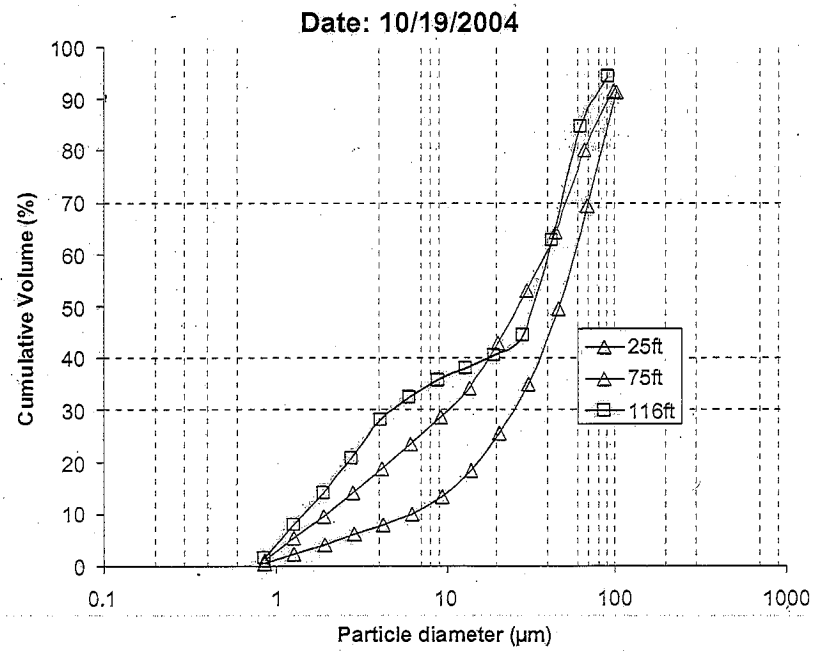
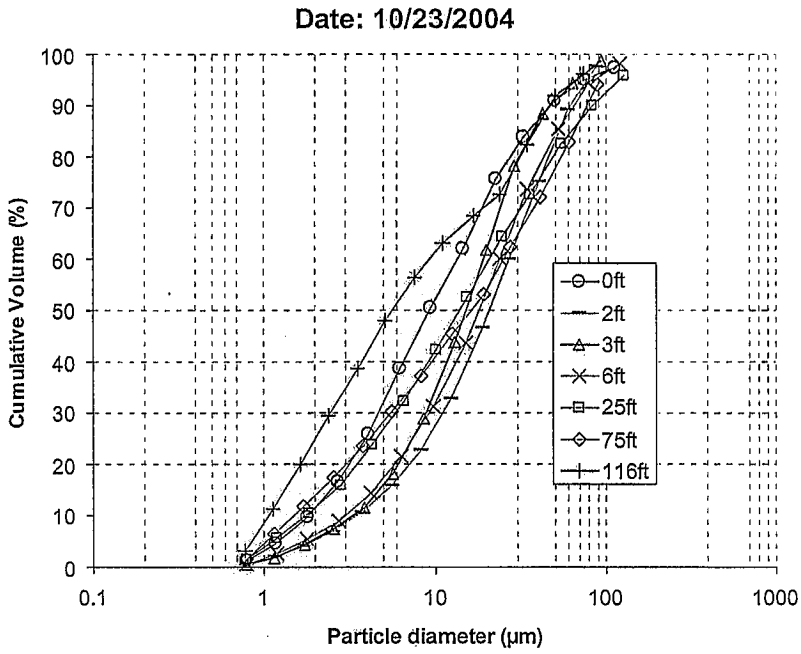


Figure O5

A0077777



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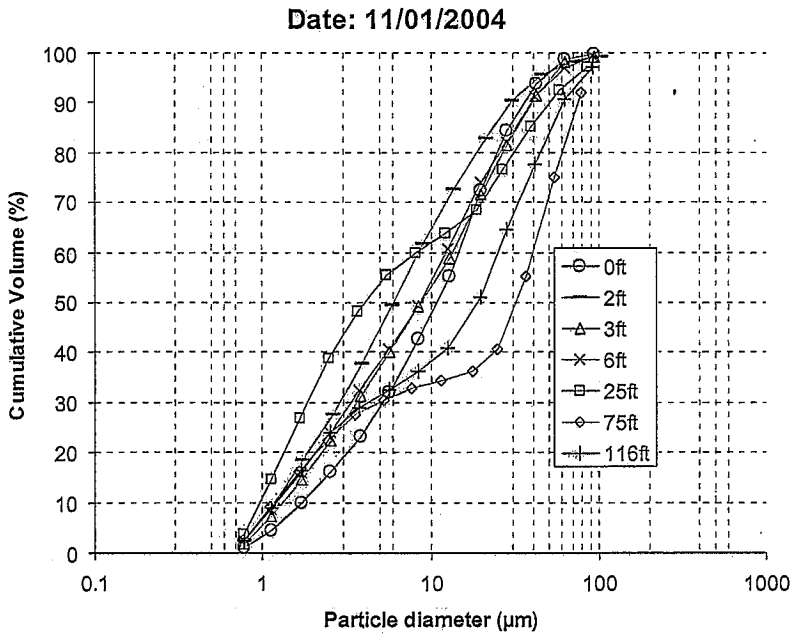


Figure O7

A007778

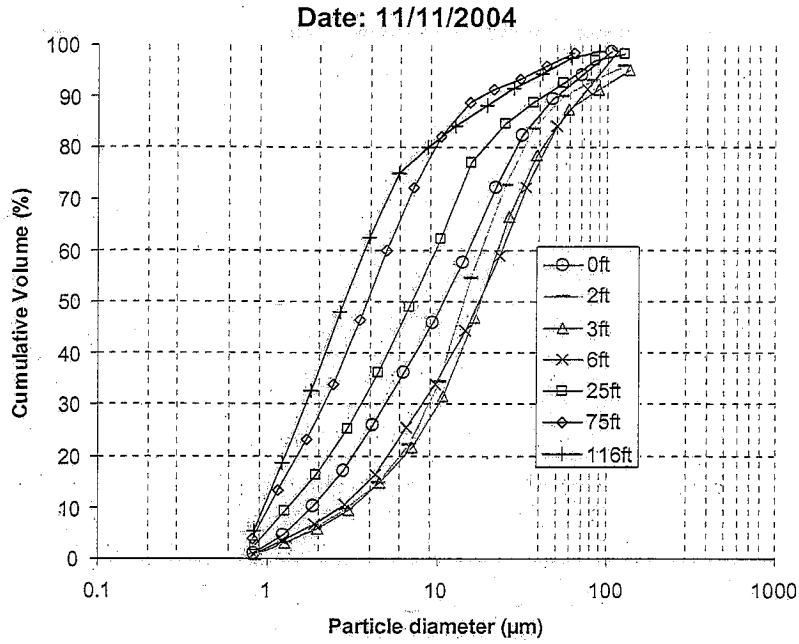


Figure O8

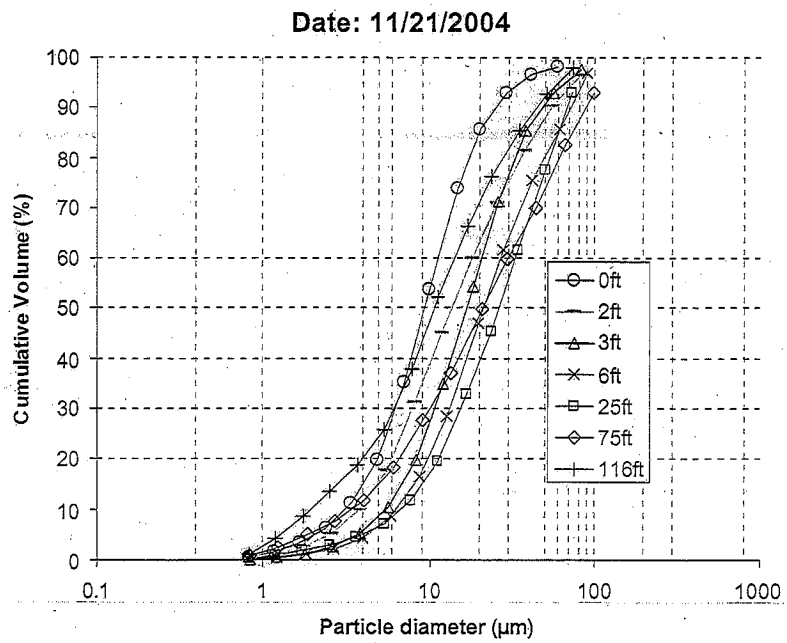


Figure O9

A007779

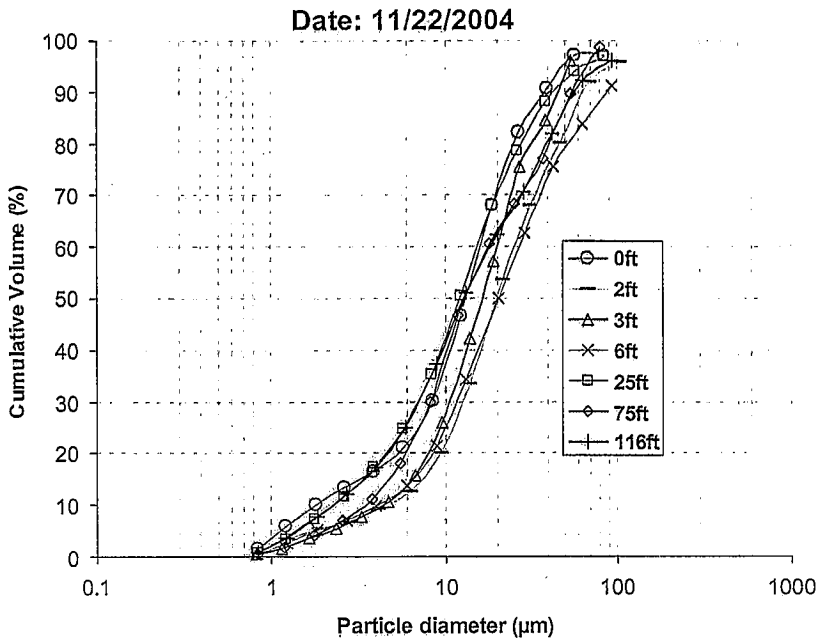


Figure O10

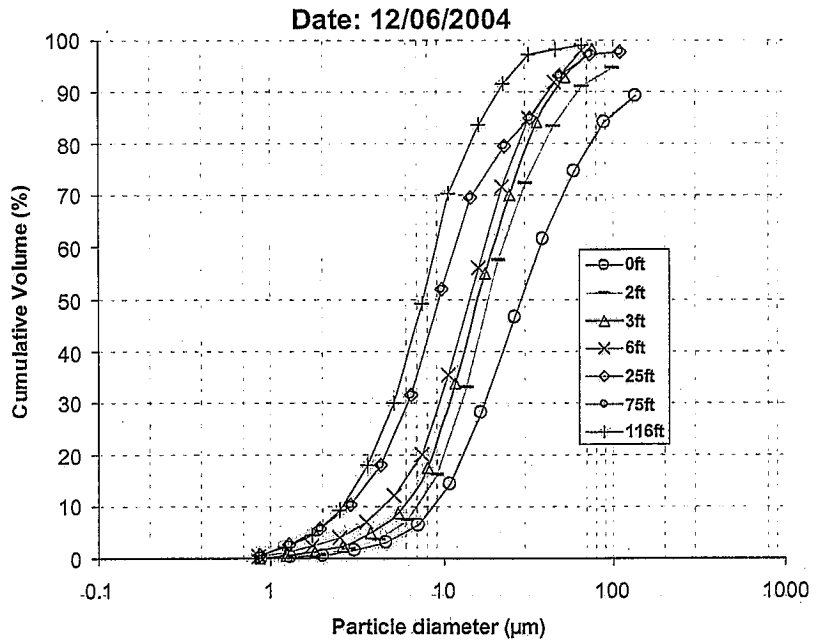


Figure O11

A007780

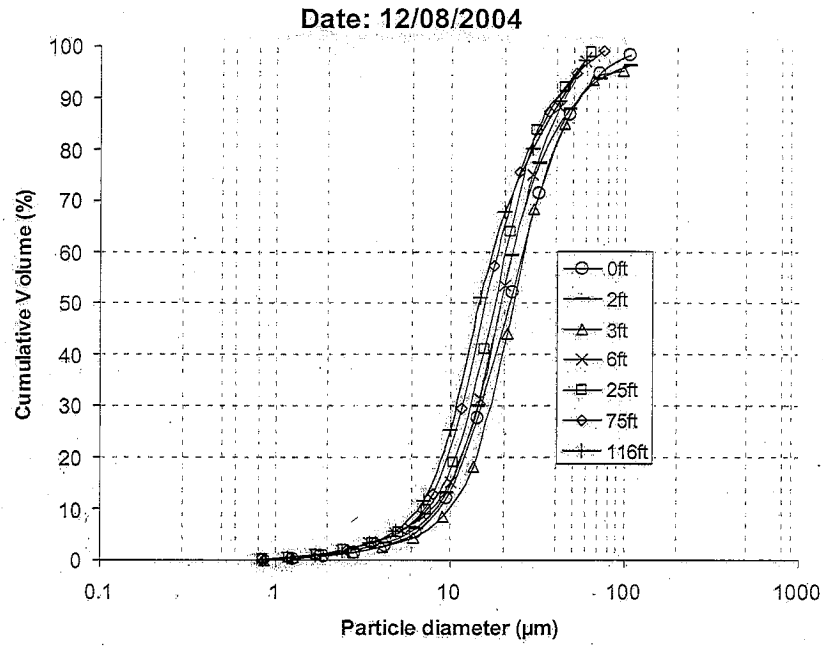


Figure O12

A007781

Appendix P: Outdoor Swale – Graphs of Sediment Concentrations for Different Particle Ranges and Observed Irreducible Concentrations

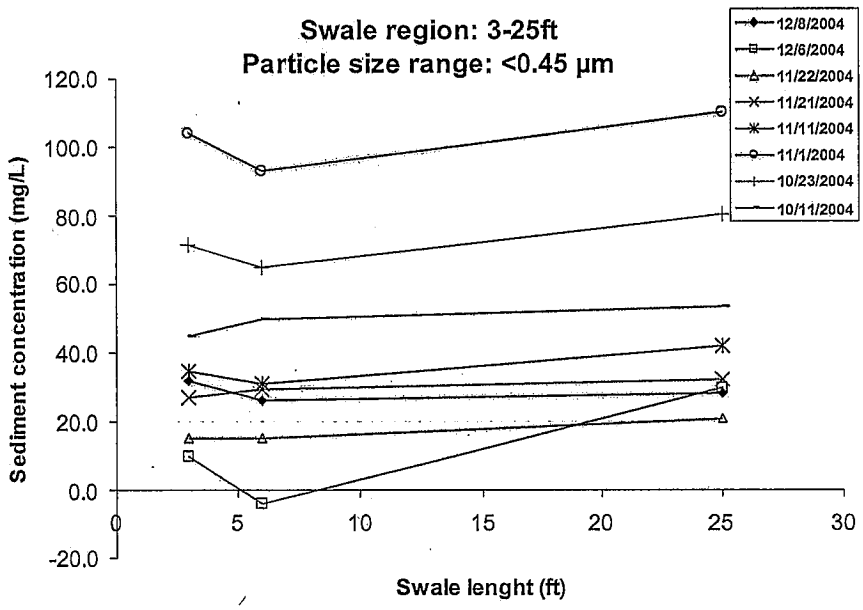
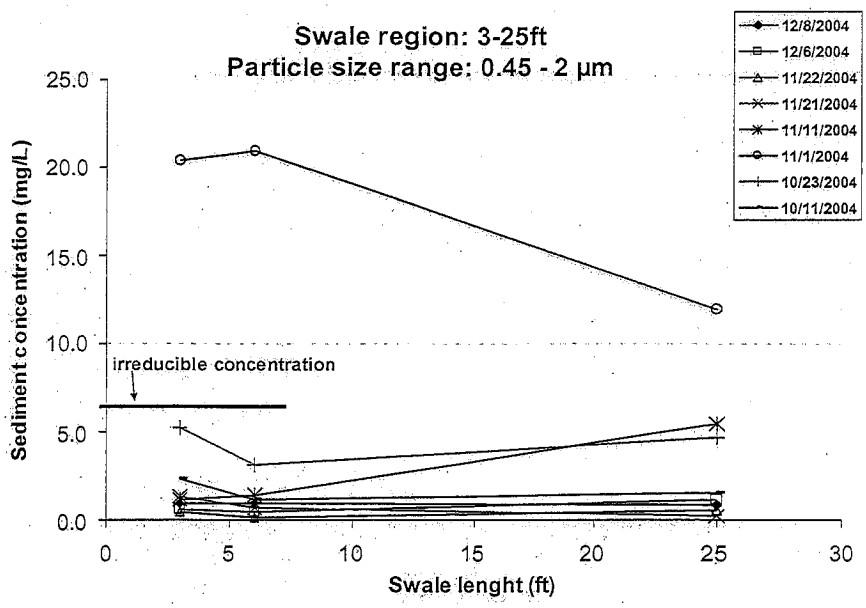


Figure P1

A007782



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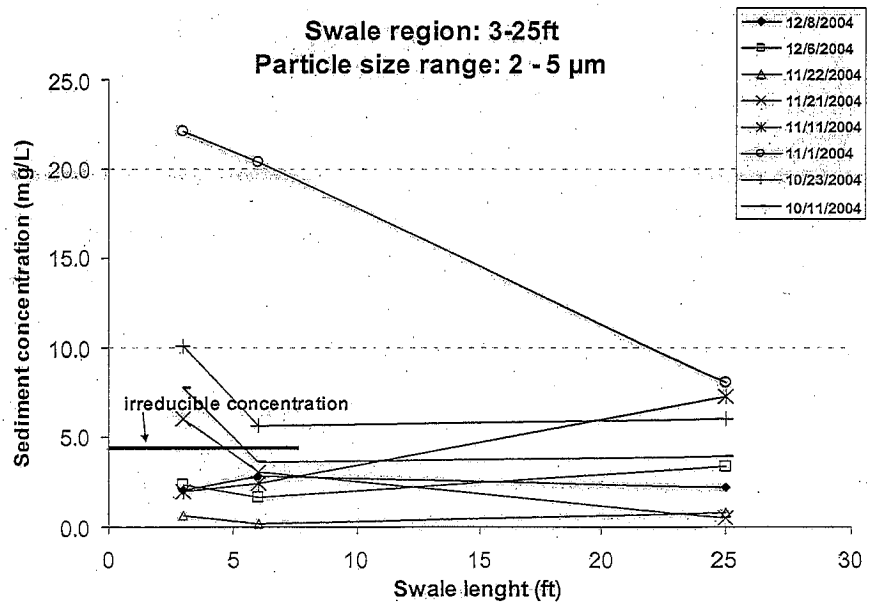
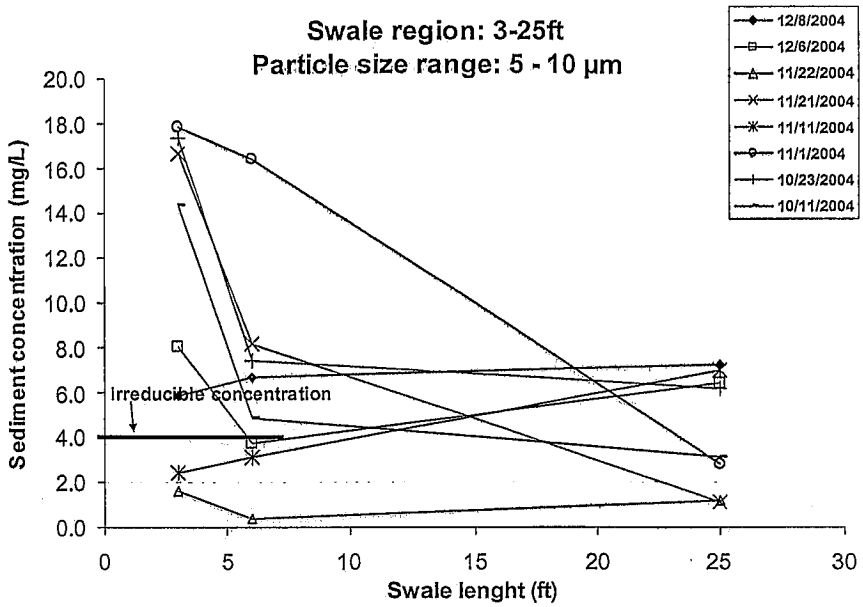


Figure P3

A007783



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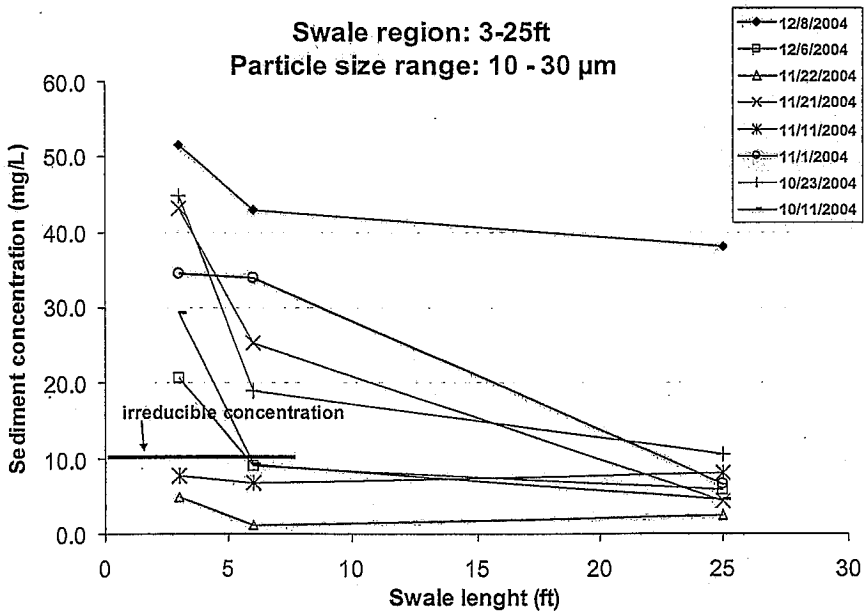


Figure P5

A0077844

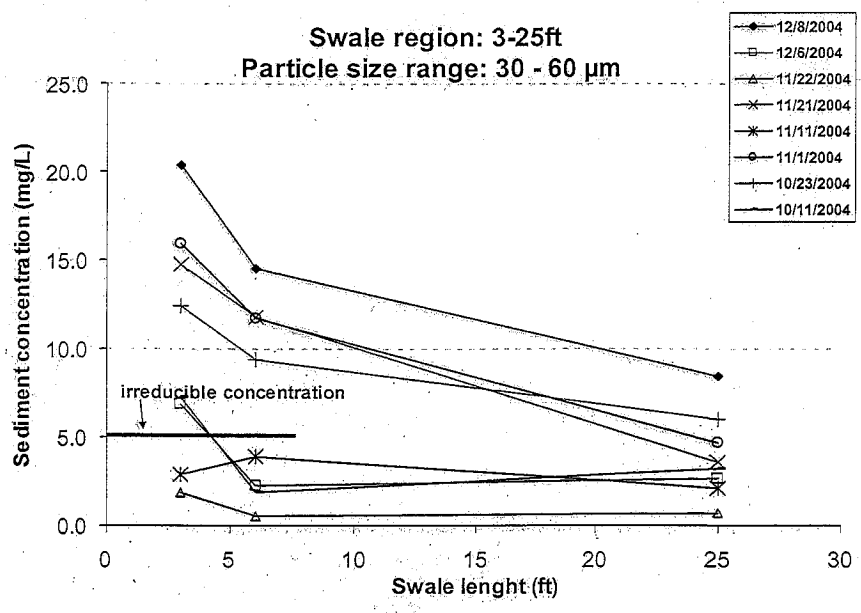


Figure P6

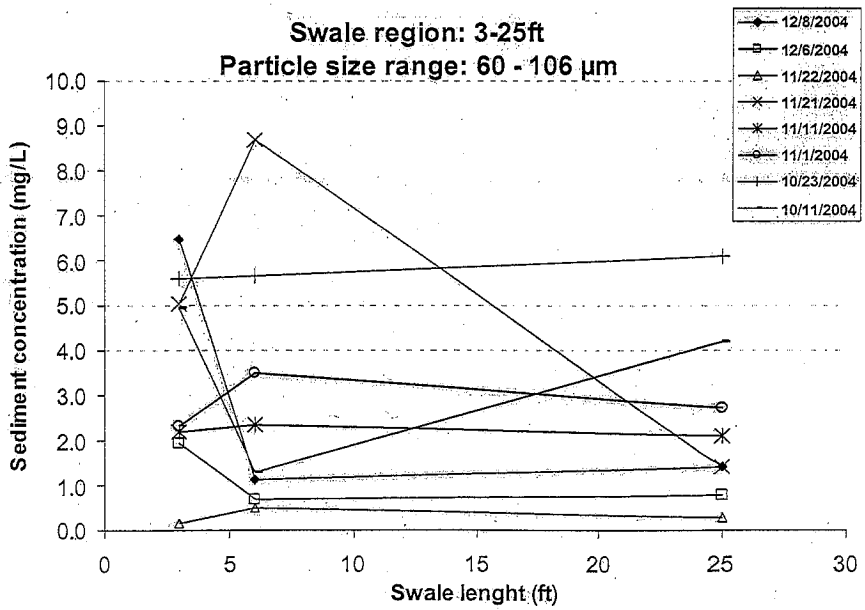
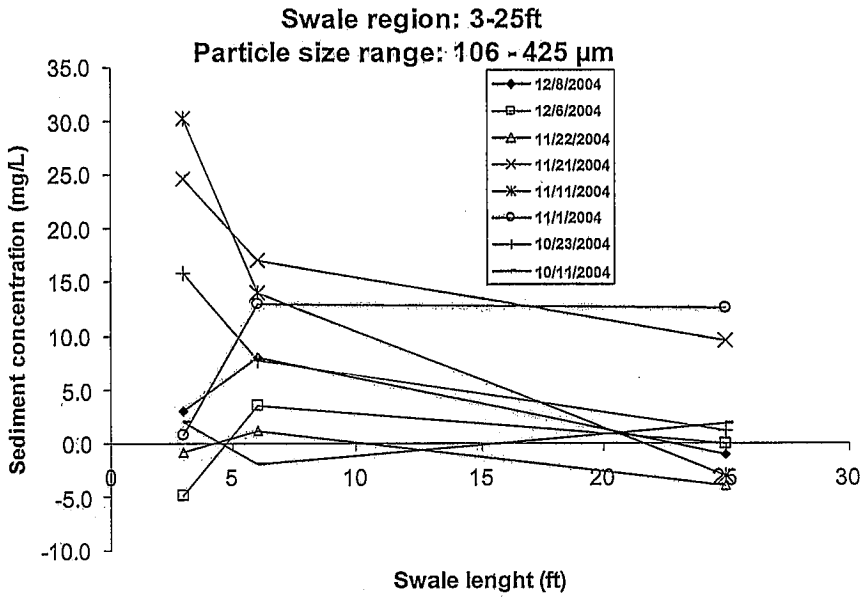


Figure P7

A007785



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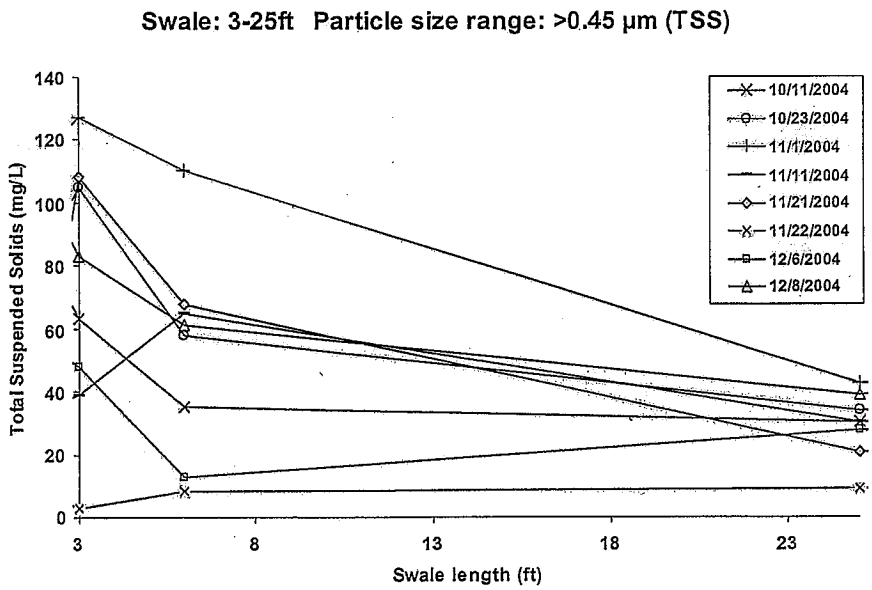

Figure P9

A007786

Appendix Q: K – Constants Plotted against Shear Stress for Different Particle Size Ranges

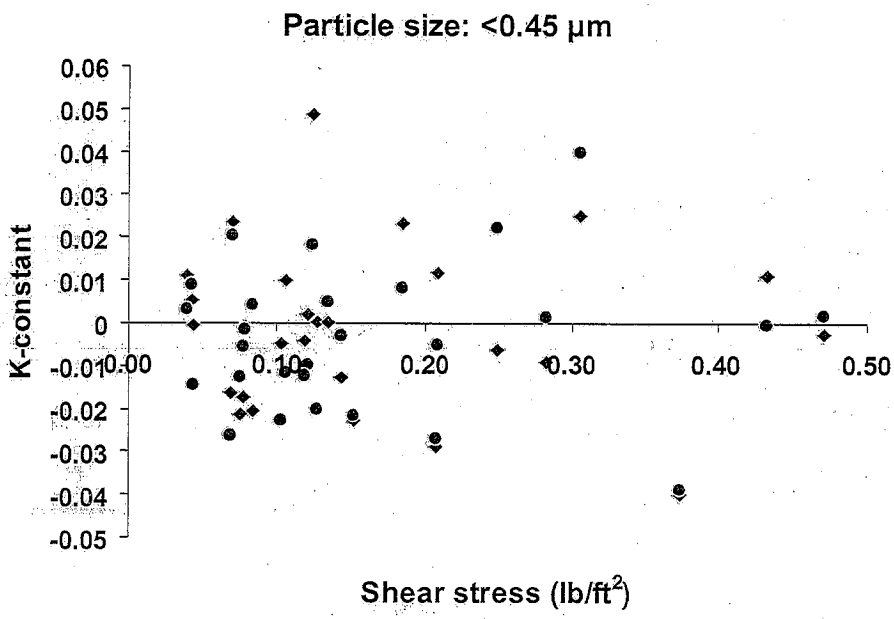

Figure Q1

A007787

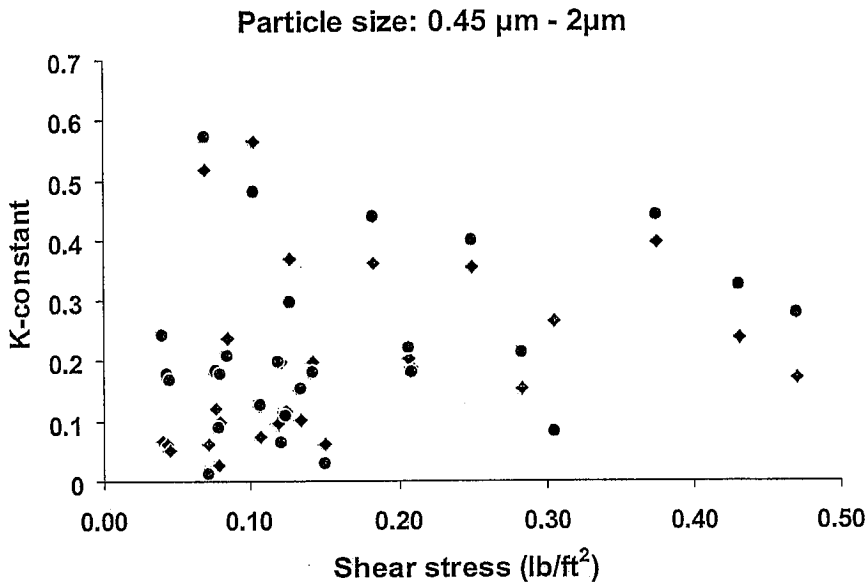

Figure Q2

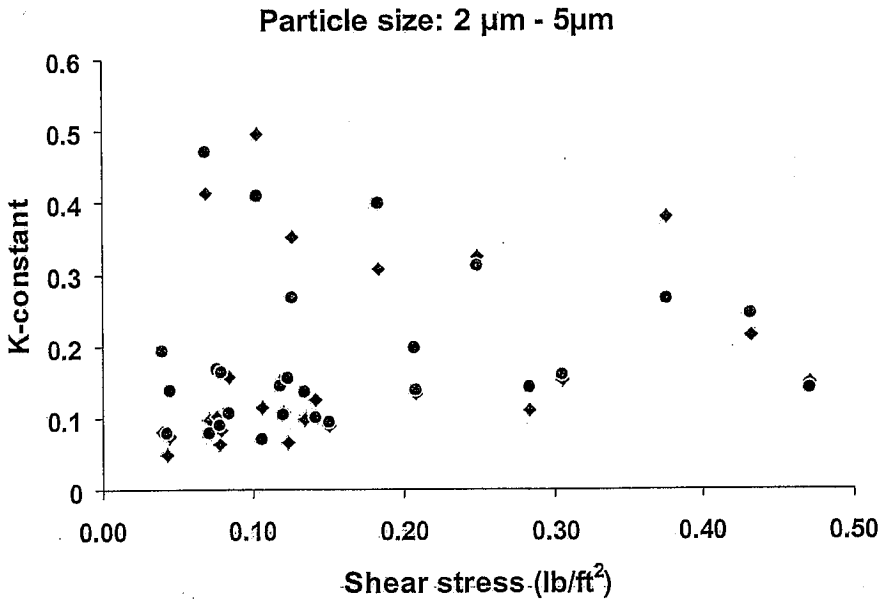

Figure Q3

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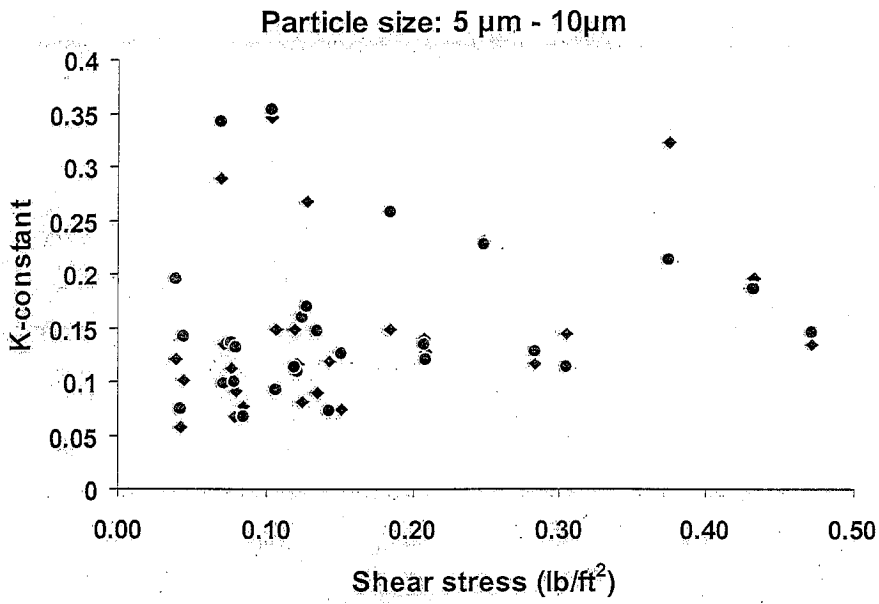

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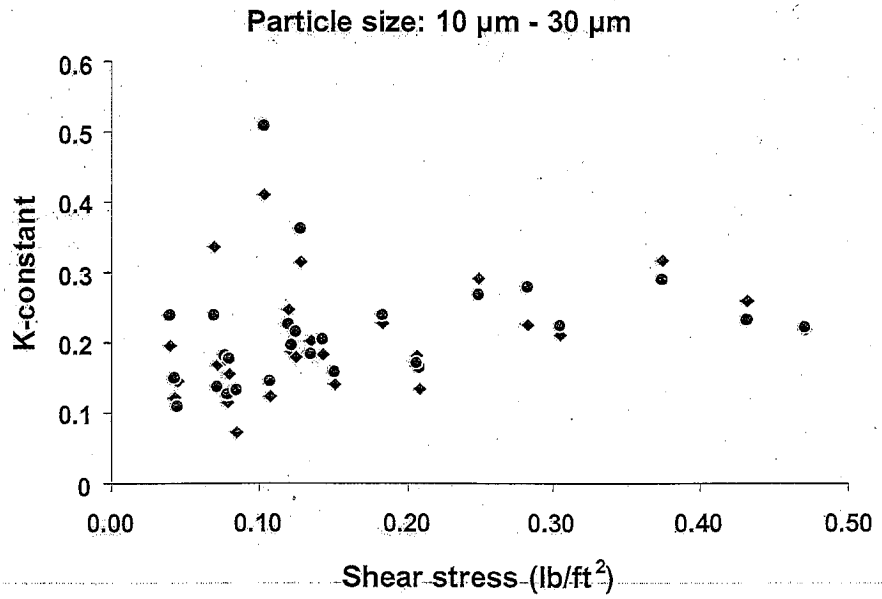
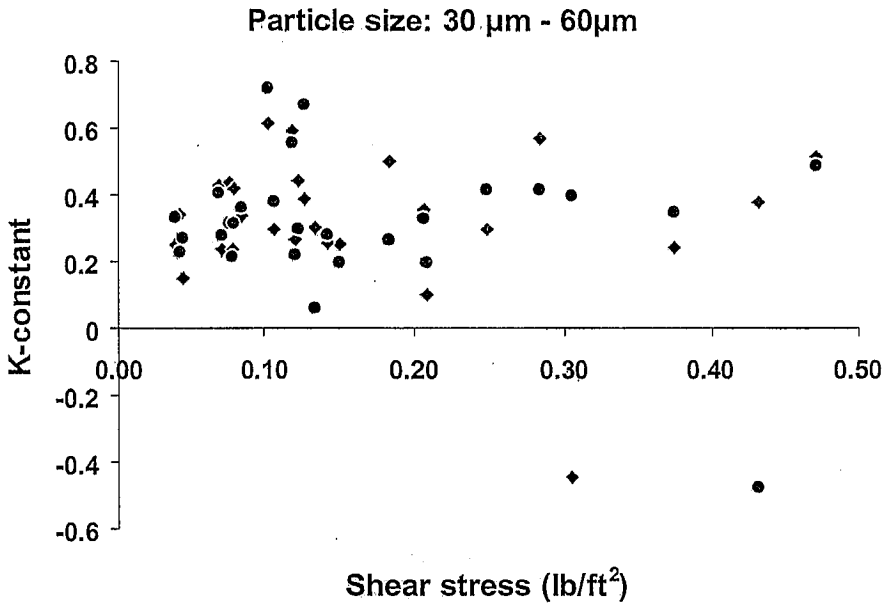


Figure Q5

A007789



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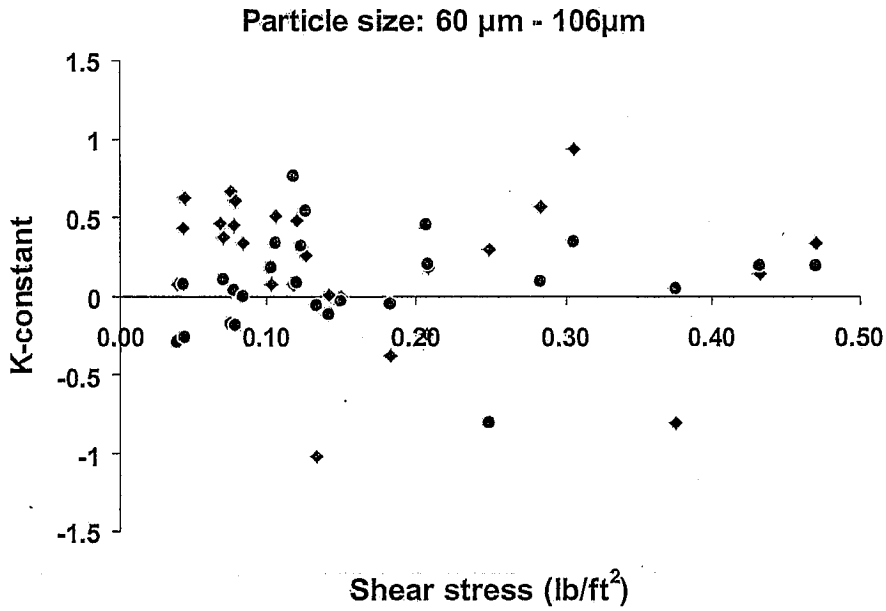

Figure Q7

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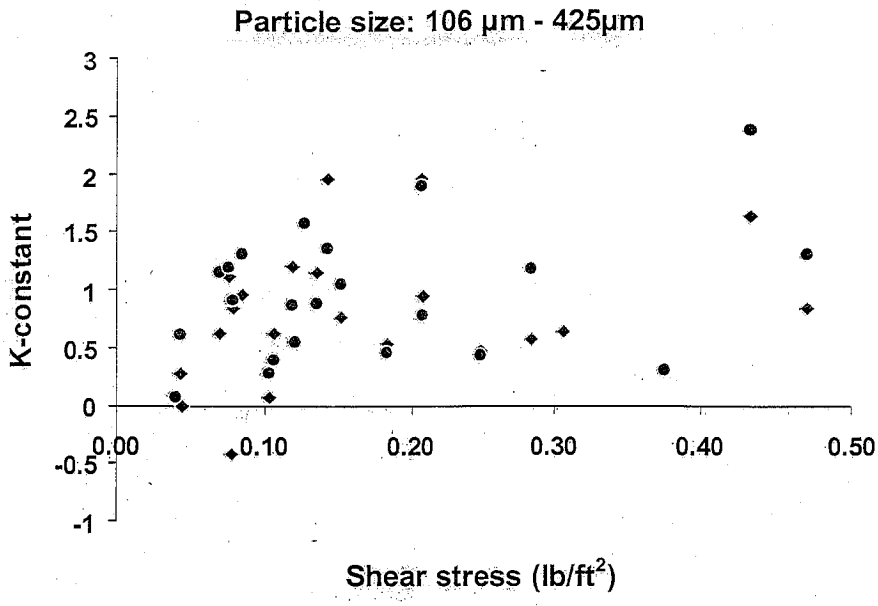

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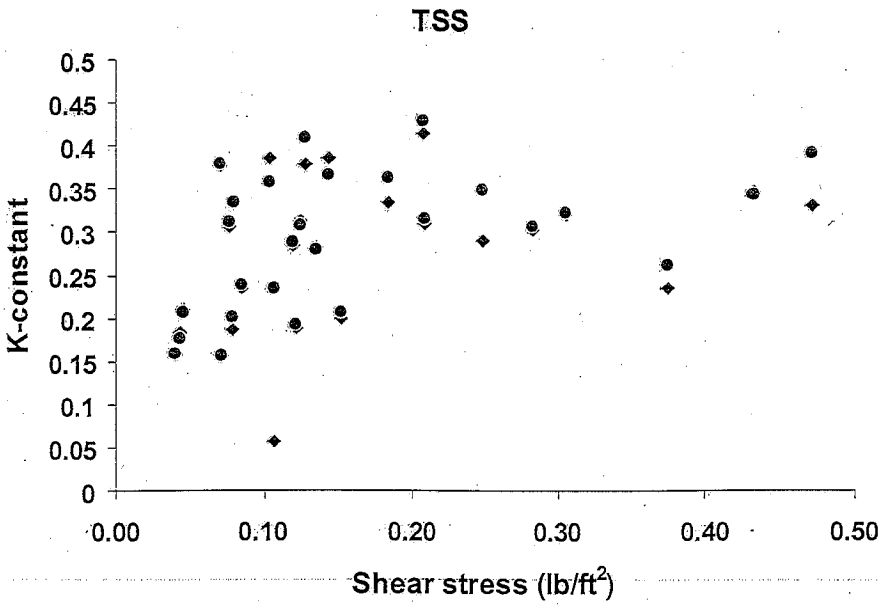

Figure Q9

A007791

Appendix R: Sediment Percent Reductions Plotted against Settling Frequency

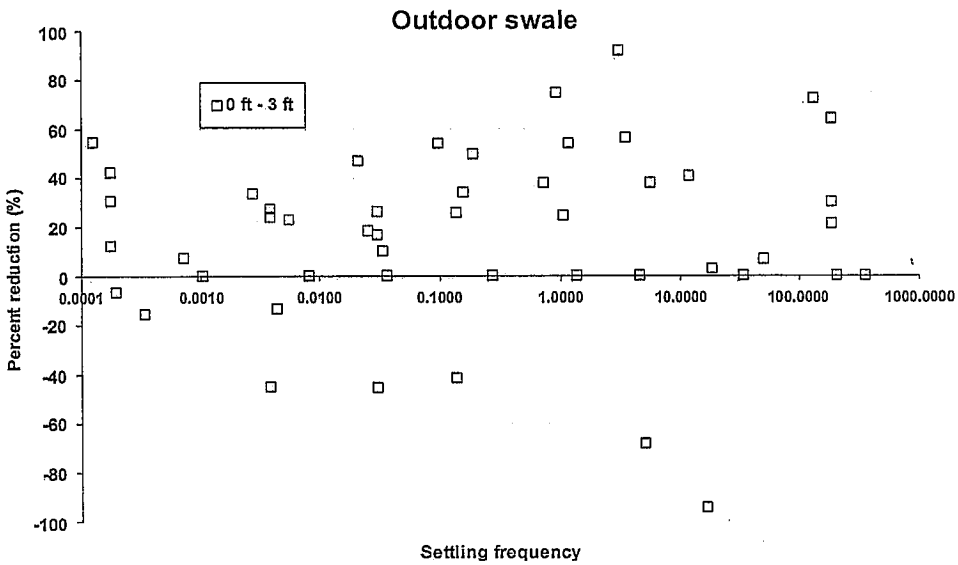

Figure R1

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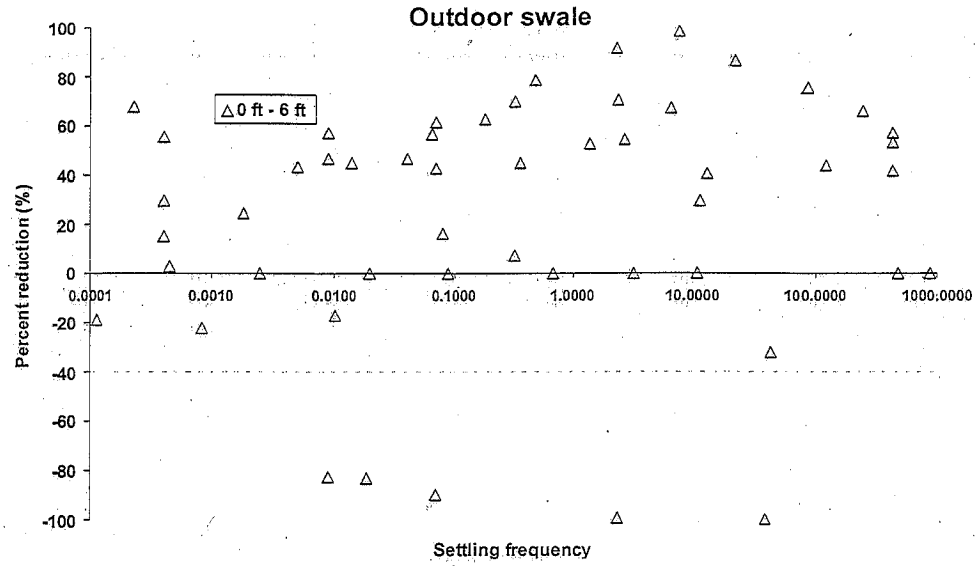


Figure R2

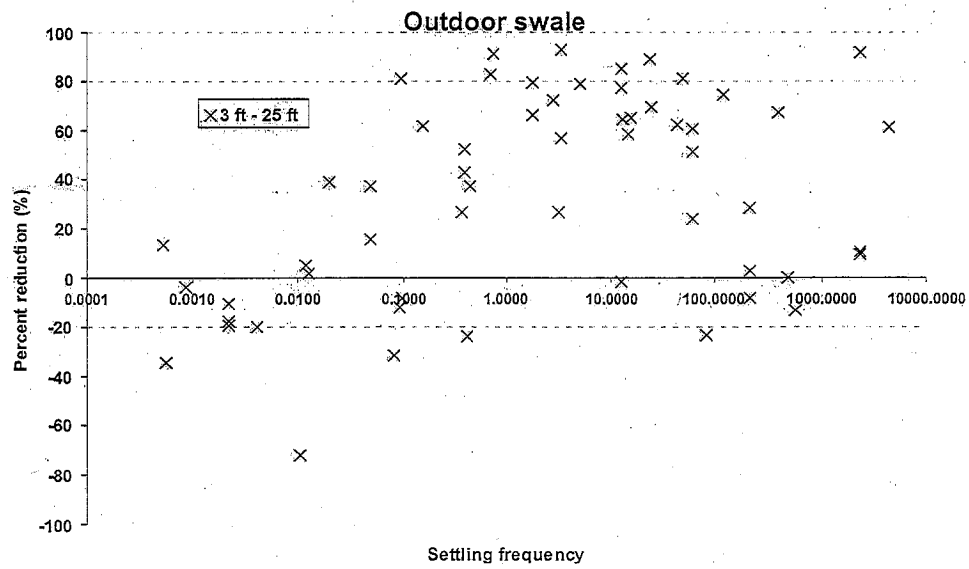
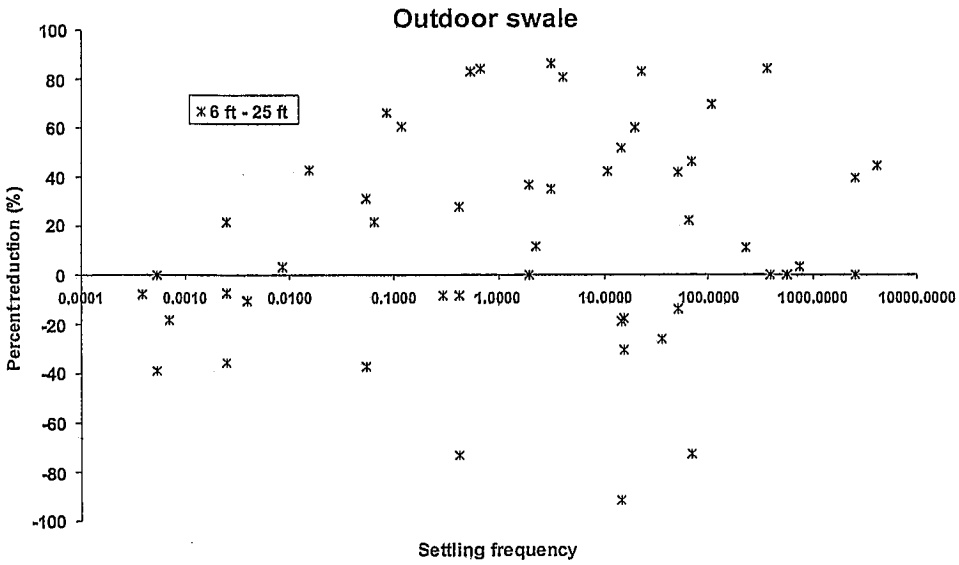


Figure R3

A007793



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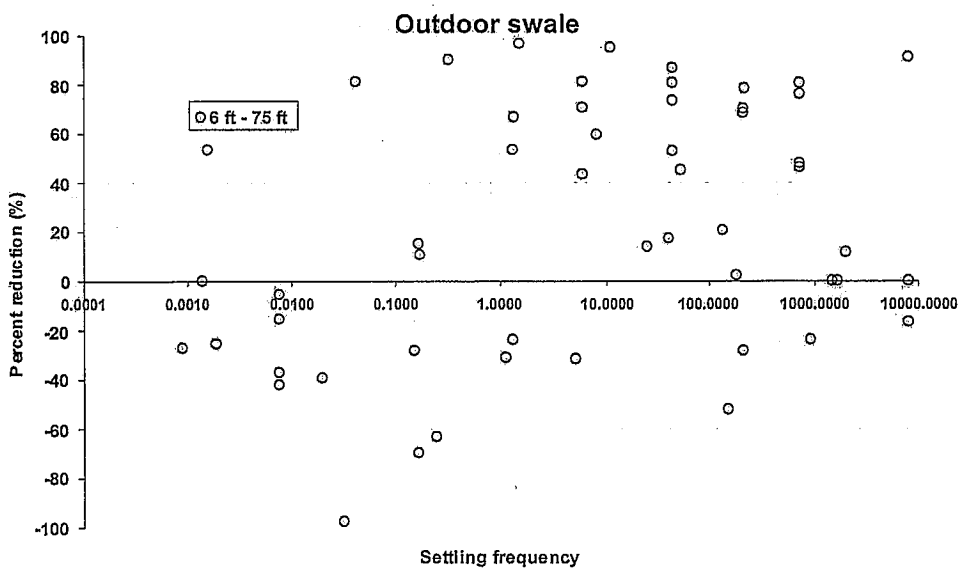

Figure R5

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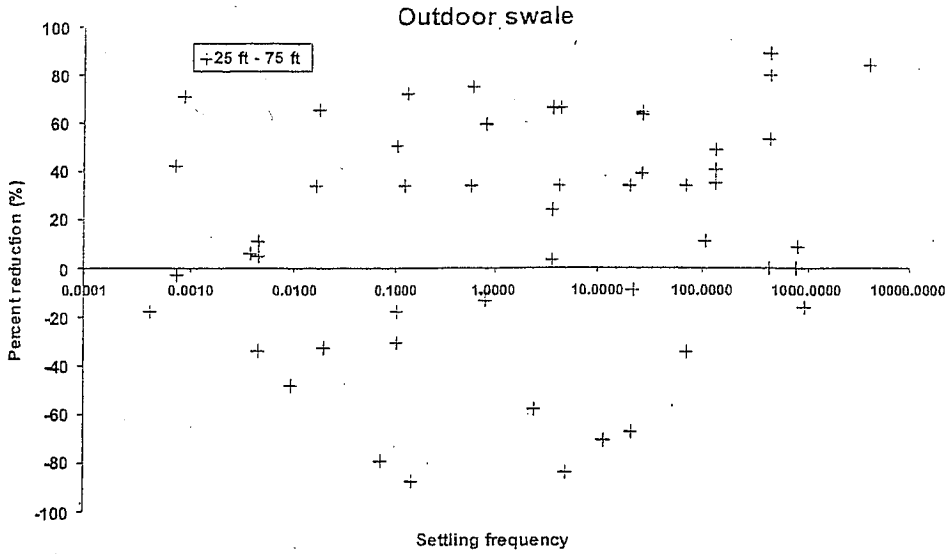

Figure R6

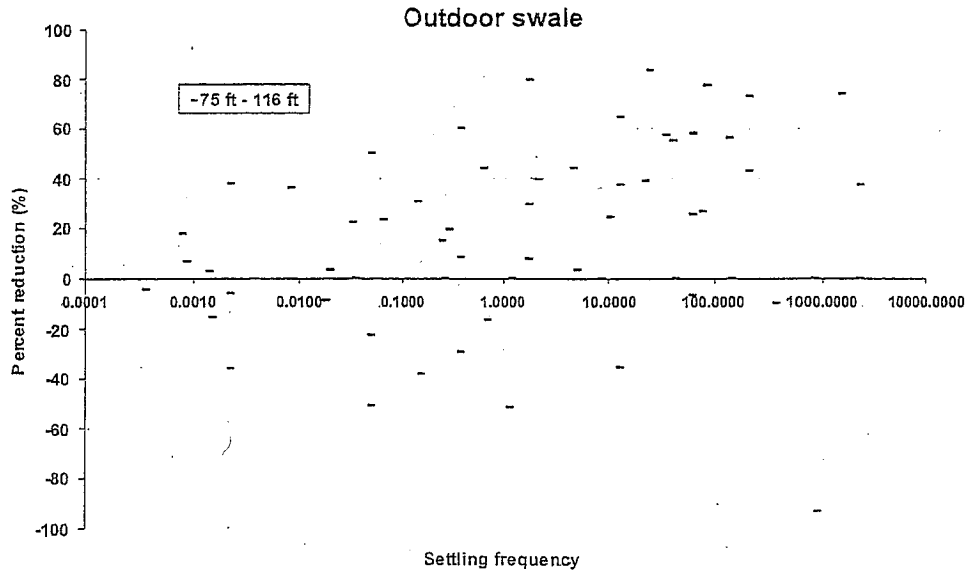

Figure R7

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