Model Monitoring Program for Municipal Separate Storm Sewer Systems in Southern California

A report from the Stormwater Monitoring Coalition's
Model Monitoring Technical Committee

August 2004

Technical Report #419

EXECUTIVE SUMMARY

This report describes a model monitoring program for receiving waters affected by urban runoff in both wet and dry weather. It provides a common design framework for municipal urban runoff programs and Regional Board staff to use in developing and/or revising program requirements for monitoring receiving waters for impacts, status and trends, toxicity, mass emissions, and source identification. This effort was funded in part by the State Water Resources Control Board (SWRCB), prompted by Senate Bill 72 (Kuehl), which addressed the standardization of sampling and analysis protocols in municipal stormwater monitoring programs. The development of the model monitoring program itself was organized through the Southern California Stormwater Monitoring Coalition (SMC), which impaneled a technical committee including representatives from:

- Regional Water Quality Control Boards (Los Angeles, Santa Ana, San Diego)
- Municipal permittees (Counties of Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego)
- Heal the Bay
- Southern California Coastal Water Research Project (SCCWRP).

As a result of the SMC's role and the makeup of the technical committee, the model stormwater monitoring program reflects issues and contexts of paramount importance in southern California and addresses some, but not all, of the requirements of SB72. Additional technical guidance related to performance standards for laboratory analysis and data reporting formats is detailed in companion documents.

The model program is structured around five fundamental management questions, with the goal of achieving a basic degree of comparability across southern California monitoring programs, while maintaining individual programs' ability to adapt to site-specific and local concerns.

The five core management questions are:

- Question 1: Are conditions in receiving waters protective, or likely to be protective, of beneficial uses?
- Question 2: What is the extent and magnitude of the current or potential receiving water problems?
- Question 3: What is the relative urban runoff contribution to the receiving water problem(s)?
- Question 4: What are the sources to urban runoff that contribute to receiving water problem(s)?
- Question 5: Are conditions in receiving waters getting better or worse?

As illustrated in Figure Ex-1, the questions are linked in a logical progression that defines an efficient sequence of study design steps.

While there is a wide range of beneficial uses defined in the Basin Plans for southern California, the model monitoring program focuses on a subset of these beneficial uses that are common to most urban runoff management programs in the region and relate to human health and habitat protection:

- Contact Water Recreation (REC1)
- Non-contact Water Recreation (REC2)
- Warm Freshwater Habitat (WARM)
- Estuarine Habitat (EST)
- Marine Habitat (MAR)
- Wildlife Habitat (WILD).

For each category of beneficial use (i.e., human health, habitat protection) the model program defines monitoring objectives and study designs. Where adequate historical data were available, statistical analyses were used to develop detailed guidance on appropriate levels of sampling effort. Rather than define a static program, the technical committee develop several tools to serve as adaptive triggers for initiating more monitoring effort if an impact was observed, or a reduction in monitoring effort if no impact (or potential for impact) was found. These tools include triggers for toxicity identification evaluations, upstream source tracking, a prioritization scheme for special studies, and a computer program for estimating sample size based on statistical power to detect trends.

The following types of stations could be integral parts of a stormwater monitoring program that address each of the five key management questions:

- Long-term, fixed, bottom-of-watershed (but above tidal influence) stations to assess cumulative water quality and aggregate loads, with monitoring based primarily on a mass emissions model including wet weather chemistry and toxicity
- Spatially extensive, perhaps randomly sited or rotating, stations to support statistically valid comparisons across multiple watersheds, and with monitoring based primarily on the Triad approach for dry weather sampling and on chemistry and toxicity for wet weather
- Site-specific stations focused on the status of high-priority inland habitats of concern, with monitoring based primarily on the Triad approach for dry weather sampling and on chemistry and toxicity for wet weather
- High-priority inland body contact recreation areas
- Site-specific stations designed to generate information to support key program goals, such as source prioritization or BMP implementation and evaluation
- Coastal estuarine stations to assess status in these key habitats, with monitoring based primarily on the Triad approach
- Coastal ocean stations to assess stormwater plume impacts, conducted primarily as part of the periodic Bight surveys.

While the idealized monitoring design in Figure 5-2 shows each type of monitoring station separately, in practice there may be overlap among two or more types of stations.

The technical committee gave significant consideration to how the model program would be used in practice. It was well aware that stormwater monitoring has been ongoing for some time in southern California and that important basic steps, such as characterization studies, have been completed by many programs. In addition, the degree to which programs have addressed the five management questions in Figure 2-1 varies substantially, in part due to each program's history and in part due to the nature of the surface waters in different parts of the region.

Thus, the model stormwater monitoring program does not assume that each program is starting with a blank sheet of paper. Nor does the model program assume that each permittee will proceed through Figure 2-1 in a linear, stepwise fashion. Instead, the model program is intended to improve each program's ability to build appropriate linkages among the five core management questions. This is best accomplished through the following steps:

1. Evaluate a program's ability to answer each of the five management questions
2. Identify critical gaps in knowledge (e.g., inability to document impacts, lack of knowledge about potential sources, absence of trend monitoring component) relevant to each program's circumstances
3. Use the monitoring designs in the model monitoring program as a framework for developing monitoring components suited to each program's circumstances.

The SMC's technical committee intended that the model program be used to direct an incremental process of adaptation using the three steps above, rather than one of wholesale change. This incremental change should be based on a prioritization of needs (i.e. using the triad approach in perennial streams before ephemeral streams). Through this process, the ultimate goal of developing regionally consistent programs that directly address key management questions in a scientifically rigorous and cost effective manner can be accomplished.

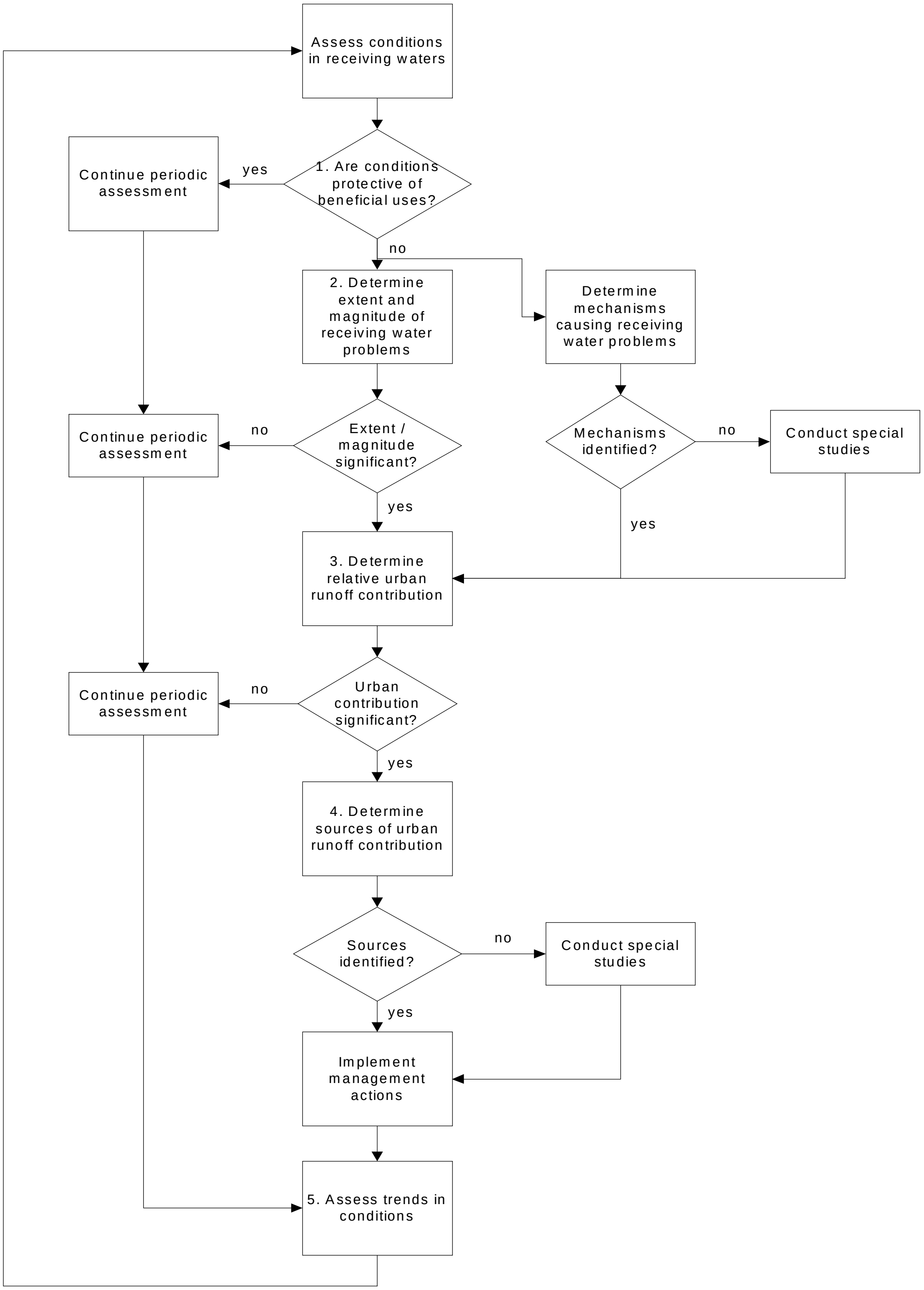


Figure Ex-1. Graphical illustration of the idealized logical flow through the five core management questions (reworded as statements to fit flowchart conventions). The answer to each question provides the basis for developing the monitoring design to answer the next. In actuality, monitoring programs may have addressed questions in parallel or out of sequence, depending on available knowledge and specific information needs.

ACKNOWLEDGEMENTS

This project was partially funded by the State Water Resources Control Board and the Southern California Stormwater Monitoring Coalition. The content of the report was developed over the course of one year a technical committee consisting of regulated, regulatory, environmental and research organizations including:

Name	Affiliation
Brock Bernstein	Facilitator
Linda Garcia	Riverside County Flood Control District
Dave Gibson	San Diego Regional Water Quality Control Board
Fred Gonzales	Los Angeles County Department of Public Works
Phil Hammer	San Diego Regional Water Quality Control Board
Karen Hauptly	Orange County Public Facilities and Resources Department
Lisa Kay	MEC Analytical (San Diego Cnty Department of Environment Health)
Eric Klein	San Diego County Department of Environment Health
Thomas Lo	Camp, Dresser & McKee (San Bernardino County Flood Control Dist)
Bruce Moore	Orange County Public Facilities and Resources Department
Ken Schiff	SCCWRP
Nate Stevenson	Los Angeles County Public of Works
Xavier Swamikannu	Los Angeles Regional Water Quality Control Board
Mitzy Taggart	Heal the Bay
Bob Whitaker	Santa Ana Regional Water Quality Control Board
Darla Wise	Ventura County Watershed Protection Division
Michael Yang	Los Angeles Regional Water Quality Control Board
Matt Yeager	San Bernardino County Department of Public Works

This page intentionally left blank

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Rationale and approach

Large municipalities in southern California are required, under the Clean Water Act (CWA) and National Pollutant Discharge Elimination System (NPDES) permits from their respective Regional Water Quality Control Boards (RWQCBs), to monitor discharges of urban runoff[1] from municipal separate storm sewer systems (MS4s) and their impacts on receiving waters. However, urban runoff monitoring programs throughout southern California often focus on different monitoring questions, approach the same question in different ways, sample different sets of parameters, and use a range of field and laboratory methods to collect and analyze samples. This inconsistency makes it difficult, if not impossible, to address questions on a broader spatial scale, to compare urban runoff monitoring results across programs, and to improve efficiency by taking advantage of opportunities for exchanging data and coordinating monitoring responsibilities at regional scales.

In response to this set of circumstances, the Southern California Stormwater Monitoring Coalition (SMC) has undertaken a project to develop regionally consistent monitoring approaches and designs. The goal of the study is to produce a "model" monitoring program that will provide a foundation for each of the urban runoff monitoring programs in southern California to build on for their respective agency's needs. The development of the model monitoring program will therefore focus on developing regionally consistent management questions, efficient monitoring designs to answer those questions, creating standardized laboratory analysis protocols, and coordinating necessary quality assurance activities to ensure comparability among programs. This document focuses specifically on management questions and monitoring designs. Standardization of laboratory analysis protocols and data transfer and reporting methods are dealt with in companion documents.

This report reflects the collaborative work of a technical committee impaneled by the SMC. The technical committee included representatives from three southern California RWQCBs (the Colorado Region was not represented), the lead municipal MS4 management programs (commonly referred to as stormwater programs), SCCWRP, Heal the Bay and the State Water Resources Control Board (SWRCB). This report makes recommendations about a model urban runoff monitoring program, assesses current monitoring practice, and recommends adjustments to bring current programs more in line with the model program.

1.2 Relationship to SB72 and State Board efforts

Senate Bill 72 (Kuehl), adopted in October 2001, required the State Water Resources Control Board (SWRCB) to develop "minimum monitoring requirements for regulated municipalities that were subject to a stormwater permit on or before December 31, 2001." The SWRCB therefore has initiated efforts to develop standardized protocols for collection and analysis of stormwater samples, as well as a standardized reporting format. Working in coordination with local stormwater agencies and RWQCBs through the SMC presents an opportunity to gain consensus towards a common shared goal.

---

[1] Urban runoff includes those discharges from residential, commercial, industrial and construction areas within the Permit Area and excludes discharges from feedlots, dairies, farms and open space.

There are, however, some important differences among the SMC and SWRCB goals. On one hand, the SWRCB goals are much larger than the SMC's goals. The SWRCB is mandated to develop statewide consistency while the goal of this project is development of consistency only for the southern California region. On the other hand, the SWRCB goals are more limited than the SMC's goals. The SWRCB is mandated to develop the "how to's" of stormwater monitoring (i.e. sampling, analysis, reporting), whereas this project starts with understanding the "why, where, and what" (i.e. monitoring questions and study designs) of developing an integrated stormwater monitoring program. Finally, the SWRCB and the SMC have different focal points of their monitoring programs. The SWRCB is mandated to develop standardized monitoring protocols for stormwater from all of their regulated discharges (i.e. municipal agencies and industrial facilities). This project, however, only addresses monitoring programs developed for municipal agencies, but examines monitoring designs for both wet and dry weather runoff.

1.3 A note on terminology

It is important to emphasize that the monitoring designs described in subsequent sections of this report focus explicitly on supporting the management of urban runoff to protect receiving water quality, with "receiving water" defined as surface Waters of the State, with the exception of ground water and lakes/reservoirs. While the SMC's technical committee recognized that there are other point and nonpoint sources of receiving water impact, the core focus of municipal stormwater programs is urban runoff, in both wet and dry weather. Thus, references to "stormwater" throughout the body of the report should be understood to refer to urban runoff.

It is also important to recognize that this document focuses on potential water quality problems and impacts, as opposed to water quality impairments. The technical committee opted to avoid the terminology of impairments because it has a distinct regulatory connotation that eventually leads to a Total Maximum Daily Load (see box on TMDLs). Water quality problems and impacts are more broad than impairments, which seemed more appropriate since some monitoring elements are meant to be early warning indicators and hopefully will avoid TMDLs in the future.

Total Maximum Daily Loads (TMDLs)

TMDLs are a regulatory framework for trying to restore beneficial uses in impaired waterbodies. Waterbodies sometimes have impaired water quality, even when all discharges to that waterbody are regulated under national pollutant discharge elimination system (NPDES) permits. The State will often use NPDES monitoring data to create the list of impaired waterbodies, also called the §303(d) list, which refers to the specific section in the Clean Water Act for TMDLs. Once promulgated, TMDLs typically call for additional monitoring either to refine source assessment or to determine if management actions implemented as a result of the TMDL are improving water quality. The model program described in this document is for urban runoff monitoring and, while there is some potential overlap with TMDL monitoring, the intent is to deliberately keep them separate. The reason is twofold. First, TMDLs are inherently site-specific and the goal of this document is to ensure regional applicability. Secondly, urban runoff may, or may not, be the cause of the water quality impairment that leads to a TMDL. If TMDL monitoring is called for, it is prudent to link monitoring from all NPDES dischargers to the impaired waterbody. Regardless of a §303(d) listing, urban runoff monitoring will be a necessity in order to characterize impacts, or lack of impacts, in receiving waters. Additional information on TMDLs in southern California can be found at www.swrcb.ca.gov

2.0 GOALS, OBJECTIVES AND IMPLEMENTATION

This model urban runoff monitoring program is intended as a framework to assist permittees and Regional Board staff in modifying existing monitoring programs, both wet and dry weather, with the goal of improving their ability to answer key management questions common to all programs in a cost effective and scientifically rigorous way. This is described in the following sections:

- The principals and philosophy for developing the model program are given in Section 3.0.
- A description of the key management questions, including rationale and expected data products, are given in section 4.0.
- The specific design elements, such as identifying the number of sampling sites and frequency of sampling, are given in Section 5.0.

This section, however, first addresses the basic program goals, how these goals address universal NPDES permit objectives as defined by the State and the Federal government, and describes an approach for applying the model monitoring program to an existing stormwater permit. Such modifications can occur when permits are periodically renewed and/or when permittees propose monitoring program revisions to their respective Regional Boards.

2.1 Monitoring program goals

Figure 2-1 summarizes the model monitoring program's ultimate goal, which is to ensure that each stormwater program has the ability to assess and manage its overall performance by answering five basic questions:

- Question 1: Are conditions in receiving waters protective, or likely to be protective, of beneficial uses?
- Question 2: What is the extent and magnitude of the current or potential receiving water problems?
- Question 3: What is the relative urban runoff contribution to the receiving water problem(s)?
- Question 4: What are the sources to urban runoff that contribute to receiving water problem(s)?
- Question 5: Are conditions in receiving waters getting better or worse?

These basic questions are universal to all MS4 programs in southern California and were prioritized by their program managers during the technical committees' early meetings.

2.2 Meeting permit objectives

Stormwater monitoring programs in southern California focus on meeting a set of NPDES permit objectives that, with some minor differences, are common to all programs in the region. These include the following (edited slightly for conciseness):

- Define water quality status, trends, and pollutants of concern associated with urban stormwater and non-stormwater discharges
- Evaluate impact of stormwater/urban runoff on biological species in receiving waters

- Identify those waters which cannot reasonably be expected to attain or maintain applicable water quality standards required to sustain beneficial uses
- Identify significant water quality problems related to urban stormwater and non-stormwater discharges
- Estimate annual mass emissions of pollutants discharged to surface waters through the MS4
- Evaluate water column and sediment toxicity in receiving waters
- Determine and prioritize pollutants of concern in stormwater
- Identify sources of urban runoff pollutants
- Identify other sources of pollutants in stormwater and non-stormwater runoff
- Evaluate the effectiveness of existing municipal stormwater quality management programs, including that of BMPs
- Identify and prohibit illicit connections
- Identify and prohibit illicit discharges.

The basic questions outlined in section 2.1 above, and described in detail in sections 4.0 and 5.0, will produce improved information that will help address many of these objectives (Table 2-1). The model program's structure, which moves from assessment monitoring, through source identification, and to tracking of longer-term trends, reflects the range of concerns represented in the set of common permit objectives.

2.3 Applying the model program

The technical committee's intent was to create the model program as guidance, providing sufficient detail to assure consistency in approach, but allowing for site-specific modifications and adaptations as necessary. This document serves as the starting point for negotiating a monitoring and reporting program. It is not a "copy and paste" list of static monitoring requirements, but an attempt to provide useful guidance. Therefore, this section outlines a procedure for implementing this guidance. We strongly recommend the user reread this section after reading sections 3.0, 4.0 and 5.0 in order to more fully understand this important implementation guidebook and place it in context.

The technical committee that developed the model program was well aware that stormwater monitoring has been ongoing for some time in many parts of southern California. Thus, important basic steps, such as stormwater characterization studies, have been completed by many programs (See Box on Discharge Characterization). In addition, the degree to which programs have addressed the five management questions in Figure 2-1 varies substantially, in part due to each program's history and in part due to the nature of the surface waters in different parts of the region. For example, inland programs in general have focused relatively more on identifying sources while coastal programs have allocated much more effort to assessing receiving

Stormwater Discharge Monitoring

The US EPA has published a manual (US EPA 1992) that provides detailed guidance for the basic elements of stormwater monitoring program design and implementation. This guidance is an extremely useful starting point for management programs faced with the necessity of performing initial characterization studies.

The manual describes when and where to sample, including defining storm event criteria, obtaining rainfall data, and dealing with the logistics of locating sampling sites. Alternative sampling methods (e.g., grab vs. composite, manual vs. automatic) are described and evaluated and special attention is given to the issue of measuring or estimating flow rates. In addition, the manual follows the analysis and reporting pathway once sampling is complete, providing detailed instructions on sample documentation, labeling, shipping, and chain of custody procedures.

water impacts, especially in high-use areas such as Newport or Santa Monica Bays.

The model stormwater monitoring program does not assume that each program is starting with a blank sheet of paper, nor that each program will implement the monitoring guidance in a linear, stepwise fashion. Instead, the model program is intended to improve each program's ability to build appropriate linkages among a key set of management questions (see Figure 2-1; Section 4.0). This is best accomplished through the following steps (see also Figure 2-3):

1. Evaluate a program's ability to answer each of the five management questions
2. Identify critical gaps in knowledge (e.g., inability to document impacts, lack of knowledge about potential sources, absence of trend monitoring component) relevant to each program's circumstances
3. Use the model program's monitoring guidance as a framework for developing monitoring components suited to each program's circumstances.

For Step 1, Appendix 1 summarizes current (as of June 2003) stormwater monitoring efforts in southern California, providing a first cut at assessing each program's ability to answer the five management questions. A full assessment under Step 1 would also involve a cumulative analysis of available historical monitoring data for each program. However, the variation among programs demonstrated in Appendix 1 suggests that implementing the model monitoring program would most likely involve focusing on different questions, and thus emphasizing different designs, for different programs. For example, source identification designs (Questions 3 and 4) might be needed for one program, but trend monitoring designs (Question 5) for another.

For Step 2, determining where to focus additional monitoring effort will depend on specific information on source characterization, patterns of development, hydrography and watershed structure, resources at risk, and levels and patterns of contamination. In addition, management initiatives in each program's area can influence decisions about what represents a critical knowledge gap. For example, TMDL development may require additional effort toward source identification. As another example, planned or ongoing BMP implementation may involve allocating additional effort to problem definition and/or to long-term trend monitoring to track BMP effectiveness.

For Step 3, the monitoring designs in the model monitoring program provide a starting point for developing detailed monitoring designs appropriate to the specifics of each program. The model framework is merely the foundation on which to build a permit-specific monitoring and reporting program. For example, the application of habitat monitoring designs based on bioassessment must take into account patterns of stream flow, the nature of biological communities, and the relative importance of urban runoff. The committee also considered the advisability of preparing explicit recommendations on the numbers and locations of sampling sites, and the degree of replication, but concluded that this was inappropriate given the amount of variation from program to program, as well as from place to place within each program. For example, numbers of stations will depend, among other things, on watershed size and complexity, amount and intensity of human use, severity and significance of potential impacts, known patterns of contamination, and hydrography of the study area. The degree of replication will depend on the kinds and amounts of variability in each area, as well as on the relative degree of certainty required by management agencies and the timeframe for decision making. Thus, the committee determined that each program should address the same five management questions and apply the same general monitoring design approaches, but then adapt the specifics of sampling to each individual situation. In this way, the model program will optimize comparability yet provide sufficient flexibility to address permit or site-specific needs

Table 2-1. Relationship between typical stormwater program monitoring objectives, as stated in NPDES permits, and the monitoring elements for which the model stormwater monitoring program prov**ides design guidance. “Q” refers to the management questions** described in Section 4.0 (e.g., Q1 refers to Question 1).

Permit objective	**Management question and type of monitoring**				
	Q1: Assessment	**Q2: Extent and magnitude**	**Q3: Urban runoff contribution**	**Q4: Source identification**	**Q5: Trends**
Define status, trends, pollutants	X				X
Evaluate impacts	X				X
Identify waters that do not attain uses	X	X			
Estimate mass emissions	X				X
Evaluate toxicity	X	X		X	
Identify polllutants of concern	X	X		X	
Identify sources of urban runoff pollutants			X	X	
Identify other sources			X	X	
Evaluate program effectiveness	X				X
Identify illicit connections				X	
Identify illicit discharges				X	

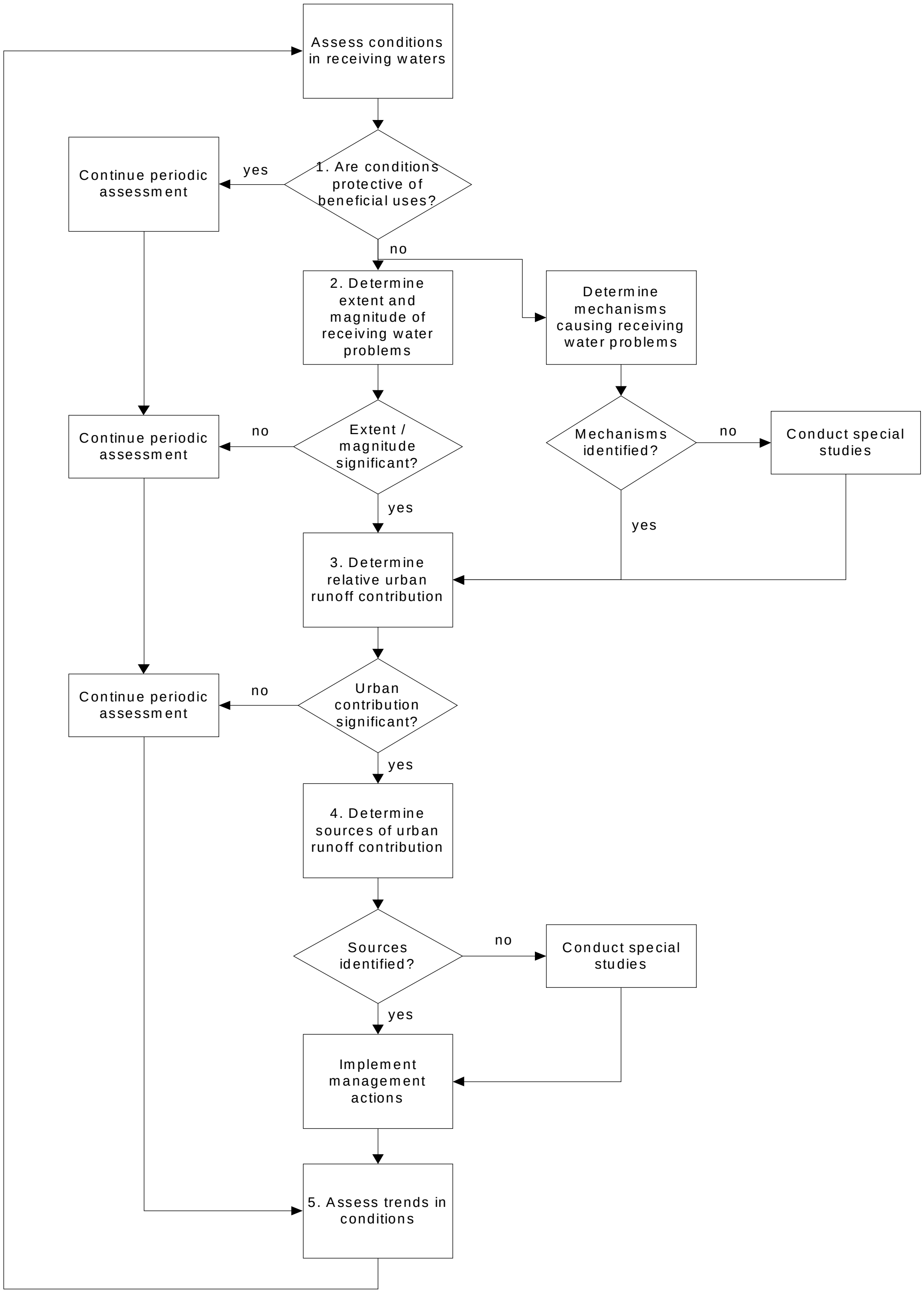


Figure 2-1. Graphical illustration of the idealized logical flow through the five core management questions (reworded as statements to fit flowchart conventions). The answer to each question provides the basis for developing the monitoring design to answer the next. In actuality, monitoring programs may have addressed questions in parallel or out of sequence, depending on available knowledge and specific information needs.

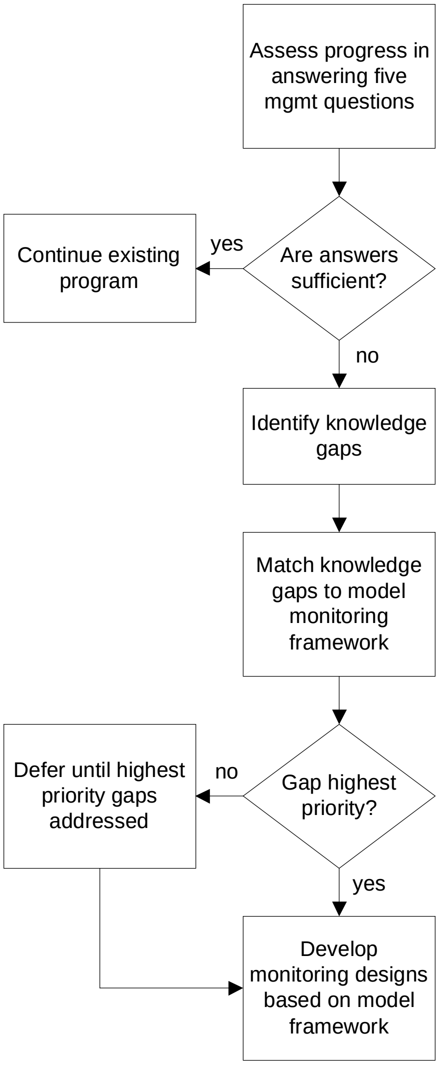


Figure 2-2. Sequence of steps involved in applying the model monitoring program framework to an existing stormwater monitoring program.

.

3.0 PRINCIPLES AND FRAMEWORK FOR A MODEL MONITORING PROGRAM

3.1 Principles for allocating monitoring effort

In developing the details of monitoring guidance to address the management questions and their related objectives, the committee was guided by three basic principles that provided an overall set of boundary conditions for monitoring design:

- Monitoring should be focused on decision making; data not helpful in making a decision about clearly defined regulatory, management, or technical issues should not be collected.
- The level of monitoring effort should reflect the potential for impact, with more monitoring allocated to situations where the potential impact (in terms both of the probability of an impact's occurrence and its extent and magnitude) is higher and less monitoring to situations where such potential is lower or where monitoring is not likely to provide useful information.
- Monitoring should be adaptive, in terms of its ability to both trigger follow-on studies as needed and make necessary mid-course corrections based on monitoring findings.

In addition, the committee identified three categories of monitoring activities that fulfill different types of information needs and defined them in the monitoring guidance in Section 5.0.

Core monitoring includes long-term monitoring, intended to track compliance with specific regulatory requirements or limits, to conduct ongoing assessments, or to track trends in certain important conditions over time. Thus, core monitoring generally occurs at fixed stations that are sampled routinely over time.

Regional monitoring includes cooperative studies that provide a larger-scale view of conditions in the southern California region. Regional monitoring can be used to assess the cumulative results of anthropogenic and natural effects on the environment. Regional monitoring also helps to place individual stormwater agencies' monitoring in perspective by comparing local results (i.e. core monitoring) to the breadth and depth of human impacts and natural variability found throughout southern California's watersheds. Regional monitoring requires the participation of all dischargers to the environment, not just MS4 permittees, thus potentially making this type of monitoring more cost-effective (see Box on Regional Watershed Monitoring). Finally, regional monitoring is best conducted periodically (i.e.

Regional Watershed Monitoring

There are many agencies in and around southern California in addition to municipal stormwater agencies that are interested in watershed to regional scale monitoring. For instance, the Statewide Ambient Monitoring Program (SWAMP) coordinated by the State Water Resources Control Board conducts monitoring throughout the southern California region in order to assess, among other things, the health of California's watersheds and estuaries. Another is the State's Wetlands Recovery Project, which has a similar goal as SWAMP, but is focused on wetland habitats. In a similar vein, the US Environmental Protection Agency coordinates the Environmental Monitoring and Assessment Program (EMAP), which monitors watersheds in the southern California region, but attempts to integrate these assessments nationally. Several other agencies are also monitoring in southern California's watersheds including the US Geological Survey's National Water Quality Assessment Program (NAWQA), the US Fish and Wildlife Service, numerous water reclamation plants, water districts, citizen monitoring organizations, and universities. Although each agency has a slightly different motive for monitoring, they all have at least one goal in common; to assess the health of the environment. Therefore, each one of these agencies represent an opportunity for a productive partnership in regional monitoring since they bring a different set of skills and perceptions to a meaningful collaboration.

every five years) because of its large spatial scale and integration among program types.

Special projects include specific targeted studies included as adaptive elements within core or regional monitoring designs. These are shorter-term efforts intended to extend or provide more insight into core monitoring results, for example, by investigating the specific sources of a receiving water problem. Special projects also include developmental research, designed to move monitoring science and policy forward. These can be used to demonstrate the value of particular analyses, to illustrate ways in which data can be used, or to develop new skills. These projects have a specified beginning, middle, and end. Stormwater programs may wish to conduct special studies individually or in coordination with the SMC.

3.2 Framework for developing monitoring questions and designs

The first major philosophical approach of the model urban runoff monitoring program is to help ensure that monitoring activities are:

- Linked directly to key management questions
- Integrated into a logically consistent whole
- Designed and structured for both cost effectiveness and scientific rigor.

To accomplish this set of ideals, the committee followed the philosophical framework of Bernstein et al. (1993), which outlines a series of successively more detailed levels of monitoring objectives. This philosophy includes series of logical steps that led from defining the key monitoring questions to specifying the technical detail of monitoring designs. This framework was defined as:

- Level I: broadly stated public and management core concerns (management questions)
- Level II: management and scientific objectives that include specific statements about time and space scales, reference conditions, and the monitoring approach to be used
- Level III: measurement goals that identify the types and amounts of change to be monitored for
- Level IV: specific technical plans and methods for implementing monitoring.

The second philosophical approach of the model program was to develop a framework that would provide broad consistency of approach, but can also be adapted or customized to meet local needs and conditions. One major concern of the technical committee was that, in its attempt to standardize monitoring programs regionwide, the model urban runoff monitoring program would become too inflexible to adapt to local site specific needs. Therefore, this document fully specifies Level I and Level II objectives (See Section 5.0), partially spells out Level III objectives, and provides examples, through technical guidance and brief case studies, of possible Level IV objectives (See Section 5.0). In addition, the companion documents that describe the laboratory intercalibration study and the data transfer and reporting formats do provide detailed Level IV objectives for two aspects of monitoring design that are important for ensuring comparability of data among programs. In this way, the model urban runoff monitoring program is not too restrictive, but provides sufficient guidance to make certain that managers throughout southern California have similar aims and approaches among programs.

4.0 MANAGEMENT QUESTIONS

There are five questions (or Level I objectives) that create a common foundation for monitoring design and urban runoff management in the region. These questions are not strictly independent, but are logically linked (Figure 2-1) where the answer to one question establishes the context for addressing the next. Thus, the management questions provide a means of organizing information about impacts, sources, and long-term trends in receiving water conditions into a logically consistent whole. The five management questions are:

- Question 1: Are conditions in receiving waters protective, or likely to be protective, of beneficial uses?
- Question 2: What is the extent and magnitude of the current or potential receiving water problems?
- Question 3: What is the relative urban runoff contribution to the receiving water problem(s)?
- Question 4: What are the sources to urban runoff that contribute to receiving water problem(s)?
- Question 5: Are conditions in receiving waters getting better or worse?

Each question can be addressed by one or more categories of monitoring effort, as summarized in Table 3-2. That is, some questions are best addressed using core monitoring, others questions are best addressed in a cooperative regional monitoring program, and others by directed special studies. The category(ies) of monitoring effort is identified within each question description.

The committee recognized that there are many beneficial uses enumerated in the region's Basin Plans and agreed that the five core management questions are equally applicable to the entire range of beneficial uses. However, for purposes of developing specific monitoring guidance, it chose to focus on a subset that is common to most municipal stormwater programs in the region and for which monitoring and regulatory approaches are relatively well established. These include:

- Contact Water Recreation (REC1)
- Non-contact Water Recreation (REC2)
- Warm Freshwater Habitat (WARM)
- Estuarine Habitat (EST)
- Marine Habitat (MAR)
- Wildlife Habitat (WILD).

The following subsections describe each question in more detail including background and rationale, explain how they are functionally interrelated (see also Figure 2-1), and describe the specific management and scientific objectives appropriate to each question including expected data products. For each question, the technical committee defined:

- What is the management goal?
- What monitoring strategy is suitable?
- What degree of certainty and precision is possible or required?
- What reference conditions are appropriate?
- What spatial scale is appropriate?

- What temporal scale is appropriate?

These questions and objectives then form the basis for the more detailed monitoring designs described in Section 5.0.

4.1 Question 1: Are conditions in receiving water protective, or likely to be protective, of beneficial uses?

4.1.1 Background to Question 1

Question 1 is a fundamental linch-pin for many, if not most, aspects of stormwater management. The presence of receiving water problems, or at least the potential for such problems, is the justification for a broad range of activities to better identify and reduce sources of contamination from urban runoff that may cause or contribute to such problems. In addition, detailed information about the nature of receiving water problems can greatly improve the effectiveness of a wide range of management actions. In principle, the design of any receiving water monitoring program should be based on reconnaissance and/or characterizations studies that target the likely sources and locations of receiving water problems. However, the southern California stormwater programs have already generated substantial information about where receiving water problems should be monitored for. Thus, the model monitoring program does not include a reconnaissance or characterization step for Question 1. However, where information on conditions in receiving waters is sparse or nonexistent, it may be necessary to initially conduct broad reconnaissance studies and/or evaluations of available historical data to determine the likely sources and locations of current or potential problems in receiving waters. In those cases, USEPA guidance (US EPA 1992) is available to direct the design of such studies.

In general, there are two often competing approaches to assessing whether conditions in receiving waters constitute a “problem”, the compliance approach and the assessment approach. The committee described a compliance approach as one in which monitoring is used to determine if the value of an indicator is above or below a quantitative regulatory threshold. In this approach, the indicator measure would be considered as evidence of recreational water quality or habitat problem, acting as a surrogate for more detailed studies involving a larger range of measures. Exceedance of compliance standards would then provide the basis for management actions such as source identification studies, source control efforts, and further iterative monitoring and management actions. In contrast, an assessment approach would not be based primarily on comparison to specific quantitative thresholds or limitations. Rather, it would focus on better understanding actual conditions in the receiving water (i.e., the actual nature of problems) and is based on a weight of evidence approach in which chemical, biological, and ecological data are used to assess impacts. This approach emphasizes developing evidence of actual impacts in receiving waters in addition to, or instead of, evidence derived only from indicator measures.

The model monitoring committee believes that these two approaches should be complementary, rather than competitive or mutually exclusive. Thus, evidence provided by indicators could help initiate further studies to determine actual problem(s) and identify sources. Quantitative thresholds or limitations could be used to trigger or justify needed management actions, and the overall timeframe would be long enough to encompass iterations of monitoring and management efforts. The program design guidance in Section 5.0 illustrate how both approaches can be used in tandem, as in, for example, the use of mortality levels of indicator organisms in toxicity tests as a trigger for follow-up TIEs to identify the source(s) of toxicity.

4.1.2 Recreational water quality objectives

The Level II objective suggested for recreational water quality for Question 1 is described in Table 4-3 that focuses primarily on identifying conditions that may present elevated risk to humans from body contact recreation. The Level II management/monitoring objective can be stated as:

> Monitor a suite of bacterial indicators at high-priority sites selected by qualitative risk characterization and affected by urban runoff, including along beaches; in enclosed bays and estuaries; and along creeks, streams, and rivers at frequencies needed to ensure that relevant freshwater and marine standards are being met, to a moderate degree of certainty and precision.

The types of data products appropriate for answering Question 1 for recreational water quality may include:

- Frequent (daily, weekly, monthly depending on the circumstance) measures of fecal coliform or E. coli, total coliform, and Enterococcus at high-priority (defined in Section 5.1.1 as having both high use and elevated levels of indicator bacteria) beaches, coastal storm drains, lagoons, bays, estuaries, and inland creeks, streams, and rivers (Tables of individual measurements and relevant averages)
- Comparisons of bacterial indicator values with relevant standards (i.e., REC1, REC2, AB411) on spatial and temporal scales that match sampling scales as closely as possible (tables that highlight exceedances, figures that show exceedances over time)
- Summaries that identify the relative degree of contamination at monitored locations (i.e., maps, Heal the Bay's Report Card for beaches in Santa Monica Bay).

4.1.3 Habitat objectives

The Level II objective suggested for habitat health for Question 1 is described in Table 4-4. The Level II management/monitoring objective can be stated as:

> Use the Triad approach as a basis for monitoring both specific sites of high concern, as well as a set of random watershed sites, at least yearly and assess overall habitat health by comparing a suite of measurements to relevant reference conditions, to a moderate degree of certainty and precision. Use the Triad results to trigger an appropriate set of adaptive follow-up studies intended to better characterize conditions.

As might be expected, given both the inherent complexity of ecosystem monitoring and the variety of measurements included in the Triad approach, there is a range of reference conditions potentially applicable to monitoring of this question. The committee therefore recommended a structured framework for using reference conditions in the interpretation of Triad monitoring results (see Section 5.0).

The types of data products appropriate for answering Question 1 for habitat include:

- Site-by-site summaries of each sampled leg of the Triad (tables of individual measurements and relevant averages)
- Site-by-site interpretations and conclusions based on synthesized Triad results (narrative conclusions, decision trees)

- Comparisons across sites for each leg of the Triad (tables highlighting differences, maps)
- Comparisons across sites for synthesized Triad results (narrative conclusions, decision trees, maps)

4.2 Question 2: What is the extent and magnitude of the current or potential receiving water problems?

4.2.1 Background to Question 2

Question 2 is framed as the logical next step once receiving water problems related to urban runoff are found or predicted. Question 2 thus expands on the information provided by Question 1as a basis for describing the spatial and temporal extent of existing or likely impacts, as well as their relative intensity. This information is necessary for assessing the relative severity or importance of different problems, targeting source identification efforts, and planning management actions such as source reduction efforts.

In most cases, monitoring designs to answer Question 1 will include only representative sites within key recreational areas or habitats. Thus, once a receiving water problem is found, data from these sites will most often be insufficient to characterize the full extent and magnitude of the problem and additional studies will normally be called for. This is because most managers need to know the severity of a problem before proceeding with some remedial action. Impacts that cover large areas or extend over long periods of time typically require more immediate attention. The information collected to answer Question 2 is important for scoping the source identification studies that are the focus of Questions 3 and 4 (see Figure 2-1).

In some cases, the extent, magnitude, and/or severity of a receiving water problem will be immediately apparent from the core monitoring data obtained under Question 1. In such cases, for example, very high bacteria counts along a popular beach or severe toxicity in an enclosed lagoon, source identification work as described in Questions 3 and 4 should begin promptly. In addition, un-permitted dry weather discharges are specifically forbidden and such discharges should therefore also be a high priority for prompt source identification studies. In other cases, broader sampling to assess spatial and temporal extent will be required, usually as shorter-term studies that are conducted once or perhaps periodically when there is reason to believe the scale of the problem has changed. In some situations, where the problem is complex and/or covers a large area, addressing Question 2 will involve regional studies that require the cooperative efforts of several agencies. Monitoring under Question 2 would be conducted in either wet or dry weather, depending on the specific issue and in accord with the findings of Question 1.

4.2.2 Recreational water quality objectives

The Level II objective suggested for recreational water quality for Question 2 is described in Table 4-6. The Level II management/monitoring objective can be stated as:

> Monitor a suite of bacterial indicators at a spatially and temporally more intensive set of stations around sites, prioritized by risk, in order to define the extent of problems to a moderate degree of certainty and precision, and compare indicator levels to relevant marine and freshwater standards in order to define the relative severity of the problem, also to a moderate degree of certainty and precision.

The types of data products appropriate for answering Question 2 for recreational water quality include:

- Measures of the spatial extent of bacterial contamination (maps)
- Measures of the temporal patterns of bacterial contamination (figures that show temporal patterns, measures of variance)
- Measures of the relative magnitude of indicator values over space and time (graphs of concentration over time or by site).

4.2.3 Habitat objectives

The Level II objective suggested for habitat for Question 2 is described in Table 4-7. The Level II management objective can be stated as:

> Monitor specific aspects of the Triad, including adaptive elements such as additional chemistry measurements or TIEs, at a spatially and temporally more intensive set of stations where impacts have been observed in order to define the extent of problems to a moderate degree of certainty and precision, and compare measurements to relevant marine and freshwater standards in order to define the relative severity of the problem, also to a moderate degree of certainty and precision.

The types of data products appropriate for answering Question 2 for habitat include:

- Measures of the spatial extent of modified communities, chemical contamination, and/or elevated toxicity (maps)
- Measures of the temporal patterns of modified communities, chemical contamination, and/or elevated toxicity (figures that show temporal patterns, measures of variance)
- Measures of the relative magnitude of indicator values over space and time (graphs of concentration or toxicity over time or by site).

4.3 Question 3: What is the relative urban runoff contribution to the receiving water problem(s)?

4.3.1 Background to Question 3

Once monitoring or other studies demonstrate that there is a current or potential impact to receiving waters (Question 1) and describe the problem’s extent and magnitude (Question 2), decisions about any management responses depend on information about the source(s) of the problem. The model monitoring framework breaks this source identification into two parts (Figure 2-1), represented by Questions 3 and 4. The purpose of this two-step process is to prioritize more detailed source identification efforts in Question 4 at only those problems for which urban runoff is a significant contributor. Question 3 begins this process by taking the information from Questions 1 and 2 and beginning to work upstream, both literally and figuratively, to better define the overall contribution of urban runoff to receiving water problems. It is important to clarify that this two-step process involving Questions 3 and 4 is not intended in any way to diminish or replace municipalities’ permit requirements to reduce contaminant inputs to the maximum extent practicable. It is rather intended to help determine when additional, more detailed and extensive, upstream source identification efforts should be conducted by a municipality, with the goal of ensuring that the full burden of source identification work not be shifted to the MS4 permittees where action by them would not solve the larger problem.

The model monitoring framework assumes that, if urban runoff contributes only a very small percentage to the receiving water problem, then there would be no need for a municipal permittee to independently carry out substantial source identification efforts in addition to those activities usually carried out under the municipal stormwater permit. For a first-cut estimation, therefore, Question 3 requires only minimal resolution, including at least a rough estimate of the identity and magnitude of the non-urban runoff contributions. In many situations, aggregate estimates of the non-urban runoff contribution, rather than source-by-source estimates, may be adequate and may already be available from previous characterization and/or monitoring studies. Only if urban runoff is found to contribute significantly to receiving water problems would a municipality be required to take the lead on conducting further source identification studies at greater resolution (as described in Question 4).

The committee engaged in substantial discussion of criteria for prioritizing source identification work and agreed that several factors should be taken into account in each instance, including:

- The severity of the problem
- The type of pollutant(s) involved
- The potential for human health risk
- The relative certainty of the estimates of relative contribution from different sources. If the estimate of urban contribution is very low, then even high uncertainty might not be important. However, if the estimate is higher, e.g., 10%, and the uncertainty is high (e.g., could be as high as 30%) then that would be a different situation
- Whether the problem occurs during dry and/or wet weather, since dry weather problems may be more easily dealt with
- The biological resources at issue
- Regulations and other legal mechanisms that require source identification and/or control
- Stakeholder involvement such as watershed group planning priorities.

The committee agreed that source identification work should be prioritized based on the factors above, and that the threshold level for further independent source identification efforts by the permittees should be somewhere between 5 – 10%. It is important to emphasize that this threshold is intended as a guideline only in situations where the source of a receiving water problem is not known. Where the source(s) of such problems are known, then relevant permit conditions related to source reduction and cleanup would come into play. As emphasized above, this threshold is not intended to diminish or replace permit requirements to reduce contaminant inputs to the maximum extent practicable (MEP) or other regulations or legal requirements.

4.3.2 Recreational water quality and habitat objectives

The Level II objective suggested for both recreational water quality and habitat for Question 3 is described in Table 4-8. The Level II management objective can be stated as:

> Using parameters relevant to the nature of the receiving water problem, estimate the proportional contribution of urban runoff at the most downstream point of input to the receiving water, based on a loads study performed at minimal to moderate resolution, and repeated every several years as needed.

The types of data products appropriate for answering Question 3 for both recreational water quality and habitat include:

- Description of all potential sources of inputs to the receiving water (maps of potential sources)
- Rough estimates of the relative magnitude of loads from all sources (table of concentrations or loads by source)
- Rough estimate of the proportional contribution of urban runoff to total loads (pie charts or stacked bar charts).

4.4 Question 4: What are the sources of the urban runoff contribution to receiving water problems?

4.4.1 Background to Question 4

Once it has been determined, either through specific studies carried out under Question 3 or through other available data, that urban runoff is, or is likely to be, a significant source of one or more receiving water problems, then more intensive source identification efforts are called for. Question 4 thus involves more thorough source identification studies intended to provide more detailed information about the nature, location, and quantity of inputs to the receiving waters identified in Question 1. This information can help refine receiving water monitoring, improve fundamental understanding of stormwater contamination processes, and help guide management actions intended to reduce sources and their attendant impacts. It can also help focus trend monitoring on those parameters that are potentially most responsive to urban runoff source reduction efforts.

In the context of Question 4, “sources” can refer to multiple layers of sources, such as a golf course that is the source of pesticides, which are in turn the source of toxicity in the receiving water. Thus, questions about sources should be framed carefully in order to clarify both the spatial definition of “upstream source” as well as the level of causality that is the central focus of the investigation.

4.4.2 Recreational water quality and habitat objectives

The Level II objective suggested for both recreational water quality and habitat for Question 4 is described in Table 4-9. The Level II management objective can be stated as:

> Using parameters relevant to the nature of the receiving water problem, prioritize receiving water sites for upstream source identification studies and perform source identification studies at the watershed scale and to a moderate degree of resolution until the appropriate stopping rules are reached.

The types of data products appropriate for answering Question 4 for both recreational water quality and habitat include:

- Prioritization of receiving water sites in terms of severity of impact (ranked list of sites)
- Description of all potential urban runoff sources of inputs to the higher priority receiving waters (map of potential sources)
- Determination of actual sources of urban runoff and their relative magnitude (table of concentrations and flows by source with estimated levels of confidence)
- Quantitative estimates of the loads from urban runoff sources(table of loads by source with estimated levels of confidence).

4.5 Question 5: Are conditions in receiving waters getting better or worse?

4.5.1 Background to Question 5

Assuming that monitoring related to Questions 1 – 4 has resulted in improved information about the nature and source(s) of current and/or potential receiving water problems, and that this in turn has led to management actions to address such sources, Question 5 provides the logical feedback to determine if such actions are improving conditions in receiving waters. Given that changes in receiving water conditions are likely to occur over several years (at the least), Question 5 is a trends monitoring question. The trends of interest are in both discharges and receiving waters and the time frame for this question is the longer-term period needed to determine if management actions are having their intended effects.

In its simplest form, a trend monitoring design involves repeated sampling over time at the same monitoring site(s). The ability of a trend design to detect change depends on:

- The amount of change it is important or necessary to detect
- The timeframe within which decision makers need information about trends
- The variability of the indicator on different time scales, typically shorter term (weekly, monthly) and longer term (yearly)
- The resources available for sampling and analysis.

Developing the specifics of the monitoring design thus involves making a series of tradeoffs among these factors.

The statistical power of a monitoring design is its ability to detect a change of a certain size, if it in fact has occurred. Power analysis, used to estimate the power of a given design, can provide insight into the sampling effort (both in terms of the number of samples per year and the number of years) required to observe trends of different size. In addition, power analyses can reveal important inherent constraints on the ability to detect trends imposed by underlying variability in the system being monitored. This can provide a realistic basis for establishing both management and monitoring goals, as well as a basis for making tradeoffs in the monitoring design (e.g., between the number of samples collected per year and the number of years over which the trend monitoring will extend).

Figure 4-1 provides an example of how site-specific power analysis results might be used. In one instance (Figure 4-1a), trend monitoring would be futile and monitoring resources should be shifted to another site and/or issue. In a second instance (Figure 4-1b), the only way to improve the design’s ability to detect a trend is to increase the number of years to be monitored. In such an instance, the length of time needed to detect a trend must be compared against both the management time horizon (i.e., how quickly is information needed?) and the timeframe over which changes are expected to occur (e.g., how rapidly are BMPs expected to reduce loads?). In a third instance (Figure 4-1c), the main way to improve the design’s power is to increase the number of samples per year. However, for some questions, there is a natural constraint imposed by the relatively small number of storms per year in southern California. In such cases, the monitoring design will have an inherent limit on its ability to detect trends within a given time period. In a final example (Figure 4-1d), sampling additional times per year and monitoring for more years must be traded off against each other, since increasing both kinds of sampling intensity improves power. Such tradeoffs should be based on both the management time horizon and the timeframe over which changes are expected to occur. Thus, if an answer to Question 5 is not immediately urgent, then the number of samples per year can be reduced and the timeframe extended into the future.

Appendix 2 uses historical data from the southern California region to provide example power analysis results for trend monitoring of bacteria and mass emissions. Sufficient data for power analyses of other data types (e.g., bioassessment, toxicity) are not yet available. Because power analysis results can vary widely from site to site and across constituents, these results should be considered only as a “starter kit” for trend monitoring designs. The committee strongly recommends that each trend monitoring program conduct its own site-specific power analyses after obtaining three years of trend data, and revise its monitoring design accordingly based on these results. To support such program-specific design efforts, the committee has developed a simple software package that automates the needed power analysis (Go to http://www.sccwrp.org to download a copy of this program). Because trend monitoring programs will typically continue for many years, this approach will enable trend monitoring to begin and then to adjust its design appropriately with little or no loss of information.

The central importance of estimates of variability in trend monitoring highlights the importance of improving our basic understanding of sources of variability in MS4s. Thus, in addition to tracking trends over time, the analysis of monitoring data under Question 5 should include efforts to examine and quantify sources and patterns of variability in monitoring data, with the overall goal of reducing any controllable variability (i.e., variability introduced through sampling techniques and laboratory analysis, or due to spatial and temporal sources that can be accounted for in the structure of the monitoring design itself).

Finally, a full answer to Question 5 should also include an assessment of changes in the extent and magnitude of impacts over time. Such an assessment can be accomplished by repeating the studies described in Question 2.

4.5.2 Recreational water quality objectives

The Level II objective suggested for recreational water quality for Question 5 is described in Table 4-10. The Level II management objective can be stated as:

> Monitor bacterial indicators at fixed stations over a number of years to determine, to a moderate degree of resolution, whether levels have increased or decreased compared to historical data and to relevant standards.

The types of data products appropriate for answering Question 5 for recreational water quality include:

- Graphs of the levels of bacterial indicators over time at each station of concern
- Periodic statistical power analysis results to confirm the power of the trend monitoring design.

4.5.3 Habitat objectives

The Level II objective suggested for habitat for Question 5 is described in Table 4-11. The Level II management objective can be stated as:

> Monitor relevant habitat indicators at fixed stations over a number of years to determine, to a moderate degree of resolution, whether levels have increased or decreased compared to historical data and to relevant standards.

The types of data products appropriate for answering Question 2 for habitat include:

- Graphs of the levels of habitat indicators over time at each station of concern
- Periodic statistical power analysis results to confirm the power of the trend monitoring design.

Table 4-1. Relationship between the five key management questions and the three basic categories of monitoring activity. Core monitoring for Questions 1 and 5 typically occurs at fixed stations over a period of time. The design of regional monitoring and special projects under Questions 2, 3, and 4 is contingent on monitoring results from other core management questions. Numbers in italics (e.g., *5.1.1*) refer to report sections that detail specific design guidance for each element of the model monitoring program.

Management Questions	Core Monitoring	Regional Monitoring	Special Projects
1. Are conditions protective?	Recreational water quality assessment (wet & dry) *5.1.1* Ecosystem assessment (dry) *5.1.2*		
2. What is extent / magnitude?		One-time or periodic larger-scale assessment (depends on Question 1) *5.2*	One-time or periodic larger-scale assessment (depends on Question 1) *5.2*
3. What is urban runoff contribution?		One-time characterization, assessment (depends on Questions 1 & 2) *5.3*	One-time characterization, assessment (depends on Questions 1 & 2) *5.3*
4. What are sources of urban contribution?			Site-specific, one-time or periodic source ID studies (wet & dry) (depends on Question 3) *5.4*
5. Are conditions getting better or worse?	Long-term trends monitoring (wet & dry) of: • Bacterial indicators *5.5.1* • Habitat indicators (incl. loads) *5.5.2*		

Table 4-2. Level II objectives for recreational water quality monitoring for Question 1: Are conditions in receiving waters protective of beneficial uses? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q1 recreational water quality	**Level II objective – Q1 recreational water quality**
Management goal	Protect human health by meeting existing standards
Monitoring strategy	Allocate sampling effort with respect to overall risk (combination of use and contamination) Monitor bacteria indicators (fecal coliform (or E. coli), total coliform, Enterococcus) Use improved indicators when available and approved by health department Adaptive link to magnitude, extent, and upstream urban runoff source identification studies
Degree of certainty and precision	Moderate
Reference conditions	Freshwater standards (REC1, REC2) Marine standards (AB411)
Spatial scale	Open-coast beaches Specific coastal storm drains Bay, lagoons, estuaries Rivers and creeks
Temporal scale	Daily (for health risk) Weekly (for health risk) Seasonal (for health risk, trends)

Table 4-3. Level II objectives for habitat monitoring for Question 1: Are conditions in receiving waters protective of beneficial uses? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q1 habitat	**Level II objective – Q1 habitat**
Management goal	Protect ecosystem health by tracking the relationship of indicators to relevant reference conditions
Monitoring strategy	Triad approach Coordinated watershed and subwatershed scales Adaptive monitoring triggers depending on triad results Sites targeted at specific management issues
Degree of certainty and precision	Moderate
Reference conditions	Basin Plan Ocean Plan Regional IBI (for stream bioassessment) CTR (for chemistry) Toxicity test reference Historical reference conditions (site-specific) Local reference conditions (site-specific) Other watersheds (regional)
Spatial scale	Site-specific (e.g., Talbert Marsh) Watershed / subwatershed Jurisdictional
Temporal scale	Yearly Several years

Table 4-4. Level II objectives for recreational water quality monitoring for Question 2: What is the extent and magnitude of receiving water problems? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q1 recreational water quality	**Level II objectives – Q1 recreational water quality**
Management goal	Define the scale of impact
Monitoring strategy	Short-term sampling at broader spatial extent Sampling appropriate to define temporal patterns at weekly to seasonal scales Measure bacteria loads at MS4 discharge locations
Degree of certainty and precision	Moderate
Reference conditions	Freshwater standards (REC1, REC2) Marine standards (AB411) Comparisons across parts of the region
Spatial scale	Watershed / subwatershed Jurisdictional Regional
Temporal scale	For REC1 objective, geomean over a season Process-based (e.g., seasonal) 3 years for impairment (303d)

Table 4-5. Level II objectives for habitat monitoring for Question 2: What is the extent and magnitude of receiving water problems? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q2 ecosystem	**Level II objectives – Q2 ecosystem**
Management goal	Receiving water conditions improve (if impaired) Receiving water conditions remain the same (if not impaired)
Monitoring strategy	Triad monitoring in key receiving waters Long-term trend monitoring Adaptive toxicity testing Adaptive upstream toxicity testing
Degree of certainty and precision	Moderate
Reference conditions	Basin Plan Ocean Plan Regional IBI (for stream bioassessment) CTR (for toxicity) Toxicity test reference Comparisons across parts of the region
Spatial scale	Watershed / subwatershed Jurisdictional Regional
Temporal scale	Periodic snapshots (yearly)

Table 4-6. Level II objectives for both recreational water quality and habitat monitoring for Question 3: What is the relative urban runoff contribution to the receiving water problem(s)? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q3 recreational water quality & habitat	**Level II objective – Q3 recreational water quality & habitat**
Management goal	Estimate the proportional contribution of urban runoff to problem(s) in specific receiving water
Monitoring strategy	Loads estimation
Degree of certainty and precision	Minimal to moderate
Reference conditions	Relative severity of local receiving water problem(s) Relative contribution of urban runoff to other receiving waters in the region
Spatial scale	Point of input to receiving water (scales depending on definition of receiving water)
Temporal scale	Periodic assessment (every 5 years)

Table 4-7. Level II objectives for both recreational water quality and habitat monitoring for Question 4: What are the sources to urban runoff that contribute to receiving water problems? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q4 recreational water quality & ecosystem	**Level II objectives – Q 4 recreational water quality & ecosystem**
Management goal	Urban sources identified and resolved
Monitoring strategy	Prioritize downstream sites Upstream source ID studies
Degree of certainty and precision	Moderate to great
Reference conditions	Internal tests of “signal” strength
Spatial scale	Watershed / subwatershed Jurisdictional Regional
Temporal scale	Until stopping rules reached

Table 4-8. Level II objectives for recreational water quality monitoring for Question 5: Are conditions in receiving waters getting better or worse? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q5 recreational water quality	**Level II objectives – Q5 recreational water quality**
Management goal	Reduction in indicator levels Identification and removal of key sources
Monitoring strategy	Repeated monitoring at specific sites over a season Long-term trend monitoring
Degree of certainty and precision	Moderate
Reference conditions	Standards Historical data as a basis of trends
Spatial scale	Specific receiving waters Where use is concentrated Watershed / subwatershed Jurisdictional
Temporal scale	For REC1 objective, geomean over a season Process-based (e.g., seasonal) 3 years for impairment (303d) Permit term (~ 5 years) for trends TMDL implementation phase (~ 10 years)

Table 4-9. Level II objectives for habitat monitoring for Question 5: Are conditions in receiving waters getting better or worse? Aspects of the objective are organized around the six categories of information that make up each Level II objective.

Level II category – Q5 habitat	**Level II objective – Q5 habitat**
Management goal	Conditions improve (if degraded) Conditions remain the same (if not degraded)
Monitoring strategy	Triad approach
Degree of certainty and precision	Moderate
Reference conditions	Basin Plan Ocean Plan Regional IBI (for stream bioassessment) CTR (for chemistry) Toxicity test reference
Spatial scale	Watershed / subwatershed Jurisdictional
Temporal scale	Permit cycle for overall assessment Process-based for specific components Bioassessment (greater than 5 years) Bioaccumulation (e.g., short-term for Se, long-term for DDT) BMP (based on site-specific geomorphology, BMP mechanism) Hydrology (annual) Toxicity (sporadic, seasonal)

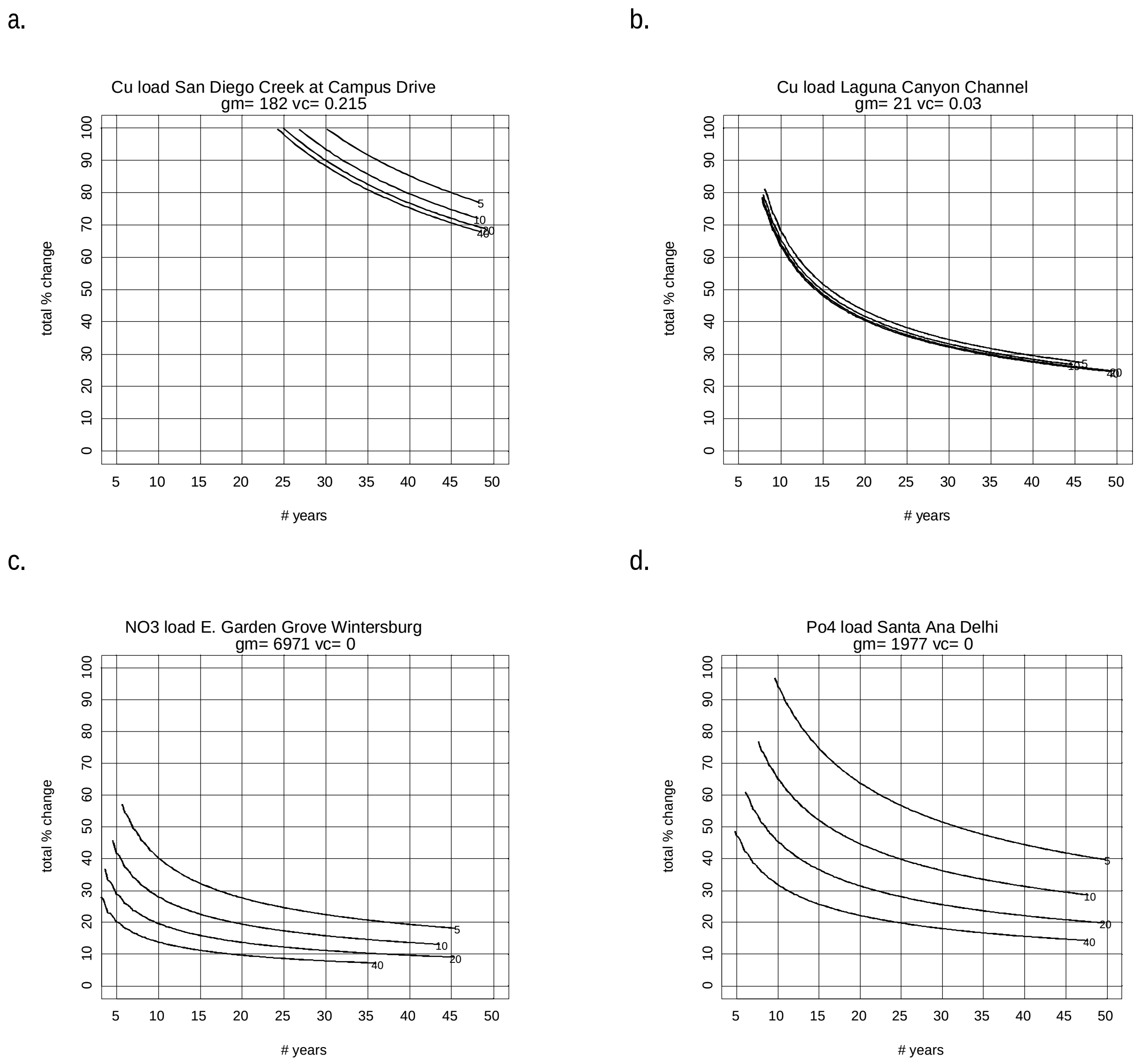


Figure 4-1. An example of the range of site-specific statistical power analysis results that can provide useful guidance for both trend monitoring design and setting management and monitoring goals. In the example figures below, the x-axis shows the number of years over which trend monitoring could continue and the y-axis the amount of change monitoring could detect. The four curves represent different amounts of sampling intensity per year. a. Even large amounts of sampling will not detect trends. b. Increasing the number of sampling events per year will not increase power because virtually all the variability is year-to-year variability. c. Increasing the number of years sampled beyond a certain point will not increase power because virtually all the variability is within-year variability. d. Both within- and between-year variability are important and increasing both kinds of sampling intensity will increase power.

5.0 MONITORING GUIDANCE

The following sections provide specific guidance for the design of core monitoring, regional monitoring, and special projects needed to address each of the core management questions (Table 4-1). The description of each monitoring design follows the same format:

- An overview that quickly summarizes the major features of the design, including a table of key design elements
- A lengthier description of specific design elements, such as station selection, monitoring frequency, indicators, triggers or thresholds for regional monitoring and/or special projects
- A discussion of design issues that describes the underlying rationale for the design and any important constraints that may affect monitoring success.

As the description of the key management questions and objectives (Section 4.0) makes clear, monitoring guidance focuses on recreational water quality and habitat issues. In some cases, distinct monitoring designs are required for each set of issues, while in other cases the same design approach is suitable for both. Where distinct monitoring designs are required, recreational water quality and habitat beneficial uses are presented separately.

5.1 Assessment monitoring

Assessment of recreational water quality and habitat conditions addresses Question 1: Are conditions in receiving waters protective, or likely to be protective, of beneficial uses? Data from such monitoring provides the basis for other aspects of the model program (Figure 3-1) intended to better characterize the extent and magnitude of any problems (Question 2), identify sources (Questions 3 and 4), and track trends in condition over time (Question 5).

Assessment monitoring effort falls exclusively into the core and regional monitoring categories (Table 4-1). Core monitoring is that conducted by individual agencies to evaluate issues related to specific sites or watershed. Regional monitoring is that conducted cooperatively by multiple agencies (see box on regional monitoring) to address issues across broader scales and time periods. In many cases, the same monitoring sites and/or approaches can meet both core and regional monitoring needs.

5.1.1 Recreational water quality assessment

5.1.1.1 Overview and philosophy

Design overview. Table 5-1 presents an overview of the technical design elements for assessment of recreational water quality conditions at beaches; bays and estuaries; and creeks, streams, and rivers. The following discussion does not include inland lakes and reservoirs, which, because they represent a special case, the committee agreed to defer until a later time.

The model monitoring framework allocates core monitoring of bacterial indicators to high-priority locations based on risk of adverse health effects. This risk is defined in terms of a combination of level of contamination and degree of human body contact use. In general, local public health departments have completed risk characterization for many waterbodies with recreational beneficial uses, particularly for marine beaches. Additionally, local health agencies have already established routine monitoring locations at many marine beaches that are sampled at least weekly. To address the assessment of recreational water quality conditions, the model program recommends that stormwater agencies build upon the monitoring data, local knowledge, and experience of the local public health departments. Thus, the model monitoring committee explicitly assumed that local public health agencies would take the lead in specifying high priority areas based on their knowledge and experience.

Somewhat different monitoring designs are recommended for linear open-coast beaches, enclosed bays and estuaries, and creeks/streams/rivers, based on differences in their basic hydrology. The number of sampling locations is dependent on the size of an area and its level of relative risk, as is the sampling frequency. However, at all monitoring sites, monitoring should measure indicator levels in the discharge itself, as well as upcoast and downcoast (or upstream and downstream) of the discharge. In addition, where the monitoring objective is to determine whether overall conditions constitute a problem as opposed to monitoring for body contact, monitoring may be focused on that portion of the year that represents the worst-case scenario.

At the moment, there are no ongoing regional monitoring efforts focused on recreational water quality, with the exception of the Bight Program's periodic snapshots of shoreline water quality and the new regional harbors monitoring program being developed by the San Diego Regional Water Quality Control Board. Both programs rely on a probability-based design intended to support general conclusions about the relative degree of contamination in different parts of the region.

Design philosophy. The model design framework specifies somewhat different approaches for core monitoring at linear open-coast beaches; enclosed bays and estuaries; and creeks, streams, and rivers. However, all three approaches reflect the basic assumption that monitoring resources should be allocated based on risk. Where the county health departments and the State Board's Beach Water Quality Work Group (BWQWG) have established monitoring approaches and/or designs, the model stormwater program will remain consistent with these. The committee felt that, ultimately, the county health departments are one end-user for much of this data since they have the responsibility for assessing if a beach should be closed or posted for swimming.

Widely accepted risk management principles recommend allocating monitoring and management effort in proportion to the relative degree of risk. The basic design feature of the model urban runoff monitoring program for Question 1 for recreational water quality therefore is to focus effort at those places and times (whether wet or dry weather) where human health risk associated with urban runoff is the highest. The model design assumes that risk, at the population level, is directly related to exposure, and estimates exposure, in turn, as the qualitative combination of estimates of bacterial contamination and the intensity of human use. While these qualitative risk estimates may be improved by future risk assessments, this improved information should not alter the basic principle of allocating monitoring in terms of relative risk.

There are three types of situations that are relevant to stormwater monitoring programs and that require somewhat different monitoring approaches:

- Linear, open-coast beaches
- Enclosed bays and estuaries
- Inland creeks, streams, and rivers.

Both linear, open-coast beaches and enclosed bays and estuaries can have many kinds of bacteria inputs, although they differ somewhat. Open-coast beaches can receive bacteria from storm drains, river discharge, wildlife, intense beach usage, pet waste, terrestrial vegetation decomposition, improperly maintained toilet facilities, and perhaps kelp decomposition. In addition to these potential sources, enclosed bays and estuaries can also be affected by bacteria from maintenance activities, homeless populations, groundwater, moored boats, failing septic systems, and concentrated populations of birds. The primary urban inputs of bacteria to inland creeks, streams, and rivers are through storm drain discharges, homeless encampments, unauthorized public use, and passage of domestic and wild animals. These and other differences stemming from their basic hydrology lead to a different approach for each situation. For each type of area, risk characterization should be completed in conjunction with the local health department.

The model design framework for regional monitoring adopts the probability-based design approach used by the Bight Program and assumes that, for purposes of assessment, the Bight Program does an adequate job of shoreline assessment. The Bight Program design is being used as a basis for developing a somewhat more spatially intensive regional monitoring program for enclosed bays and estuaries in the San Diego Region. Once this is completed, it can act as a design template for regional monitoring in other enclosed bays and estuaries throughout southern California. The model monitoring committee determined that, at present, concerns about recreational water quality in inland creeks, streams, and rivers were site specific enough to be dealt with by the core monitoring design. If there is a need for a regional assessment in the future, the basic stratified random sampling design used in the Bight Program would also apply here (see Section 5.1.2 Habitat assessment for more detail on regional watershed designs).

5.1.1.2 Design elements

Somewhat different monitoring designs are recommended for core monitoring at the three types of monitoring locations.

Linear open-coast beaches. Monitoring of storm drains (i.e., MS4s) discharging to beaches should conform to the prioritization framework (Table 5-2) established by the State Board's Beach Water Quality Work Group (BWQWG).

In this framework, the highest monitoring frequency of daily to five times per week is targeted at beaches with lifeguards and many potential sources of bacteria and a lower monitoring frequency (e.g., weekly to monthly) is applied to less heavily used beaches and/or beaches with only a few probable sources. Monitoring should measure indicator levels in the discharge itself, as well as upcoast and downcoast of the discharge. The basic monitoring approach includes stations situated both upcoast and downcoast of monitored storm drains because the ocean current direction in a portion of beach can frequently change, and because the dispersion of storm drain discharges in the surfzone can vary widely from place to place (due to discharge volume, bacteria concentration, beach configuration, current patterns, tidal height, and water temperature). The specific location of these stations should be determined after a characterization study of plume behavior to estimate the average seasonal range of influence of the storm drain discharge. This zone of influence will often extend further along the beach in one direction than the other, and will typically be much larger during wet weather. The upcoast and downcoast stations should then be located within the outer bounds of this influence, with a wet weather zone of influence applied to those stations that are routinely sampled during wet weather.

The model monitoring program does not include monitoring of beach coastal stations directly in front of storm drains, or "Point 0", the point in the surfzone where the storm drain discharge meets ocean water. Instead, most of the coastal beach monitoring completed by the local health departments and others is conducted at varying distances from the drain, depending on the sampling agency. Currently, county health departments do not monitor directly in front of storm drains and freshwater outlets because all flowing outlets are posted with permanent warning signs of poor water quality. The model program follows this approach in accord with its primary intent to maximize coastal monitoring efforts by remaining consistent with the health departments' sampling protocols. However, since the ultimate management goal is to ensure that all locations at the beach are safe for swimming, stormwater monitoring agencies should be aware that the impacts to beaches directly in front of most storm drains and freshwater outlets is unknown, but are conservatively considered impacted by the health departments and the SWRCB. As stormwater monitoring and management programs progress, monitoring near drains and freshwater outlets at the beach may need to be adapted to include Point 0 monitoring. The issue of Point 0 sampling is being reevaluated by the State's Beach Water Quality Workgroup and, if the BWQWG revises the recommended health department sampling protocols, the model stormwater program should adjust to reflect this structure.

Enclosed bays and estuaries. In general, beaches in enclosed bays and estuaries (e.g., Newport Bay, Mission Bay) should be an important concern for allocating monitoring resources. This is because there is more potential for retention of bacteria, such waterbodies often have more numerous inputs, populations of birds are often denser, and children are more likely to engage in body contact recreation at these beaches. As at the open-coast beaches, monitoring effort should be allocated in proportion to relative risk, with high-use areas that have numerous inputs receiving the highest priority (Table 5-2). If all portions of an enclosed beach have equal risk, and it is not possible to monitor all urban runoff inputs, then a random subset of such inputs should be monitored, with the number of samples set based on analyses of the statistical power of alternative subsampling schemes. Monitoring should measure indicator levels in the targeted discharges themselves, as well as upcoast and downcoast of the discharge.

Creeks, streams, and rivers. As for the other two types of areas, monitoring of creeks, streams, and rivers should measure indicator levels in targeted discharges themselves, as well as upstream and downstream of the discharge. Because many inland waters in southern California are seasonal or intermittent, rather than perennial, monitoring should be prioritized with the risk-based approach described in Section 5.1.1. This approach prioritizes potential monitoring locations based on both their amount of body contact recreation and levels of bacteria contamination.

The Aliso Creek watershed in southern Orange County (which has been monitored intensively for the past two years) provides one example of how this approach can be applied. In this watershed, a recreational use survey indicated that human use “where the ingestion of water is reasonably possible” (Basin Plan definition of REC1 beneficial use) is concentrated in the lower portion of the Creek in the summer and early fall, when temperatures are warmest. An examination of two years’ of monitoring data showed (Figure 5-2) that the late summer and early fall are also the period when bacterial levels are the highest. (The selection of monitoring sites was based on a field reconnaissance to identify those drains above a threshold size that typically had dry weather flow.) Given that bacterial levels are consistently elevated during this time period, if compliance with the Basin Plan REC1 objective could be demonstrated with one or two 30-day, 5-sample monitoring efforts in the late summer and early fall, which would represent the worst-case scenario, compliance is more likely during the rest of the year. This design is the most efficient approach to assessing the condition of the beneficial use; however, because large portions of the year are not monitored, it does not fulfill public health monitoring requirements.

This example from Aliso Creek illustrates the application of the criterion of allocating monitoring effort based on a qualitative risk assessment. It also demonstrates the difference between monitoring to address Question 1 and monitoring to fulfill public health requirements. Thus, even though exceedances occur during other periods of the year, the purpose of the monitoring design in the example was to assess receiving water quality during the high-priority period. When bacteria levels in the high-priority period consistently drop to near the Basin Plan objectives in the future, it might be worthwhile at that point to expand monitoring to other parts of the year, on the assumption that indicator levels will have dropped below the objectives by that point (assuming the historical pattern stays the same, with the highest levels typically found in the late summer and early fall).

Indicators. Monitoring should use existing indicators (Table 5-1) and use comparable methods across the region. Laboratory intercalibration exercises for bacterial indicators were conducted as part of the Bight '98 and Bight '03 regional studies. Another intercalibration study, sponsored by the City of Los Angeles, will begin in early 2004 and includes most of the laboratories analyzing monitoring samples for SMC member agencies. With all indicators, the emphasis for assessment of recreational water quality conditions should be on comparison to existing standards, the Basin Plan REC1and REC2 for inland areas and AB411 for beaches.

5.1.1.3 Design issues

In general, there is currently a spatial distribution of responsibility for assessing recreational water quality conditions in the region, with county health departments having primary responsibility for beaches and for major inland water bodies (e.g., rivers, bays, lakes and reservoirs) where substantial body contact recreation occurs. In contrast, stormwater programs (i.e., MS4 permittees) tend to monitor inland storm drains and channels and, in some cases, storm drains that discharge directly to the beach. Thus, while there is some overlap between the two sets of agencies, health departments have a responsibility to protect public health while stormwater agencies focus on receiving water conditions and identifying urban runoff contributions to impaired receiving waters. As a result of their respective responsibilities, health departments typically monitor more frequently than do stormwater agencies.

To address Question 1, stormwater agencies should build upon the existing recreational water monitoring programs already implemented by local county health agencies. As a starting point, the stormwater agency should become thoroughly familiar with the existing health agencies' monitoring programs including risk characterization of beaches, monitoring locations, and sampling frequencies for both wet and dry weather. Next, with consultation from the health agency, the following types of questions should be answered to determine if additional monitoring should be conducted by the stormwater agency to answer Question 1:

- Are there urban runoff discharge points at marine beaches that are currently not monitored by the health agency?
- Are there marine beaches impacted by wet or dry urban runoff that are not monitored by the health agency?
- At marine beaches, what is the distance from the point the discharge enters the surfzone and the local health agency's monitoring location?
- What freshwater locations are frequently used for recreation? Are any of these currently monitored by the health agency or another entity? Which of these are potentially impacted by dry and wet weather urban runoff?
- Does the health agency monitor their routine sites during wet weather?

In general, data gaps in the existing health agency monitoring programs that may require new monitoring locations sampled by the stormwater agencies will likely include marine beaches where the health agencies' monitoring location is located away from the storm drain discharge point (thus, existing data may not indicate if the stormwater discharge is causing a problem on the beach) and at freshwater locations that are currently not monitored by the health agencies. The stormwater agency should work with the health agencies to identify any new monitoring locations and to develop risk characterizations of these locations.

Stormwater agencies may be already working with local health agencies in southern California in many instances. For example:

- For the Pathogen TMDL in Newport Bay, the Orange County Health Care Agency conducts sampling while the Orange County Stormwater Program reports on the results
- In southern Orange County, the Stormwater Program samples and prioritizes coastal storm drains and reports the data to the Health Care Agency
- The Orange County Stormwater Program contracts with the Health Care Agency to conduct sampling and laboratory analyses
- The Riverside County Flood Control and Water Conservation District and San Bernardino County Flood Control District are conducting a bacterial source identification study on the Santa Ana River
- Orange County and San Diego Counties carry out routine IC/ID programs on their respective MS4s during dry weather, with a major focus on bacteria
- The City of Los Angeles conducts daily monitoring of more than two dozen beaches in Santa Monica Bay.

Such collaborative efforts formed the basis for the model monitoring committee’s recommendation that such functional coordination be encouraged and expanded throughout the region, in two primary ways:

- Stormwater monitoring programs should strive to fill gaps in spatial coverage of high-priority areas not monitored by County Health Departments and characterized by the combination of elevated indicator levels and human use
- The application of adaptive triggers that would initiate upstream source identification studies by stormwater management agencies when receiving water monitoring has identified a receiving water problem.

Such a division of labor improves overall efficiency by emphasizing the respective strengths of each type of agency.

5.1.2 Habitat assessment

5.1.2.1 Overview and philosophy

Design overview. Table 5-3 presents an overview of the technical design elements for assessment of habitat status, using six distinct station types that fall into both core and regional monitoring categories (see detailed design elements in Section 5.1.2.2).

The model monitoring framework for habitat assessment is based primarily on the Triad approach, in which bioassessment, chemical, and toxicity data provide a variety of perspectives on conditions at a site. It is especially suited to situations where the primary concern is habitat or ecosystem condition and no single or simple suite of indicators afford an unambiguous measure of status (see Box on Bioassessment and Index of Biological Integrity). The framework identifies six different types of stations designed to capture the range of issues related to habitat condition, and capturing both core and regional monitoring issues. In addition to describing a decision framework for interpreting Triad results, the framework includes adaptive features intended to furnish the flexibility needed to adjust to specific local conditions and to accommodate the needs of both wet weather and dry weather sampling. However, the bioassessment leg of the Triad is best suited to perennial streams. Ephemeral stream systems may not be appropriate for routine bioassessment monitoring because they lack established biological communities except perhaps during periods in the spring.

Bioassessment and the Index of Biological Integrity

Rapid bioassessments of macrobenthic invertebrates are quickly becoming a valuable monitoring tool because biological communities are integrators of anthropogenic impacts. These organisms respond to both physical and chemical disturbances and can integrate these impacts over several storms or an entire wet season. The California department of Fish and Game (CDFG) has developed protocols for rapid bioassessments in wadeable rivers and streams and has conducted numerous surveys throughout the State. The CDFG has also developed an Index of Biological Integrity (IBI) for quantitatively assessing the status of biological communities in the San Diego Region. The Stormwater Monitoring Coalition has formed a partnership with the CDFG and the State Water Resources Control Board to build a monitoring infrastructure and standardize bioassessments throughout southern California, then refine an assessment tool, such as the IBI, for the entire region. The CDFG rapid bioassessment manual can be found at www.dfg.ca.gov/cabw/cabw/professionals.PDF

Design philosophy. The inherent complexity of watershed structure, and the variability in structure across watersheds, leads to a range of concerns about the effects of urban runoff on habitat conditions. Each concern is somewhat distinct, requiring a somewhat different monitoring approach, sampling frequency, and set of indicators. For example, some sites may be intended to measure conditions in specific, high-priority habitats (core monitoring), others to provide information about the watershed as a whole (core and/or regional monitoring), and yet others to improve knowledge about certain management issues related to urban runoff (special projects). This complexity is reflected in the several different types of habitat monitoring stations that can be established. In addition, the model monitoring design framework uses the Triad approach to organize this range of possible monitoring needs. The strength of the Triad approach (which is essentially a weight of evidence approach) is that it relies on multiple types of measures to reduce the chance of mistakenly concluding there is no impact when one in fact does exist.

5.1.2.2 Design elements

Types of monitoring sites. The committee identified several kinds of core and regional monitoring stations that could be required in assessing habitat conditions at the watershed scale:

- Long-term, fixed, bottom-of-watershed (but above tidal influence) mass emissions stations to assess cumulative water quality and aggregate loads, with monitoring based primarily on a mass emissions model and including wet weather chemistry and toxicity (core station)
- Spatially extensive, perhaps randomly sited or rotating, stations to support statistically valid comparisons across multiple watersheds, and with monitoring based primarily on the Triad

approach for dry weather sampling and on chemistry and toxicity for wet weather (regional station)
- Site-specific stations focused on the status of high-priority inland habitats of concern, with monitoring based primarily on the Triad approach for dry weather sampling and on chemistry and toxicity for wet weather (core station)
- Site-specific stations designed to generate information to support key program goals, such as source prioritization or BMP implementation and evaluation (core station, special project)
- Coastal estuarine stations to assess status in these key habitats, with monitoring based primarily on the Triad approach (core and/or regional station)
- Coastal ocean stations to assess stormwater plume impacts, conducted primarily as part of the periodic Bight surveys (regional station).

Given this potential variety of station types, monitoring within any particular watershed must be carefully integrated to achieve design efficiencies as well as an overall picture of the watershed. For example, Figure 5-1 presents an example watershed monitoring design, with a range of types of watershed monitoring stations, that illustrates how individual stations can serve more than one function within the watershed design (also see the US EPA strategy for randomized watershed sampling in US EPA 2002).

While there is an extensive body of experience in the region to support the development of core monitoring designs, this is less so for regional monitoring, or watershed-based, designs. The committee therefore outlined the following types of regional assessment designs that could be developed and implemented:

- Probability based designs, similar to the Bight Program design, in which stations are located randomly in order to provide the ability to draw statistically valid inferences about an area as a whole, rather than just the site itself. For example, the probability design used in the Bight Program permits statements about the percentage of the area that is above/below particular levels of different indicators. Such designs can allocate monitoring sites randomly throughout the entire region, or can subdivide the region into a number of strata that are relatively homogeneous. Strata can be defined on any number of grounds, depending on the questions or concerns that have motivated the program. For example, watershed strata could be based on relative amount of urbanization, general habitat type, or channel morphology, among others. Whatever the stratification scheme, the basic design principle is that samples are allocated randomly among strata, with the number of samples per stratum based on a consistent weighting factor (e.g., area of the respective strata). The level of sampling effort required in probability based designs depends, as in all designs, on the specific questions being asked, the underlying levels of variability in the data, and on the level of precision needed for decision making. The intent of the Bight Program's design, for example, is to be purely descriptive, rather than to test for conformity to a predetermined threshold or to detect a particular amount of change over time. Thus, the Program's requirement of 30 samples per stratum is based on a subjective decision by the Program's designers about the size of the confidence limit they are willing to accept in the descriptive statistics.
- Systematic designs, in which stations are located at set intervals along one or more underlying spatial or conceptual frameworks. For example, regional stations could be located on a 1-mile grid, every 1-mile along each river, creek, or stream, at every major discharge into rivers, and so on. One value of systematic designs is that they allow for more detailed mapping of indicator levels across a region. In addition, if resources permit, systematic designs can provide more thorough coverage than do probability based designs. The sampling

requirements in systematic designs are typically based on the degree of spatial resolution desired.

- Early warning designs, in which stations that are considered to be particularly vulnerable a particular impact are monitored as "canaries in the coal mine." Such monitoring can take place on a regular schedule or after the occurrence of an event thought to increase the probability of an impact past an acceptable level. The number of stations in an early warning design will depend on the number of suitable locations available and whether the potential for impact is homogeneous across the region. If the impact potential is homogeneous, then a subset of locations could adequately represent the entire region. If the impact potential is heterogeneous, then the region should be stratified in terms of impact potential and sampling within each stratum scheduled accordingly.
- Rotating designs, in which a different subset of stations in sampled during each sampling event, with the goal of sampling the entire set of stations over a certain period of time. Such designs have the virtue of maximizing the impact of limited monitoring resources because the entire suite of monitoring stations need not be sampled each time. However, because conditions change over time, rotating designs have a diminished ability to support valid comparisons between sets of stations sampled at different times in the rotation schedule. This can be compensated for to some extent by defining comparisons of interest during the design process and then ensuring that such stations are sampled during similar index periods or seasons. The location of stations in rotating designs can be random, systematic, or early warning depending on the kinds of questions being asked.

Evaluating Triad results. Once monitoring data are available, determining whether conditions are protective of beneficial uses depends on a combination of explicit definitions of reference conditions (see Table 4-4) and the ability to interpret results in the context of individual watershed conditions. Given the potential complexity of ecosystem impacts, the committee agreed that no single benchmark should be automatically used as evidence of impact. Thus, there are no hard and fast rules for determining that a receiving water impact has occurred. However, Table 5-4 provides an organized set of rules of thumb for interpreting Triad results and determining if further studies are warranted. Where the full Triad has not been sampled, Basin Plan, Ocean Plan, and other reference benchmarks listed in Table 4-4 could be applicable.

Adaptations of the basic design. Because of the range of specific situations that may occur in different watersheds, the basic design shown in Figure 5-1 may be adapted with a variety of alternative approaches. For example:

- Chemistry and toxicity could be used in wet weather when the bioassessment leg of the Triad is not feasible (e.g., in high flow conditions when biological communities. Any finding of impact could be investigated further with the complete Triad during dry weather (except in ephemeral streams, which rarely have dry-weather flow)
- Toxicity tests could be used in lieu of broader chemistry scans where historical data demonstrates no evidence of impacts at the site and there is no *a priori* reason to believe there are significant sources of chemical contamination
- Bioassessment could be used in lieu of toxicity tests and chemistry scans where the primary concern is the status of a particular habitat and historical data demonstrates no evidence of impacts from urban runoff at the site
- The spatial and temporal intensity of sampling could be adapted to match the spatial scale of the site and the temporal scale of the processes that influence habitat condition
- The suite of chemical analyses can be adjusted (see Tables 5 and 6, and following subsection) based on prior knowledge about sources of contamination.

Thus, the model framework provides an overall context for assessing and tracking habitat status, while allowing for the flexibility needed to make the best use of available information to adapt to specific management information needs.

Constituent list. While the committee emphasizes that the Triad approach (bioassessment, toxicity testing, chemistry monitoring) works best when all three legs are consistently sampled, it also recognized that certain situations may call for sampling only one or two, rather than all three, legs. Thus, the particular combination of Triad measurements to be collected at any individual site or time could be based on the season of the year (wet vs. dry), the location and purpose(s) of the station, the specific problem or question being addressed, the past history of monitoring results at that location. In general, however, sampling effort might be distributed as in Table 5-3 and Table 5-5 (core monitoring column).

The model monitoring committee gave particular attention to the suite of chemical constituents that should be measured at the watershed stations, attempting to balance a desire for regional comparability with the ability to adapt to the specifics of each situation. The committee developed a short list of common constituents (Table 5-6) to be sampled routinely by all programs and an expanded list, some of which would be sampled if needed. In addition, the full EPA priority pollutant list would be sampled once every several years in concert with the regional Bight Program.

A decision about when to add constituents from the expanded list would be dependent on both available information and the management question(s) being asked. For example, past monitoring data or data on historical land uses indicating the presence of legacy pesticide contamination could cause these constituents to be added to the program. As another example, where the focus is on total loads or trends, as at the mass emissions stations, then total metals would be the appropriate monitoring target. In contrast, where receiving water impacts are the primary concern, as at specific habitat stations, then dissolved metals should be measured. It will thus be important to consider the potential use(s) of the monitoring data when deciding which constituents to monitor. Dissolved metals might also be measured when toxicity has been found, the site is on the 303(d) list, or total metals exceeds the relevant CTR value, which is often used as a benchmark in receiving waters for stormwater effects.

Flow measurement and compositing approaches. Many field sampling methods relevant to stormwater monitoring programs are described and reviewed in BASMAA (1995), as well as in various USEPA guidance documents (e.g., USEPA 1992). Of particular interest are methods for estimating flow and compositing approaches for deriving mass emissions estimates.

In general, there are two basic methods for estimating flow. The first is based on engineering equations that use gravity, the height of water in an idealized pipe, the slope of the pipe, and a friction coefficient to derive the flow. The second is based more on direct measurement of the speed of the flow, combined with an estimate of the cross sectional area of the water (computed from the shape of the channel and the height of the water) to derive the flow. There are variations within each of these basic methods. For example, the engineering equations can use unimpeded flow in a pipe or channel or, alternatively, the height of flow over a weir. Similarly, direct flow measurements can be based on the rate of spin of a paddlewheel or on ultrasonic signals from sensors in the water. In addition, there is a range of methods for measuring the height of the water in a channel, the other key input to flow estimates. These methods range from simple staff gauges to various types of pressure transducers or ultrasonic sensors suspended over the water. As a rule of thumb, the more engineered a hydrologic system is, the easier it is to rate for flow. For example, a concrete channel will typically have a constant cross section and the slope will be constant.

Different approaches have different strengths and weaknesses depending on the particular situation. For example, flow sensors that are mounted in the water are vulnerable to damage from debris carried in storm flows. Downward looking flow sensors can be more suited to smaller channels with space constraints, however, foam on the surface of the water can degrade the accuracy of the reading. Various pressure transducer models differ in their sensitivity and the maximum height of water they can accurately measure. Where the channel configuration permits, flow can be routed through a flume for more accurate measurements; however, flumes cannot handle large volumes of flow.

The United States Geological Survey (USGS), which is generally recognized as producing the most accurate and precise flow estimates, measures flow velocity at several points along a channel cross section at several times with different water heights. These data are then used to develop a flow rating curve specific to that channel. The rating curve can then be used to estimate flow based simply on the height of water at any given time, on the premise that water at a particular height will be moving at a specific speed. This is an empirically derived relationship as opposed to one based on modeled engineering principles. While this method can be the most accurate, it is also the most difficult to implement in terms of up-front effort and costs. In addition, changes to the channel morphology due, for example, to siltation or erosion can undermine the accuracy of a flow rating curve.

The various approaches to flow measurement also differ in terms of their relative accuracy and precision. The USGS attempts to achieve accuracy to within 5%, but that level can be difficult to achieve in channels with scouring, filling, and other sources of bias. Despite the potential drawbacks of empirical methods, they are considered to have better accuracy than the model-based engineering methods, although it can be very expensive to improve the precision of the empirical estimates. In contrast, the engineering methods can produce relatively precise estimates, but the accuracy may be less than that achievable with empirical methods, depending on the degree to which model assumptions are violated. The model monitoring committee was reluctant to propose specific performance standards for flow monitoring. The preferred approach in any particular situation will depend on site characteristics and the use(s) intended for the data.

In contrast, the committee considered that performance standards for the measurement of mass emissions, especially as part of a long-term trends monitoring program, were more relevant. There are two primary methods for estimating the concentrations of constituents of interest in urban runoff. The first, flow compositing, collects water samples for analysis at specific increments of flow. The second, time compositing, collects water samples at specific increments of time. These two approaches were described in more detail and compared in an intensive year-long sampling program (Leecaster et al., 2002) that found that flow compositing was the most efficient sampling approach to achieve a given degree of accuracy and precision. A minimum of 10 to 12 samples per composite using a flow-weighted scheme efficiently reduced bias and improved precision. Time-weighted composites can achieve similar levels of precision and bias, but required a far greater number of samples; more than 42 samples per composite were necessary.

5.1.2.3 Design issues

Ecosystem perspective. There are four major habitat types in the region:

- Ocean
- Estuaries / wetlands
- Streams, creeks, and channels
- Lakes and reservoirs.

Because they are somewhat of a special case, the committee agreed to set lakes and reservoirs aside for possible consideration at a later time. Based on the Bight '98 study in the coastal ocean, which showed that riverine effects on the benthic ecosystem are small, the committee agreed that further study of stormwater impacts in the coastal zone should be the focus of regional efforts (as in Bight '03). Such regional studies could then provide more concrete guidance to individual programs where urban runoff plume effects (perhaps on the water column) are found to be substantial. Thus, the model monitoring program framework focuses explicitly on streams, creeks, channels, and rivers, and on estuaries and wetlands.

Habitat monitoring for these habitat types can involve a wide range of methods, including:

- Water chemistry
- Sediment chemistry
- Aqueous toxicity
- Sediment toxicity
- Bioaccumulation
- Bioassessment
- Hydrology

Given this variety of potential measurements, the committee determined that monitoring should be based on an ecosystem perspective, rather than consisting of collections of functionally disconnected measurements on the one hand, or focusing on individual species or chemical parameters on the other. The Triad approach, which combines chemistry, toxicity, and bioassessment (including physical habitat measures) provides a practical means of integrating a wide range of measurements, as well as a structure on which to base adaptive follow-up monitoring. It should be noted that the bioassessment leg of the Triad may not be applicable in some situations, such as ephemeral streams, where minimum requirements are not consistently met. However, the overall watershed monitoring framework (see Figure 5-1) also provides a structure for including sites targeted at specific management issues such as problem characterization or BMP evaluation.

5.2 Extent and magnitude monitoring

Evaluation of the extent and magnitude of receiving water problems addresses Question 2: What is the extent and magnitude of the current or potential receiving water problems? Monitoring related to Question 2 provides useful information for prioritization of both source identification studies (Questions 3 and 4) and specific management actions intended to remediate the problem. Monitoring of the extent and magnitude of problems falls primarily into the special projects category (Table 4-1) because these are typically efforts targeted at specific problems and with clear beginning and ending points. However, to the extent that such studies require collaboration among multiple responsible parties and/or extend over large areas, they would also have some of the characteristics of regional monitoring.

5.2.1Extent and magnitude assessment – recreational water quality

5.2.1.1 Overview and philosophy

Table 5-7 presents an overview of the technical design elements for regional monitoring of recreational water quality monitoring focused on estimating the extent and magnitude of receiving water problems.

The model monitoring framework for assessing the extent and magnitude of recreational water quality problems assumes that the stormwater agency will work with local health departments to determine those high-priority (i.e., combination of human use and contamination) locations where extent and magnitude of a bacteria problem should be defined. Currently, coastal beach monitoring by local health agencies near urban runoff discharge points is comprised of one or two fixed stations located at various distances from the point of discharge. Thus, often the length of beach impacted by urban runoff has not been fully characterized. In most cases, even less data is likely available for inland freshwater sites. The monitoring design to determine the extent and magnitude of bacterial contamination should include estimates of bacterial loads, in addition to upcoast/downcoast (at beaches) or upstream/downstream (along creeks, streams, and rivers) arrays of samples. An estimate of temporal persistence would depend on monitoring through at least one complete year.

The extent and magnitude monitoring design is essentially the same for both regional monitoring and special projects aspects of the program, with regional monitoring encompassing a larger area and/or greater numbers and kinds of potential sources (see 5.2.1.2 Design elements).

5.2.1.2 Design elements

Regional monitoring to establish extent and magnitude is distinguished from special projects in its larger geographic scale and/or greater number and kinds of potential sources. The committee did not establish an explicit dividing line between these two categories of monitoring (i.e., regional and special projects), since real-world situations will exist on a continuum of scale and complexity. Regional monitoring will therefore most likely involve a wider range of parties and require more collaborative implementation. However, this is not a substantive design issue because the basic design approach is the same for both regional monitoring and special projects.

A monitoring design to establish the extent and magnitude of bacterial contamination must have the ability to determine:

- The degree of temporal persistence of a particular receiving water problem
- The spatial extent of a particular receiving water problem
- The relative severity of a particular receiving water problem, compared to other parts of the region.

Therefore, the monitoring design for this question should include:

- The core or regional monitoring assessment site(s) in the location of interest
- Measures of bacteria loads, which requires flow estimates
- Measures of the spatial extent of actual impact in receiving waters, which requires an array of upstream/downstream samples in creeks, and upcoast/downcoast samples, regularly spaced grids, or random arrays on the beach and in bays/estuaries
- Measures of temporal persistence or pattern, such as between wet and dry weather, which requires at a minimum samples through one calendar year.

Depending on the extent of existing knowledge, these design elements may be scaled as needed to fill data gaps. For example, where the spatial extent of contamination is well understood, additional sampling at only a few representative stations might be required to define the temporal extent of contamination. Conversely, where the spatial extent is not well understood, a survey of shorter-term but more intensive monitoring at an array of stations (either regularly spaced or random, depending on the site) might be necessary to define the boundary of contamination during periods when human use and contamination combine to create a high-priority period. Finally, if the spatial and temporal extent are well defined, a focused sampling effort during one or more representative subsets of the high-priority period might be used to determine peak loads and/or receiving water levels. A rule of thumb in such studies is to use the highest sampling frequency possible in order to better characterize the nature of variability in extent and magnitude. The key adaptive element of the bacteria monitoring design for assessing extent and magnitude thus includes the ability to modify the spatial and temporal intensity of sampling as needed, both in the discharge and the receiving waters.

Indicators in studies of the magnitude and extent of recreational water quality problems should include the levels and loads of the three main bacterial indicators (Table 5-7), along with other measures that may add useful information (e.g., stream or channel flow, patterns of human use).

5.2.13 Design issues

Existing sampling effort may be adequate in many cases to characterize the spatial and temporal extent of bacterial contamination, along with its severity. For example there already exist substantial monitoring data on levels of bacterial indicators at many coastal monitoring sites. Additional monitoring effort is being initiated along the San Diego and southern Orange County coasts, targeted at coastal storm drains, and at specific inland sites as part of these counties' dry weather reconnaissance and IC/ID programs.

In many cases, however, existing monitoring designs may not be optimal for measuring the extent, magnitude, and severity of bacterial contamination associated with urban runoff. At coastal locations near urban runoff discharges, sampling data that provides length of beach impacted by bacteria densities above the health standards may not available. Many factors can affect the length of beach impacted including the bacteria densities and flow rate of the urban runoff discharge, surfzone conditions including swell, wind and tide, and the configuration of the storm drain and beach relative to the incoming swell. Routine coastal monitoring completed by local health agencies may not capture extent. At freshwater inland sites, less routine monitoring data are collected by local health agencies and data on the extent of the problem will typically be limited to special studies. The extent and magnitude of bacteria problems along inland creeks, streams, and rivers resulting from urban runoff discharges may be particularly difficult to assess because there are often many, diffuse sources of bacteria, including natural sources. For both coastal and freshwater sites, defining extent of impact from individual discharges during wet weather may be difficult because plumes from separate discharges will often overlap and because of increased loading of bacteria from natural sources (particularly at freshwater locations). A further complication stems from the fact that extent and magnitude are likely to be very different in wet and dry weather.

In addition to these issues, data from the various bacterial monitoring programs are not aggregated, making it difficult to identify broad spatial patterns and temporal trends, and only recently has a laboratory intercalibration study for bacteria been undertaken. Further, there are growing concerns that the bacterial indicators, alone, may not provide an accurate picture of the extent and magnitude of actual human pathogen contamination. Not only do the indicators not measure pathogens directly, there is some evidence that the indicators themselves may propagate in the MS4 system and may derive partly or entirely from animals and birds. Thus, even a data aggregation and mapping exercise that described indicator patterns in detail might not necessarily describe the extent and magnitude of actual pathogen problems associated with urban runoff.

While the model monitoring committee developed quantitative metrics to assist in prioritizing studies under other aspects of the overall program (e.g., TIEs, upstream bacterial source identification, it determined that the expert judgment of health department staff is the best source of information for triggering efforts to determine the extent and magnitude of bacterial contamination in each of the three kinds of areas (linear open-coast beaches; enclosed bays and estuaries; creeks, streams, and rivers). Thus, stormwater program staff would review monitoring data with health department staff and representatives of other potential sources to determine if they have completed additional sampling or have knowledge of data that establish the extent and magnitude of contamination, and to receive recommendations from health agency staff about which monitoring locations should be the first priority for additional efforts.

5.2.2 Extent and magnitude assessment – habitat

5.2.2.1 Overview and philosophy

The model monitoring framework for assessing the extent and magnitude of habitat problems builds on the core monitoring Triad approach, by adding repeated measurements to characterize temporal persistence, upstream sampling of the Triad components to describe spatial extent, and/or adaptive features such as TIEs or targeted upstream source identification studies to better define the magnitude of the problem (see Table 5-4). These latter two types of studies begin to merge into the kinds of special project source identification efforts described in Sections 5.3 and 5.4, illustrating the fact that real-world distinctions between monitoring categories are not always clear cut.

The extent and magnitude monitoring design is essentially the same for both regional monitoring and special projects aspects of the program, with regional monitoring encompassing a larger area and/or greater numbers and kinds of potential sources.

5.2.2.2 Design elements

Regional monitoring to establish extent and magnitude is distinguished from special projects in its larger geographic scale and/or greater number and kinds of potential sources. The committee did not establish an explicit dividing line between these two categories of monitoring (i.e., regional and special projects), since real-world situations will exist on a continuum of scale and complexity. Regional monitoring will therefore most likely involve a wider range of parties and require more collaborative implementation. However, this is not a substantive design issue because the design approach is the same for both regional monitoring and special projects.

Table 5-4 provides an overall framework for a set of adaptive monitoring and special study responses to a finding that there is or could be a receiving water problem, many of which focus on determining the magnitude, extent, and/or severity of any such problem. The type and design of any such adaptive monitoring in a particular instance will depend on the results of the Triad measurements, site-specific factors, and other types of relevant knowledge such as land use data or information on upstream sources. For example, additional toxicity tests at higher dilutions, accompanied in some instances by TIEs, can provide more information about the nature of toxicity (as described above, this is one example where assessment of the extent and magnitude of a problem would overlap somewhat with source identification special projects). Or, repeating toxicity tests with different toxicity test organisms could also improve the understanding of toxicity. In addition, repeating routine measurements over time at a specific station or group of related stations will determine the temporal extent of the problem. Similarly, extending an array of stations upstream and downstream of the original monitoring station will help assess the spatial extent of the problem.

While Table 5-4 presents a conceptual overview of possible studies, the specific efforts required in any particular situation will depend on which leg(s) of the Triad have been sampled, on the nature of the monitoring findings, and on the characteristics of the environment. Issues that should be considered in designing adaptive studies of extent and magnitude include:

- The nature of the “signal,” e.g., which leg(s) of the Triad are involved
- The strength of the “signal”
- Available information about possible causes of actual or potential problems
- The spatial and temporal extent of the habitat of concern
- Local geography and hydrology.

The preferred monitoring design, whether it be regional or a special study, is described in detail within the section on habitat assessment (Section 5.1.2). There are a variety of approaches for allocating sites including stratified random, systematic, or rotating designs depending on the specific area to be evaluated and indicators to be measured. For sure, managers will want to integrate the extent and magnitude designs into design(s) for assessment, which will maximize continuity and cost-efficiency.

5.2.2.2 Design issues

Assessing the extent and magnitude of impacts on ecosystem health will begin with an assessment of results from the suite of core watershed stations. As described in more detail in Section 5.1.2, stations should be located in receiving waters with key beneficial uses, where significant contamination problems related to urban runoff are known to exist, where the likelihood of such problems is high, in high-value habitats whose continued protection is a high priority, at core mass emissions stations, and at distributed locations that will provide a basis for comparisons among watersheds.

5.3 Urban runoff contribution assessment

Assessment of the relative contribution of urban runoff to a receiving water problem addresses Question 3: What is the relative urban runoff contribution to the receiving water problem(s)? Data from this monitoring element are useful primarily in prioritizing more extensive source identification efforts under Question 4. Assessments of the urban runoff contribution fall into the special projects category (Table 4-1) because such studies are targeted, one-time efforts. However, they may also take on the collaborative aspects of regional monitoring if they involve multiple parties and/or cover large areas (Table 4-1).

5.3.1 Overview and philosophy

The model monitoring framework for assessing the relative urban runoff contribution to both recreational water quality and habitat problems is primarily a matter of loads estimation at a fixed downstream reference point. Similar loads estimation approaches apply to both recreational water quality and habitat indicators, as described in the following sections, including expert judgment, visual reconnaissance, land use modeling, empirical tributary monitoring, the use of conservative tracers, and the evaluation of existing data (see Box on Modeling). The actual combination of methods in any particular instance will depend on the quantity and quality of historical data, the nature of the receiving water problem, the number and types of potential sources, and the physical structure and hydrography of the watershed. In addition, many of the methods applicable to this issue are also directly applicable to the more detailed source identification special projects described in Section 5.3 and 5.4.

The extent and magnitude monitoring design is essentially the same for both regional monitoring and special projects aspects of the program, with regional monitoring encompassing a larger area and/or greater numbers and kinds of potential sources. The source identification case studies in Appendix 3 include examples of both. For example, the Contaminated Sediment Task Force study in Los Angeles Harbor was a regional study involving many participants, while the investigation of elevated total dissolved solids in Orange County was a special project conducted by the County Stormwater Program alone.

Modeling

Watershed modeling is a useful tool for estimating flow, concentrations or loads from unmonitored watersheds or unmonitored storm events. There are a variety of models available to watershed managers, from very simplistic spreadsheet-based techniques to very complex time-variable algorithms. The decision on which model to use is a function of the management questions and types of assumptions watershed managers are willing to make, as well as the availability of data for running the model. Simplistic models (i.e. rational method) answer questions at large temporal and spatial scales, make the most assumptions, and require the least data. Complex models (i.e. HSPF, SWMM, etc.) answer questions at finer temporal and spatial scales, make fewer assumptions, but require the most data. See Singh and Woolheiser (2002) for a recent review of watershed hydrology models.

5.3.2 Design elements

This section describes a general set of approaches to source identification, accompanied by a set of illustrative case studies presented in Appendix 3. The committee chose this approach because the wide variety of specific situations in which source identification studies might be required makes it impossible to define a standard approach.

Assessing the relative urban runoff contribution to a particular receiving water problem involves loads estimation at a fixed downstream point, which is in or near the affected receiving water. Depending on how the receiving water is defined in a particular instance, “downstream” may be at the point where a tributary enters a larger creek, where a creek enters a wetland or estuary, or where a river empties into the ocean. Similar loads estimation approaches apply to both recreational water quality and habitat indicators, including:

- Expert judgment
- Visual reconnaissance and observation
- Land use modeling
- Empirical tributary monitoring
- The use of unique and/or conservative tracers
- Evaluation of existing data.

These approaches can be extended with more detailed information provided in US EPA (1993), Pitt (2001), and SWRCB (2001), which describe a range of methods for identifying sources of stormwater pollution. A decision about which approach(es) to use in any particular instance will depend on the quantity and quality of historical data, the nature of the receiving water problem, the number and types of potential sources, and the physical structure and hydrography of the watershed. Thus, even a preliminary loads estimation for a high-priority bathing beach, such as in Mission Bay in San Diego, might proceed through several steps from expert judgment which provides the basis for targeting visual observation which in turn forms the basis for modeling and/or empirical measurement. Where information from the Triad approach is available, Table 5-4 provides an example of a decision framework for interpreting monitoring results to better focus preliminary source identification efforts.

One key element of the committee's thinking is that such preliminary loads assessments should ideally be a collaborative effort, undertaken by all the parties responsible for potential inputs to the receiving water. Such regional, collaborative efforts will be more efficient and more productive because they will streamline data acquisition, integration, and evaluation. They can also provide a basis for future, more intensive, collaborative source identification efforts, should they be required.

While in general the needed accuracy and precision is only low to moderate, the degree of accuracy and precision needed will depend in part on the relative size of the urban contribution to the overall loads. For example, if the urban contribution is small (i.e., less than 5% of the cumulative load), there would probably be no need to refine the estimate any further because large variability does not change the answer to the question; urban runoff is still a small contribution. In contrast, if the urban contribution is 15% +/- 15%, there would be a need to refine the estimate to determine whether and to what extent to proceed to the more detailed source identification work described in Section 5.4. Thus, monitoring designs for this issue might proceed through multiple iterations.

When identifying and characterizing potential sources, it is important to use terminology that is consistent with standard USEPA usage. Thus:

• Urban runoff:	both wet (stormwater) and dry weather (non-stormwater) runoff from urban land uses
• Dry weather runoff:	runoff from urban land uses in dry weather
• Stormwater runoff:	runoff from urban land uses during storms

In addition, there are other land uses and sources that discharge to MS4s but that are typically not under the jurisdiction of municipalities, including:

- Industry and POTW discharges (which are regulated by state permit)
- Other discharges permitted by the RWQCB
- State and federal facilities
- Agriculture
- Augmented water
- Open lands
- Native American lands
- Special districts, school districts, parks
- Utilities
- Aerial deposition.

5.3.3 Design issues

There are two primary design issues associated with determining the relative urban runoff contribution to a receiving water problem. The first is the fact that the wide variety of specific situations likely to be encountered makes it infeasible to recommend a standard design. The committee resolved this issue by providing general guidance on study design, referencing two reports that describe detailed monitoring methods, and including a set of representative case studies in Appendix 3. The second is that there may be cases in which the relative urban runoff contribution is small. In such cases, the committee agreed that a municipal permittee should not be obligated to independently conduct detailed source identification studies beyond the activities already required in their respective NPDES permits. The committee therefore recommended a threshold level of urban runoff contribution above which permittees would be required to independently perform detailed source identification studies, and set this level at 5 – 10%. A lengthier discussion of the threshold issue is provided in Section 4.3.

5.4 Source identification studies

More detailed source identification studies address Question 4: What are the sources to urban runoff that contribute to receiving water problems? These are almost always special studies and are conducted when preliminary source identification work under Question 3 (Table 4-1) shows that urban runoff constitutes a significant portion of the source(s) of a receiving water problem. Information from these more detailed special projects can help refine receiving water monitoring, improve fundamental understanding of stormwater contamination processes, and help guide management actions intended to reduce sources and their attendant impacts.

5.4.1 Overview and philosophy

Table 5-8 presents an overview of the technical design elements for special projects monitoring of recreational water quality and habitat focused on source identification. Since the primary philosophy of the model program is not to design site-specific studies, this section provides guidance on adaptive triggers for special studies. Therefore, this section creates a series of starting and stopping rules for when to initiate detailed source identification studies and tools for prioritizing locations on where to conduct them.

The model monitoring framework for detailed source identification for both recreational water quality and habitat involves two kinds of studies. The first are studies at downstream stations to gain additional insight into the sources of the problem. For bacteria, this may include more traditional sanitary survey methods and/or more sophisticated biological testing. For habitat, this may include toxicity tests with a broader suite of test organisms, TIEs, or more detailed analyses of the pattern of impact in communities or on key organisms. The second kind of study will be upstream source tracking and source identification studies that may use a variety of methods. In general, however, they will share the same design, which will involve using a basic indicator of impact (e.g., bacterial indicator, toxicity) to trace the strength of the impact signal upstream, in either wet or dry weather, combined with more powerful and/or targeted methods (e.g., genetic source identification, TIEs, chemical reconnaissance, physical reconnaissance) to locate the specific source(s) of pollution.

5.4.2 Design elements – recreational water quality

There are two primary design elements for source identification related to recreational water quality. The first is to identify and then prioritize the upstream sites at which source identification efforts will be conducted. The second is to identify a core set of methods for bacterial source tracking at these sites. The approaches for these issues are somewhat different for beaches and for inland waters because inland waters (i.e., creeks, streams, and rivers) have a clear upstream – downstream morphology while beaches may not. Instead, contamination from a discharge can often spread out in both directions along a beach.

Open-coast and enclosed beaches. In contrast to creeks, there is no consistent and obvious upstream – downstream relationship between urban runoff inputs (typically storm drains) and the receiving water. Thus, it is not possible to estimate impact in terms of the difference between an upstream and a downstream station. The committee therefore proposed a prioritization approach based on the relationship between bacterial levels in individual storm drains and levels in the nearby receiving water.

Figure 5-3 demonstrates this approach with bacterial monitoring data from San Diego County. The figure is divided into five sections that reflect different relationships between indicator levels in the receiving water and those in the outflow of the coastal storm drain itself. In general, higher priority is given to storm drain discharges that are consistently high and receiving water densities that exceed health standards. While Figure 5-3 illustrates a prioritization approach specifically for fecal coliform, parallel methods could readily be developed for total coliforms and Enterococcus, since standards for these indicators in marine waters have been developed.

Once a subset of inputs has been identified for further source identification efforts, the well-accepted approaches described in US EPA (1993), Pitt (2001), and SWRCB (2001) are excellent sources of guidance. When implementing such approaches, it will be important to be systematic and thorough yet also have clear stopping points (Figure 5-4). In particular, the stopping rules are prioritized to focus on determining, first, whether there identifiable sources of human sewage and, second, whether there are other controllable anthropogenic sources. First and foremost, stormwater agencies need to identify and remove all sources of human inputs (See Box on Microbial Source Tracking). The committee agreed that further source identification efforts for nonhuman inputs should await the development of more powerful microbial source identification tools with the ability to more accurately distinguish among a range of specific sources (e.g., livestock, pets, birds, other wildlife). This testing is currently being conducted by the SMC and others (Griffith *et al* 2003).

Microbial Source Tracking

Microbial Source Tracking (MST) is a class of potentially powerful tools for identifying sources of bacteria in receiving waters. The traditional fecal indicator bacteria typically measured by county health departments are not human specific and can arise from any warm-blooded organism including birds, dogs, cats, livestock, horses or other mammals. Thus, the goal of most MST techniques is to determine if the measured indicator bacteria are of human origin and, if not, what was their host of origin. There are numerous MST techniques available, but all are still experimental. The Stormwater Monitoring Coalition co-sponsored a study in 2002 to test 11 MST techniques by 22 of the nations' leading researchers for their accuracy and precision in southern California. The results, which are summarized in the *Journal of Water and Health* (Volume 1, No. 4, November 2003), show that none of techniques worked perfectly and many were susceptible to false positives. As a result of the intercalibration study, research continues on refining and improving the more promising methods, but a single definitive technique(s) is still unavailable.

Creeks, streams, and rivers. Source identification studies in creeks, streams, and rivers are particularly problematic because bacteria are not conservative in the MS4, may originate from a wide range of small, diffuse sources, and can be highly variable in both space and time. However, because bacteria die off due to ultraviolet (UV) exposure as they flow downstream, there may be an upper limit on the distance bacteria can travel in longer natural creeks and streams and still impact high-priority areas of concern. (Bacteria can also be removed through sedimentation; however, during the low flow conditions characteristic of dry weather in southern California, UV exposure is the dominant factor.) Therefore, the committee developed a conceptual model (Figure 5-5; Appendix 4) to identify and prioritize inputs for upstream source identification work. This conceptual model also assumes that core monitoring has shown there is an exceedance of a bacteria water quality objective in a high-priority recreational use area, and that either regional monitoring or special projects that it is persistent and large enough to warrant further action, and that urban runoff constitutes a substantial proportion of the source(s).

The following steps describe how to apply this conceptual model in a particular situation:

1. Locate high-priority use area
2. Define upstream boundary of high-priority use area
3. Calculate the number of days required for 95% of bacteria to die off, using the equation in Appendix 4 and an inactivation rate selected from the range presented in Appendix 4
4. Calculate average net downstream flow rate of the creek or stream in meters/day
5. Calculate the linear distance required for 95% of bacteria to die off, using the following equation:
   Days required for 95% die off x flow rate in meters/day = X meters
6. Define an upstream segment with its bottom edge at the upstream boundary of the high-priority use area and its upstream edge X meters upstream above that.

There are two constraints that would affect the application of this conceptual model. First, it may be most appropriate in dry weather in longer natural creeks and streams with relatively slow flow rates, because bacteria die off rates in creeks that are partially or fully concrete-lined may be less than transport times. For example, it would be less applicable to systems with discontinuous flow. Second, spatial and temporal variability in bacteria densities mean that deriving more than rough estimates of the upstream segment may require substantial sampling effort. However, even a somewhat rough estimate could prove valuable in focusing upstream source identification studies. Thus, this conceptual model is not directly applicable to all situations and should be applied carefully. For example, in the Santa Ana River above Prado Dam, flow during dry weather is discontinuous and consists of disinfected POTW effluent and rising groundwater. Though bacteria levels in this case exceed REC1 standards, there are no dry weather urban runoff discharges and the conceptual model would not be directly applicable.

Within this upstream portion of the drainage system, termed a "potential source segment," there may be a number of discharges or other inputs that must be prioritized for source identification study. The committee developed a unique tool for prioritizing such inputs, based on a combination of their loads and local impact on the receiving water, as explained in the following paragraph.

The influence of inputs within the potential source segment on the downstream high-priority recreational use area will result from a combination of the size of the input (bacterial load) and the effect of each input on the receiving water (impact). This is because loads alone do not reflect a discharge's potential impact on the receiving water. A large load discharged into a creek section with high flow may have little downstream effect, while a small load discharged into a creek section with low flow may have a disproportionately large downstream effect. Thus, prioritization of inputs for upstream source identification efforts, as well as monitoring of the inputs in the potential source area, should be based on both loads and impact, with impact measured as the difference between bacterial indicator levels at upstream and downstream stations. Table 5-9 demonstrates the committee's approach for combining measurements of both load and impact into a single metric for prioritizing a series of inputs. Generating this metric involves the following steps:

1. Calculate the bacterial load of each direct input to the creek within the potential source segment

2. Calculate the receiving water impact of each direct input, measured as the simple difference in bacterial concentration between stations 25 feet upstream and downstream of the input
3. Scale loads values from 0 – 1, with the lowest load assigned the value of 0 and the highest the value of 1
4. Scale impact values from 0 – 1
5. For each input, calculate the average of the scaled loads and impact values as:

$$\frac{\text{Scaled load + scaled impact}}{2}$$

6. Rank inputs within the potential source segment in terms of their average scaled value
7. Select highest ranked inputs for further source identification efforts upstream of each input.

If desired, loads and/or impact estimates could be weighted to emphasize one or the other to a greater degree. The highest ranked inputs would be selected for further source identification efforts, with the threshold established based on the pattern of average scaled values and cost and logistical constraints. It will be important to ensure that the data used for calculating this metric be gathered during that portion of the year when human health risk is the highest. It is also important to recognize that the relationship of each individual input in potential source segment to health-based water quality objectives in their immediate vicinity is not directly relevant to the prioritization exercise. There are two reasons for this. First, the prerequisite for the upstream prioritization exercise is that the downstream high-priority recreational use area has been determined to exceed water quality objectives on a regular basis. Second, a series of inputs could all contribute to a cumulative problem at the downstream use area, even if none of them individually exceeds water quality objectives.

Similar to the approach for beaches, once a set of inputs have been identified as potential sources of receiving water problems, upstream source identification studies on creeks, streams, and rivers should be conducted. The stopping rules described above for beaches and in Figure 5-4, are also directly applicable to creeks, streams, and rivers.

5.4.3 Design elements – habitat

The design elements for source identification for habitat are somewhat more complex than for recreational water quality. There are two main reasons for this. First, it is more difficult to quantitatively prioritize sites because the Triad approach involves three distinct types of data and there are no established standards or benchmarks for two of these, toxicity and bioassessment. Second, because these three data types sometimes produce inconsistent results (see Table 5-4 for examples), it can be difficult to establish clear benchmarks for when the weight of evidence calls for upstream source identification efforts. In addition, the availability of complete Triad data, as well as the interpretation of monitoring results, may be more complex in certain situations, such as ephemeral streams.

Rather than a quantitative metric, such as that shown for bacterial indicators in Table 5-9, the committee developed an overall framework for implementing a weight of evidence approach to triggering additional, targeted source identification studies (Tables 5-10 and 11). Table 5-10 provides expanded definitions of the thresholds in Table 5-4 that would trigger additional adaptive studies in response to combinations of Triad results. Table 5-11 then assigns a priority for source identification studies to each possible combination of Triad results from Table 5-4. Thus, in Table 5-11, the combination of results represented by Row 3 of Table 5-4 (persistent chemical exceedances, no toxicity, no benthic impact) would have a low priority for source identification studies. In contrast, the combination of results represented in Table 5-11 by Row 7 (no chemical exceedances, high toxicity, benthic impact) would have a high priority.

Monitoring results should be evaluated, using Table 5-4 as guidance, to determine whether the probable source(s) of impact is physical, chemical, or unknown. Upstream source identification efforts should then be initiated according to the set of priorities suggested in Table 5-21. Upstream source identification efforts should build on those performed to preliminarily assess the urban runoff contribution to receiving water problems, and should include detailed visual inspection of MS4s, water courses, and drainage areas as a first step. Visual inspections can then be followed with the water quality based source identification methods described in U.S. EPA (1993) and Pitt (2001).

As part of this overall framework, the committee did develop a quantitative method for combining toxicity testing results into a single metric (see Appendix 5) that would assist in ranking stations in terms of their aggregate toxicity. This ranking can then be used to assign priorities to stations for follow-up TIEs, as part of a source identification effort. The metric combines information about the degree of toxicity, the persistence of toxicity at a station throughout the year, and the percentage of test species found to exhibit toxicity.

Table 5-11 sets forth a set of starting rules for source identification efforts targeted at habitat impacts. Stopping rules are similar to those described for recreational water quality (Figure 5-6), with the same emphasis on identifying controllable sources.

5.4.4 Design issues

The same basic methods for detailed source identification apply to both recreational water quality and habitat. While the specific methods used in any instance will, of course, differ somewhat depending on the watershed structure and the constituents involved, they will include one or more of the following set of approaches, which are listed in order of increasing effort involved:

1. Evaluation of existing data
2. Visual reconnaissance and observation
3. Empirical tributary monitoring, which involves sampling tributary mouths upstream of the receiving water impact in order to identify the most likely point(s) of input
4. Sampling, or chemical "fingerprinting" of individual sources, including further upstream along tributaries, which can include the use of unique and/or conservative tracers.

These are similar to the methods described for the preliminary source identification in Question 3. However, Question 4 involves a more detailed focus on identifying specific sources of urban runoff and a greater degree of quantification than needed for Question 3. These methods are described more fully in US EPA (1993), Pitt (2001), and SWRCB (2001), which provide detailed descriptions of study designs, field sampling, and data analysis and interpretation appropriate for tracking sources of both bacteria and chemical pollutants.

The committee also recognized the need to supplement these methods descriptions with more explicit starting and stopping rules for detailed source identification studies. Starting rules are necessary for ensuring that source identification studies, which can be costly and time consuming, are triggered where and when monitoring data strongly suggest the presence of a persistent problem. Such rules are also needed to focus available resources on the highest priority problems. Stopping rules are essential for ensuring that source identification studies do not continue indefinitely, but end when reasonable and realistic expectations have been met. Such rules are proposed for receiving water problems associates with both recreational water quality and habitat.

5.5 Trend monitoring

Assessment of trends, for both recreational water quality and habitat, addresses Question 5: Are conditions in receiving waters getting better or worse? Question 5 provides the logical feedback to determine if management actions are having their intended effects. While this is a core monitoring element, the locations of stations and the relative emphasis on specific indicators may depend on information developed in answer to other questions (Table 4-1) related to the where problems exist (Question 1), the extent and magnitude of such problems (Question 2), and the nature and number of sources (Questions 3 and 4). Trends monitoring is a core monitoring program element (Table 4-1).

5.5.1 Recreational water quality trends

5.5.1.1 Overview

Table 5-12 presents an overview of the technical design elements for trend monitoring of recreational water quality at beaches; bays and estuaries; and creeks, streams, and rivers.

The model monitoring framework for trend monitoring of recreational water quality is based on statistical power analysis of a monitoring design that involves repeated sampling over time at fixed stations. For recreational water quality, sampling data from one inland watershed (Aliso Creek) suggests that trend monitoring might productively focus on one period of the year when both bacteria levels and human use are highest. Power analysis results from this watershed also suggest that the statistical power of the trend monitoring design can vary widely from station to station, as well as across indicators. However, comparable data were not available to support analogous conclusions for beaches and bays and estuaries. Thus, the committee recommends that programs begin trend monitoring with ten to fifteen weekly samples per year for three years, and then conduct site-specific power analyses with the software package developed by the committee and made available on the SCCWRP website. Power analyses on available data from southern California show clearly that differences across sites mean that a “one size fits all” approach to trend monitoring design will not work. The recommended approach will therefore ensure appropriate levels of both within-year replication and number of years of trend monitoring. Given that trend monitoring will most likely need to continue for a minimum or ten or fifteen years, devoting the first three years to obtaining site-specific data will not result in any substantial reduction in the longer-term power of the trend monitoring design. Any such reduction will be outweighed by gains in site-specific efficiency and statistical power.

See Section 4.5, for an expanded discussion of the use of statistical power analysis in the core trend monitoring aspects of the model monitoring design.

5.5.1.2 Design elements

The following subsections address, in turn, trend monitoring design in high-priority recreational areas where use is concentrated and then in the upstream areas that are the sources of contamination. Where such upstream source areas have been identified and are the targets of active source reduction efforts, it may be useful to monitor trends in the levels of these sources.

Conditions in high-priority recreational areas. Figure 5-2 shows that fecal coliform levels (the basis of the REC1 Basin Plan standard in this case) vary considerably among months in the high-priority area in lower Aliso Creek. While there are not equally intensive data records from other creeks throughout the region, it is reasonable to assume that similar variability would be present elsewhere. Thus, it would statistically be most efficient to stratify trend analyses by month, with separate trend analyses for each month. Lumping months that normally have highly divergent fecal coliform counts would increase the within-year variability and make it more difficult to detect trends over time.

Power tests (see Section 4.5.1 and Figure 4-1 for a discussion of the importance of statistical power analyses as part of a trend monitoring design) on the monthly Aliso Creek data were thus conducted to estimate the number of years and number of samples within a 30-day period that might be required to detect different percentages of decrease in fecal coliform counts. Power tests were performed only at stations and for months for which more than one year was sampled because the power tests require an estimate of between-year variability. Figure A2.1 (Appendix 2), with plots for each station organized in order of increasing geomean, shows that the ideal months to sample differ from station to station. For example, the highest power for a given sampling effort occurs in August for the SOCWA treatment plant site (Figure A2.1d) but in June for the Aliso Wood Canyon Park Site (Figure A2.1c).

These results provide guidance that illustrates how the details of a trend monitoring design could be developed. Figure 5-5 shows that in the study of Aliso Creek the peak bacteria levels coincide with the period of highest recreational use in the late summer and early fall. Thus, it would be most efficient to target a trend monitoring program at one or more of the months in that portion of the year. Once a monitoring period is chosen, power analyses such as those in Figure A2.1 can be used to determine a preferred combination of reduction in indicator values, short-term sampling intensity, and length in years of the monitoring program. As mentioned above, the software package available on the SCCWRP website provides a straightforward means for each program to conduct power analysis with site-specific data.

High-priority inputs. Trend monitoring may also be useful where specific upstream inputs have been identified that contribute to contamination at a high-priority recreational use area. The key trend monitoring question for such inputs is whether the loads of bacteria, and their local impacts on the receiving water, are decreasing over time. Loads are a clear measure of the size of the input itself, and directly reflect the relative success of BMPs in the local drainage area. However, loads alone are insufficient to measure a discharge's potential impact on the receiving water. Thus, trend monitoring of high-priority inputs should include both loads and impact (measured as the difference between stations upstream and downstream of the discharge). A quantitative method for prioritizing upstream inputs for management actions and for trend monitoring is described above in Section 5.4.2, which discusses source identification approaches.

The monitoring data from Aliso Creek provide a useful illustration of how power analysis can be used to design a site-specific trend monitoring program. Figure A2.2 (Appendix 2) shows that bacterial levels in the high-priority drains in Aliso Creek, as well as at the upstream and downstream stations associated with each, are typically highest in the June – September period and lower throughout the rest of the year. The illustrative power analyses therefore focused on this period in order to reduce the within-year variability. Power analyses were performed for two measures, the load from each drain (Figure A2.3) and the impact of each drain (Figure A2.4) measured as the difference between the downstream and upstream stations. These results suggest that it will not be feasible to track loads at station J06 (Figure A2.3) nor to track impacts at station J01P08 (Figure A2.4). With the exception of these parameters at these stations, however, the power analysis also suggests that a sampling frequency of 20 samples, collected in the June – September period, would be adequate to detect an average 50% reduction in loads and an average 30% reduction in impact over a ten year period.

5.5.1.3 Design issues

Trends monitoring of existing bacterial indicators is complicated by their extreme variability in space and time. Thus, there may be limitations on our ability to detect change with current monitoring technology.

There are two aspects of trend monitoring with regards to recreational water quality. The first is related to conditions in the high-priority recreational use area(s) that are the major focus of concern. The question here is therefore whether indicator levels are trending downward toward applicable water quality objectives. The second aspect of such trend monitoring is related to whether the high-priority inputs upstream of the high-priority recreational area are improving. The question here is somewhat different, instead being whether loads and localized impacts (a measure of the direct effect on the receiving water) are declining. This is why the recommended indicators include both a measure of concentration and a measure of loads.

5.5.2 Habitat trends

5.5.2.1 Overview

Assessment of habitat trends addresses Question 5: Are conditions in receiving waters getting better or worse? Question 5 provides the logical feedback to determine if management actions are having their intended effects. While this is a core monitoring element, the locations of stations and the relative emphasis on specific indicators may depend on information developed in answer to other questions (Table 4-1) related to the where problems exist (Question 1), the extent and magnitude of such problems (Question 2), and the nature and number of sources (Questions 3 and 4).

Table 5-13 presents an overview of the technical design elements for trend monitoring of habitat conditions.

The model monitoring framework for trend monitoring of habitat conditions is based on statistical power analysis of a trend monitoring design that involves repeated sampling over time at fixed stations. For habitat, the timing of trend monitoring will differ depending on the parameters being tracked, with mass emissions monitored during wet weather and bioassessment during dry weather. Available data indicate that power analysis results can vary widely from station to station, as well as across parameters. Thus, the committee recommends that programs begin trend monitoring with two or three samples per year for three years, and then conduct site-specific power analyses with the software package developed by the committee and made available on the SCCWRP website.

5.5.2.2 Design elements

Trend monitoring is relevant to all aspects of habitat monitoring in the watershed design. Trend monitoring can occur at one or more of the core monitoring assessment stations depending on criteria such as the level of management concern or whether a receiving water problem has previously been documented.

Appendix 2 provides example statistical power analysis results for two aspects of a trend monitoring design (event mean concentration (EMC) and mass emissions) for which sufficient data currently exist for such an analysis. These results Figures A2.5 - and A2.14, which use data from several representative long-term stations in Orange County, reflect, as do the bacteria results described above, large differences in power from station to station and across parameters. (Data from other monitoring programs were not suitable for power analysis.) As a result, it is not possible to recommend levels of sampling effort that would be generally applicable across the region. Therefore, the committee recommends that trend monitoring programs for habitat begin by collecting two or three samples per year for three years and then use these data to conduct site-specific power analyses to refine the following aspects of the design:

- The amount of change expected or desired
- The number of samples to be collected per year
- The number of years before the expected change is detected.

These analyses can be carried out with the software package available on the SCCWRP website. While results will undoubtedly vary from site to site, the committee's analyses of available historical monitoring data (Appendix 2) suggests that it is unlikely that substantial amounts of change (e.g., reductions of 50% or more) will be observable in less than ten years and that management targets and monitoring designs should be developed accordingly.

5.5.2.3 Design issues

Trends monitoring of habitat indicators is complicated by the variety of station types, the long list of monitored constituents, and the complexity of ecosystem processes that influence observed trends. Therefore, general guidance is presented for two main categories of monitoring data – mass emissions and toxicity. As for the recreational water quality aspect of Question 5, the power analysis software available on the SCCWRP website will enable each program to perform relevant site-specific power analyses as required

Table 5-1. Design overview for assessment monitoring of recreational water quality.

Type of area	**Site location**	**Frequency**	**Indicator(s)**
Open-coast beach	Gaps in Health Department coverage • High-priority areas • Flowing stormdrains Drain itself Upcoast and downcoast of drain Characterize dispersion of drain plume prior to siting upcoast and downcoast stations	Based on BWQWG prioritization Daily – monthly (see Table 5-2)	Total coliform Fecal coliform Enterococcus
Enclosed bays and estuaries	Gaps in Health Department coverage High priority areas Subsample of flowing stormdrains Drain itself Upcoast and downcoast of drain	Based on BWQWG prioritization Daily – monthly (see Table 5-2)	Total coliform Fecal coliform Enterococcus
Creeks, streams, and rivers	High-priority areas Drain or other input Upstream and downstream of input	Weekly in high-use season	Total coliform or E. coli Fecal coliform Enterococcus

Table 5-**2. The Beach Water Quality Workgroup's risk-based approach fo**r determining sampling frequency. The presence of lifeguards is an indicator of high-use beaches that are most likely above the 50,000 users threshold in Assembly Bill 411.

	Likelihood of Contamination			
Usage	**High**: e.g., stormdrains that flow continuously, frequently exceeding bacterial standards; pier areas	**Medium**: e.g., stormdrains that flow intermittently or continuously with infrequent exceedances of standards	**Low**: source nearby, do not expect a problem, stormdrain not flowing but if had a sewage spill it would flow to beach, if a problem it would be long term	**No known source**
High use beach: lifeguarded, high use surf/dive area	Daily or 5X per week	5X per week	Weekly or 5X per month	Weekly or 5X per month
Accessible sandy beach: low use surf/dive area or other water contact recreation area (wind surfing, kayaking)	2 – 3X per week	Weekly or 5X per month	Weekly or 5X per month	None
Other accessible shoreline: rocky coastline, small coves accessible by trails, private homes limit access	Weekly or 5X per month	Weekly or 5X per month	Monthly or other identification system	None
Inaccessible: beach area > 1 mile from access area	None	None	None	None

Table 5-3. Design overview for assessment monitoring of habitat.

Type of area	**Site location**	**Frequency**	**Indicator(s)**
Mass emissions	Bottoms of watersheds	3 storms / yr for 3 yrs, then modify per results of power analyses	Chemistry (see Table 5-16) Toxicity
Watershed	Random or rotating, perhaps per Bight design	Every few years, perhaps per Bight Program schedule	Triad in dry weather Chemistry, toxicity in wet weather
High-priority inland habitat	High-value habitat either impacted or threatened	1 or 2 / yr in dry weather	Triad
Program goals	As needed based on nature of specific goal(s)	Dependent upon problem, question	Dependent upon problem, question
Estuaries	Random per Bight design Key habitats and/or downstream of major inputs	Every few years per Bight design 1 or 2 / yr, in wet and/or dry, depending on problem, question	Chemistry (see Table 5-16) Toxicity
Nearshore ocean	Random and/or clustered in plumes, per Bight design	Every few years per Bight design	Chemistry (see Table 5-16) Toxicity

Table 5-4. Decision framework for interpreting triad results. Possible conclusions and actions/decisions are intended as general guidance, dependent on the specific monitoring results found and the actual relationships among chemistry, toxicity, and benthic data.

	Chemistry	Toxicity	Benthic Alteration	Example Conclusions	Example Actions or Decisions
1.	Persistent exceedance of water quality objectives	Evidence of toxicity	Indications of alteration	Strong evidence of pollution-induced degradation	Toxicity tests at higher dilutions to better quantify toxicity Use TIE to identify contaminants of concern, based on TIE metric Initiate upstream source identification as a high priority
2.	No persistent exceedances of water quality objectives	No evidence of toxicity	No indications of alteration	No evidence of current pollution-induced degradation Potentially harmful pollutants not yet concentrated enough to cause visible impact	No immediate action necessary Conduct periodic broad scans for new and/or potentially harmful pollutants
3.	Persistent exceedance of water quality objectives	No evidence of toxicity	No indications of alteration	Contaminants are not bioavailable Test organisms not sensitive to problem pollutants	TIE would not provide useful information with no evidence of toxicity Continue monitoring for toxic and benthic impacts Consider whether different or additional test organisms should be evaluated Initiate upstream source identification as a low priority
4.	No persistent exceedances of water quality objectives	Evidence of toxicity	No indications of alteration	Unmeasured contaminant(s) or conditions have the potential to cause degradation Pollutant causing toxicity at very low levels Synergistic effects of multiple chemicals at low levels causing toxicity	Recheck chemical analyses and evaluate detection limits relative to reported toxic levels Verify toxicity test results Consider additional advanced chemical analyses Toxicity tests at higher dilutions to better quantify toxicity Use TIE to identify contaminants of concern, based on TIE metric Initiate upstream source identification as a medium priority

	Chemistry	Toxicity	Benthic Alteration	Example Conclusions	Example Actions or Decisions
5.	No persistent exceedances of water quality objectives	No evidence of toxicity	Indications of alteration	Alteration may be due to physical impacts, not toxic contamination Test organisms not sensitive to problem pollutants Synergistic effects of multiple chemicals at low levels causing toxicity	No action necessary due to toxic chemicals Initiate upstream source identification (for physical sources) as a high priority Consider whether different or additional test organisms should be evaluated
6.	Persistent exceedance of water quality objectives	Evidence of toxicity	No indications of alteration	Toxic contaminants are bioavailable, but in situ effects are not demonstrable Benthic analysis not sensitive enough to detect impact Potentially harmful pollutants not yet concentrated enough to change community	Determine if chemical and toxicity tests indicate persistent degradation Recheck benthic analyses; consider additional data analyses Toxicity tests at higher dilutions to better quantify toxicity If recheck indicates benthic alteration, perform TIE to identify contaminants of concern, based on TIE metric Initiate upstream source identification as a high priority If recheck shows no effect, use TIE to identify contaminants of concern, based on TIE metric Initiate upstream source identification as a medium priority
7.	No persistent exceedances of water quality objectives	Evidence of toxicity	Indications of alteration	Unmeasured toxic contaminants are causing degradation Pollutant causing toxicity at very low levels Synergistic effects of multiple chemicals at low levels causing toxicity Benthic impact due to habitat disturbance, not toxicity	Recheck chemical analyses and consider additional advanced analyses Toxicity tests at higher dilutions to better quantify toxicity Use TIE to identify contaminants of concern, based on TIE metric Initiate upstream source identification as a high priority Consider potential role of physical habitat disturbance
8.	Exceedance of water quality objectives	No evidence of toxicity	Indications of alteration	Test organisms not sensitive to problem pollutants Benthic impact due to habitat disturbance, not toxicity	TIE would not provide useful information with no evidence of toxicity Initiate upstream source identification as a high priority Consider whether different or additional test organisms should be evaluated Consider potential role of physical habitat disturbance

Table 5-5. Example distribution of monitoring effort among the various kinds of stations in the watershed design. Special studies would be implemented when results of core or regional monitoring indicated a need for them. Specific triggers initiate adaptive monitoring and special studies designed to answer questions about the magnitude, extent, and source(s) of problems.

Station type	**Core monitoring**	**Regional monitoring**	**Further monitoring / special studies**
Mass emissions	Triad, including broader suite of chemistry		TIEs (Q4) Upstream source ID (Q4)
Watershed		Bioassessment Basic chemistry Some toxicity	Expanded toxicity, chemistry (Q2) TIEs (Q4) Upstream source ID (Q4)
High-priority habitat	Bioassessment Chemistry (if prior reason) *		Toxicity, chemistry (Q1, 2) TIEs (Q4) Upstream source ID (Q4)
Program goals	Dependent on question(s)		
Estuaries	Toxicity Chemistry (if prior reason) *		TIEs (Q4) Upstream source ID (Q4) Process studies (Q1 – 4) Biology (e.g., benthos, bioaccumulation) (Q1, 2)
Nearshore ocean +		Plume tracking Plume toxicity Plume chemistry	

* Chemical monitoring could be deferred until bioassessment or toxicity results suggest a potential problem.
+ Conducted as part of the periodic regional Bight program.

Table 5-6. The short list of chemical constituents that should be sampled routinely by all programs and an expanded list to be sampled where routine monitoring data or other information suggest the need for additional information and/or where appropriate to the management question being asked.

Category	**Short list**	**Expanded list**
Trace metals	total Cd, Cr, Cu, Ni, Pb, Zn	dissolved (with hardness)
Nutrients	NH_3, total Kjeldahl Nitrogen (TKN), NO_3, total P	
Bacteria	total coliform, fecal coliform or E. coli, Enterococcus	
Pesticides	diazinon, chlorpyrifos, other OP pesticides	others as necessary, e.g., legacy pesticides (DDT, chlordane, lindane), emergent pesticides (e.g., pyrethroids)
Conventionals	temperature, pH, hardness, specific conductance, dissolved oxygen	chemical oxygen demand (COD), sulfides
PAHs	if methods are available that are suitable for measuring on particles, at low detection limits	
Volatiles		dry weather only
Suspended solids	total suspended solids (TSS)	
Priority pollutants	every 5 years, with Bight Program	

Table 5-7. Design overview for extent and magnitude monitoring of recreational water quality problems. Regional monitoring is distinguished from special projects in its larger geographic scale and/or greater number and kinds of potential sources

Type of area	Site location	Frequency	Indicator(s)
Open-coast beach	Input(s) of concern Spaced array upcoast and downcoast of input of concern	One calendar year to establish basic pattern, then: Daily within representative periods (e.g., storms, dry weather, dominant current regimes)	Concentration and loads: • Total coliform • Fecal coliform • Enterococcus Dye
Enclosed bays and estuaries	Input(s) of concern Based on nature of problem, either: • Spaced array around input of concern • Regular grid throughout area of concern • Random array throughout area of concern • Gradient array downcurrent of input of concern	One calendar year to establish basic pattern, then: Daily within representative periods (e.g., storms, dry weather, dominant current regimes)	Concentration and loads: • Total coliform • Fecal coliform • Enterococcus Dye
Creeks and streams	Regular grid throughout high-priority use area	One calendar year to establish basic pattern, then: Daily within subsample of high-use period	Total coliform or E. coli Fecal coliform Enterococcus Dye

Table 5-8. Design overview for both recreational water quality and habitat source identification under Question 4: What are the sources to urban runoff that contribute to receiving water problems?

Type of area	Site location	Frequency	Indicator(s)
Recreational water quality			
Open-coast beach	Inputs that fall in upper right section of Figure 5-3	Ongoing until reach stopping rules in Figure 5-7	Total coliform Fecal coliform Enterococcus
Enclosed bays and estuaries	Inputs that fall in upper right section of Figure 5-3	Ongoing until reach stopping rules in Figure 5-7	Total coliform Fecal coliform Enterococcus
Creeks and streams	High-priority inputs as identified with conceptual model in Figure 5-3	Ongoing until reach stopping rules in Figure 5-7	Total coliform or E. coli Fecal coliform Enterococcus
Habitat			
All areas except coastal ocean	At core monitoring site Upstream of core monitoring site	Ongoing until reach stopping rules in Figure 5-8	Constituents identified in Questions 1 - 3

Table 5-9. Aliso Creek stations in order of scaled load and impact. Impact = downstream **concentration – upstream concentration on each date. Load = factor x flow (csf) x concentration in pipe on each date. Scaled values are rescaled to 0 – 1. Average scaled** values = average of scaled impact and load values. Stations are ranked in order of average scaled values.

Station	Avg scaled	Impact scaled	Load scaled	Impact	Load
J01P08	0.45442	0.30327	0.60558	1.09240	5.12476
J01P28	0.42830	0.16437	0.69223	0.59208	5.80725
J02P05	0.41653	0.21205	0.62102	0.76381	5.24640
J04	0.41279	0.12574	0.69984	0.45291	5.86718
J01P01	0.40517	0.22449	0.58585	0.80864	4.96939
J02TBN1	0.40237	0.23424	0.57049	0.84376	4.84841
J03P01	0.39515	0.17026	0.62004	0.61328	5.23868
J01TBN8	0.39016	0.27729	0.50303	0.99881	4.31707
J01P03	0.35542	0.10754	0.60331	0.38738	5.10688
J03P02	0.34631	0.04993	0.64270	0.17984	5.41714
J01P27	0.34413	0.05564	0.63262	0.20040	5.33780
J01P30	0.34067	0.10229	0.57906	0.36847	4.91588
J03P05	0.33684	0.04794	0.62573	0.17270	5.28352
J03TBN2	0.33178	0.19535	0.46821	0.70366	4.04286
J01P23	0.32485	0.09907	0.55062	0.35686	4.69191
J03P13	0.32480	0.09263	0.55698	0.33365	4.74199
J06	0.32433	0.09277	0.55589	0.33415	4.73343
J01P06	0.30957	0.12342	0.49573	0.44455	4.25962
J01P26	0.30500	0.05205	0.55794	0.18750	4.74956
J05	0.28978	0.05328	0.52628	0.19192	4.50018
J01P05	0.28974	0.08773	0.49175	0.31600	4.22829
J01TBN2	0.28929	0.12163	0.45695	0.43812	3.95419
J03TBN1	0.28574	0.09032	0.48116	0.32534	4.14483
J01P22	0.28419	0.06092	0.50745	0.21944	4.35194
J07P01	0.26681	0.09332	0.44031	0.33613	3.82309
J01TBN4	0.26512	0.05184	0.47840	0.18674	4.12309
J01P04	0.25812	0.06553	0.45072	0.23603	3.90509
J01P25	0.25406	0.05010	0.45801	0.18047	3.96254
J01TBN3	0.24684	0.04788	0.44580	0.17248	3.86634
J01P33	0.24246	0.05250	0.43242	0.18909	3.76094
J01P24	0.20587	0.03620	0.37553	0.13040	3.31286
J01P21	0.14696	0.04556	0.24836	0.16411	2.31128

Table 5-10. Definitions of the triggers in Table 5-4, the Triad interpretation framework, designed to initiate further adaptive studies to **identify potential sources of impact. “BRI”** refers to the regional Benthic Response Index for estuaries developed by the Bight **Program. “IBI” refers to the Index of Biotic** Integrity, a regional bioassessment index under development by the Stormwater Monitoring Coalition.

Possible trigger in Table 5-4	**Definition of trigger**
Persistent exceedance of water quality objectives	Exceedance of relevant Basin Plan or CTR objectives by 20% for 3 sampling periods
Evidence of toxicity	High score, in relation to other stations, on metric that combines magnitude and persistence of toxicity observed over an entire year (see Appendix 5: TIE Metric)
Evidence of benthic alteration	BRI score that indicates substantially degraded community (in estuaries) IBI score that indicates substantially degraded community (in freshwater creeks, streams, and rivers)

Table 5-11. Summary of the upstream source identification priorities from Table 4-7, based on combinations of the chemical, toxicity, and benthic components of the triad approach. **"Yes" and "No" refer to whether or not data from each component exceeded the triggers** described in Table 5-20.

Table 4-7 Row	Triad Component	Yes	N o	Source ID Priority
1	chemistry	X		
	toxicity	X		
	benthos	X		High
2	chemistry		X	
	toxicity		X	
	benthos		X	None
3	chemistry	X		
	toxicity		X	
	benthos		X	Low[1]
4	chemistry		X	
	toxicity	X		
	benthos		X	Medium
5	chemistry		X	
	toxicity		X	
	benthos	X		High (for physical components)
6	chemistry	X		
	toxicity	X		
	benthos		X	Medium
7	chemistry		X	
	toxicity	X		
	benthos	X		High
8	chemistry	X		
	toxicity		X	
	benthos	X		High

[1] If further testing indicates appropriate and sensitive enough toxicity tests were used and analytical results suggest pollutant is not bioavailable.

Table 5-12. Design overview for trends monitoring of recreational water quality.

Type of area	Site location	Frequency	Duration	Indicator(s)
Open-coast beach	Input(s) of concern at high-priority beaches Upcoast and downcoast stations	Weekly within representative periods (e.g., storms, dry weather, dominant current regimes) Repeated yearly	10 – 15 per year for 3 years, then based on power analysis	Concentration and loads: • Total coliform • Fecal coliform • Enterococcus Dye
Enclosed bays and estuaries	Input(s) of concern at high-priority sites Stations bracketing input(s)	Weekly within representative periods (e.g., storms, dry weather, dominant current regimes) Repeated yearly	10 – 15 per year for 3 years, then based on power analysis	Concentration and loads: • Total coliform • Fecal coliform • Enterococcus Dye
Creeks and streams	High-priority use area High-priority upstream inputs	Weekly with representative periods (e.g., storms, dry weather, dominant current regimes) Repeated yearly	10 – 15 per year for 3 years, then based on power analysis	Concentration and loads: • Total coliform or E. coli • Fecal coliform • Enterococcus Dye

Table 5-13. Design overview for trends monitoring of habitat.

Type of area	**Site location**	**Frequency**	**Duration**	**Indicator(s)**
Mass emissions	Bottoms of watersheds	3 storms / yr for 3 yrs, then modify per results of power analyses	Based on power analysis	Chemistry (see Table 4-8) Toxicity
Watershed	Random or rotating, perhaps per Bight design	Every few years, perhaps per Bight Program schedule	Ongoing	Triad in dry weather Chemistry, toxicity in wet weather
High-priority habitat	High-value habitat either impacted or threatened	1 or 2 / yr in dry weather	Based on power analysis Revisit when habitat status changes	Triad
Program goals	As needed	Dependent upon problem, question	Based on power analysis Until goals met / change	Dependent upon problem, question
Estuaries	Random per Bight design Key habitats and/or downstream of major inputs	Every few years per Bight design 1 or 2 / yr, in wet and/or dry, depending on problem, question	Ongoing for Bight Based on power analysis for key habitats and downstream stations	Chemistry (see Table 4-8) Toxicity
Nearshore ocean	Random and/or clustered in plumes, per Bight design	Every few years per Bight design	Ongoing	Chemistry (see Table 4-8) Toxicity

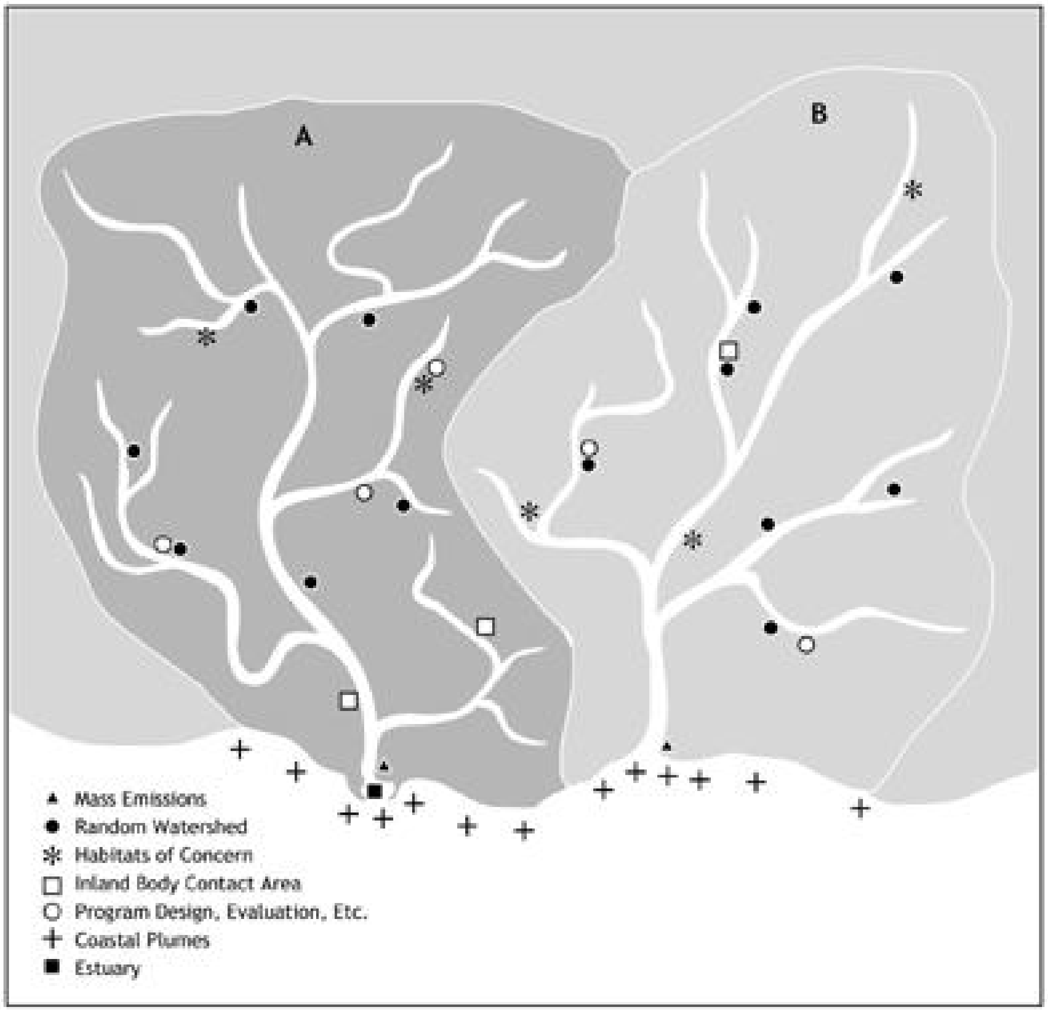


Figure 5-1. Example model monitoring program design in an idealized watershed.

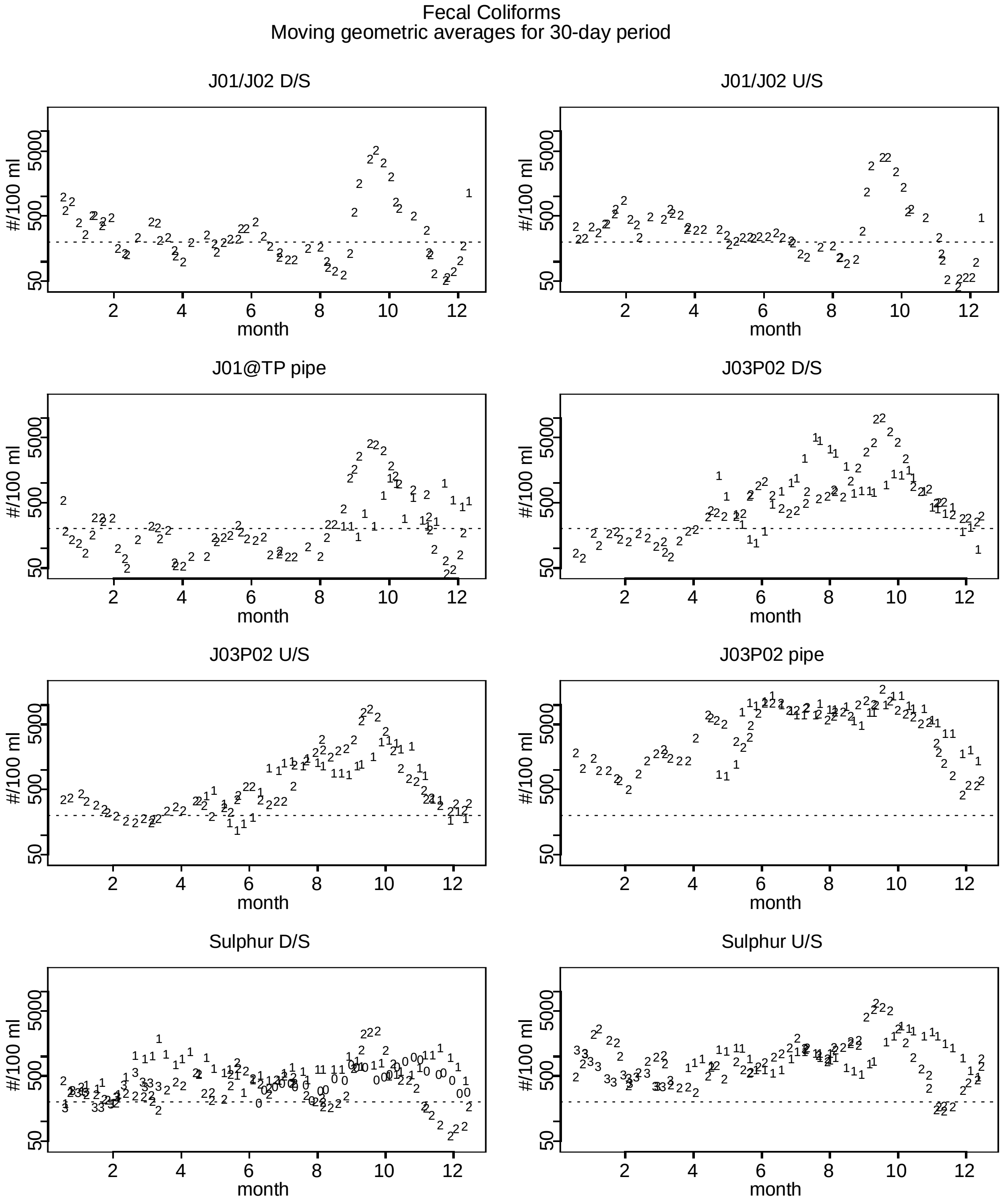


Figure 5-2a. Fecal coliform measurements at and upstream/downstream of discharge points in lower Aliso Creek. Data points are 5-sample moving geometric averages. The horizontal dashed line represents the Basin Plan REC1 objective for fecal coliforms (geomean not higher than 200/100 ml). The point symbols indicate the year of sampling (i.e., 1 for 2001, 2 for 2002).

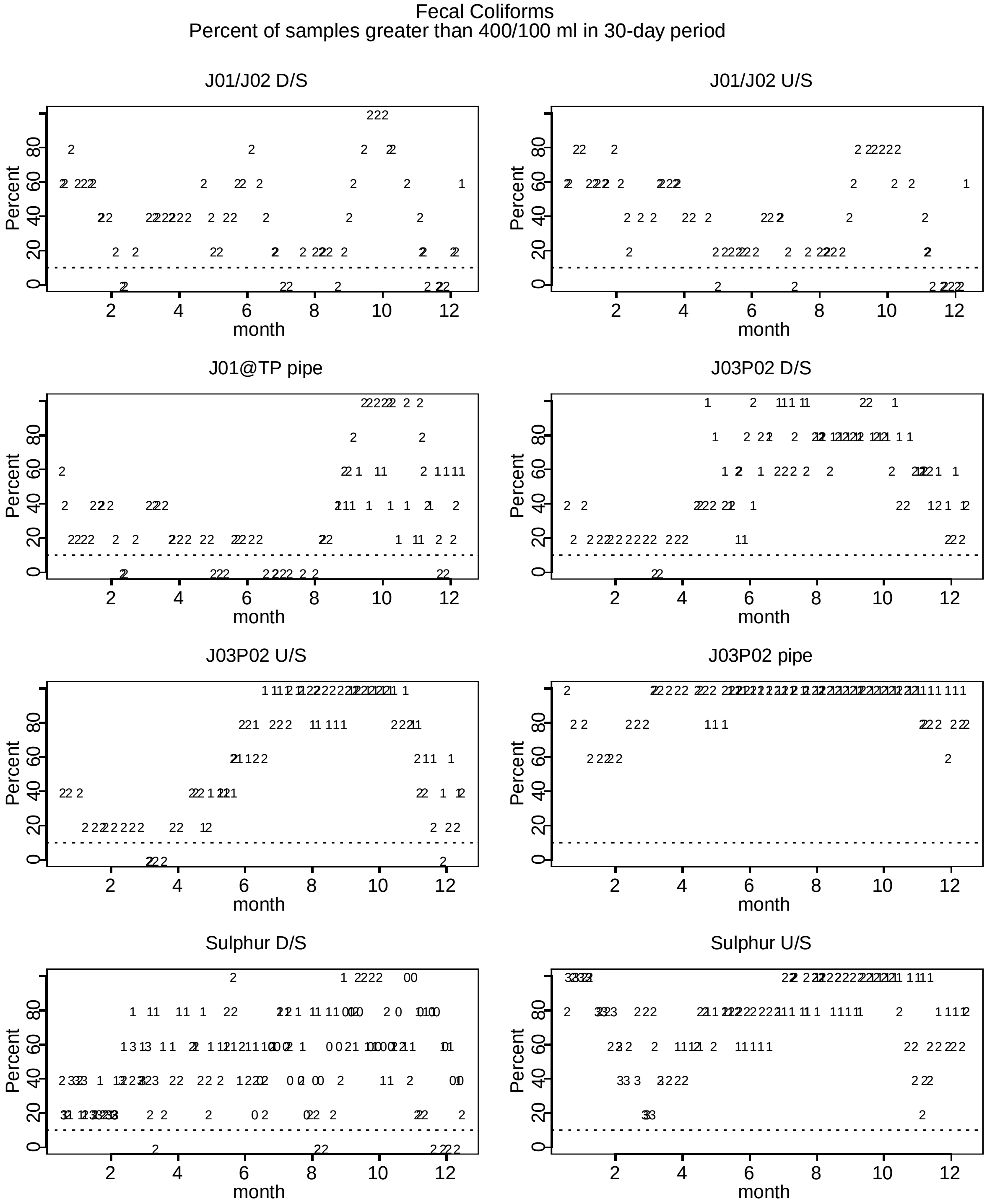


Figure 5-2b. Fecal coliform measurements at and upstream/downstream of discharge points in lower Aliso Creek. The data points are the percent of fecal coliform samples above 400/100 ml in the five most recent samples. The horizontal dashed line represents the Basin Plan REC1 objective for fecal coliforms (no more than 10% above 400/100 ml). The point symbols indicate the year of sampling (i.e., 1 for 2001, 2 for 2002).

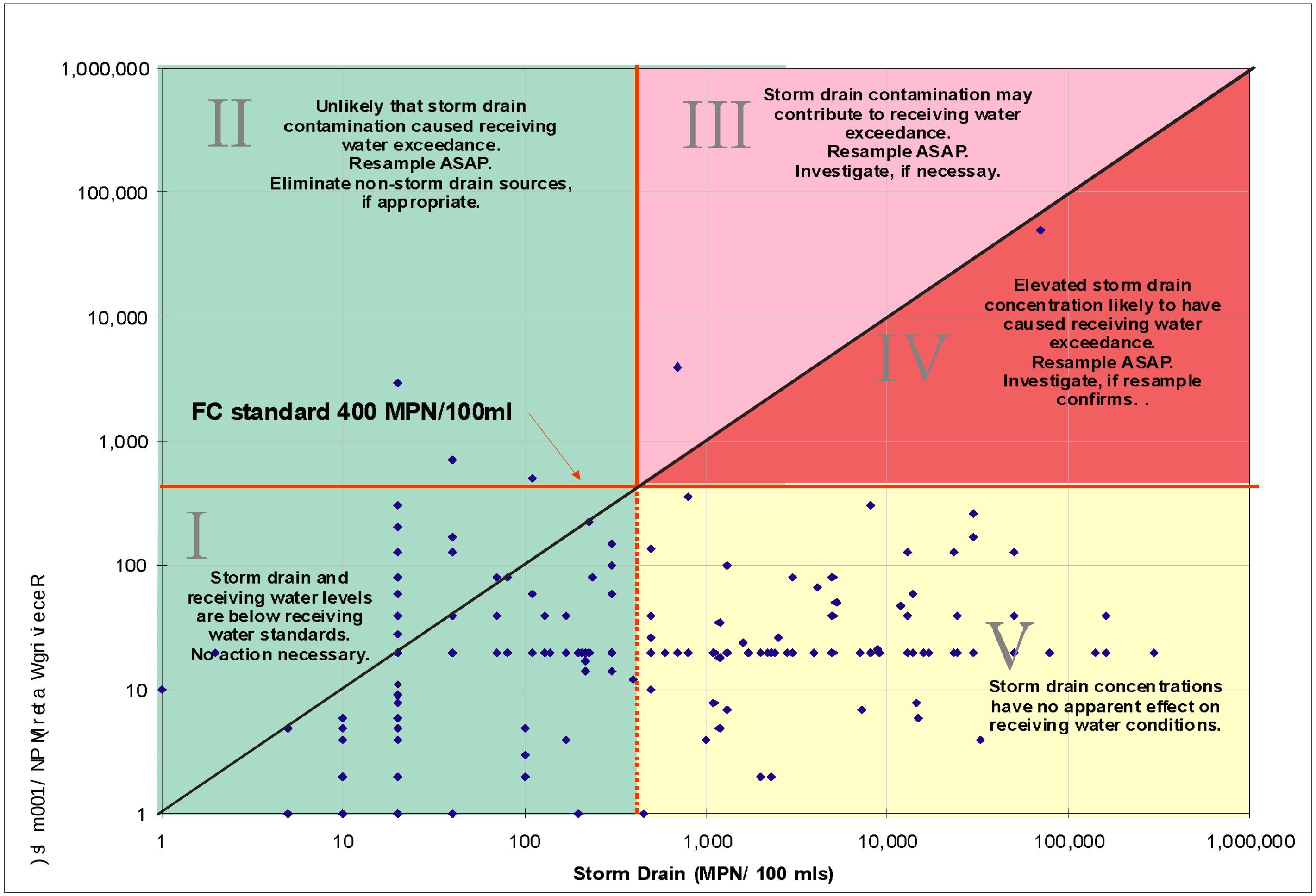


Figure 5-3. Approach for prioritizing coastal and estuarine bacterial inputs for further upstream source identification efforts. The highest priority is given to situations in which elevated bacterial indicator levels in the discharge are matched with elevated levels in the receiving water. This figure shows an example using fecal coliform, and analagous figures could be prepared with other indicator data.

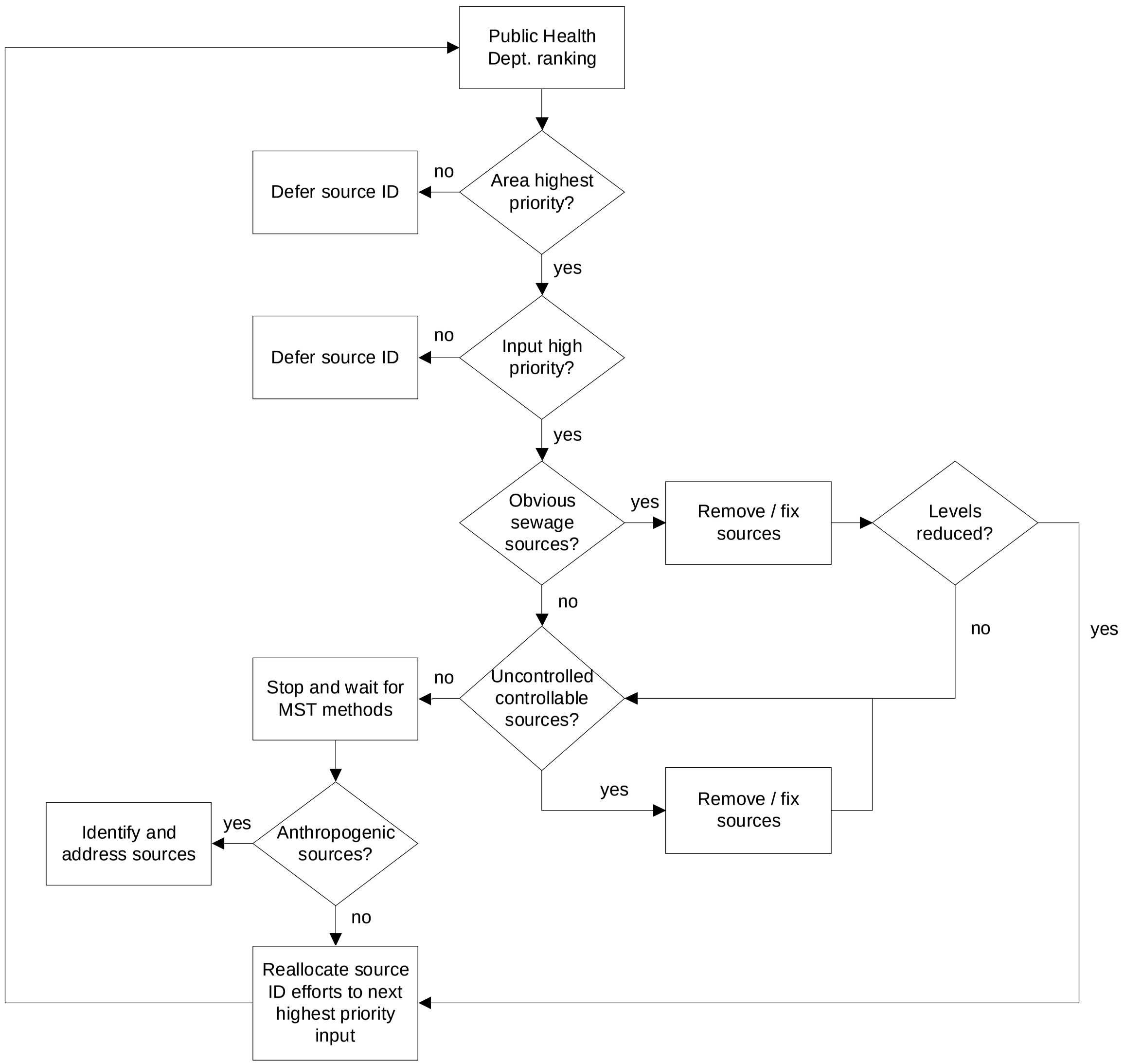


Figure 5-4. Decision tree that organizes starting and stopping rules for upstream bacterial source identification efforts. MST refers to microbial source tracking methods.

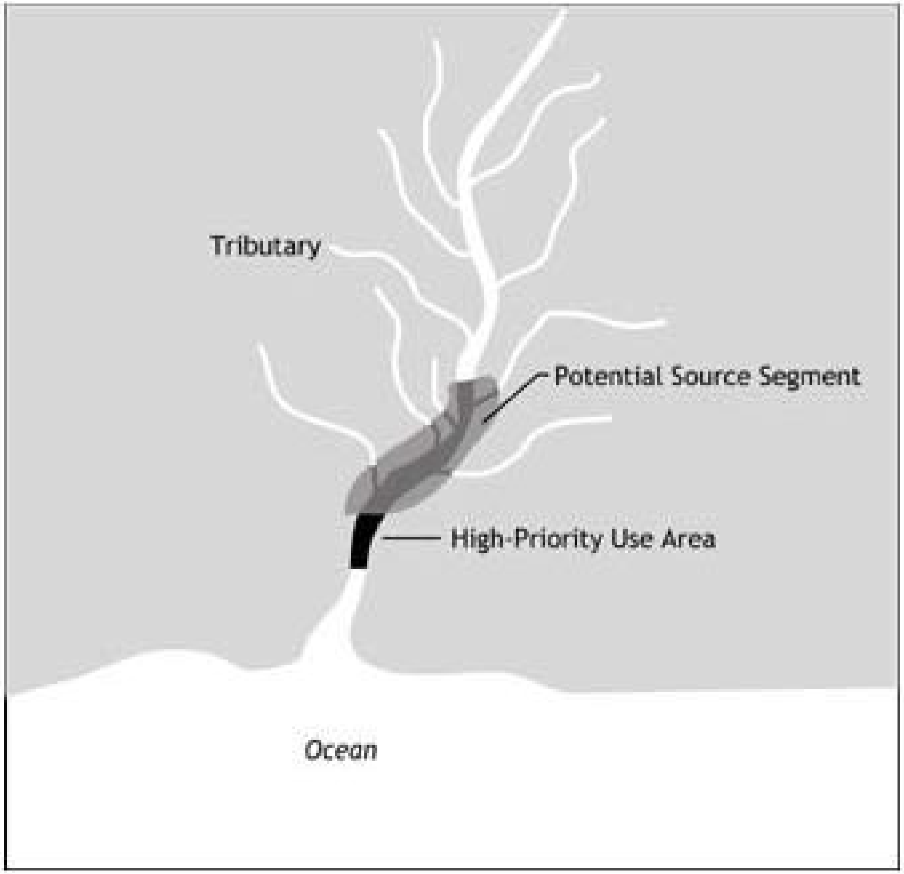


Figure 5-5. Conceptual model for determining the upstream segment of a creek or stream that should be the focus of source identification efforts for bacterial contamination. The model assumes that bacterial dieoff as water flows downstream places an upper limit on the distance bacteria can travel and still impact the high-priority use area.

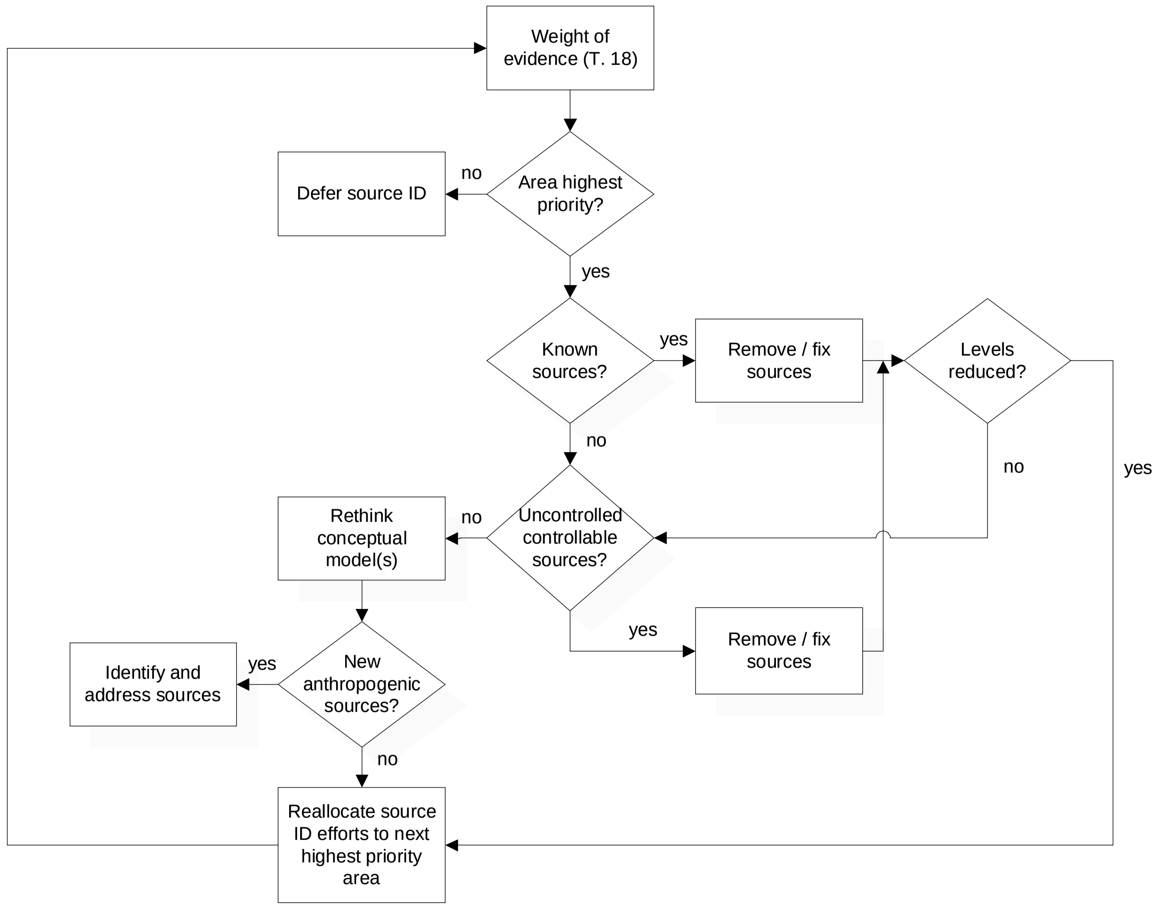


Figure 5-6. Decision tree that organizes starting and stopping rules for upstream source identification efforts targeted at habitat.

6.0 REFERENCES

Ackerman, D., K. Schiff, H. Trim, and M. Mullin. 2003. Characterization of water quality in the Los Angeles River. *Bulletin of the Southern California Academy of Sciences* 102:17-25

Bay Area Stormwater Management Agencies Association (BASMAA). 1995. Monitoring Project Standardization Project. Prepared in collaboration with San Francisco Estuary Institute and Woodward-Clyde Consultants. Oakland, CA.

Bernstein, B. B., B.E. Thompson and R.W. Smith. 1993. A combined science and management framework for developing regional monitoring objectives. *Coastal Management*. 21:185-195.

Griffith, J., S. Weisberg, and C. McGee. 2003. Evaluation of microbial source tracking methods using mixed fecal sources in aqueous test samples. *Journal of Water and Health* 1(4):1-12

Leecaster, M., K. Schiff, and L. Tiefenthaler. 2002. Assessment of efficient sampling designs for urban stormwater monitoring. *Water Research* 36:1556-1564

Pitt, R. 2001. Illicit discharge detection and elimination. Presentation at the EPA National Stormwater Coordinator's Meeting, Orlando, FL. May 1-3, 2001.

Singh, V. and D. Woolheiser. 2002. Mathematical modeling of watershed hydrology. *Journal of Hydrologic Engineering* 7:270-292

State Water Resources Control Board (SWRCB). 2001. Report to the Legislature. Includes Final Report AB-538 Study by M. Stenstrom.

U.S. EPA. 1993. Investigation of inappropriate pollutant entries into storm drainage systems. Office of Research and Development, Washington, DC. EPA/600/R-92/238.

U.S. EPA. 1992. NPDES stormwater sampling guidance document. Office of Water, Washington, DC. EPA# 833B92001

U.S. EPA. 2002. Research Strategy Environmental Monitoring and Assessment Program. http://www.epa.gov/emap/html/pubs/docs/resdocs/resstrat02.html.

7.0 APPENDICES

Appendix 1: Summary of Existing Municipal Stormwater Monitoring Programs in Southern California

June 2003

As part of the effort to develop a model stormwater monitoring program, we have reviewed and summarized the existing monitoring designs being implemented by each of the major stormwater programs in southern California. This information will be used, in a later step of the project, as a starting point for assessing what sorts of changes might be advisable to bring existing monitoring efforts more into line with the recommendations of the model program.

Program-specific details

There are six basic types of monitoring approaches currently used in NPDES stormwater monitoring programs throughout southern California, including:

- End of watershed designs that typically measure the cumulative mass emissions from all discharges
- Dispersed watershed designs that assess overall conditions and impacts in freshwater habitats
- Site-specific watershed designs that assess conditions and trends in freshwater or estuarine habitats of particular concern
- Beach stormdrain designs that assess stormwater impacts on the surfzone
- Near-coastal designs that assess the impact of stormwater plumes on near-coastal habitats
- Dry-weather reconnaissance designs focused on identifying sources of pollution to the MS4 system.

While all of these approaches can be found in the region, not every stormwater program includes all six, as illustrated in Table A1-1.

Table A1-1. Distribution of monitoring approaches across the separate stormwater programs in southern California.

Program	End of watershed	Dispersed watershed	Site-specific watershed	Beach	Near-coastal	Recon-naissance
Ventura		X				
Los Angeles	X		X			
Long Beach	X		X			
Orange	X	X	X	X	X	X
San Bernardino	X					
Riverside	X	X				
San Diego	X	X	X	X		X

In addition, the relative attention paid to each type of monitoring varies across programs. This reflects differences in habitat types, regulatory emphasis, stage of program development, and patterns of urbanization across the region. For example, monitoring in the northern part of Orange County focuses more heavily on problems intrinsic to more urbanized areas than does monitoring in Ventura County, which has a larger proportion of agricultural and open space land uses.

The following set of tables summarizes the existing distribution of effort in each of the programs. Information was drawn from the most recent set of program documents available for each program.

Table A1-2 shows the distribution of end of watershed monitoring efforts across the region's programs. All the programs except for San Bernardino County and Riverside County have ongoing end of watershed designs focused primarily on estimating mass loads from larger watersheds. The lack of such stations from San Bernardino and Riverside Counties partly reflects the fact that these inland areas are at the upper ends of large watersheds (such as for the Santa Ana River), which is a quite different situation than in the coastal counties. However, the lack of mass emissions stations in the inland counties also hampers their ability to estimate the proportional contribution of these inland areas to cumulative loads downstream.

Table A1-2. End of watershed monitoring efforts in each stormwater program.

Program	**No. Sites**	**No. Events/Yr**	Indicators	**Notes**
Ventura	3	2 wet, 5 dry		
Los Angeles	7 6/trib	3 storms, 2 dry 4 storms, 1 dry	Water qual, tox, trash Water qual	Adaptive TIE Rotate among tributaries each year
Long Beach	4	4 storms, 2 dry	Water qual, tox	Adaptive TIE Additional sites in LA and San Gabriel river watersheds as decided by Reg. Board
Orange	12 * 6	3 storms, 3 dry 3 storms	Water qual, tox Water qual, tox	Adaptive tox, TIE, source ID Adaptive TIE
San Bernardino	-			
Riverside	-			
San Diego	11	3 storms	Water qual, tox	Link to bioassessment at other sites

* For Orange County, the upper set of information refers to the Santa Ana Region of the County and the lower to the San Diego Region of the County, which have somewhat different monitoring programs.

Table A1-3 shows the distribution of dispersed watershed monitoring efforts across the monitoring programs in the region. Dispersed watershed monitoring efforts are typically used to assess the extent and magnitude of impact on watersheds and their beneficial uses. All the programs except for Long Beach (which is a relatively small, heavily urbanized area) include this approach, and four of these six programs contain bioassessment sampling. This reflects a growing awareness that chemical measurements alone, or even chemical measurements combined with toxicity testing, will not necessarily capture impacts to aquatic habitats. The inclusion of bioassessment monitoring is an effort to directly measure habitat quality in areas where this is of concern. The model program will identify the types of locations where dispersed watershed monitoring should occur and define the measurement indicators, including bioassessment, that should be monitored at these sites.

Table A1-3. Dispersed watershed monitoring efforts in each stormwater program.

Program	No. Sites	No. Events/Yr	Indicators	*Notes*
Ventura	3 landuse	1 dry	Water qual	Characterize landuse discharges
	2 rec. water	1 dry	Water qual	
	14 bioass	1 dry	Bioassessment	Characterize receiving water quality in smaller tributaries
Los Angeles	20	1 dry	Bioassessment	CDFG methods
Long Beach	-			
Orange	11	2 dry	Water qual, tox, bioassessment	Includes reference sites Adaptive chem, tox, TIEs, source ID
	15	2 dry	Water qual, tox, bioassessment	
San Bernardino	5	4 storms	Water quality	
Riverside	25	1 – 5 wet	Water qual	
	25	3 dry	Water qual	
San Diego	23	2 dry	Bioassessment	Link to mass emissions, tox at other sites

Table A1-4 shows the distribution of site-specific watershed monitoring across the region. These efforts are targeted at locations that are considered of concern because of their high ecological and societal value. The uneven distribution of such effort across the region reflects the uneven distribution of high-value habitats such as lagoons and estuaries (e.g., Newport Bay), as well as the varying degree to which management agencies have addressed this issue. The effect of sample size has not been fully evaluated in southern California. Too few samples will lead to conclusions with low confidence or even erroneous conclusions while oversampling leads to wasted resources. The model program will address this issue through power analysis of historical data to assess the optimal number of samples.

Table A1-4. Site-specific watershed monitoring efforts in each stormwater program.

Program	No. Sites	No. Events/Yr	Indicators	Notes
Ventura	-			
Los Angeles	-			
Long Beach	1	4 storms, 2 dry	Water qual, tox, bacteria	Alamitos Bay receiving water
Orange	12 estuary 6 channel	2 storms, 2 dry 2 storms, 2 dry	Water qual, tox, seds, benthos	Adaptive tox, TIE, source ID, link to Bight '03
San Bernardino	-			
Riverside	11	4	Water qual	
San Diego	13 lagoon	1 dry	Sed chem, tox, benthos	Adaptive prioritization using triad

Table A1-5 shows the distribution across the region of monitoring efforts targeted at storm drains discharging directly to the beach or coastal zone. The absence of such sites in San Bernardino and Riverside Counties is due to their inland location. In other coastal counties, beach monitoring may be conducted by county health departments rather than by stormwater programs. The stormwater model monitoring technical workgroup has teamed up with the SWRCB's Beach Water Quality Workgroup to evaluate potential collaborative monitoring designs that would coordinate with the county health department and other shoreline monitoring efforts.

Table A1-5. Beach drain monitoring efforts in each stormwater program.

Program	**No. Sites**	**No. Events**	**Indicators**	Notes
Ventura	-			Co DHS
Los Angeles	26	Daily	Bacteria	City of LA conducts
Long Beach	-			City DHS
Orange	TBD	Weekly	Bacteria	In addition to HCA; monitor surfzone up- and downcoast, adaptive source ID, risk assessment
	36	Weekly	Bacteria	
San Bernardino	-			
Riverside	-			
San Diego	60	Weekly	Bacteria	Cities conduct program, monitor drain and receiving water, adaptive source ID

Table A1-6 shows the distribution of near-coastal monitoring effort across the programs in the region. This is a relatively new priority for stormwater programs, as reflected in the fact that only the Los Angeles County and Orange County programs include this component. The model monitoring program is looking to integrate this monitoring with existing near coastal monitoring through southern California Regional Monitoring.

Table A1-7 shows the distribution of dry-weather reconnaissance monitoring efforts across the region's stormwater monitoring programs. This type of monitoring is targeted specifically at source identification, and is contained only in the Orange and San Diego County programs. Source characterization monitoring is important and the model monitoring program is looking to integrate this design as an adaptive element, triggered by the extent and magnitude of impacts described in Table A1-3.

Table A1-6. Near-coastal monitoring efforts in each program.

Program	No. Sites	No. Events/Yr	Indicators	Notes
Ventura	-			
Los Angeles	50	1 / permit period	Sed chem, tox, benthic infauna	Paired sites at and beyond mouths of rivers Adaptive TIE
Long Beach	-			
Orange	0 8	 2 storm, 2 dry	 Water qual, tox	 Adaptive drain characterization and nearshore plume tracking
San Bernardino	-			
Riverside	-			
San Diego	-			

Table A1-7. Dry-weather reconnaissance monitoring efforts in each program.

Program	No. Sites	No. Events/Yr	Indicators	Notes
Ventura	-			
Los Angeles	-			
Long Beach	-			
Orange	40 58	5 / dry 5 / dry	Water qual	Adaptive source ID
San Bernardino	-			
Riverside	-			
San Diego	90 County > 500 cities	3 / per permit period 1 / per permit period	Water qual	Adaptive source ID

Summary and Discussion

The monitoring programs described above were designed and implemented to address issues specific to each county or city. Thus, many of the differences between the programs reflect a logical amount of variety, given the variability across the entire region in factors such as degree of urbanization, type and amount of critical habitat, design of the MS4 system, and kinds of beneficial uses. However, there are other differences that are more arbitrary in nature, for example the frequency of sampling events, the analyte list, and whether to include a dry weather reconnaissance program. In addition, some programs have moved aggressively to include adaptive elements, while others have chosen designs that remain relatively constant across sampling events throughout the permit term.

In addition, the monitoring programs currently in place in the region have to some extent accreted over time, with new elements being added as permits are renewed. Thus, programs have not all been designed with the goal of addressing, in a logical and integrated way, the core management questions the technical committee has identified:

1. Are conditions in receiving water protective of beneficial uses?
1a. What are the mechanism(s) causing receiving water problems?
2. What is the extent and magnitude of the receiving water problems?
3. What is the relative urban runoff (both storm and non-storm, wet and dry) contribution to the receiving water problem(s)?
4. What are the sources of the urban runoff contribution to receiving water problems?
5. Are conditions in receiving waters getting better or worse?

As a result, information about the extent and magnitude of impacts on receiving waters is not always available, nor are loadings estimates (Question 3) that separate out the urban runoff component always an integral part of monitoring designs. In addition, upstream source identification efforts occur in some programs but not others, and are designed to different standards of rigor.

This overview of current monitoring practice provides a concrete starting point for two distinct but complementary considerations. First, the variety across programs provides insight into the breadth and flexibility the model program needs to encompass to be applicable to programs throughout the region. Second, the overview presents information needed for assessing what adjustments could be made to individual programs to bring them more into accord with the model monitoring program, once it is fully fleshed out. The model monitoring program must balance the desire for consistency, standardization, and regional efficiency with reasonable requirements for program-specific differences in design needed to address site-specific issues.

Appendix 2: Power Analysis Results

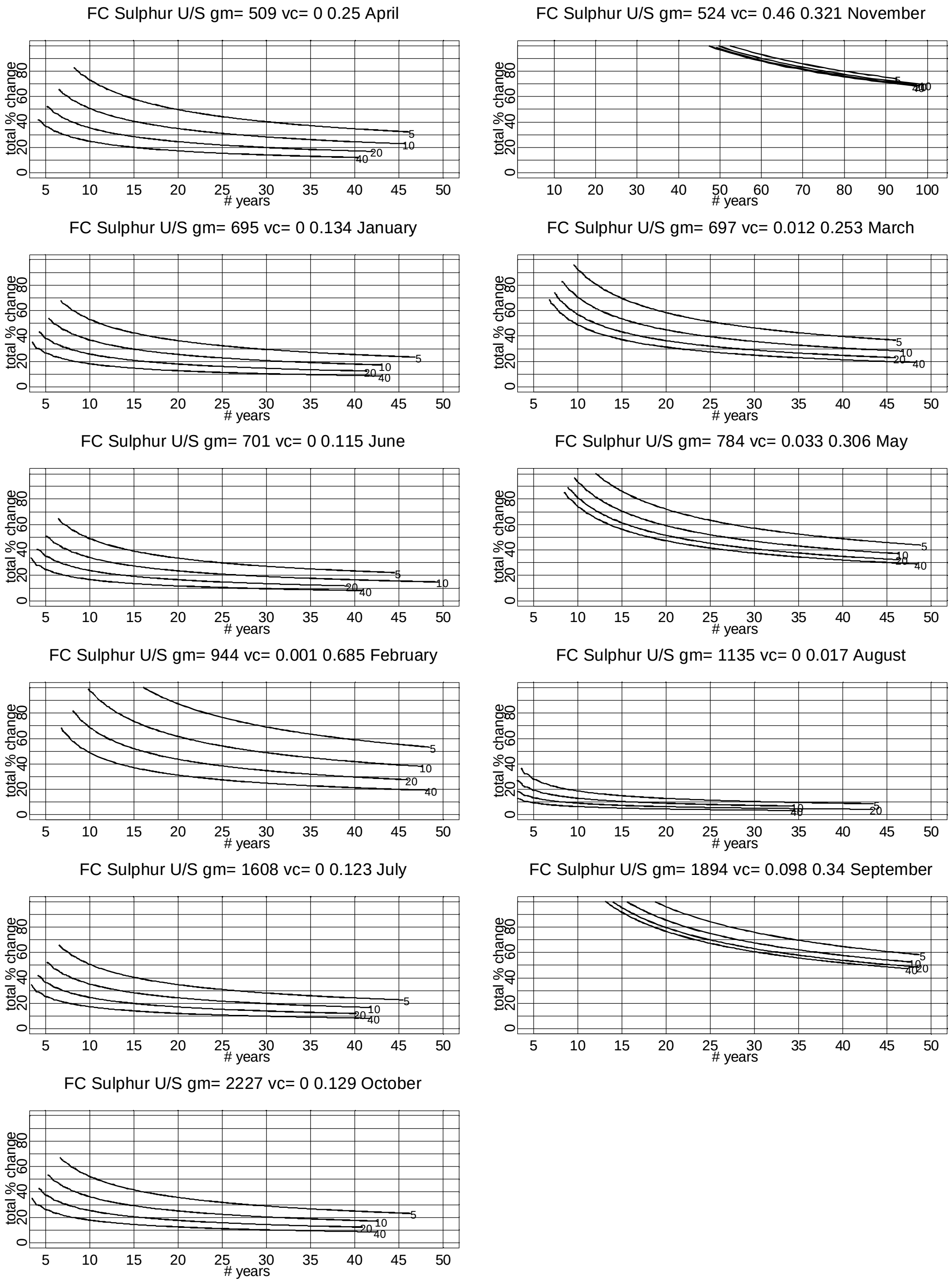
This appendix contains results of statistical power analyses for long-term trend with several types of historical monitoring data from southern California, including:

- Bacteria indicators at a high-priority recreational use area on Aliso Creek
- Bacteria indicators at stations upstream of the high-priority use area
- Bacteria loads from discharges upstream of the high-priority use area
- Bacteria impacts from discharges upstream of the high-priority use area
- Event mean concentrations (EMC) at a series of mass emissions stations
- Loads at a series of mass emissions stations.

Bacteria loads were calculated as the difference between indicator levels 25 feet upstream and 25 feet downstream of the discharge. The specific figures included in this appendix are listed in the following table:

Figure	Content
Fig A3.1	Aliso Creek, downstream use area power analysis results
Fig A3.2	Levels of bacterial indicators at upstream Aliso Creek stations
Fig A3.3	Power analysis results for bacteria loads at upstream Aliso Creek stations
Fig A3.4	Power analysis results for bacteria impact at upstream Aliso Creek stations
Fig A3.5	Power analysis results for EMC, Anaheim Barber Channel
Fig A3.6	Power analysis results for EMC, Westminster Channel
Fig A3.7	Power analysis results for EMC, Santa Ana Delhi Channel
Fig A3.8	Power analysis results for EMC, San Diego Creek at Campus
Fig A3.9	Power analysis results for EMC, Oso Creek
Fig A3.10	Power analysis results for loads, Anaheim Barber Channel
Fig A3.11	Power analysis results for loads, Westminster Channel
Fig A3.12	Power analysis results for loads, Santa Ana Delhi Channel
Fig A3.13	Power analysis results for loads, San Diego Creek at Campus
Fig A3.14	Power analysis results for loads, Oso Creek

In each figure, the X-axis shows the number of years over which monitoring may continue, the Y-axis the cumulative percent change to be detected, and the four curves options for the number of samples per year that could be taken. Thus, each figure shows the amount of change that could be detected (at a statistical power of 80%) at each combination of within- and between-year sampling intensity.


FC Sulphur U/S gm= 509 vc= 0 0.25 April

FC Sulphur U/S gm= 524 vc= 0.46 0.321 November

FC Sulphur U/S gm= 695 vc= 0 0.134 January

FC Sulphur U/S gm= 697 vc= 0.012 0.253 March

FC Sulphur U/S gm= 701 vc= 0 0.115 June

FC Sulphur U/S gm= 784 vc= 0.033 0.306 May

FC Sulphur U/S gm= 944 vc= 0.001 0.685 February

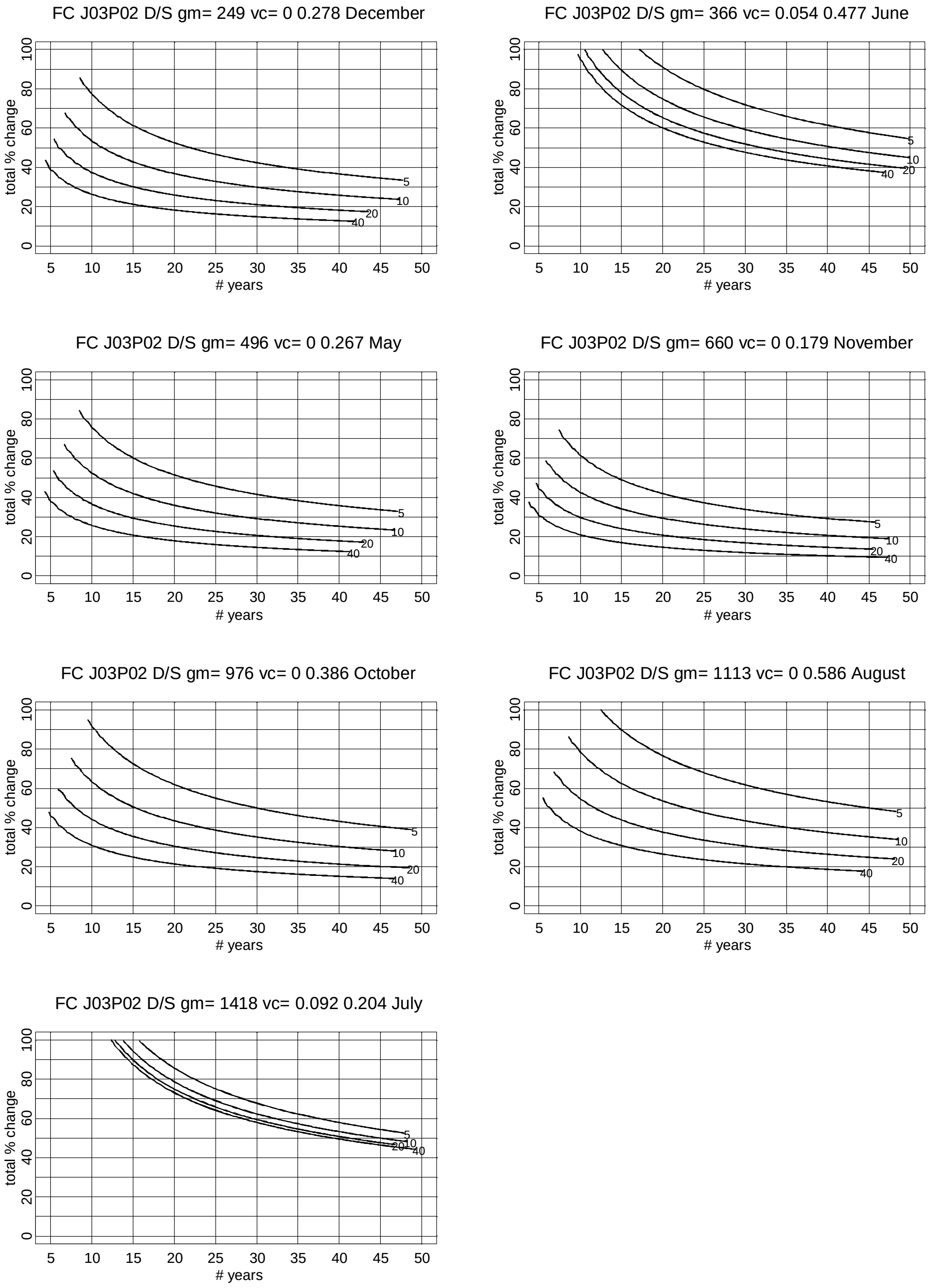
FC Sulphur U/S gm= 1135 vc= 0 0.017 August

FC Sulphur U/S gm= 1608 vc= 0 0.123 July

FC Sulphur U/S gm= 1894 vc= 0.098 0.34 September

FC Sulphur U/S gm= 2227 vc= 0 0.129 October

Figure A2.1a. Power analysis of a trend monitoring design at the AWMA ROAD Bridge, station Sulphur Creek upstream. The y-axis shows the amount of change detectable, the x-axis the years of sampling, and the different curves the number of samples in a given 30-day period (5, 10, 20, 40) needed for 80% power.


FC J03P02 D/S gm= 249 vc= 0 0.278 December

FC J03P02 D/S gm= 366 vc= 0.054 0.477 June

FC J03P02 D/S gm= 496 vc= 0 0.267 May

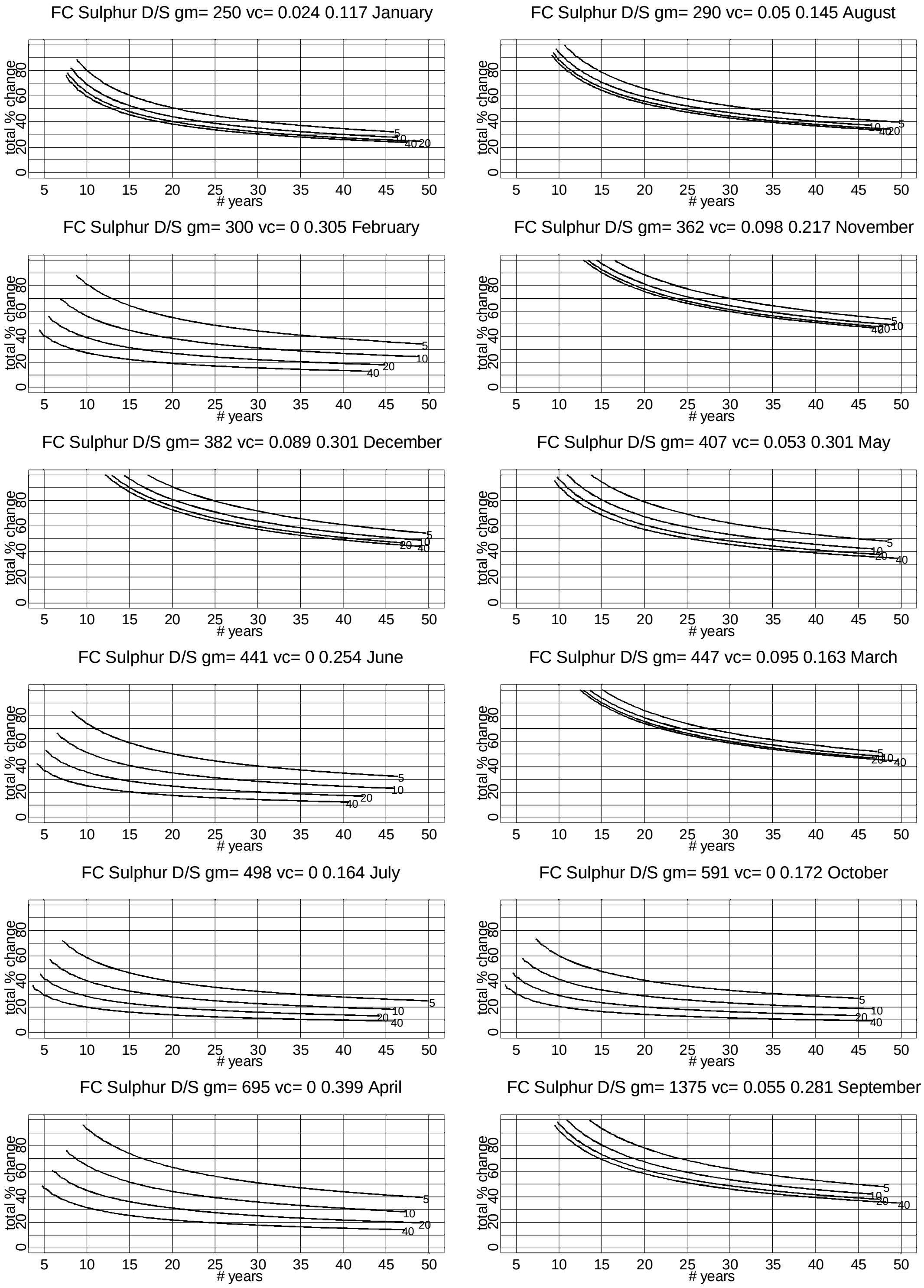
FC J03P02 D/S gm= 660 vc= 0 0.179 November

FC J03P02 D/S gm= 976 vc= 0 0.386 October

FC J03P02 D/S gm= 1113 vc= 0 0.586 August

FC J03P02 D/S gm= 1418 vc= 0.092 0.204 July

Figure A2.1b. Power analysis of a trend monitoring design at the confluence of Aliso and Sulphur Creeks, station J03P02 downstream. The y-axis shows the amount of change detectable, the x-axis the years of sampling, and the different curves the number of samples in a given 30-day period (5, 10, 20, 40) needed for 80% power.



FC Sulphur D/S gm= 250 vc= 0.024 0.117 January

FC Sulphur D/S gm= 290 vc= 0.05 0.145 August

FC Sulphur D/S gm= 300 vc= 0 0.305 February

FC Sulphur D/S gm= 362 vc= 0.098 0.217 November

FC Sulphur D/S gm= 382 vc= 0.089 0.301 December

FC Sulphur D/S gm= 407 vc= 0.053 0.301 May

FC Sulphur D/S gm= 441 vc= 0 0.254 June

FC Sulphur D/S gm= 447 vc= 0.095 0.163 March

FC Sulphur D/S gm= 498 vc= 0 0.164 July

FC Sulphur D/S gm= 591 vc= 0 0.172 October

FC Sulphur D/S gm= 695 vc= 0 0.399 April

FC Sulphur D/S gm= 1375 vc= 0.055 0.281 September

Figure A2.1c. Power analysis of a trend monitoring design at Aliso Wood Canyon Park, station Sulphur Creek downstream. The y-axis shows the amount of change detectable, the x-axis the years of sampling, and the different curves the number of samples in a given 30-day period (5, 10, 20, 40) needed for 80% power.

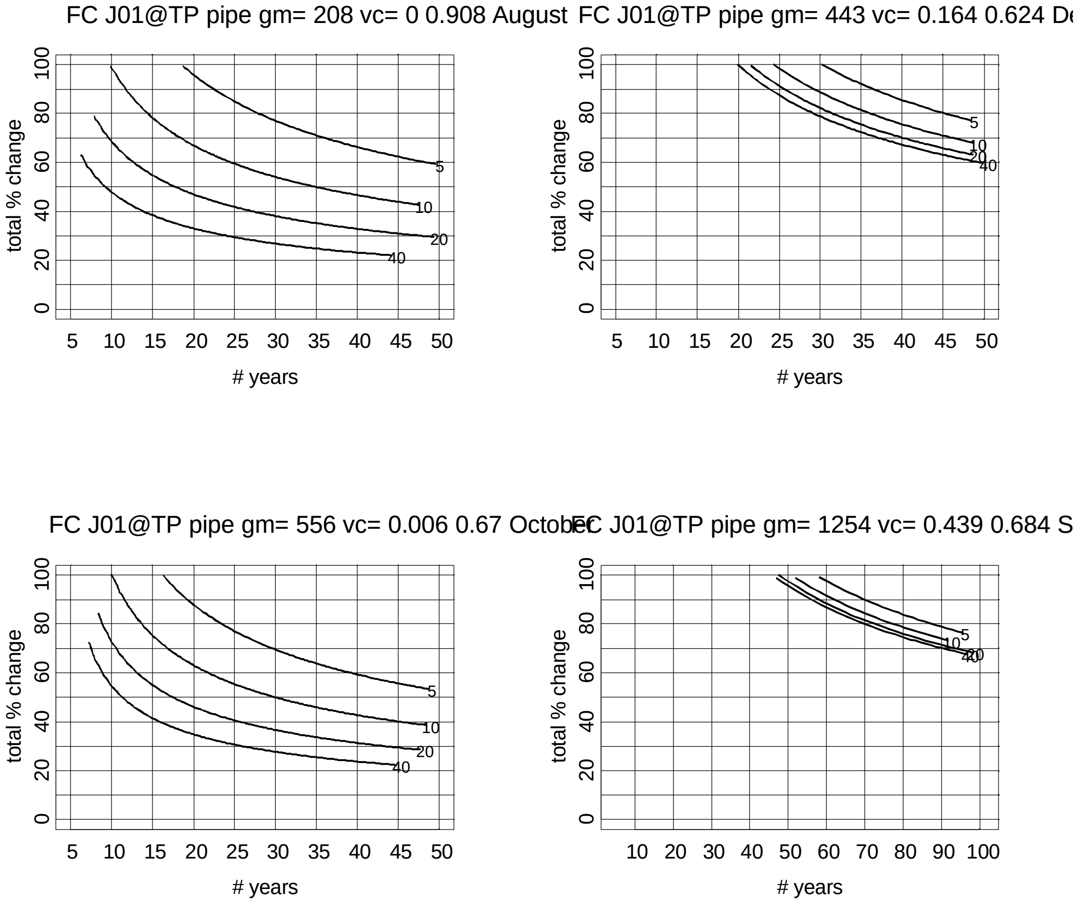


Figure A2.1d Power analysis of a trend monitoring design at the SOCWA treatment plant, station J01@TP. The y-axis shows the amount of change detectable, the x-axis the years of sampling, and the different curves the number of samples in a given 30-day period (5, 10, 20, 40) needed for 80% power.

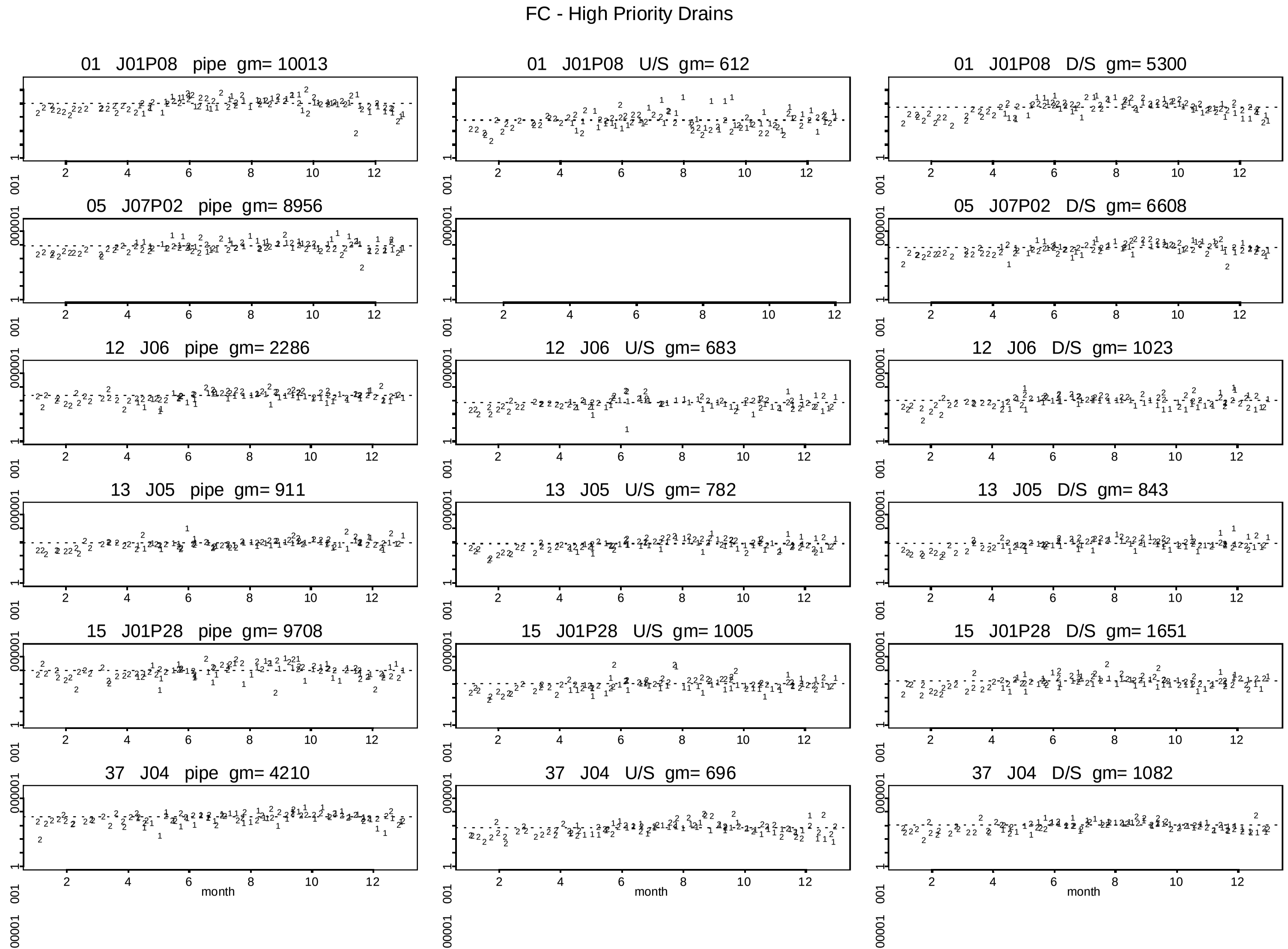


Figure A2.2. Levels of bacterial indicators at the upstream stations in Aliso Creek that are the focus of source reduction efforts.

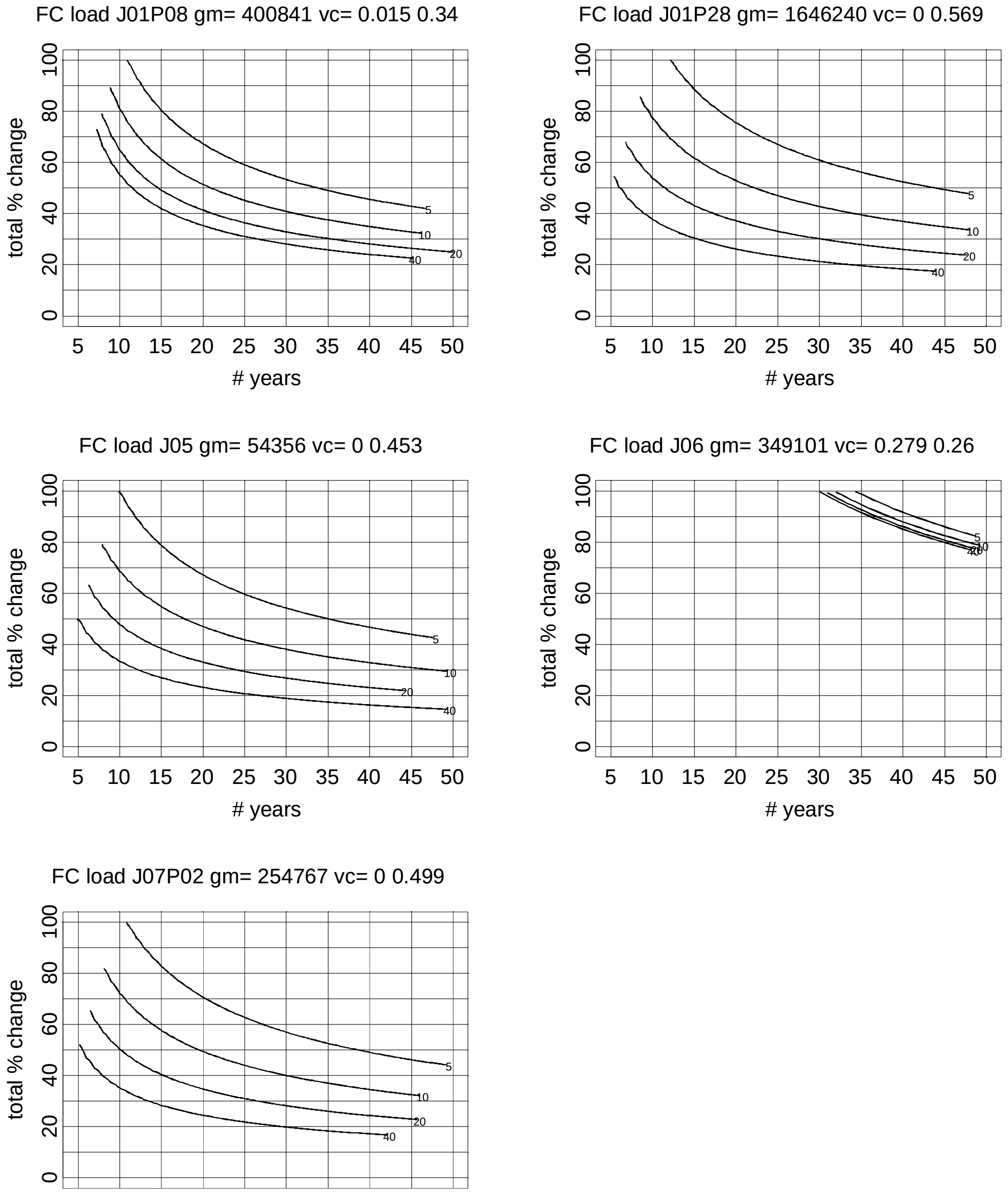


Figure A2.3. Statistical power analysis results of a trend monitoring design for bacterial loads at the upstream stations in Aliso Creek.

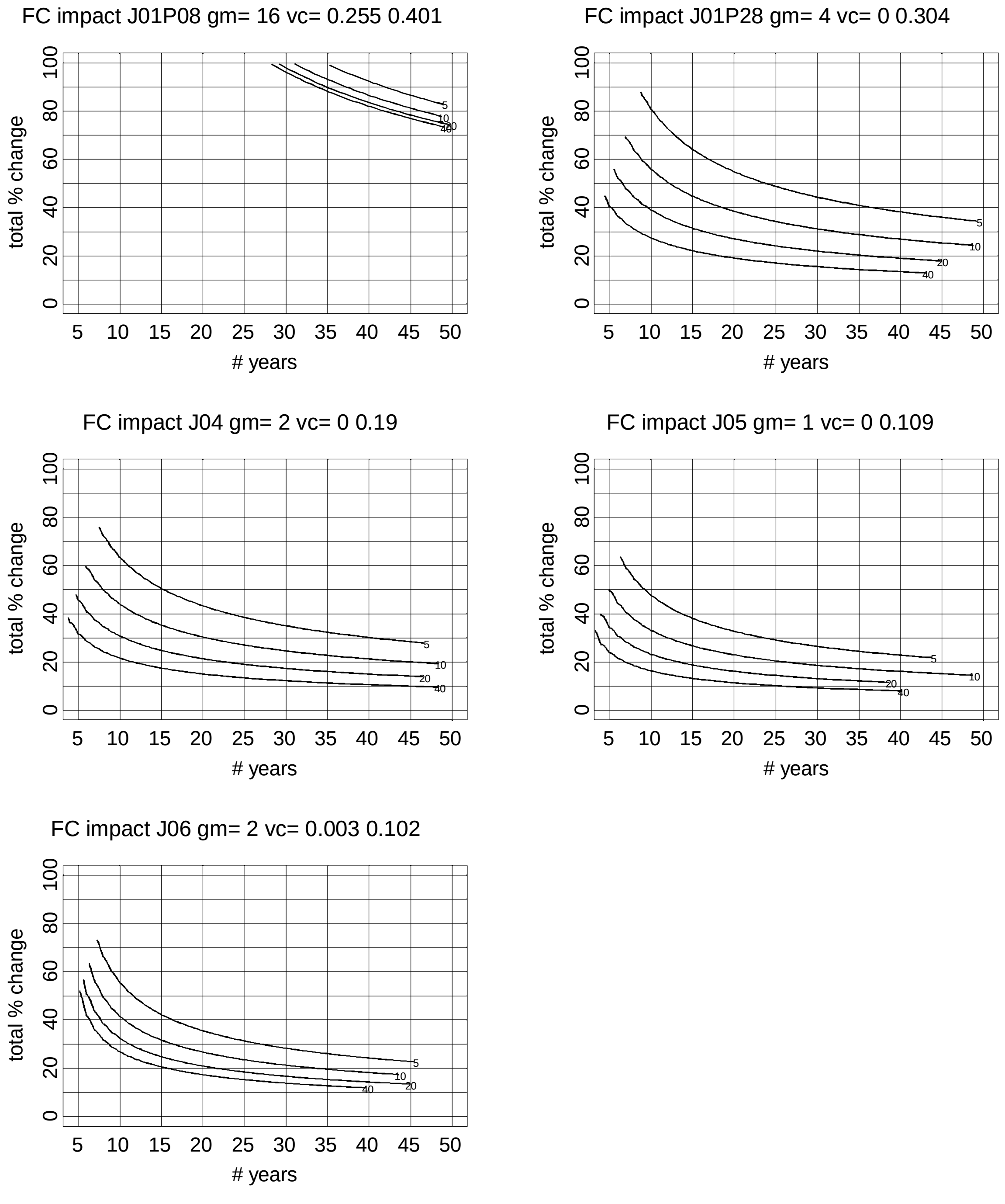


Figure A2.4. Statistical power analysis results of a trend monitoring design for receiving water impact (measured as the difference in bacterial levels between stations 25 feet upstream and downstream of the discharge point) at upstream stations in Aliso Creek.

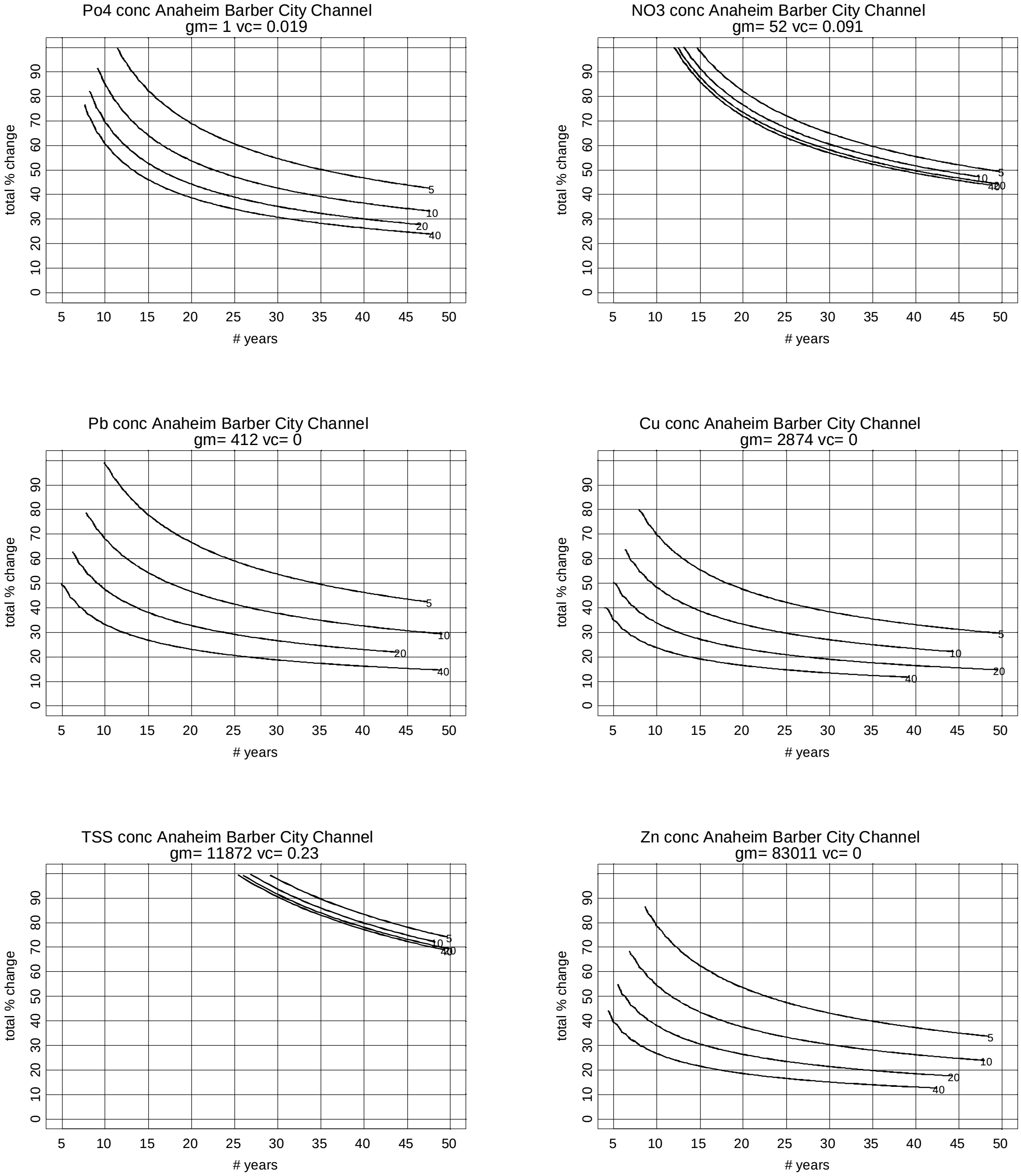


Figure A2.5. Statistical power analysis results for a trend monitoring design for event mean concentrations (EMC) of several parameters at Anaheim Barber City Channel, a long-term mass emissions station in Orange County.

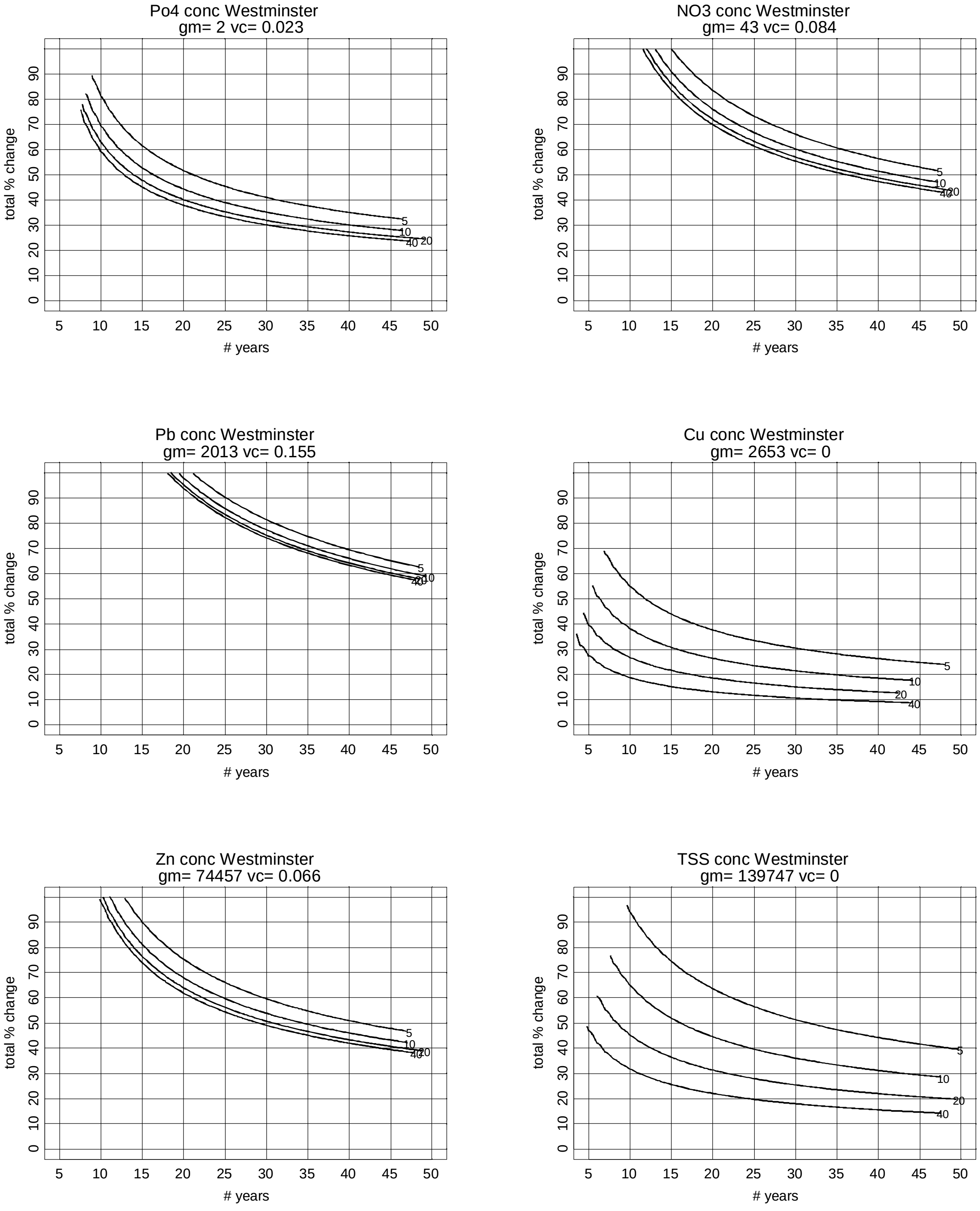
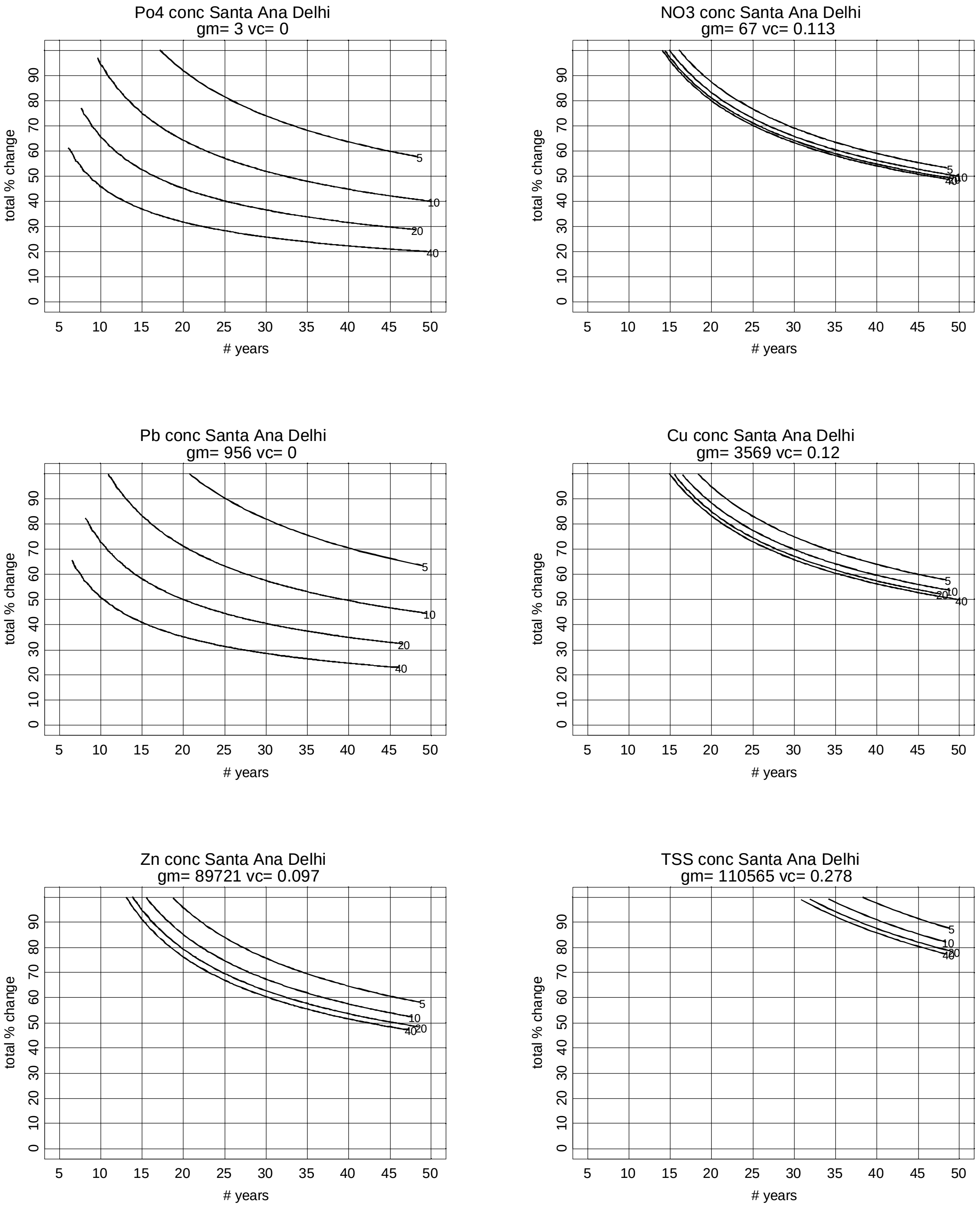


Figure A2.6. Statistical power analysis results for a trend monitoring design for event mean concentrations (EMC) of several parameters at Westminster Channel, a long-term mass emissions station in Orange County.



Po4 conc Santa Ana Delhi
gm= 3 vc= 0

NO3 conc Santa Ana Delhi
gm= 67 vc= 0.113

Pb conc Santa Ana Delhi
gm= 956 vc= 0

Cu conc Santa Ana Delhi
gm= 3569 vc= 0.12

Zn conc Santa Ana Delhi
gm= 89721 vc= 0.097

TSS conc Santa Ana Delhi
gm= 110565 vc= 0.278

Figure A2.7. Statistical power analysis results for a trend monitoring design for event mean concentrations (EMC) of several parameters at Santa Ana Delhi Channel, a long-term mass emissions station in Orange Couinty.

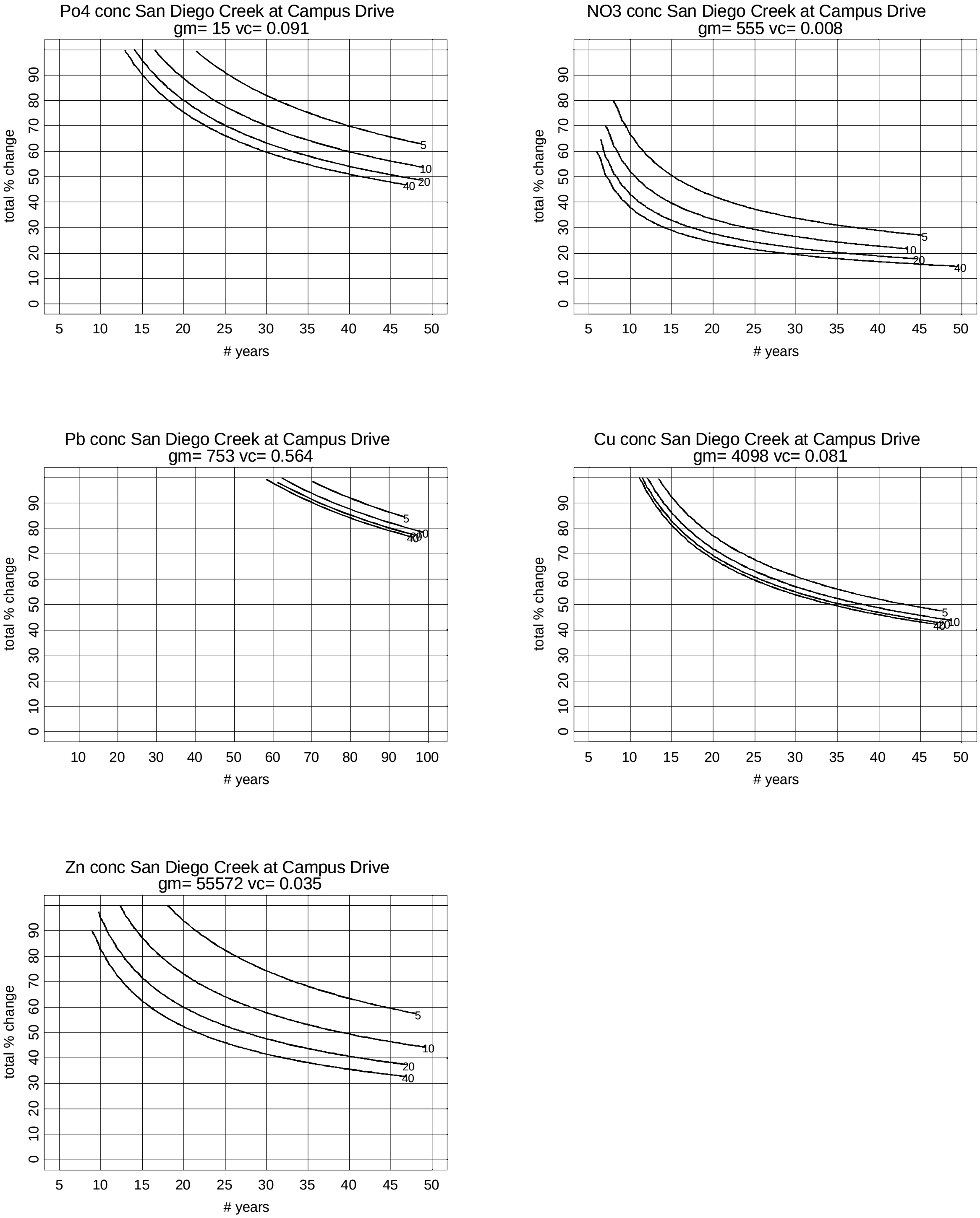


Figure A2.8. Statistical power analysis results for a trend monitoring design for event mean concentrations (EMC) of several parameters at San Diego Creek at Campus Drive, a long-term mass emissions station in Orange County.

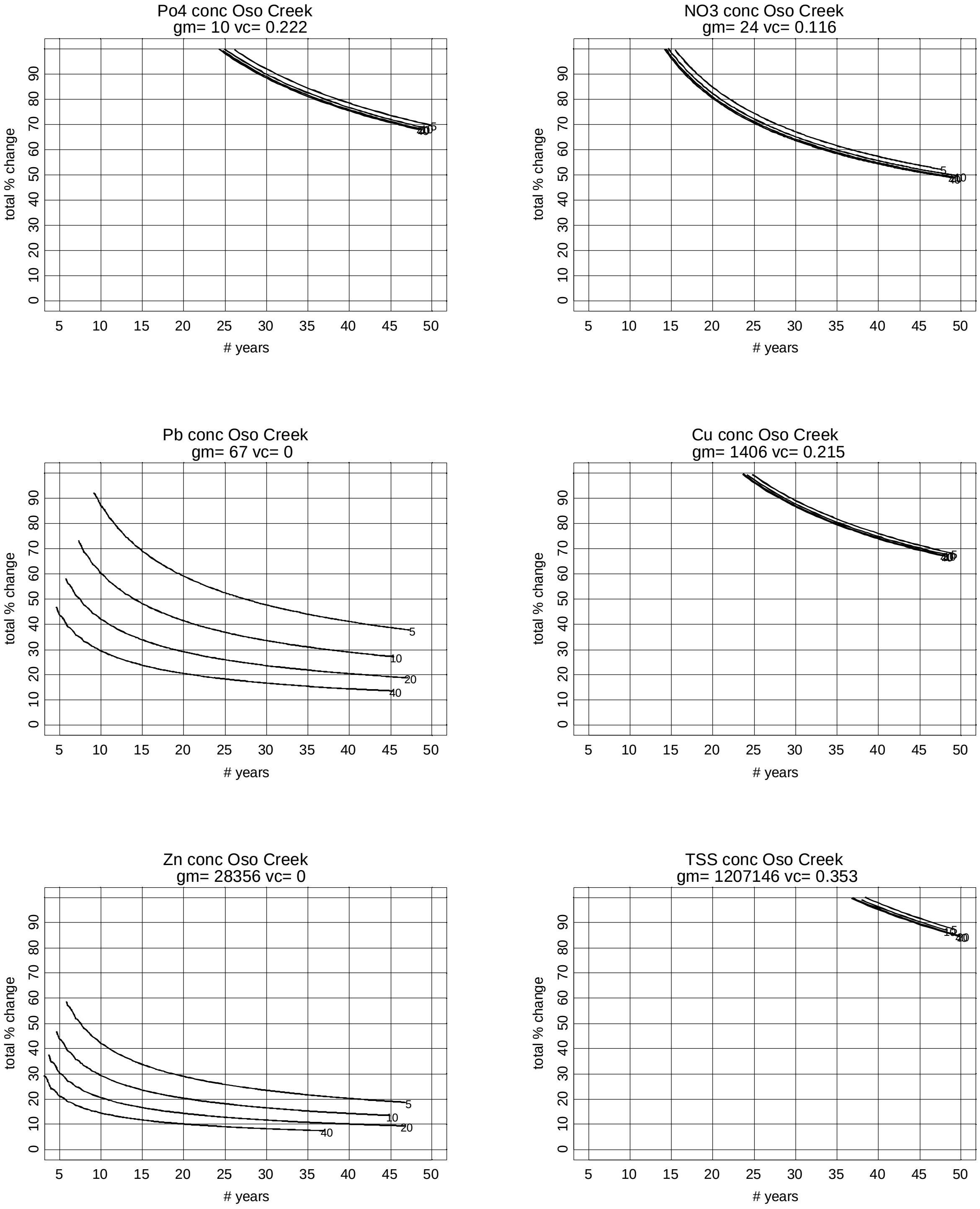


Figure A2.9. Statistical power analysis results for a trend monitoring design for event mean concentrations (EMC) of several parameters at Oso Creek, a long-term mass emissions station in Orange County.

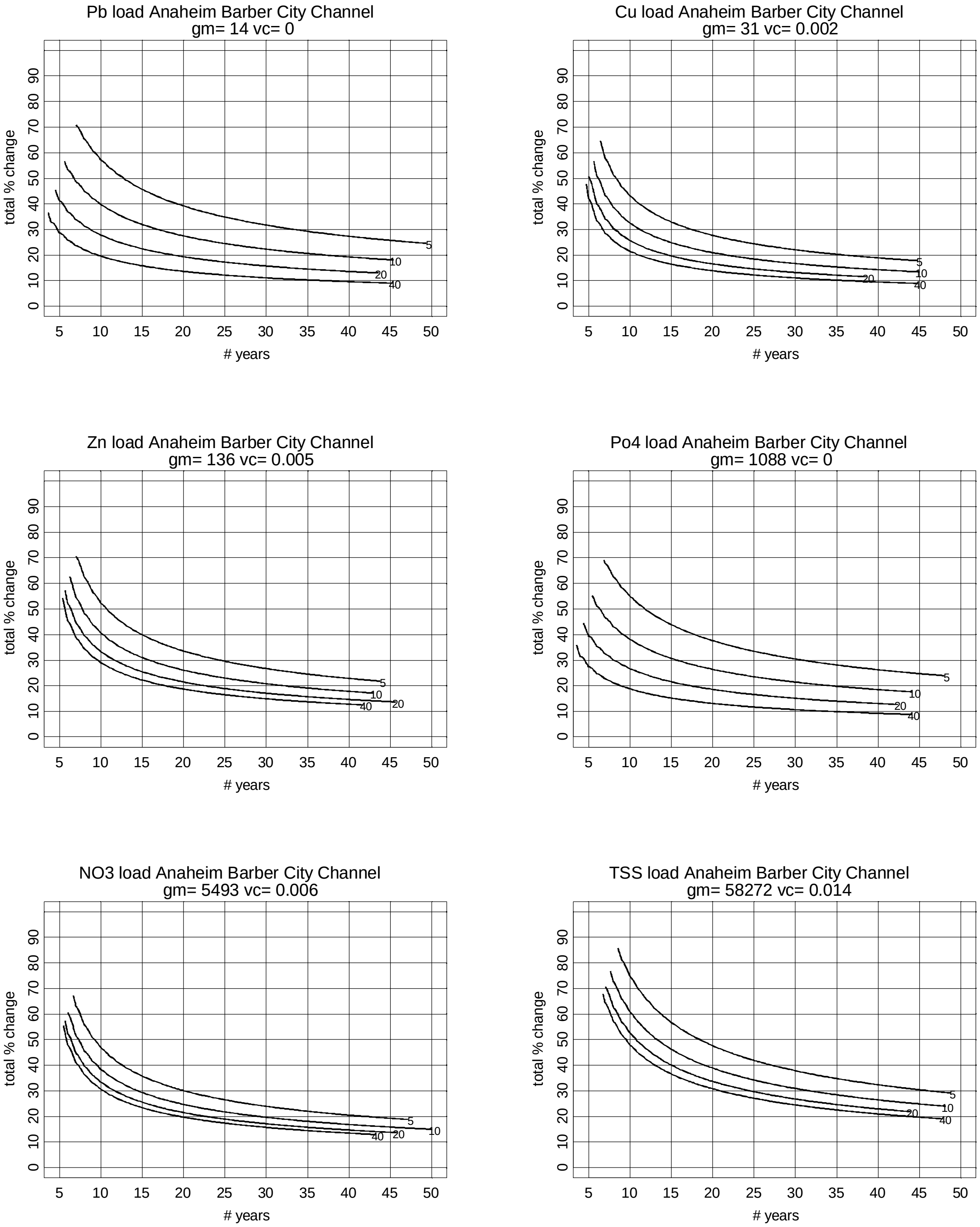
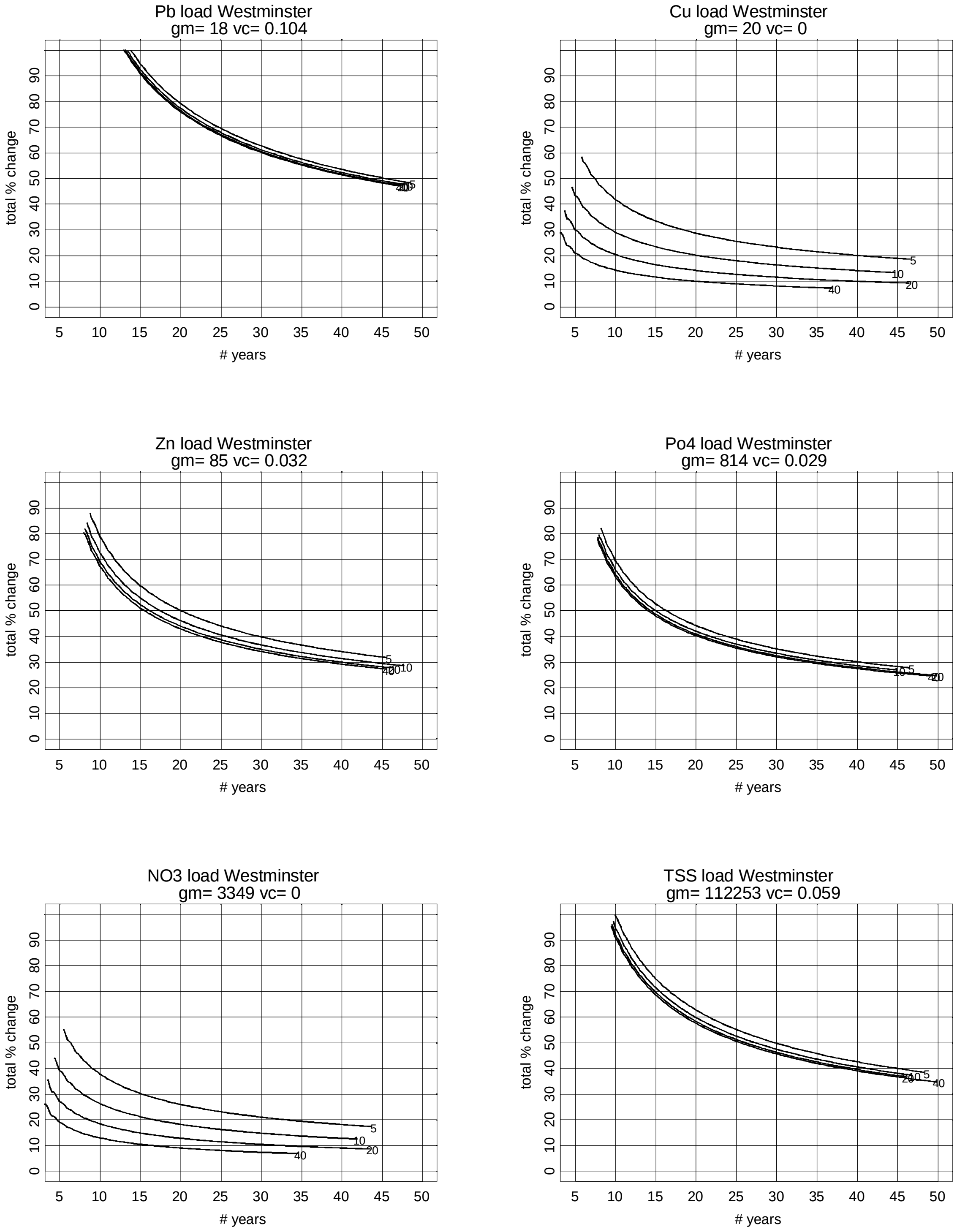


Figure A2.10. Statistical power analysis results for a trend monitoring design for loads of several parameters at Anaheim Barber Channel, a long-term mass emissions station in Orange County.



Pb load Westminster
gm= 18 vc= 0.104

Cu load Westminster
gm= 20 vc= 0

Zn load Westminster
gm= 85 vc= 0.032

Po4 load Westminster
gm= 814 vc= 0.029

NO3 load Westminster
gm= 3349 vc= 0

TSS load Westminster
gm= 112253 vc= 0.059

Figure A2.11. Statistical power analysis results for a trend monitoring design for loads of several parameters at Westminster Channel, a long-term mass emissions station in Orange County.

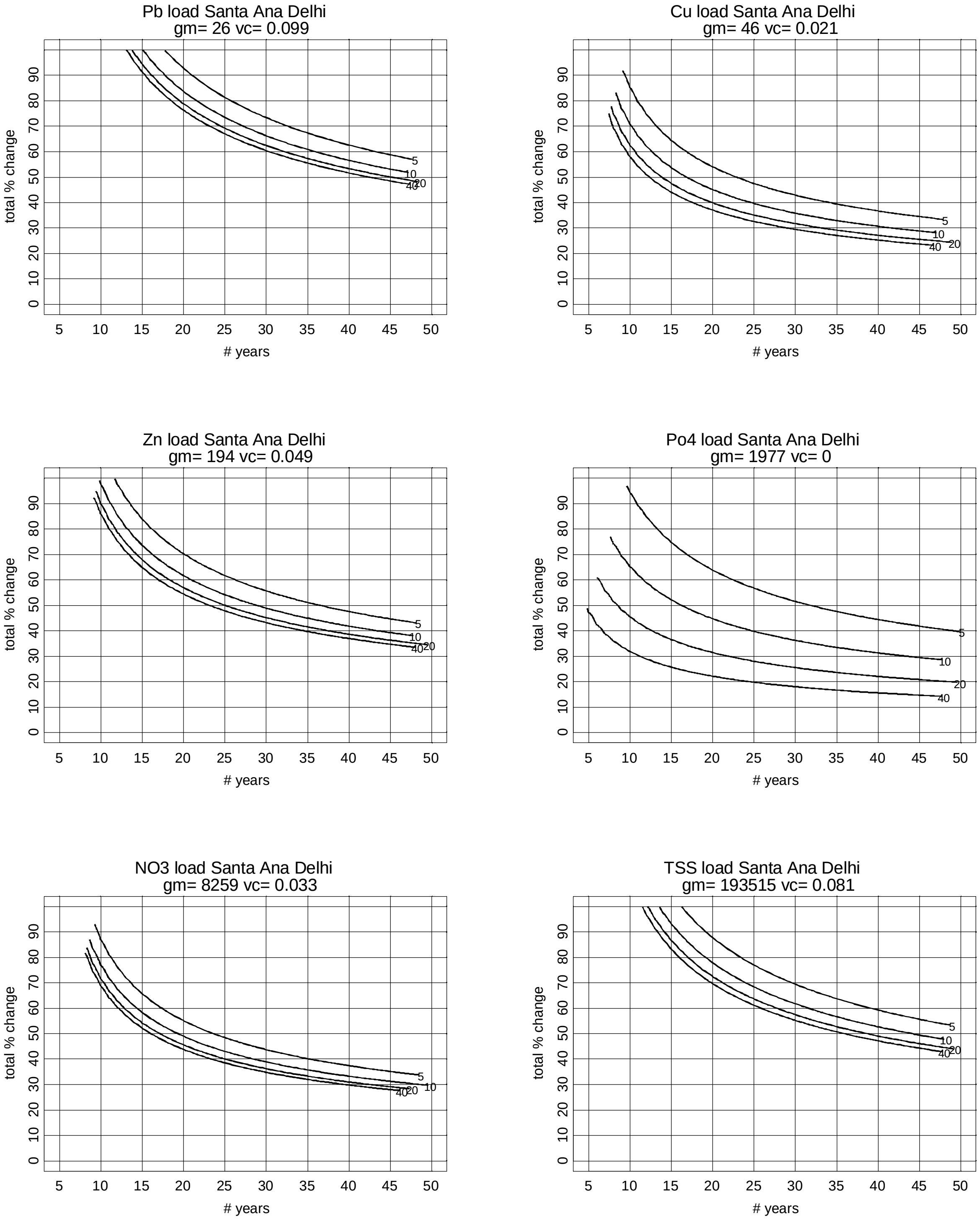


Figure A2.12. Statistical power analysis results for a trend monitoring design for loads of several parameters at Santa Ana Delhi Channel, a long-term mass emissions station in Orange County.

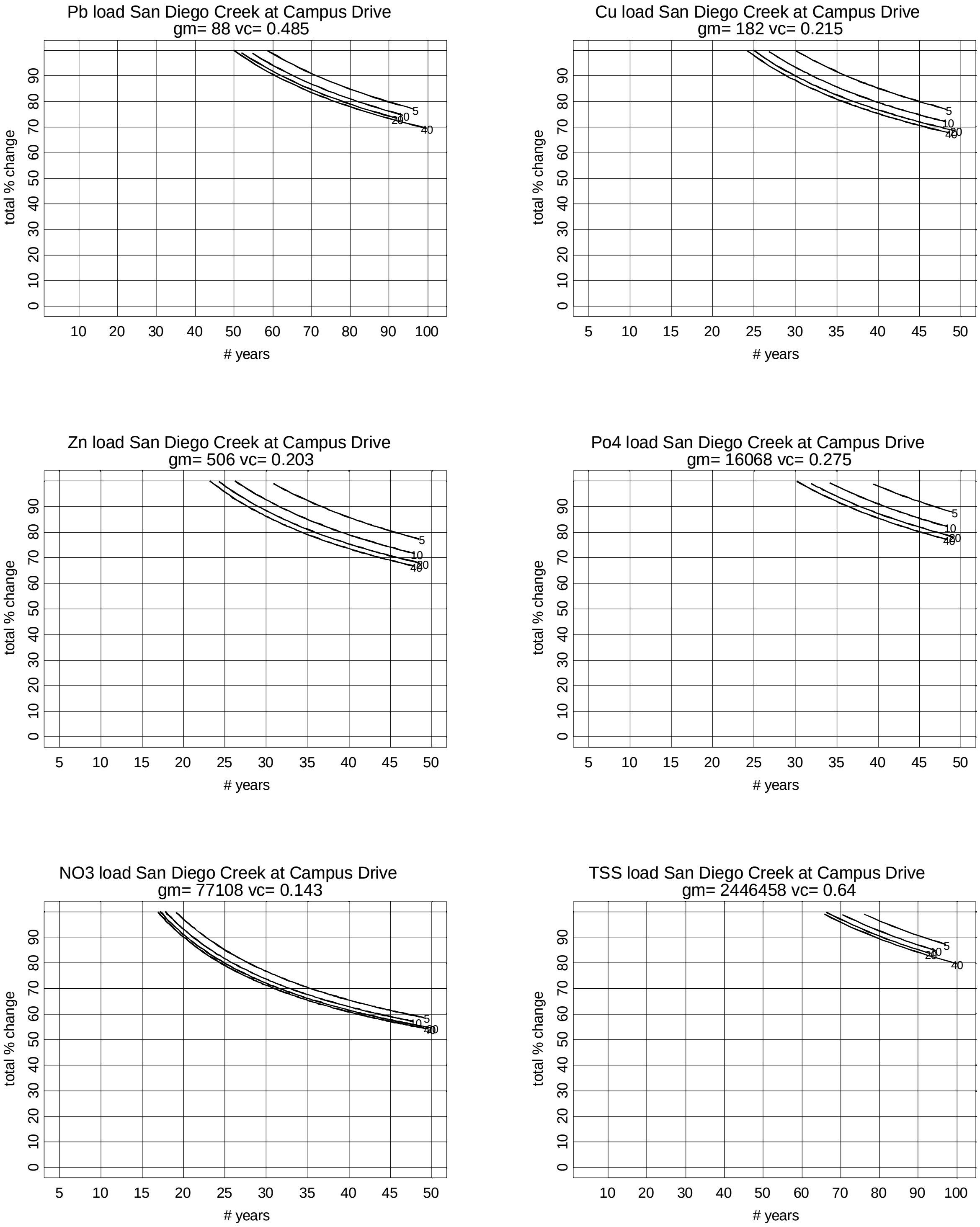


Figure A2.13. Statistical power analysis results for a trend monitoring design for loads of several parameters at San Diego Creek at Campus Drive, a long-term mass emissions station in Orange County.

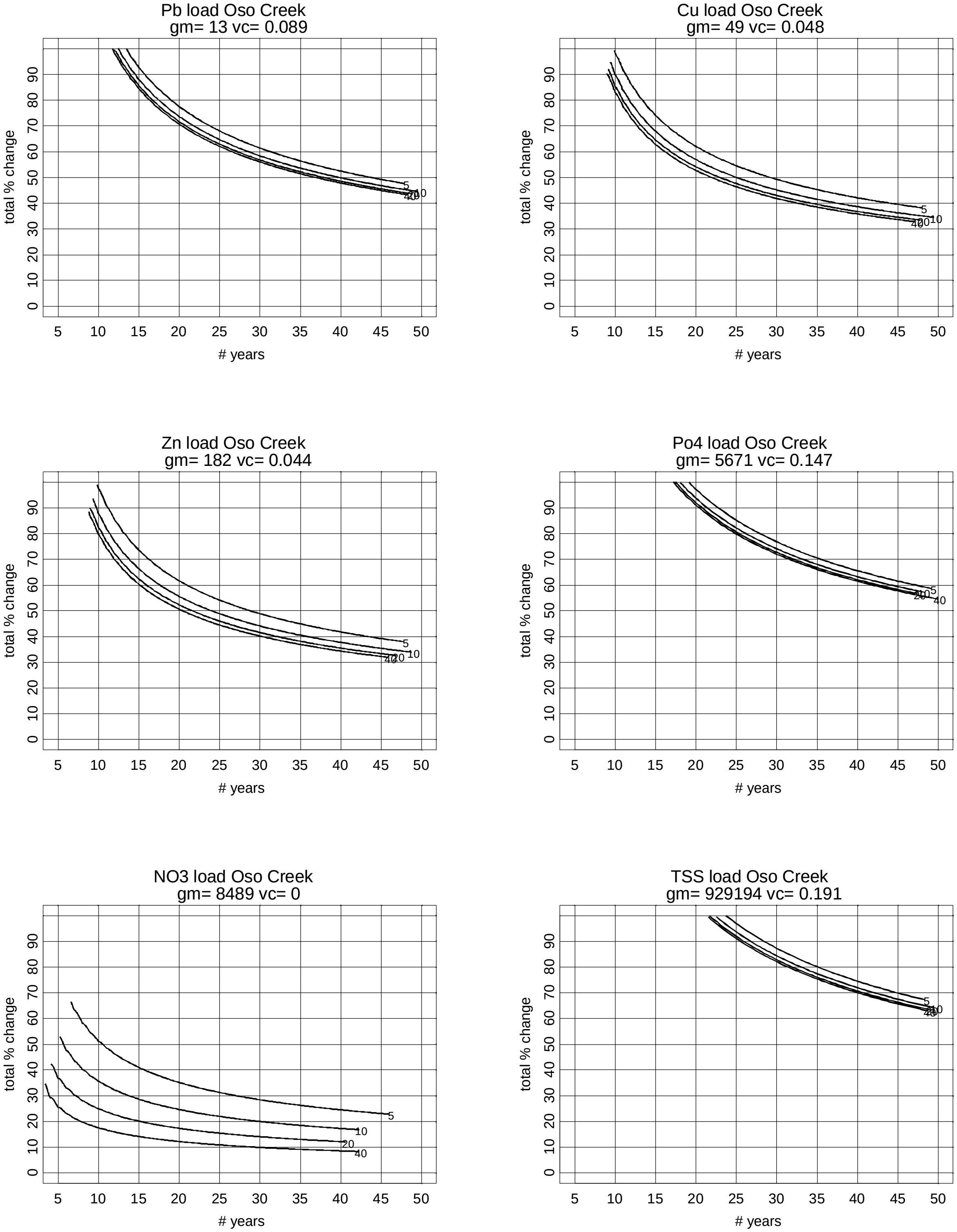


Figure A2.14. Statistical power analysis results for a trend monitoring design for loads of several parameters at Oso Creek, a long-term mass emissions station in Orange County.

Appendix 3: Source Identification Case Studies

The following case studies present examples of source identification efforts conducted to determine the rough proportion of input from urban runoff sources. They include several different kinds of problems and study approaches and exemplify the variety of methods that might be employed to address Question 3. The majority of the case studies were conducted in dry weather. This reflects difficulties of performing source identification studies in wet weather, given the large flow volumes and the typically increased number of possible sources. The cases also exhibit a range of level of effort, from evaluation of routine monitoring data and interviews to a series of iterative special field studies.

A3.1 Contaminated sediment taskforce (LA Harbor)

Sediments in ports, harbors, and marinas are subject to numerous pollutant inputs including sediments, trace metals, and organic contaminants. These sediments eventually need to be dredged to maintain navigable waterways, but the level of sediment contamination has a tremendous effect on the eventual disposal of these dredged materials. Clean sediments can be used for beach replenishment or even disposed at sea, but contaminated sediments need to be sent to a landfill or some other confined disposal area so they will not harm the environment. As the Port Districts, RWQCB and Coastal Commission (collectively known as the Contaminated Sediment Task Force) design a long-term dredged material management program, they are carefully considering ways to reduce the inputs of pollutants to the areas that need periodic maintenance dredging. One way to accomplish this is to identify and reduce or eliminate the sources of pollutants to these locations.

In order to begin reducing pollutant loads, the Contaminated Sediments Task Force asked SCCWRP to estimate the relative magnitude of pollutant loading from several potential sources to Los Angeles and Long Beach Harbors and Marina del Rey. A particular emphasis of the study was estimating loads from the Los Angeles River and Dominguez Channel to San Pedro Bay and from Ballona Creek to Marina del Rey. Primary questions addressed included:

- What are the predominant sources of contaminants?
- What are the long-term (i.e. decadal) trends in annual loading?
- What is the typical range of annual loading that should be expected?
- Which watersheds typically contribute the greatest annual loading?
- What land use types are the largest contributors to annual loading?

These questions were evaluated with an assessment study that involved existing data and limited modeling to estimate watershed loading patterns. Because historic data were somewhat limited, SCCWRP estimated loads with a ratio estimation technique. This involves establishing a relationship between flow and loads using available data and then applying this relationship to an entire storm season. Flow was estimated by applying rainfall data and standard runoff coefficients to different land use types. This combination of methods allowed loads to be approximated for a variety of land uses for entire years in the periods 1971-72, 1979-80, 1986-87, and 1987-88.

The analysis confirmed that the largest source of contamination to San Pedro Bay is watershed-derived loading from the Los Angeles River and Dominguez Channel watersheds. The Los Angeles River watershed contributed the greatest overall mass loading, but the Dominguez Channel watershed contributed the largest proportional loading (i.e. loading normalized for watershed size). In general, industrial and residential land uses are the largest contributors of contaminants. Data from the 1990s also revealed that dry season (i.e. non-storm) loading may make up a significant portion of total annual loading, and in dry years, can be the predominant source of contaminants to the harbor. Analysis of temporal trends in the data showed that metals loading has not substantially changed since the 1970s, but loading of DDT and PCBs has declined.

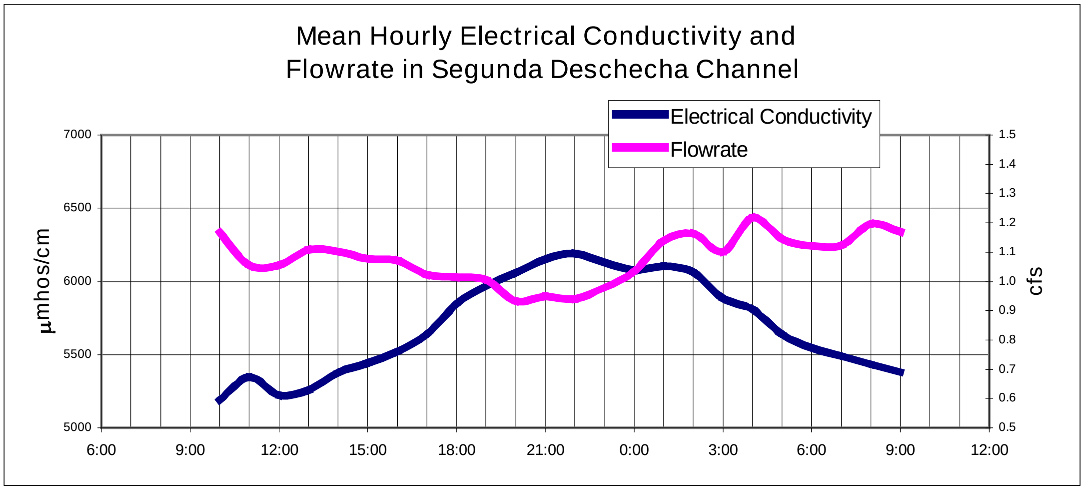
Annual loadings of metals varied between 10^3 and 10^5 kg/year, with zinc and copper loading typically exceeding loads of other metals. Variations in annual loading appear to correspond with changes in rainfall and runoff; however, direct analysis of the relationship between rainfall intensity and duration and loading produced only weak correlation coefficients. This correlation would likely be improved by analyzing a larger data set on more homogenous land use types.

Because the study depended on available data, not all possible sources of loading could be evaluated and key data gaps remained. These included the lack of data on loading of PAH and pesticides, lack of long-term data on dry season loading, lack of information on inputs from the Dominguez Channel Watershed, and the need for more temporally resolved loading data from specific land use types. Information on the transport and fate of runoff-derived contaminants within the study area would also be needed to improve estimates of the impact of loadings on sediment contamination.

Summary based on SCCWRP Technical Report #143. Watershed-based sources of contaminants to San Pedro Bay and Marina del Rey: Patterns and trends. October 13, 2003. ftp://ftp.sccwrp.org/pub/download/PDFs/413_cstf_watershed.pdf

A3.2 Elevated total dissolved solids in Prima and Segunda Deshecha channels (Orange County)

Routine monitoring during the 2001-2002 monitoring year documented elevated levels of total dissolved solids (TDS) at monitoring stations in Prima and Segunda Deshecha channels in Orange County. Special studies involving hourly measurements of conductivity and flow rate, conducted in both channels, showed that the peak TDS concentration was not a function of tide (i.e., did not reflect a higher concentration of saltwater) and that the TDS concentration was inversely proportional to flow rate in the channel (see the figure below).



This strongly suggested that urban runoff diluted a naturally high level of dissolved solids in the channels. Subsequent to this finding, an upstream reconnaissance survey identified the presence of hundreds of weepholes in the concrete sidewalls of the channel. These weepholes appeared to be allowing subsurface drainage to leach salts from soils and carry them into the channel. Preliminary sampling of three weepholes during the reconnaissance survey showed them to have extremely high levels of electrical conductivity, an indicator of TDS. In addition, the crystalline residue on the channel walls near the routine monitoring location was found to have high concentrations of sodium and soluble sulfate.

These findings provided the basis for a more substantial upstream source identification study in the Prima Deshecha channel in March 2002 that included monitoring at several weepholes, as well as upstream and downstream of the weepholes. The resulting data (see following table) indicate that the seepage from the channel seams and weepholes increases the concentrations of dissolved solids in the channel downstream of the seepage.

Reach of Channel	Time	Monitoring Point	EC (μmhos)	TDS (mg/L)
At Diamante	13:00	Prima Deshecha Channel (M01)	Dry	
At Calle Nuevo	13:40	M01	5,150	
u/s Avenida Vacquero	14:48	M01 50' u/s weeping seam	5,510	4,880
	14:45	weeping seam	19,870	18,900
	14:42	M01 50' d/s weeping seam	7,510	7,330
	14:50	36" pipe discharging to M01	3,800	
d/s I-5	15:20	M01 in Shorecliff Golf Course	7,550	
u/s Calle Grande Vista	15:37	M01 50' u/s bubbling weepholes	7,750	7,490
	15:34	Bubbling weepholes	14,480	12,800
	15:40	48"pipe discharging to M01, 20' d/s weepholes	5,850	
At Calle Grande Vista	15:30	M01	8,480	

The conclusion was corroborated by soil samples collected from the levee of the Prima Deshecha channel above a weeping seam and from the levee of San Juan Creek, a channel with no history of elevated TDS levels (see following table).

Location	Chloride	Soluble Sulfate	Calcium	Magnesium	Potassium	Sodium
	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg
Prima Deshecha Ch. Levee	61.3	0.447	861	275	37.2	582
San Juan Creek levee	13/7	0.048	34.1	11.1	15.4	202

Information obtained from the 2001-2002 annual report of the Orange County Stormwater Program

A3.3 SCCWRP's study of sources of loads to the LA River

The Los Angeles River drains most of Los Angeles County and extends 56 miles, starting from its headwaters in the San Fernando Valley, flowing past downtown Los Angeles, and eventually draining to San Pedro Bay near Long Beach. The highly developed watershed is 834 mi^2 and is comprised of residential (35%), commercial (5%), industrial (8%), and open land (51%) uses. The river's mainstem and tributaries are listed as impaired waterbodies for many constituents including nutrients (N), bacteria (fecal coliform), and trace metals (copper, lead, and zinc). The three primary sources of these pollutants included water reclamation plants (WRPs), major tributaries, and storm drain outfalls. As part of efforts to establish TMDLs for the river, SCCWRP conducted a short-term study to characterize the water quality in the Los Angeles River and the various loads to the system.

This study was comprised of two parts. The first identified and sampled the inputs to the Los Angeles River and major tributaries. The second sampled the mainstem of the river to assess spatial distributions of water quality. The input monitoring was conducted using citizen volunteers while the spatial distribution monitoring was conducting using professionals. Visual observations were made of the outfall size and location, flow, and general characteristics (such as water discoloration; the presence of foam or oily sheens, trash or algae; and water quality). Flow was measured using either timed-volumetric or depth-velocity methods.

Water quality parameters included flow, total suspended solids (TSS), total organic carbon (TOC), biological oxygen demand (BOD5), nutrients (nitrate, nitrite, ammonia, TKN, and total phosphorous), and trace metals (cadmium, chromium, copper, iron, lead, nickel, mercury, and zinc). Sampling was accomplished on September 11, 2000 and included eight locations along the mainstem of the Los Angeles River and at the head of all seven tributaries Existing flow gages maintained by the Los Angeles County Department of Public Works provided flow information.

Table A3-3 shows the relative magnitude of the various inputs to the LA River. The majority of the dry weather flow in the river arose from the three inland POTW discharges in this watershed. In accordance, POTWs were the largest source of nutrients and some trace metals. In contrast, storm drains were the major source of bacteria and the remaining trace metals during dry weather. This preliminary sampling effort provided data sufficient to characterize the relative contributions of the major sources of pollutant loads to the system and a basis for more detailed source identification and loadings studies in the future.

Table A3-3. Total pollutant loads and the relative contributions among major sources to theLos Angeles River on September 10-11, 2000.

Constituent		**Total Mass Emissions**	**Units**		**% Contribution**	
				POTWs	**Tributaries**	**Storm Drains**
Bacteria						
	E. coli	12,022	(10^9)/day	0	11	89
	Enterococcus	2,948	(10^9)/day	0	33	67
	Total Coliforms	113,854	(10^9)/day	1	65	35
Metals						
	Copper	3.7	kg/day	73	22	6
	Iron	39	kg/day	4	23	73
	Lead	0.53	kg/day	0	54	46
	Nickel	0.19	kg/day	0	0	100
	Zinc	11	kg/day	79	17	4
Nutrients						
	Ammonia-N3, 357		85	14	0	34
	Nitrate-N		kg/day	32	35	2
	TKN		kg/day	82	17	2
	Total Phosphate-P		kg/day	82	15	3

Ackerman, D., K. Schiff, H. Trim, and M. Mullin. 2003. Characterization of water quality in the Los Angeles River. *Bulletin of the Southern California Academy of Sciences* 102:17-25 or at ftp://ftp.sccwrp.org/pub/download/PDFs/2001_02ANNUALREPORT/08_ar08-drew.pdf.

A3.4 Elevated levels of diazinon in Bouquet Canyon Creek (Los Angeles County)

Toxicity tests conducted in late 2001 on water from Bouquet Canyon Creek documented elevated toxicity (4 – 5 toxic units). Subsequent TIEs showed the toxicity to be due primarily to diazinon, and water samples collected through late 2002 from inputs to the Creek (tributaries and storm drains) showed extremely high levels of diazinon (as high as 4000 ng/l). Following these findings, the Regional Board instructed Los Angeles County and the City of Santa Clarita to investigate the potential sources of diazinon and to eliminate any illicit discharges found.

By late November 2002, preliminary reconnaissance efforts, which included qualitative land use characterization) had identified several potential sources, including homeowner associations, exterminator companies, landscaping companies, and discharge outfalls. These efforts, including review of sales reports from hardware stores, suggested that there was no dominant single source of diazinon but, rather, that the diazinon contamination stemmed from widespread use by residents in the area. This conclusion led to the implementation of an aggressive pollution prevention approach in the area.

Monitoring continued at several key sites in parallel with the ongoing pollution prevention efforts. Monitoring data showed that, through March 2003, diazinon levels had dropped substantially (see following table), although some levels remained above the California Department of Fish and Game acute (0.08 ug/l) and chronic (0.05 ug/l) water quality criteria for diazinon.

Sample date	NR1	NR5	S2	S3	S7
08/28/02	5.698[1]	No data	4.214	No data	No data
10/16/02	0.95	3.76	1.19	0.46	0.53
11/20/02	0.20	0.02	0.17	No sample	No sample
01/14/03	0.34	No sample	0.16	0.41	0.31
02/03/03	0.05	No sample	0.04	0.08	0.08
03/05/03	0.15	No sample	0.10	0.22	0.08

[1] All data values reported as ug/l

The City of Santa Clarita is continuing with their educational outreach program, as part of ongoing pollution prevention efforts, to reduce diazinon levels to below State standards.

Information obtained from correspondence between the Los Angeles Regional Water Quality Control Board and the City of Santa Clarita.

A3.5 Elevated ammonia in Calleguas Creek stormwater flow (Ventura County)

Routine monitoring during the November 2001 detected an extremely high value of ammonia (52 mg/l) in Calleguas Creek. After the value was confirmed by reanalysis at the chemistry laboratory, Program staff conducted reconnaissance in the Calleguas watershed to attempt to identify the source of the ammonia. The reconnaissance was carried through in-person and telephone interviews to assess uses of ammonia in the watershed, which has a large percentage of agricultural land use. These interviews revealed that celery farmers typically inject ammonia into celery during wet weather to prevent the celery from becoming pithy.

Based on this information, the Program established five additional sites at the confluence of tributaries and at the inputs of major drains entering the creek from agricultural lands. This sampling, conducted in dry weather, found no additional "hits" of ammonia. Nor did routine wet weather monitoring detect any further instances of elevated ammonia. Based on the information obtained about the use of ammonia by celery farmers, the presence of several celery farms upstream of the monitoring point, and the absence of any additional findings of elevated levels in either wet or dry weather samples, Program staff concluded that the elevated ammonia was most likely due to an unreported spill that occurred during the injection process. Because agriculture is exempt from the municipal NPDES permit, this was not pursued further.

Information obtained from personal communication with Ventura County Public Works Agency staff.

Appendix 4: Bacterial Die-off Rates in Freshwater Streams

This appendix reviews data on the inactivation of indicator microorganisms in freshwater as a basis for prioritizing sources of fecal contamination in southern California for further source identification work.

Fecal indicator bacteria, and the pathogenic organisms that they are meant to be the proxies for, have a limited ability to survive in most aquatic environments. Factors such as pH, temperature, solar (both UV and visible) irradiation, predation, osmotic stress, nutrient deficiencies, particulate levels, turbidity, oxygen concentrations, and microbial community composition affect bacteria inactivation once they reach receiving waters (Berry and Noton 1976, Mancini 1978, Kapuscinski and Mitchell 1980, Fujioka *et al.* 1981, Gerba and Bitton 1984, Auer and Niehaus 1992, Davies-Colley *et al.* 1994 , and Johnson *et al.* 1997). Indicator bacteria inactivation, that is, the rate at which the indicator bacteria die, is considered to be adequately represented by a first-order equation (see Thomann and Mueller, 1987). The first order decay rate (or inactivation) is usually referred to as k_D, and is usually reported as a per hour, or per day rate (e.g. 0.1 h^{-1}). In practice, people often use the term T_{90} , which describes the decline of bacteria in the time that it takes to obtain 90% mortality of the original number of bacteria, assuming a first-order loss. Throughout the rest of this document, the process will be referred to as inactivation, rather than decay, due to the fact that inactivation refers more specifically to the loss of the metabolic capabilities of the cell.

It is possible, with an adequate knowledge of environmental conditions, to create simple models of indicator bacteria inactivation using first order decay constants. In addition, several die-off equations can potentially be used in sequence with each other in order to estimate inputs from several stream inputs. There are existing models, like QUAL2E, that will permit the input of a particular coliform bacteria concentration, with temperature information, to estimate indicator bacteria levels downstream.

This document will outline a range of inactivation rates that could potentially be utilized to model bacterial inactivation in freshwater streams of southern California. However, it is particularly important to remember key points regarding bacterial inactivation rates, and the attempt to model such. First, even though most studies of rates of inactivation of indicator bacteria have been focused on single factors, we know that the process of inactivation is complex, and dependent upon multiple factors. For this reason, most of the studies that have been conducted in the laboratory to date should be reviewed suspiciously. Most of the studies have focused on analyzing the effects of one, two, or three factors independently (like temperature, pH, and TSS), and in doing so have ignored the biological complexities of the inactivation process. Second, solar irradiation/UV light is known to be one of the most important factors governing bacterial inactivation, and many studies have simply been conducted in the laboratory using UV lamps, ignoring the range of damage caused by visible, UV A, UV B, and UV C. Third, most studies have been conducted using laboratory strains of either *E. coli* or *enterococcus spp*. bacteria. These bacteria may not reflect the naturally found phylogenetic diversity of indicator bacteria inoculated into aquatic environments. Therefore the laboratory strains may be more susceptible to degradation than their outdoor counterparts. Finally, many different methods have been used to assess inactivation/decay/degradation. This is an issue that deserves much attention but in the interest of brevity, an example might be more useful. If two methods, membrane filtration, and chromogenic substrate kits (like Colilert-18®), were used to study rates of inactivation of *E. coli* in freshwater, the rate of inactivation determined with the use of the membrane filtration method would be much more rapid than that observed using the chromogenic substrate kits. The reason for this discrepancy is that bacterial cells find it much more difficult, energetically speaking, to form a colony on a plate (the criteria for growth by membrane filtration), than to breakdown a growth substrate enzymatically (the criteria for growth by chromogenic substrate kits).

Given the cautions outlined above in interpreting data on bacterial inactivation, there are many useful studies that have been conducted that can be used to provide some general estimates of bacterial inactivation rates. Most studies have been conducted at a variety of temperatures, but presented here are the studies that have been conducted at temperate water temperatures that are applicable to southern California waters (ranging from 8-22° C).

One of the first things to do to understand the inactivation process is to determine whether or not sunlight will be considered in your estimates of bacterial inactivation rates. The detrimental effect of sunlight on survival of enteric bacteria in aquatic systems has been recognized for decades (Fujioka *et al.* 1981). Sunlight is capable of increasing inactivation rates by at least a factor of five compared to dark inactivation rates. Barcina *et al.* (1990) reported that EC was more resistant to damage by sunlight than *E. coli,* but Noble et al. (2003) demonstrated greater inactivation rates for EC than for *E. coli* even under low solar irradiation levels. The effect of sunlight is important to note, especially in sub-temperate latitudes such as southern California, where fluctuations in solar irradiation need to be considered. Published kD values for *E. coli* in freshwater can range from 0.03 to 0.06 h^{-1} (e.g., Barcina *et al.* 1986, Auer and Niehaus 1992, Menon 1993, and Mezrioui *et al.* 1995). However, other reports with kD as low as 0.001 h^{-1} and as high as 0.29 h^{-1} have been reported by Davies and Evison (1991), and Sinton *et al*. (2002), respectively. Obviously, different studies have revealed different rates of inactivation.

Given the concentration of the indicator bacteria of interest (C, in cfu or MPN/100 ml), an average decay coefficient (k_D, h^{-1}), a distance (D, meters or kilometers), and a stream or river velocity (U, translate into meters or kilometers per hour). An expected concentration of indicator bacteria can be calculated by:

$$C= C_0 * \exp(-k_D*D/U)$$

A general recommendation might be to assess the given conditions (high sunlight, low sunlight, etc.) and use a low rate of inactivation (conservative estimate), and a high rate of inactivation (liberal estimate) to provide a range of values of indicator bacteria that you will achieve downstream. The following table provides estimates of rates of inactivation, from several well-conducted and rigorously designed studies. Most rates of inactivation fall within the ranges observed here. In addition, the studies conducted by Noble et al. (2003) were specifically conducted in southern California waters, and so are a system specific representation of inactivation.

Table A4-1: Rates of inactivation for a range of studies.

Indicator	k_D (hr^{-1})	Notes	Reference
Total coliform	0.041-0.23	Ranges, freshwater, measured for 20° C	Thomann and Mueller, 1987
Total coliform	0.02	Riverine freshwater	Baudisova, 1997
Fecal coliforms	0.0162 0.007	Waste stabilization pond Raw sewage (conducted in the dark)	Sinton et al. 2002

Fecal coliforms	0.086 0.275	Waste stabilization pond Raw sewage (conducted in sunlight)	Sinton et al. 2002
E. coli	0.008	Natural surface water	Medema et al. 1997
E. coli	0.134	High solar radiation	Noble et al. 2003
E. coli	0.054	Low solar radiation	Noble et al. 2003
E. coli	0.001	Freshwater, dark	Davies and Evison 1991
E. coli	0.0171 0.023	Waste stabilization pond Raw sewage (conducted in the dark)	Sinton et al. 2002
E. coli	0.078 0.287	Waste stabilization pond Raw sewage in freshwater (conducted in sunlight)	Sinton et al. 2002
E. coli	0.03-0.06	Freshwater	Barcina et al. 1986,
Enterococci	0.27	High solar radiation	Noble et al. 2003
Enterococci	0.24	Low solar radiation	Noble et al. 2003
Enterococci	0.0168 0.012	Waste stabilization pond Raw sewage (conducted in the dark)	Sinton et al. 2002
Enterococci	0.276 0.137	Waste stabilization pond Raw sewage (conducted in sunlight)	Sinton et al. 2002
Enterococcus faecalis	0.016-0.038	Freshwater at 20° C	Thomann and Mueller, 1987

Literature Cited

Auer, M.T. and S.L. Niehaus. 1992. Modeling fecal coliform bacteria- I. Field and laboratory determination of loss kinetics. *Water Resources* 27:693-701.

Barcina, I., I. Arana, J. Iriberri and L. Egea. 1986. Influence of light and natural microbiota of the Butron River on Escherichia coli survival. *Antonie van Leeuwenhoek* 52:555-566.

Barcina, I., B. Ayo, A. Muela, L. Egea and J. Iriberri. 1991. Predation rates of flagellate and ciliated protozoa on bacterioplankton in a river. *FEMS Microbiology Letters* 85:141-149.

Barcina, I., J. Gonzalez, J. Iriberri and L. Egea. 1990. Survival strategy of Escherichia coli and *Enterococcus faecalis* in illuminated fresh and marine systems. *Journal of Applied Microbiology* 68:189-198.

Barcina, I., P. Lebaron and J. Vives Rego. 1997. Survival of allochthonous bacteria in aquatic ecosystems: A biological approach. *FEMS Microbiology Ecology* 23:1-9.

Baudisova, D. 1997. Evaluation of *Escherichia coli* as the main indicator of fecal pollution. Water Science Technology. 35 (11-12):333-336.

Beaudeau, P., N. Tousset, F. Bruchon, A. Lefevre and H.D. Taylor. 2001. *In situ* measurement and statistical modeling of *Escherichia coli* decay in small rivers. *Water Research* 35:3168-3178.

Berry, S. A. & Noton, B. G. 1976. Survival of bacteriophages in seawater. *Water Res* 10: 323-327.

Davies, C.M. and L.M. Evison. 1991. Sunlight and the survival of enteric bacteria in natural waters. *Journal of Applied Microbiology* 70:265-274.

Davies-Colley, R., R. Bell and A. Donnison. 1994. Sunlight inactivation of enterococci and fecal coliforms in sewage effluent diluted in seawater. *Applied and Environmental Microbiology* 60:2049-2058.

Fujioka, R.S., H.H. Hashimoto, E.B. Siwak and R.H.F. Young. 1981. Effect of sunlight on survival of indicator bacteria in seawater. *Applied and Environmental Microbioogy* 41:690-696.

Gerba, C. and G. Bitton. 1984. Microbial pollutants: Their survival and transport pattern to groundwater. pp. 65-88 *in:* G. Bitton and C. Gerba (eds.), Groundwater Pollution Microbiology. John Wiley & Sons. New York, NY.

Johnson, D.C., C.E. Enriquez, I.L. Pepper, T.L. Davis, C. Gerba and J. Rose. 1997. Survival of Giardia, Cryptosporidium, poliovirus, and Salmonella in marine waters. *Water Science and Technology* 35:261-268.

Kapuscinski, R.B. and R. Mitchell. 1980. Processes controlling virus inactivation in coastal waters. *Water Research* 14:363-371.

Kapuscinski, R.B. and R. Mitchell. 1981. Solar radiation induces sublethal injury in Escherichia coli in seawater. *Applied and Environmental Microbiology* 41:670-675.

Mancini, J.L. 1978. Numerical estimates of coliform mortality rates under various conditions. *Journal of the Water Pollution Control Federation.* 50:2477-2484.

Medema, G.J., M.Bahar, and F.M. Schets. 1997. Survival of *Cryptosporidium parvum*, *Escherichia coli*, fecal enterococci, and *Clostridium perfringens* in river water: influence of temperature and autochthonous microorganisms. Water Science and Technology. 35 (11-12): 249-252.

Menon, P. 1993. Mortalite des bacteries allochtones rejetees dans les milieux aquatiques. pp. 140 *in:* Specialite Sciences de la Terre. Universite Paris. Paris, France.

Mezrioui, N., B. Baleux and C. Troussellier. 1995. A microcosm study of *Escherichia coli* and *Salmonella typhimurium* in brackish water. *Water Research* 29:459-465.

Noble, R. T., I. M. Lee, and K. Schiff. 2003. Inactivation of indicator bacteria from various sources of fecal contamination in seawater and freshwater. In press. Journal of Applied Microbiology.

Sinton, L.W., C.H. Hall, P.A. Lynch and R.J. Davies-Colley. 2002. Sunlight inactivation of fecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. *Applied and Environmental Microbiology.* 68:1122-1131.

Thomann, R. V., and J. A. Mueller. 1987. Principles of surface water quality modeling and control. Harper and Row, New York, NY.

Appendix 5: TIE Prioritization Metric

This appendix describes the calculation of a metric for prioritizing TIEs (Toxicity Identification Evaluations) to better identify the potential source(s) of toxicity in receiving waters. As discussed in the main body of the report, the model monitoring design recommends that a full year of toxicity testing be conducted and then TIEs be performed in the subsequent year, based on the relative magnitude and persistence of toxicity at the monitoring stations. The metric described below results in a single number for each site for each year and is an approach for combining the magnitude of toxicity (measured as mortality relative to a control), the breadth of toxicity across multiple test species, and the persistence of toxicity over multiple monitoring events in a given year. The metric provides users the ability to weight each of these three components differently, depending on the nature of toxicity and the specific management concern(s). However, all sites being considered for TIEs must be evaluated with the same metric weighting in order to ensure a consistent comparison among sites.

The experimental design is illustrated below:

	Time 1	Time 2	Time 3
Species 1			
Species 2			
Species 3			

At a specific site, three different species toxicity tests are performed at three different times over the course of the monitoring year. Each cell of the design contains a measure of the strength of water toxicity. A test with no measured toxic effects is represented by a value of zero.

The index is computed as the cell average toxicity value adjusted for consistency of toxic hits within species (rows) and/or time (columns). A toxic hit is defined as a toxicity value greater than zero. The consistency of toxicity within columns (across species) is measured by a cumulative score that depends on the numbers of toxic hits in the columns. For each column with three toxic hits, 1 is added to the total score (see the tables below), and for each column with two toxic hits, ½ is added to the total score. Nothing is added to the total score for 0 or 1 toxic hits in a column. A similar total score based in toxic hits in the rows is computed for consistency within rows.

Variables used to compute the index value are:

C_{col} = the column consistency score,

C_{row} = the row consistency score,

A_{col}=percent adjustment for column consistency,

A_{row}=percent adjustment for row consistency, and

M=the mean of all cells.

The index is computed as

$$I = M\left(1+\frac{A_{col}}{100}\frac{C_{col}}{3}+\frac{A_{row}}{100}\frac{C_{row}}{3}\right). \qquad (1)$$

The value 3 in equation (1) is the maximum consistency score for rows (C_{row}) or columns (C_{col}). Thus, when the consistency score is maximal, the full percent adjustment (A) is added to the value in the parentheses, and lesser amounts are added for less than maximal scores. The values of 100 in equation (1) convert the adjustment percents to proportions.

It can be seen that equation (1) is the cell mean with upward adjustments for consistency within rows or columns. The user must decide what percent adjustment of the cell mean will be associated with the maximum score for both rows and columns. For example, if the user wants to emphasize consistency of toxicity across species at the same time, the user could set A_{col}=30 and A_{row}=0, which will adjust the cell mean upward by 30% for maximal within-column consistency, and ignore within-row consistency. Some example calculations with these A values are provided for below.

Example data with minimum within-column consistency might be as follows:

	Time 1	Time 2	Time 3	# hits
Species 1	30	40	20	3
Species 2	0	0	0	0
Species 3	0	0	0	0
# hits	1	1	1	

The calculations for these data with A_{col}=30 and A_{row}=0 are shown in equation (2).

$$I = M\left(1+\frac{A_{col}}{100}\frac{C_{col}}{3}+\frac{A_{row}}{100}\frac{C_{row}}{3}\right) = 10\left(1+\frac{30}{100}\frac{0}{3}+\frac{0}{100}\frac{1}{3}\right) = 10 \qquad (2)$$

Example data with some within-column consistency might be as follows:

	Time 1	Time 2	Time 3	# hits
Species 1	30	0	0	1
Species 2	40	0	0	1
Species 3	20	0	0	1
# hits	3+1	0	0	

The calculations for these data with A_{col}=30 and A_{row}=0 are shown in equation (3).

$$I = M\left(1+\frac{A_{col}}{100}\frac{C_{col}}{3}+\frac{A_{row}}{100}\frac{C_{row}}{3}\right) = 10\left(1+\frac{30}{100}\frac{1}{3}+\frac{0}{100}\frac{0}{3}\right) = 11 \qquad (3)$$

Note that the index value for the data used in equation (3) is higher than the index value for the data used in equation (2). This is because the equation (3) data have more within-column consistency and the A values were set to emphasize the within-column consistency. A more dramatic difference between the two index values would have resulted if a higher value for A_{col} was used.

It is important to stress that the intended use of the index (I) values is to help prioritize stations for follow-up TIEs. Thus, stations with higher index values would be a higher priority when allocating a fixed amount of resources for TIEs.