United States
Environmental Protection
Agency

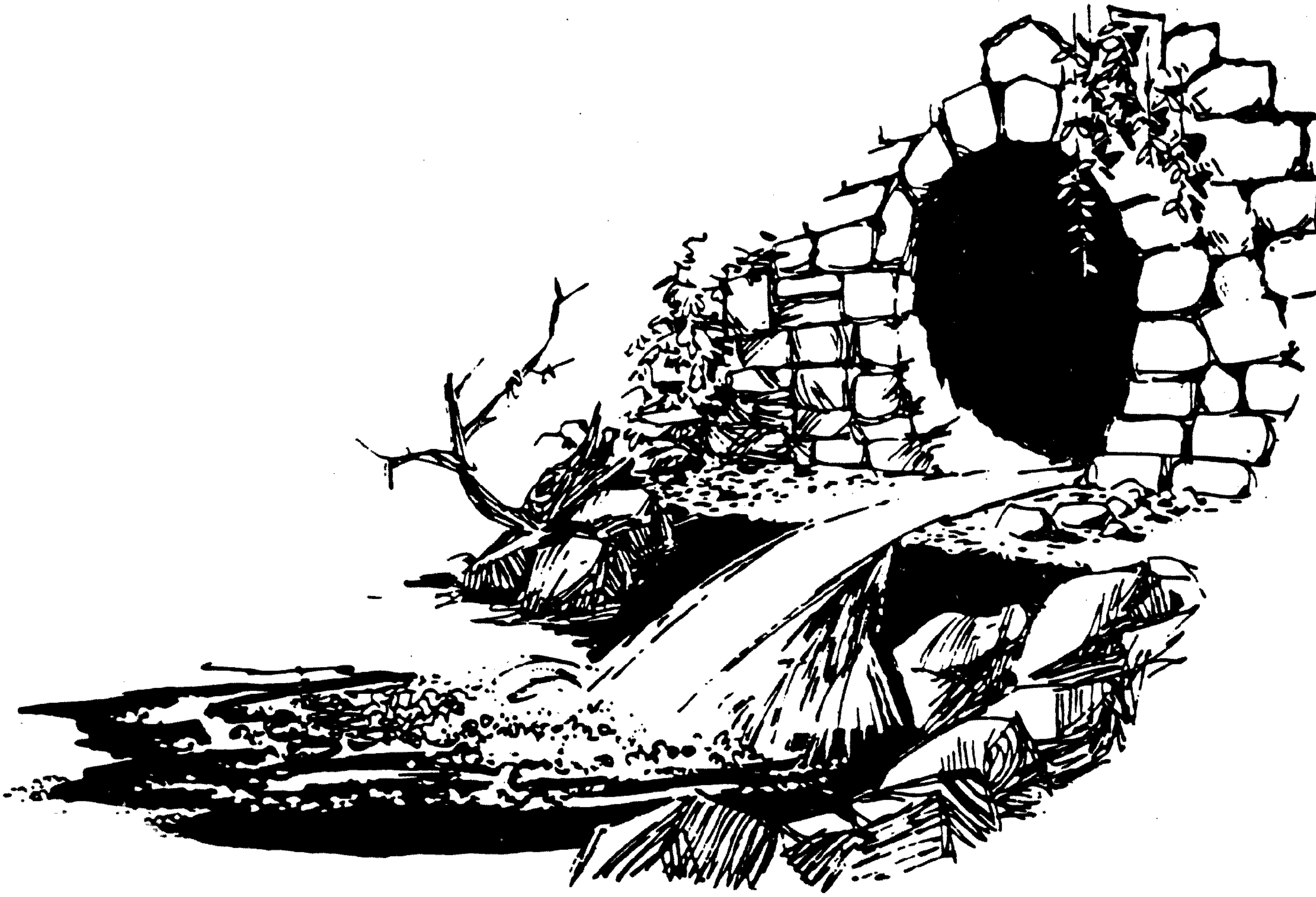
Office Of Water
(4204)

EPA 832-B-97-001
Draft

EPA

Combined Sewer Overflows

Guidance For Monitoring And Modeling



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 16 1996

OFFICE OF WATER

SUBJECT: Combined Sewer Overflows-Guidance for Monitoring and Modeling

FROM: James F. Pendergast, Acting Director
Permits Division (MC: 4203)

TO: Interested Parties

I am pleased to provide, for your review and comment, an external review draft of EPA's guidance document *Combined Sewer Overflows - Guidance for Monitoring and Modeling*.

On April 11, 1994, EPA issued the final Combined Sewer Overflow (CSO) Control Policy. The Policy establishes a consistent national approach for controlling discharges from combined sewer systems to the Nation's waters through the National Pollutant Discharge Elimination System (NPDES) permit program.

EPA's CSO Control Policy encourages municipalities, NPDES permitting authorities, State water quality standards authorities, and the public to engage in a comprehensive and coordinated planning effort to achieve cost effective CSO controls that ultimately comply with the requirements of the Clean Water Act (CWA). The policy recognizes the site specific nature of CSOs and their impacts and provides the necessary flexibility to tailor controls to local situations.

EPA is committed to aggressively implementing the Policy by providing the required tools for effective implementation. EPA has issued five final guidance documents to support implementation of the national CSO control policy. These guidance documents are:

1. Combined Sewer Overflows-Guidance for Permit Writers
2. Combined Sewer Overflows-Guidance for Screening and Ranking
3. Combined Sewer Overflows-Guidance for Nine Minimum Controls
4. Combined Sewer Overflows-Guidance for Long-Term Control Plan
5. Combined Sewer Overflows-Guidance for Funding Options

EPA has released a sixth guidance document (*Combined Sewer Overflows - Guidance for Financial Capability Assessment and Schedule Development*) for external review. EPA plans to issue this document as final in the very near future.

The attached document, *Combined Sewer Overflows - Guidance for Monitoring and Modeling*, is the final guidance document that EPA will develop in support of the National CSO Control Policy. We are requesting that you review this manual and submit your comments to us. I welcome your comments on this draft and assure you that EPA will give serious consideration to all comments and information received. Please note that this guidance is currently in draft form and should not be used as the Agency's final guidance. It is intended as guidance only and does not modify or supersede the CWA or Agency regulations.

This document presents in-depth information on the development of monitoring and modeling plans and various levels of monitoring and modeling for both the combined sewer system and the receiving water body. EPA wants communities to develop monitoring and modeling programs that are appropriate for their situation. Medium and large communities with significant combined sewer systems with numerous CSOs may need more sophisticated monitoring and modeling programs to develop a cost-effective CSO control program. Many users of this document, however, are small communities with limited resources and much simpler monitoring and modeling needs. It is essential that this document provide guidance to all communities, regardless of size, on development of monitoring/modeling programs commensurate with their CSO problems. Therefore, EPA specifically requests comments on how this document can be improved to provide clear guidance to small communities.

Please send your comments by February 15, 1997 to:

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Thank you very much for your participation in this process. If you have questions, you may contact Tim Dwyer or Ross Brennan of my staff. Tim's telephone number is 202-260-6064; Ross's number is 202-260-6928.

Attachment

COMBINED SEWER OVERFLOWS

GUIDANCE FOR MONITORING AND MODELING

Office of Wastewater Management
U.S. Environmental Protection Agency
401 M Street, S.W.
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December 1996

NOTICE

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Mention of trade names or commercial products in this document does not constitute an endorsement or recommendation for use.

LIST OF ACRONYMS

BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
BPJ	Best Professional Judgment
CAD	Computer Aided Design
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
EMC	Event Mean Concentration
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
I/I	Infiltration/Inflow
LA	Load Allocation
LTCP	Long-Term Control Plan
NCDC	National Climatic Data Center
NGO	Nongovernmental Organization
NMC	Nine Minimum Controls
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NURP	National Urban Runoff Program
O&M	Operations and Maintenance
POTW	Publicly Owned Treatment Works
RBP	Rapid Bioassessment Protocol
QA	Quality Assurance
QC	Quality Control
SCS	Soil Conservation Service
SSES	Sewer System Evaluation Studies
STORET	Storage and Retrieval of U.S. Waterways Parametric Data
SWMM	Storm Water Management Model
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USGS	U.S. Geological Survey
VOC	Volatile Organic Compounds
WBS	Water Body System
WLA	Wasteload Allocation
WQS	Water Quality Standards

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Combined sewer systems (CSSs) are wastewater collection systems designed to carry sanitary sewage (consisting of domestic, commercial, and industrial wastewater) and storm water (surface drainage from rainfall or snowmelt) in a single pipe to a treatment facility. CSSs serve about 43 million people in approximately 1,100 communities nationwide. Most of these communities are located in the Northeast and Great Lakes regions. During dry weather, CSSs convey domestic, commercial, and industrial wastewater to a publicly owned treatment works (POTW). In periods of rainfall or snowmelt, total wastewater flows can exceed the capacity of the CSS or the treatment facilities. When this occurs, the CSS is designed to overflow directly to surface water bodies, such as lakes, rivers, estuaries, or coastal waters. These overflows—called combined sewer overflows (CSOs)—can be a major source of water pollution in communities served by CSSs.

Because CSOs contain untreated domestic, commercial, and industrial wastes, as well as surface runoff, many different types of contaminants can be present. Contaminants may include pathogens, oxygen-demanding pollutants, suspended solids, nutrients, toxics, and floatable matter. Because of these contaminants and the volume of the flows, CSOs can cause a variety of adverse impacts on the physical characteristics of surface water, impair the viability of aquatic habitats, and pose a potential threat to drinking water supplies. CSOs have been shown to be a major contributor to use impairment and aesthetic degradation of many receiving waters and have contributed to shellfish harvesting restrictions, beach closures, and even occasional fish kills.

1.2 HISTORY OF THE CSO CONTROL POLICY

Historically, the control of CSOs has proven to be extremely complex. This complexity stems partly from the difficulty in quantifying CSO impacts on receiving water quality and from the site-specific variability in the volume, frequency, and characteristics of CSOs. In addition, the financial considerations for communities with CSOs can be significant (1994 NEEDS Survey). The U.S. Environmental Protection Agency (EPA) estimates the CSO abatement costs for the 1,100 communities served by CSSs to be approximately $50.0 billion based on preliminary modeling results from the 1996 Clean Water Needs Survey.

To address these challenges, EPA's Office of Water issued a National Combined Sewer Overflow Control Strategy on August 10, 1989 (54 *Federal Register* 37370). This Strategy reaffirmed that CSOs are point source discharges subject to National Pollutant Discharge Elimination System (NPDES) permit requirements and to Clean Water Act (CWA) requirements. The CSO Strategy recommended that all CSOs be identified and categorized according to their status of compliance with these requirements. It also set forth three objectives:

- Ensure that if CSOs occur, they are only as a result of wet weather
- Bring all wet weather CSO discharge points into compliance with the technology-based and water quality-based requirements of the CWA
- Minimize the water quality, aquatic biota, and human health impacts from CSOs.

In addition, the CSO Strategy charged all States with developing state-wide permitting strategies designed to reduce, eliminate, or control CSOs.

Although the CSO Strategy was successful in focusing increased attention on CSOs, it fell short in resolving many fundamental issues. In mid-1991, EPA initiated a process to accelerate implementation of the Strategy. The process included negotiations with representatives of the regulated community, State regulatory agencies, and environmental groups. These negotiations were conducted through the Office of Water Management Advisory Group. The initiative resulted in the development of a CSO Control Policy, which was published in the *Federal Register* on April 19, 1994 (59 *Federal Register* 18688). The intent of the CSO Control Policy is to:

- Provide guidance to permittees with CSOs, NPDES permitting and enforcement authorities, and State water quality standards (WQS) authorities

- Ensure coordination among the appropriate parties in planning, selecting, designing, and implementing CSO management practices and controls to meet the requirements of the CWA

- Ensure public involvement during the decision-making process.

The CSO Control Policy contains provisions for developing appropriate, site-specific NPDES permit requirements for all CSSs that overflow due to wet weather events. It also announces an enforcement initiative that requires the immediate elimination of overflows that occur during dry weather and ensures that the remaining CWA requirements are complied with as soon as possible.

1.3 KEY ELEMENTS OF THE CSO CONTROL POLICY

The CSO Control Policy contains four key principles to ensure that CSO controls are cost-effective and meet the requirements of the CWA:

- Provide clear levels of control that would be presumed to meet appropriate health and environmental objectives

- Provide sufficient flexibility to municipalities, especially those that are financially disadvantaged, to consider the site-specific nature of CSOs and to determine the most cost-effective means of reducing pollutants and meeting CWA objectives and requirements

- Allow a phased approach for implementation of CSO controls considering a community's financial capability

- Review and revise, as appropriate, WQS and their implementation procedures when developing long-term CSO control plans to reflect the site-specific wet weather impacts of CSOs.

In addition, the CSO Control Policy clearly defines expectations for permittees, State WQS authorities, and NPDES permitting and enforcement authorities. These expectations include the following:

- Permittees should immediately implement the nine minimum controls (NMC), which are technology-based actions or measures designed to reduce CSOs and their effects on receiving water quality, as soon as practicable but no later than January 1, 1997.

- Permittees should give priority to environmentally sensitive areas.

- Permittees should develop long-term control plans (LTCPs) for controlling CSOs. A permittee may use one of two approaches: 1) demonstrate that its plan is adequate to meet the water quality-based requirements of the CWA ("demonstration approach"), or 2) implement a minimum level of treatment (e.g., primary clarification of at least 85 percent of the collected combined sewage flows) that is presumed to meet the water quality-based requirements of the CWA, unless data indicate otherwise ("presumption approach").

- WQS authorities should review and revise, as appropriate, State WQS during the CSO long-term planning process.

- NPDES permitting authorities should consider the financial capability of permittees when reviewing CSO control plans.

Exhibit 1-1 illustrates the roles and responsibilities of permittees, NPDES permitting and enforcement authorities, and State WQS authorities.

In addition to these key elements and expectations, the CSO Control Policy also addresses important issues such as ongoing or completed CSO control projects, public participation, small communities, and watershed planning.

Exhibit 1-1. Roles and Responsibilities

Permittee	NPDES Permitting Authority	NPDES Enforcement Authority	State WQS Authorities
• Evaluate and implement NMC • Submit documentation of NMC implementation by January 1, 1997 • Develop LTCP and submit for review to NPDES permitting authority • Support the review of WQS in CSO-impacted receiving water bodies • Comply with permit conditions based on narrative WQS • Implement selected CSO controls from LTCP • Perform post-construction compliance monitoring • Reassess overflows to sensitive areas • Coordinate all activities with NPDES permitting authority, State WQS authority, and State watershed personnel	• Reassess/revise CSO permitting strategy • Incorporate into Phase I permits CSO-related conditions (e.g., NMC implementation and documentation and LTCP development) • Review documentation of NMC implementation • Coordinate review of LTCP components throughout the LTCP development process and accept/approve permittee's LTCP • Coordinate the review and revision of WQS as appropriate • Incorporate into Phase II permits CSO-related conditions (e.g., continued NMC implementation and LTCP implementation) • Incorporate implementation schedule into an appropriate enforceable mechanism • Review implementation activity reports (e.g., compliance schedule progress reports)	• Ensure that CSO requirements and schedules for compliance are incorporated into appropriate enforceable mechanisms • Monitor adherence to January 1, 1997, deadline for NMC implementation and documentation • Take appropriate enforcement action against dry weather overflows • Monitor compliance with Phase I, Phase II, and post-Phase II permits and take enforcement action as appropriate	• Review WQS in CSO-impacted receiving water bodies • Coordinate review with LTCP development • Revise WQS as appropriate: Development of site-specific criteria Modification of designated use to – Create partial use reflecting specific situations – Define use more explicitly Temporary variance from WQS

1.4 GUIDANCE TO SUPPORT IMPLEMENTATION OF THE CSO CONTROL POLICY

To help permittees and NPDES permitting and WQS authorities implement the provisions of the CSO Control Policy, EPA has developed the following guidance documents:

- *Combined Sewer Overflows – Guidance for Long-Term Control Plan* (EPA, 1995a) (EPA 832-B-95-002)
- *Combined Sewer Overflows – Guidance for Nine Minimum Controls* (EPA, 1995b) (EPA 832-B-95-003)
- *Combined Sewer Overflows – Guidance for Screening and Ranking* (EPA, 1995c) (EPA 832-B-95-004)
- *Combined Sewer Overflows – Guidance for Funding Options* (EPA, 1995d) (EPA 832-B-95-007)
- *Combined Sewer Overflows – Guidance for Permit Writers* (EPA, 1995e) (EPA 832-B-95-008).

1.5 PURPOSE OF GUIDANCE

This manual explains the role of monitoring and modeling in the development and implementation of a CSO control program. It expands discussions of monitoring and modeling introduced in the CSO Control Policy and presents examples of data collection and CSS simulation.

This manual is not a "how-to" manual defining how many samples to collect or which flow metering technologies to use. The CSO Control Policy is not a regulation. Rather, it is a set of guidelines that provides flexibility for a municipality to develop a site-specific strategy for characterizing its CSS operation and impacts and for developing and implementing a comprehensive CSO control plan. CSSs vary greatly in their size, structure, operation, and receiving water impacts. A monitoring and modeling strategy appropriate for a large city such as New York or San Francisco would generally not apply to a small CSS with only one or two flow regulators and outfalls. In addition, communities have varying degrees of knowledge about how their CSSs react hydraulically to wet weather and how their CSOs affect receiving water quality. A municipality that does not know the location of its CSO outfalls has different information collection needs from a municipality that has already conducted CSS flow and water quality studies.

This manual provides guidance for communities of all sizes. It presents low-cost monitoring and modeling techniques, which should prove particularly helpful to small communities. However, communities with large CSSs should note that inexpensive techniques often prove useful in extending monitoring resources and in verifying the performance of more sophisticated techniques and equipment.

To use this manual, a municipality should already be familiar with the basic functioning of its CSS, basic monitoring procedures, and the general purpose of modeling. Since basic monitoring and modeling techniques are already covered extensively in other technical literature, this manual focuses mainly on the process of characterization as described in the CSO Control Policy, referring to other literature for more in-depth explanations of specific techniques or procedures.

1.6 MANUAL ORGANIZATION

This manual begins with an overview of monitoring and modeling under the CSO Control Policy, and then provides a detailed discussion of the monitoring and modeling activities that should be conducted for NMC implementation and LTCP development and implementation. These activities (and the chapters in which they are discussed) are as follows:

- 2.0 Introduction To Monitoring and Modeling
- 3.0 Initial System Characterization—Existing Data Analyses and Field Investigation
- 4.0 Monitoring and Modeling Plan
- 5.0 Combined Sewer System Monitoring
- 6.0 Receiving Water Monitoring
- 7.0 Combined Sewer System Modeling
- 8.0 Receiving Water Quality Modeling
- 9.0 Assessing Receiving Water Impacts and Attainment of Water Quality Standards.

CHAPTER 2

INTRODUCTION TO MONITORING AND MODELING

Monitoring and modeling activities are central to implementation of the Combined Sewer Overflow (CSO) Policy. Thoughtful development and implementation of a monitoring and modeling plan will support the selection and implementation of cost-effective CSO controls and assessment of their impacts on receiving water quality.

This chapter describes general expectations for monitoring and modeling activities as part of a permittee's CSO control program. It also describes how monitoring and modeling efforts conducted as part of CSO control program implementation can be coordinated with other key EPA and State programs and efforts (e.g., watershed approach, other wet weather programs).

While this chapter will describe general expectations, EPA encourages the permittee to take advantage of the flexibility in the CSO Control Policy by developing a monitoring and modeling program that is cost-effective and tailored to local conditions, providing adequate but not duplicative or unnecessary information.

2.1 MONITORING AND MODELING FOR NINE MINIMUM CONTROLS AND LONG TERM CONTROL PLAN

The CSO Control Policy urges permittees to develop a thorough understanding of the hydraulic responses of their CSSs to wet weather events. Permittees may also need to estimate pollutant loadings from CSOs and the fate of pollutants in receiving water both for existing conditions and for various CSO control options. The CSO Control Policy states that permittees should "immediately undertake a process to accurately characterize their CSSs, to demonstrate implementation of the nine minimum controls, and to develop a long-term CSO control plan." Characterizing the CSS and its hydraulic response to wet weather events, implementing the NMC and producing related documentation, and developing an LTCP will involve gathering and reviewing existing data, and, in most cases, conducting some field inspections, monitoring, and modeling. Since flexibility is a key principle in CSO Control Policy implementation, these activities will be carried out to different degrees based on each permittee's situation. In particular, the type and complexity of necessary modeling will vary from permittee to permittee.

2.1.1 Nine Minimum Controls

The CSO Control Policy recommends that a Phase I permit require the permittee to immediately implement technology-based requirements, which in most cases will be the NMC, as determined on a best professional judgment (BPJ) basis by the NPDES permitting authority. The NMC are:

1. Proper operation and regular maintenance programs for the sewer system

2. Maximum use of the collection system for storage

3. Review and modification of pretreatment requirements to assure CSO impacts are minimized

4. Maximization of flow to the publicly owned treatment works (POTW) for treatment

5. Prohibition of CSOs during dry weather

6. Control of solids and floatable materials in CSOs

7. Pollution prevention

8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts

9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

The NMC are technology-based controls, applied on a site-specific basis, to reduce the magnitude, frequency, and duration of CSOs and their impacts on receiving water bodies. NMC measures typically do not require significant engineering studies or major construction and thus implementation is expected by January 1, 1997. EPA's guidance document *Combined Sewer Overflows – Guidance for Nine Minimum Controls* (EPA, 1995b) provides a detailed description of the NMC, including example control measures and their advantages and limitations.

Monitoring is specifically included as the ninth minimum control. Implementation of this control would typically involve the following activities:

- Mapping the drainage area for the combined sewer system (CSS), including the locations of all CSO outfalls and receiving waters

- Identifying, for each receiving water body, designated and existing uses, applicable water quality criteria, and whether WQS are currently being attained

- Developing a record of overflow occurrences

- Compiling existing information on water quality impacts associated with CSOs (e.g., beach closings, evidence of floatables wash-up, fish kills, and sediment accumulation).

Monitoring as part of the NMC is not intended to be extensive or costly. Implementation is expected to entail collection of existing information from relevant agencies about the CSS, CSOs, and the receiving water body, as well as preliminary investigation activities such as field inspections and simple measurements using chalk boards, bottle boards, and block tests. The information and data collected will be used to establish a baseline of existing conditions for evaluating the efficacy of the technology-based controls and to develop the LTCP (as described in the Section 2.1.2).

Data analysis and field inspection activities also support implementation of several other NMC:

- *Proper operation and regular maintenance programs for the sewer system*—Characterization of the CSS will support the evaluation of the effectiveness of current operation and maintenance (O&M) programs and help identify areas within the CSS that need repair.

- *Maximum use of the collection system for storage*—Information gained during field inspections, such as the system topography (e.g., location of any steep slopes) and the need for regulator or pump adjustments, can assist in identifying locations where minor modifications to the CSS can increase in-system storage.

- *Review and modification of pretreatment requirements to assure CSO impacts are minimized*—Pretreatment program information and existing monitoring data will support assessment of the impacts of nondomestic discharges on CSOs.

- *Control of solids and floatable materials in CSOs*—Existing information about receiving water impacts and observations made during field inspections of the CSS will help determine the extent of solid and floatable materials present and the effectiveness of any controls installed.

- *Dry weather overflows*—Field inspections will assess the presence of dry weather overflows, the conditions under which they occur, and the effectiveness of any control measures in place.

Because specific NMC implementation requirements will be embodied in a permit or other enforceable mechanism that is developed on a site-specific basis, the permittee should coordinate NMC implementation with the NPDES permitting authority on an ongoing basis.

2.1.2 Long-Term Control Plan Development

The CSO Control Policy recommends that a Phase I permit require the permittee to develop and submit an LTCP that, when implemented, will ultimately result in compliance with CWA requirements. The permittee should use either the presumption approach or the demonstration approach in developing an LTCP that will provide for WQS attainment. The permittee should evaluate the data and information obtained through the initial system characterization to determine which approach is more appropriate based on site-specific conditions. Generally, the demonstration approach would be selected when the permittee thinks sufficient data are available to "demonstrate" that a proposed LTCP is adequate to meet the water quality-based requirements of the CWA. If sufficient data are not available and cannot be developed to allow use of the demonstration approach, and the permit writer believes it is likely that implementation of a control program that meets certain performance criteria will result in attainment of CWA requirements, the permittee would use the presumption approach. The two approaches are discussed in more detail below and in Chapters 7 and 8.

Demonstration Approach. Under the demonstration approach, the permittee demonstrates the adequacy of its CSO control program to meet the water quality-based requirements of the CWA. As stated in the CSO Control Policy, the permittee should demonstrate each of the following:

> "i. *The planned control program is adequate to meet WQS and protect designated uses, unless WQS or uses cannot be met as a result of natural background conditions or pollution sources other than CSOs;*
>
> ii. *The CSO discharges remaining after implementation of the planned control program will not preclude the attainment of WQS or the receiving waters' designated uses or contribute to their impairment. Where WQS and designated uses are not met in part because of natural background conditions or pollution sources other than CSOs, a total maximum daily load, including a wasteload allocation and a load allocation, or other means should be used to apportion pollutant loads;*
>
> iii. *The planned control program will provide the maximum pollution reduction benefits reasonably attainable; and*
>
> iv. *The planned control program is designed to allow cost effective expansion or cost effective retrofitting if additional controls are subsequently determined to be necessary to meet WQS or designated uses."* (II.C.4.b).

Generally, monitoring and modeling activities will be integral to successfully demonstrating that these criteria have been met.

Presumption Approach. This approach is based on the presumption that WQS will be attained with implementation of an LTCP that provides for certain performance-based controls. For the presumption approach, the CSO Control Policy states that:

> *"A program that meets any of the criteria listed below would be presumed to provide an adequate level of control to meet the water quality-based requirements of the CWA, provided the permitting authority determines that such presumption is reasonable in light of the data and analysis conducted in the characterization, monitoring, and modeling of the system and the consideration of sensitive areas described above. These criteria are provided because data and modeling of wet weather events often do not give a clear picture of the level of CSO controls necessary to protect WQS.*
>
> i. *No more than an average of four overflow events per year...*

ii. *The elimination or the capture for treatment of no less than 85% by volume of the combined sewage collected in the CSS during precipitation events on a system-wide annual average basis...*

iii. *The elimination or removal of no less than the mass of pollutants, identified as causing water quality impairment..., for the volumes that would be eliminated or captured for treatment under paragraph ii..."* (II.C.4.a.)

Monitoring and modeling activities are also likely to be necessary in order to obtain the permitting authority's approval for using the presumption approach.

Whether the LTCP ultimately reflects the demonstration approach or the presumption approach, it should contain the same elements, as identified in the CSO Control Policy:

- Characterization, monitoring, and modeling of the combined sewer system
- Public participation
- Consideration of sensitive areas
- Evaluation of alternatives
- Cost/performance considerations
- Operational plan
- Maximization of treatment at the POTW treatment plant
- Implementation schedule
- Post-construction compliance monitoring program.

Of these elements, the first and last are directly linked to monitoring and modeling.

Characterization, monitoring, and modeling of the combined sewer system

The first step in developing an LTCP involves characterization, monitoring, and modeling of the combined sewer system. The CSO Control Policy states:

"In order to design a CSO control plan adequate to meet the requirements of the CWA, a permittee should have a thorough understanding of its sewer system, the response of the system to various precipitation events, the characteristics of the overflows, and the water quality impacts that result from CSOs. The permittee should adequately characterize through monitoring, modeling, and other means as appropriate, for a range of storm events, the response of its sewer system to wet weather events including the number, location and frequency of CSOs, volume, concentration and mass of pollutants discharged and the impacts of the CSOs on the receiving waters and their designated uses. The permittee may need to consider information on the contribution and importance of other pollution sources in order to develop a final plan designed to meet water quality standards. The purpose of the system characterization, monitoring and modeling program initially is to assist the permittee in developing appropriate measures to implement the nine minimum controls and, if necessary, to support development of the long-term CSO control plan. The monitoring and modeling data also will be used to evaluate the expected effectiveness of both the nine minimum controls and, if necessary, the long-term CSO controls, to meet WQS." (II.C.1)

Characterization, monitoring, and modeling of the combined sewer system can be broken into the following elements:

1. Examination of rainfall records and other existing data
2. Characterization of the CSS
3. Monitoring of CSOs and receiving water
4. Modeling of the CSS and receiving water.

Analysis of existing data should include an examination of rainfall records. This analysis, as well as information from field inspections and simple measurements using chalk boards, bottle boards, and block tests, provide the basis for the preliminary system characterization. This initial characterization of the system (described in more detail in Chapter 3) should identify the number, location, and frequency of overflows and clarify their relationship to sensitive areas, pollution sources within the collection system (e.g., indirect discharges from nondomestic sources), and other pollution sources discharging to the receiving water (e.g., direct industrial discharges, POTWs, storm water discharges).

Since some of these activities are also conducted as part of NMC implementation, the LTCP should be developed in coordination with NMC implementation efforts. Ultimately, because the LTCP is based on more detailed knowledge of the CSS and receiving waters than is necessary to implement the NMC, the extent of monitoring and modeling for LTCP development is expected to be more sophisticated.

Examination of rainfall data, field inspections and simple measurements, and other preliminary characterization activities will serve as the basis for the development of a cost-effective monitoring and modeling plan (discussed in Chapter 4). The monitoring and modeling plan should be designed to provide the information and data needed to develop and evaluate CSO control alternatives and to select the most cost-effective CSO controls.

Chapter 4 provides an overview of the development of a monitoring and modeling plan. Chapters 5 and 7 discuss CSS monitoring and modeling, and Chapters 6 and 8 discuss receiving water monitoring and modeling, respectively. It is important to remember that the monitoring and modeling plan should be based on the site-specific conditions of the CSS and receiving water. Therefore the permittee should, on an ongoing basis, consult and coordinate these efforts with the NPDES permitting authority.

Implementation of the monitoring and modeling plan should enable the permittee to predict the CSS's response to various wet weather events and evaluate CSO impacts on receiving waters for alternative control strategies. Evaluation of CSO control alternatives is discussed in *Combined Sewer Overflows – Guidance for Long Term Control Plan* (EPA, 1995a).

Based on the evaluation of control strategies, the permittee, in coordination with the public, the NPDES permitting authority, and the State WQS authority, should select the most cost-effective CSO controls needed to provide for the attainment of WQS. Specific conditions relating to implementation of these CSO controls will be incorporated into the NPDES permit as described in Section 2.1.4.

Post-construction compliance monitoring program

Not only should the LTCP contain a characterization, monitoring, and modeling plan adequate to evaluate CSO controls, but it should also contain a post-construction compliance monitoring plan to ascertain the effectiveness of long-term CSO controls in achieving compliance with CWA requirements. Generally, post-construction compliance monitoring will not occur until after development and at least partial implementation of the LTCP. Nevertheless, the permittee should consider its needs for post-construction monitoring as its monitoring and modeling plan develops. The development of a post-construction compliance monitoring program is discussed in Section 2.1.4 and Chapter 4.

2.1.3 Monitoring and Modeling During Phase I

The CSO Control Policy recommends that the Phase I permit require permittees to:

- Immediately implement BAT/BCT, which at a minimum should include the nine minimum controls, as determined on a BPJ basis by the NPDES permitting authority
- Submit appropriate documentation on NMC implementation activities within two years of permit issuance/modification but no later than January 1, 1997
- Comply with applicable WQS expressed as narrative limitations
- Develop and submit an LTCP as soon as practicable, but generally within 2 years after permit issuance/modification.

The permittee should not view NMC implementation and LTCP development as independent activities, but rather as related components in the CSO control planning process. Implementation of the NMC establishes the baseline conditions upon which the LTCP will be developed.

In many cases, the LTCP will be developed concurrent with NMC implementation. As described in Sections 2.1.1 and 2.1.2, both efforts require the permittee to develop a thorough understanding of the CSS. For example, monitoring done as part of the NMC to *effectively characterize CSO impacts and the efficacy of CSO controls* should provide a base of information and data that the permittee can use in conducting more thorough characterization, monitoring, and modeling activities for LTCP implementation.

Therefore, the characterization activities needed to implement the NMC and develop the LTCP should be a single coordinated effort.

2.1.4 Monitoring and Modeling During Phase II

The CSO Control Policy recommends that a Phase II permit include:

- Requirements to implement technology-based controls including the NMC on a BPJ basis
- A narrative requirement that selected CSO controls be implemented, operated, and maintained as described in the LTCP
- Water quality-based effluent limits expressed in the form of numeric performance standards
- Requirements to implement the post-construction compliance monitoring program
- Requirements to reassess CSOs to sensitive areas
- Requirements for maximizing the treatment of wet weather flows at the treatment plant
- A reopener clause authorizing permit modifications if CSO controls fail to meet WQS or protect designated uses.

The post-construction compliance monitoring program should provide sufficient data to determine the effectiveness of CSO controls in attaining WQS. The frequency and type of monitoring in the program will be site-specific. In most cases, some monitoring will be conducted during the construction/implementation period to evaluate the effectiveness of the long-term CSO controls. In some cases, however, it may be appropriate to delay implementation of the post-construction monitoring program until construction is well underway or completed.

The post-construction compliance monitoring program may also include appropriate measures for determining the success of the CSO control program. Measures of success, which are also discussed in Section 2.3, can address both CSO flow and quality issues. For example, flow-related measures could include the number of dry weather overflows or CSO outfalls eliminated, and reductions in the frequency and volume of CSOs. Quality-related measures could include decreases in loadings of conventional and toxic pollutants in CSOs. Environmental measures focus on human and ecosystem health trends such as reduced beach closures or fish kills, improved biological integrity indices, and the full support of designated uses in receiving water bodies.

2.2 MONITORING AND MODELING AND THE WATERSHED APPROACH

The watershed approach represents EPA's holistic approach to understanding and addressing all surface water, ground water, and habitat stressors within a geographically defined area, instead of addressing individual pollutant sources in isolation. It serves as the basis for place-based solutions to ecosystem protection.

EPA's watershed approach is based on a few main principles:

- ***Geographic Focus***—Activities are focused on specific drainage areas.

- ***Environmental Objectives and Strong Science/Data***—Using strong scientific tools and sound data, the priority problems are characterized, environmental objectives are determined, action plans are developed and implemented, and effectiveness is evaluated

- ***Establishment of Partnerships***—Management teams representing various interests (e.g., regulatory agencies, industry, concerned citizens) are formed to jointly evaluate watershed management decisions

- ***Coordinated Priority Setting and Integrated Solutions***—Using a coordinated approach across relevant organizations, priorities can be set and integrated actions taken that consider all environmental issues in the context of various water programs and resource limitations.

Point and nonpoint source programs, the drinking water program, and other surface and ground water programs are all integrated into the watershed approach. Under the watershed approach, these programs address watershed problems in an effective and cooperative fashion. The CSO Policy encourages NPDES permitting authorities to evaluate CSO control needs on a watershed basis and coordinate CSO control program efforts with the efforts of other point and nonpoint source control activities within the watershed.

The application of the watershed approach to a CSO control program is particularly timely and appropriate since the ultimate goal of the CSO Control Policy is the development of long-term CSO controls that will provide for the attainment of WQS. Since pollution sources other than CSOs are likely to be discharging to the receiving water and affecting whether WQS are attained, the permittee needs to consider and understand these sources in developing its LTCP. The permittee should compile existing information and monitoring data on these sources from the NPDES permitting authority, State watershed personnel, or even other permittees or dischargers within the watershed. If other permittees within the watershed are also developing long-term CSO control plans, an opportunity exists for these permittees to pursue a coordinated and cooperative approach to CSO control planning.

If the permittee determines during its LTCP development that WQS cannot be met because of other pollution sources within the watershed, a total maximum daily load (TMDL), including wasteload allocation (WLA) and load allocation (LA), may be necessary to apportion loads among dischargers. Several EPA publications provide TMDL guidance (see References). In many cases a TMDL may not have been developed for the permittee's watershed. In these cases, the monitoring and modeling conducted as part of the development and implementation of long-term CSO controls will support an assessment of water quality and could support the development of a TMDL.

Use of the comprehensive watershed approach during long-term CSO planning will result in a more cost-effective program for achieving WQS in a watershed.

2.3 MEASURES OF SUCCESS

Before developing a monitoring plan for characterizing the CSS and determining post-construction compliance, the permittee should determine appropriate measures of success based on site-specific conditions. Measures of success are objective, measurable, and quantifiable indicators that illustrate trends and results over time. Measures of success generally fall into four categories:

- ***Administrative measures*** that track programmatic activities;
- ***End-of-pipe measures*** that show trends in the discharge of CSS flows to the receiving water body, such as reduction of pollutant loadings, the frequency of CSOs, and the duration of CSOs;
- ***Receiving water body measures*** that show trends of the conditions in the water body which receives the CSOs, such as trends in dissolved oxygen levels and sediment oxygen demand;
- ***Ecological, human health, and use measures*** that show trends in conditions relating to the use of the water body, its effect on the health of the population that uses the water body, and the health of the organisms that reside in the water body, including beach closures, attainment of designated uses, habitat improvements, and fish consumption advisories. Such measures would be coordinated on a watershed basis as appropriate.

EPA's experience has shown that measures of success should include a balanced mix of measures from each of the four categories.

As municipalities begin to collect data and information on CSOs and CSO impacts, they have an important opportunity to establish a solid understanding of the "baseline" conditions and to consider what information and data are necessary to evaluate and demonstrate the results of CSO control. The permittee should choose measures of success that can be used to indicate reductions in CSOs and their effects. Municipalities and NPDES permitting authorities should agree early in the planning stages on the data and information that will be used to measure success. (Measures of success for the CSO program are discussed in *Combined Sewer Overflows–Guidance for Long-Term Control Plan.* (EPA, 1995a) and *Performance Measures for* *the National CSO Control Program* (AMSA, 1996)). The permittee should consider these measures of success when determining which parameters to include in its monitoring plan.

2.4 COORDINATION WITH OTHER WET WEATHER MONITORING AND MODELING PROGRAMS

The permittee may be subject to monitoring requirements for other regulated wet weather discharges, such as storm water, in addition to monitoring activities for a CSO control program. Due to the unpredictability of wet weather discharges, monitoring of such discharges presents challenges similar to those for monitoring CSOs. The permittee should coordinate all wet weather monitoring efforts. Developing one monitoring and modeling program for all wet weather programs will enable the permittee to establish a clear set of priorities for monitoring and modeling activities.

2.5 REVIEW AND REVISION OF WATER QUALITY STANDARDS

A key principle of the CSO Control Policy is the review and revision, as appropriate, of WQS and their implementation procedures to reflect the site-specific wet weather impacts of CSOs. Review and revision of WQS should be conducted concurrent with the development of the LTCP to ensure that the long-term CSO controls will be sufficient to provide for the attainment of applicable WQS.

The WQS program contains several types of mechanisms that could potentially be used to address site-specific factors such as wet weather conditions. These include the following:

- Adopting partial uses to reflect situations where a significant storm event precludes the use from occurring

- Adopting seasonal uses to reflect that certain uses do not occur during certain seasons (e.g., swimming does not occur in winter)

- Defining a use with greater specificity (e.g., warm-water fishery in place of aquatic life protection)

- Granting a temporary variance to a specific discharger in cases where maintaining existing standards for other dischargers is preferable to downgrading WQS.

These potential revisions are described in detail in the *Water Quality Standards Handbook, Second Edition* (EPA, 1994).

Reviewing and revising WQS requires the collection of information and data to support the proposed revision. In general, a use attainability analysis (UAA) is required to support a proposed WQS revision. The process for conducting UAAs for receiving waters has been described in various EPA publications (see References).

The information and data collected during LTCP development could potentially be used to support a UAA for a proposed revision to WQS to reflect wet weather conditions. Thus, it is important for the permittee, NPDES permitting authority, State WQS authority, and EPA Regional offices to agree on the data, information and analyses that are necessary to support the development of the long-term CSO controls as well as the review of applicable WQS and implementation procedures, if appropriate.

2.6 OTHER ENTITIES INVOLVED IN DEVELOPING AND IMPLEMENTING THE MONITORING AND MODELING PROGRAM

Development and implementation of a CSO monitoring and modeling program should not be solely the permittee's responsibility. Development of a successful and cost-effective monitoring and modeling program should reflect the coordinated efforts of a team that includes the NPDES permitting authority, State WQS authority, State watershed personnel, EPA or State monitoring personnel, and any other appropriate entities.

NPDES Permitting Authority

The NPDES permitting authority should:

- Develop appropriate system characterization, monitoring, and modeling requirements for NMC implementation and LTCP development (in a Phase I permit), LTCP implementation (in a Phase II permit) and post-construction (Phase II and ongoing)

- Coordinate with the permittee to ensure that the monitoring requirements in the permit are appropriately site-specific

- Assist in compiling relevant existing information, monitoring data, and studies at the State and/or EPA Regional level

- Coordinate the permittee's CSO monitoring and modeling efforts with monitoring and modeling efforts of other permittees within the watershed

- Coordinate the team review of the monitoring and modeling plan, monitoring and modeling data and results, and other components of the LTCP. To ensure team review of the monitoring and modeling plan, the permitting authority could recommend that the plan include a signature page for endorsement by all the team members after their review.

State WQS Authority

The State WQS authority should:

- Provide input on the review and possible revision of WQS including conduct of a use attainability analysis

- Assist in compiling existing State information, monitoring data, and studies for the receiving water body

- Ensure that the permittee's monitoring and modeling efforts are coordinated and integrated with ongoing State monitoring programs

- Evaluate any special monitoring activities such as biological testing, sediment testing, and whole effluent toxicity testing.

State Watershed Personnel

State watershed personnel should:

- Ensure that the permittee's monitoring activities are coordinated with ongoing watershed monitoring programs

- Assist in compiling existing State information, monitoring data, and studies for the receiving water body

- Ensure the permittee's monitoring and modeling efforts are integrated with TMDL application or development.

EPA/State Monitoring Personnel

EPA and State monitoring personnel should:

- Provide technical support and reference material on monitoring techniques and equipment

- Assist in compiling relevant existing monitoring data and studies for the receiving water body

- Provide information on available models and the monitoring data needed as model inputs

- Assist in the evaluation and selection of appropriate models.

The public should also participate in development and implementation of the system characterization activities and the monitoring and modeling program. Throughout the LTCP development process, the public should have the opportunity to review and provide comments on the results of the system characterization, monitoring, and modeling activities that are leading up to the selection of long-term CSO controls.

CHAPTER 3

INITIAL SYSTEM CHARACTERIZATION - EXISTING DATA ANALYSES AND FIELD INVESTIGATIONS

As explained in Chapter 2, implementation of the nine minimum controls (NMC) and development of a long-term control plan (LTCP) requires a thorough characterization of the CSS. Accurate information on CSS design, CSS responses to changing flows, chemical characteristics of CSOs, and biological and chemical characteristics of receiving waters is critical in identifying CSO impacts and the projected efficacy of proposed CSO controls. Before in-depth monitoring and modeling efforts begin, however, the permittee should assemble as much information as possible from existing data sources and preliminary field investigations. Such preliminary activities will contribute to a baseline characterization of the CSS and its receiving water and help focus the monitoring and modeling plan.

The primary objectives of the existing data analyses and field investigations are:

- To determine the current level of understanding and knowledge of the CSS and receiving water
- To assess the design and current operating condition of the CSS
- To identify CSO impacts on receiving waters
- To identify the data that need to be collected through the monitoring and modeling program
- To assist in NMC implementation and documentation.

The activities required to meet these objectives will vary widely from system to system. Many permittees have already made significant progress in conducting initial system characterizations under the 1989 CSO Strategy or through other efforts. For example, permittees that have begun NMC implementation probably have compiled a substantial amount of information on their CSSs. Studies by EPA, State agencies, or other organizations may provide substantial information and data for the receiving water characterization.

This chapter generally describes the following types of activities conducted during the initial system characterization:

- ***Physical Characterization of CSS***—identification and description of all functional elements of the CSS, including sources discharging into the CSS, as well as the delineation of the CSS drainage areas, analysis of rainfall data throughout the drainage area, identification of all CSO outfalls, and preliminary CSS hydraulic analyses.

- ***Characterization of Combined Sewage and CSOs***—analysis of existing data to determine volume, chemical characteristics, and pollutant loadings of CSOs.

- ***Characterization of Receiving Waters***—identification of the designated uses and current status of the receiving waters affected by CSOs, chemical characterization of those receiving waters, and identification of biological receptors potentially impacted by CSOs.

The permittee should consult with the NPDES permitting authority and the review team (see Section 2.6) while reviewing the results from the initial system characterization and in preparation for development of the monitoring and modeling plan (Chapter 4). Performing and documenting initial characterization activities may help satisfy certain requirements for NMC implementation and documentation. Thus, it is essential that the permittee coordinate with the NPDES permitting authority on an ongoing basis throughout the initial characterization process.

3.1 PHYSICAL CHARACTERIZATION OF CSS

3.1.1 Review Historical Information

For the first part of the physical characterization, the permittee should compile, catalogue, and review existing information on the design and construction of the CSS to clarify and evaluate how the CSS operates, particularly in response to wet weather events. The permittee should compile, for the entire CSS, information on the contributing drainage areas, the location and capacity of the POTW and interceptor network, the location and operation of flow regulating structures, the location of all known or suspected CSO outfalls, and the general hydraulic characteristics of the system. Historical information is often available from the following sources:

- *Sewer Maps of Suitable Scale*—Sewer maps define the pipe network of the sewer system and may indicate the drainage areas that contribute to each CSO outfall. Ideally, they should include the combined, separate sanitary, and separate storm sewer systems. Data provided from these maps, such as the invert elevations, can be used to calculate individual pipe capacities and to develop detailed hydraulic models. Sewer maps should be field checked because field conditions may differ significantly from the plans (see System Field Investigations, Section 3.1.3).

- *Topographic Maps*—The U.S. Geological Survey (USGS) provides topographic maps, usually with 10-foot contour intervals. The local municipality or planning agency may have prepared topographic maps with finer contour intervals, which may be more useful in identifying drainage areas contributing to CSOs.

- *Aerial Photographs*—When overlaid with sewer maps and topographic maps, aerial photos may aid in identifying land uses in the drainage areas. Local planning agencies, past land use studies, or State Departments of Transportation may have aerial photographs suitable for the initial characterization.

- *Diversion Structure Drawings*—Drawings of CSS structures, in plan and section view, indicate how the structures operate, how they should be monitored, and how they could be altered to facilitate monitoring or improve flow control.

- *Rainfall Data*—Rainfall data are one of the most important and useful types of data collected during the initial system characterization. Reliable rainfall data are necessary to understand the hydraulic response of the CSS and, where applicable, to model this response. Sources of data may include long-term precipitation data collected from a weather station within or outside the CSS drainage basin, or short-term, site-specific precipitation data from stations within the drainage basin or sub-basins.

  Long-term rainfall data collected within the drainage basin provide the best record of precipitation within the system and hence have the greatest value in correlating historic overflow events with precipitation events and in predicting the likelihood of wet weather events of varying intensities. If such data are not available, however, both long-term regional and short-term local data may be used.

  National rainfall data are available from the National Weather Service, which operates thousands of weather monitoring stations throughout the country. The local municipality, airports, universities, or other State or Federal facilities can also provide rainfall data. The National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC)'s Climate Services Branch is responsible for collecting precipitation data. Data on hourly, daily, and monthly precipitation for each monitoring station (with latitude and longitude) can be obtained on computer diskette, microfiche, or hard copy by calling (704) 259-0682, or by writing to NCDC, Climate Services Branch, The Federal Building, Asheville, NC 28071-2733. The NCDC also provides a computer program called SYNOP for data analysis. Additionally, permittees with few or no rain gages located within the system drainage basin may want to install one or more gages early in the CSO control planning process. The collection and analysis of rainfall data are discussed in Chapters 4 and 5.

Other Sources of Data

A variety of other historical data sources may be used in completing the physical characterization of a CSS. As-built plans and documentation of system modifications can provide reliable information on structure location and dimensions. Similarly, any recent surveys and studies conducted on the system can verify or enhance sewer map information. Additional information may be available from:

- As-built plans
- Documentation of system modifications
- Treatment plant upgrade reports
- Other related surveys and reports
- Design specifications
- Infiltration/inflow (I/I) studies
- Sewer system evaluation studies (SSES)
- Storm water master plans
- Section 208 areawide waste treatment plans
- Section 201 facility plans.

The availability of these sources of information varies widely among permittees. Collection system operations and maintenance personnel can be invaluable in determining the existence and location of such data, as well as providing system knowledge and insight.

3.1.2 Study Area Mapping

Using the historical data, the permittee should develop a map of the CSS, including the drainage basin of combined sewer areas and separate storm sewer areas. Larger systems will find it useful to map sub-basins for each regulating structure and discharge point. This map will be used for analyzing system flow directions and interconnections, analyzing land use and runoff parameters, locating monitoring networks, and developing model inputs. The map can also be a valuable planning tool in identifying areas of special concern in the CSS and coordinating further investigation efforts and logistics. The map should be modified as necessary to reflect additional CSS and receiving water information and data (such as the locations of other point source discharges to receiving water, the location of sensitive areas, and planned or existing monitoring locations), when it becomes available.

The completed map should include the following information:

- Delineation of contributing drainage areas
- General land uses
- POTW and interceptor network
- Main line locations and sizes
- Diversion structures
- CSO outfalls
- Access points (e.g., manholes; flat, open areas accessible for sampling)
- Pump stations
- Rain gages
- Existing monitoring locations
- USGS gage stations
- Receiving water bodies

- Sensitive areas (including drinking water intakes, downstream beaches, and other public access areas)
- Soil types
- Ground water flow
- Other point source discharges such as industrial discharges and separate storm water system discharges
- Existing treatment facilities.

It may be useful to generate two or more maps with different scales, such as a coarse-scale map (e.g., 7.5-minute USGS map) for land uses and other watershed scale information and a finer-scale map (e.g., 1" = 200' or 1" = 400') for sewer system details. In some cases, a Computer Aided Design (CAD) or Geographic Information System (GIS) approach can be used. Some advanced sewer models can draw information directly from CAD files, eliminating the duplication of entering data into the model. A municipality's planning department may be another useful source for the hardware, software, and data needed for such mapping efforts.

3.1.3 System Field Investigations

Before a monitoring and modeling program is developed, historical information on a CSS will generally need to be supplemented with field observations of the system to verify findings or fill data gaps. For example, visual inspection of regulator chambers and overflow structures during dry and wet weather verifies information included in drawings and provides data on current conditions. Further, it is necessary to verify that gates or flow diversion structures operate correctly so that ensuing monitoring programs collect information representative of the expected behavior of the system.

In general, field inspection activities may be used to:

- Verify the design and as-built drawings
- Locate and clarify portions of the system not shown on as-built drawings
- Identify dry weather overflows

- Identify locations of CSO outfalls
- Identify non-standard engineering or construction practices
- Examine the function of flow regulating equipment
- Identify areas in need of maintenance, repair, or replacement.

Several references provide useful descriptions of system evaluations (WPCF, 1989).

Although generally beyond the scope of a small system characterization effort, in-line TV cameras can be used to survey the system, locate connections, and identify needed repairs. Such surveys may have been done as part of an infiltration/inflow study. In-line inspection methods are also described in detail in WPCF (1989).

The field investigation may also involve preliminary collection of flow and depth data, which can support the CSS flow monitoring and modeling activities later in the CSO planning process. Preliminary CSS flow and depth estimates can help answer the following questions:

- How much rain causes an overflow at each outfall?

- How many dry weather overflows occur? How frequently and at which outfall(s)?

- Do surcharging or backwater effects occur in intercepting devices or flow diversion structures?

- How deep are the maximum flows at the flow diversion structures for investigated storms (i.e., are the maximum flows at a depth that, if slightly altered, would affect whether a CSO occurs)?

A variety of simple flow measurement techniques may be employed to answer these questions prior to development and implementation of monitoring and modeling plans. These include:

- ***Chalk Board***—A chalk board is a simple depth-measuring device, generally placed in a manhole. It consists of a vertical board with a vertical chalk line drawn on it. Sewer flow passing by the board washes away a portion of the chalk line, roughly indicating the maximum flow depth that occurred since the board was placed in the sewer.

- ***Bottle Boards***—A bottle board is a vertical board with a series of attached open bottles. As flow rises the bottles with openings below the maximum flow are filled. When the flow recedes the bottles remain full indicating the height of maximum flow (see **Exhibit 5-6**).

- ***Block Tests***—Block tests do not measure depth, but are used to detect the presence of an overflow. A block of wood or other float is placed atop the overflow weir. If an overflow occurs, it is washed off the weir indicating that the event took place. The block can be tethered to the weir for retrieval.

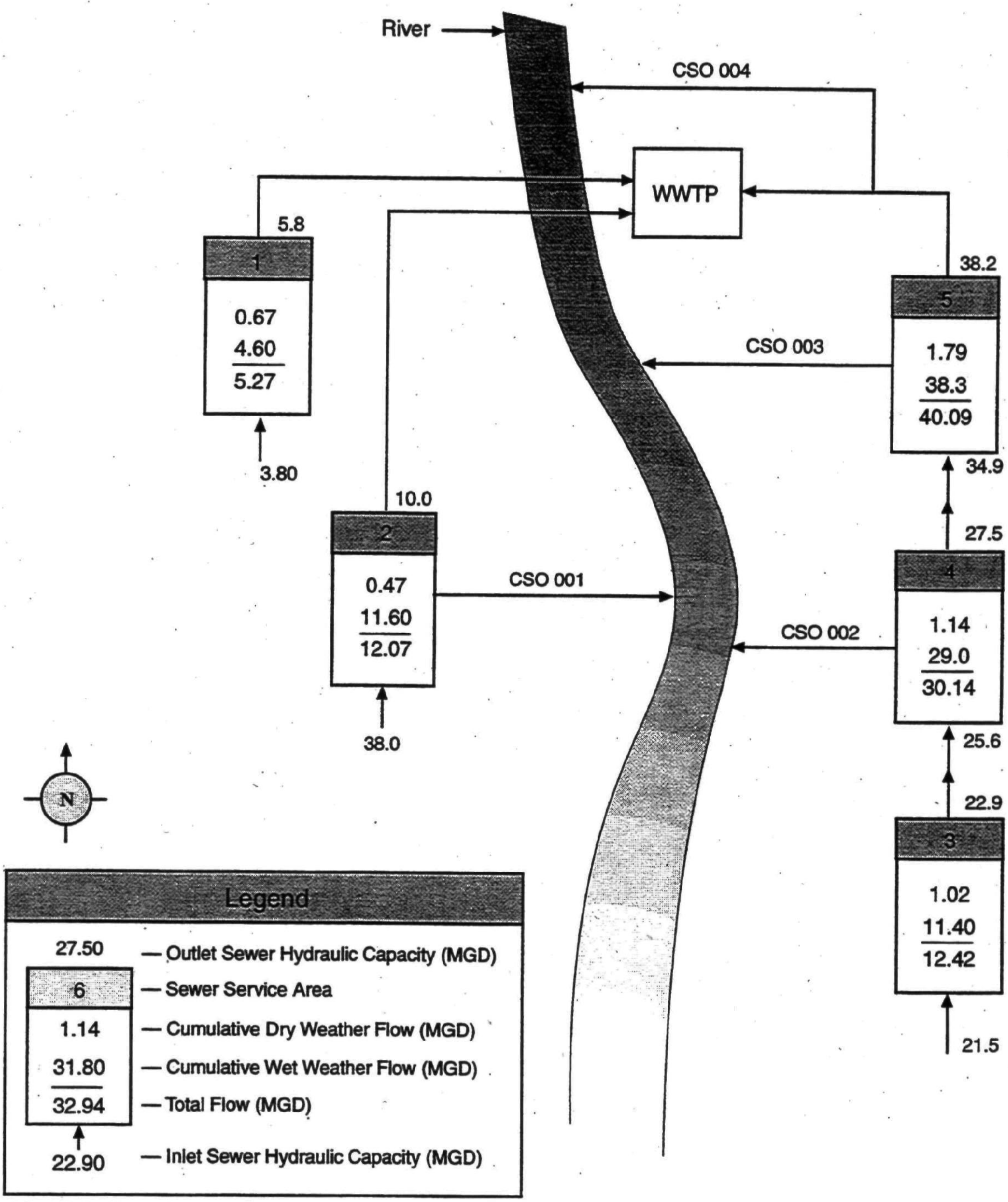
These simple flow measurement techniques could also be considered as NMC measures for monitoring to characterize CSO impacts and the efficacy of CSO controls. The permittee may wish to discuss this with the permitting authority. In some limited cases, automated continuous flow monitoring may be used. These techniques are discussed with other CSS monitoring techniques in Chapter 5.

3.1.4 Preliminary CSS Hydraulic Analysis

The physical characterization of the CSS should include a flow balance, using a schematic diagram of the collection system like that in Exhibit 3-1. The schematic diagram, together with the historical data review and supplemental field study, should enable the permittee to assign typical flows and maximum capacities to various interceptors for non-surcharged flow conditions. Flow capacities can be approximated from sewer maps or calculated from invert elevations. The resulting values provide a preliminary estimate of system flows at peak capacity. Calculations of flow within intercepting devices or flow diversion structures and flow records from the treatment plant help in locating sections of the CSS that limit the overall hydraulic capacity.

> **Note to reviewers:** If you do not think **Exhibit 3-1** is useful, please comment on how it can be improved. If you find another type of diagram more useful, submitting an example with your comments would be helpful.

Exhibit 3-1. Flow Balance Diagram



* Cumulative flows = flows from the service area and service areas upstream in the collection system. Wet weather flow values are for the average of several sampled storm events.

The preliminary hydraulic analysis, together with other physical characterization activities, will be useful in designing the CSS monitoring program. This preliminary analysis can help in determining likely CSO locations, the magnitude of rainfall events that result in CSOs, estimated CSO volumes, and potential control points. Application of a hydraulic model may be useful in conducting the analysis.

3.2 CHARACTERIZATION OF COMBINED SEWAGE AND CSOS

3.2.1 Historical Data Review

As part of the initial system characterization, the permittee should review existing data to determine the pollutant characteristics of combined sewage during both dry and wet weather conditions, and, if possible, CSO pollutant loadings to the receiving water. The purpose of this effort is to identify pollutants of concern in CSOs, their concentrations, and where possible, likely sources of such pollutants. Together, these data will support decisions on what constituents should be monitored and where. This is discussed in detail in Chapter 4.

The POTW's records can provide influent chemical and flow data for both dry weather and wet weather conditions. Such data can be analyzed to address important questions, such as:

- How do the influent volume, loads, and concentrations at the plant change during wet weather?
- What is the average concentration of parameters such as solids and BOD at the plant during wet weather flow?
- Which portions of the CSS are contributing significant pollutant loadings?
- Which pollutants are discharged by industrial users, particularly significant industrial users?

For example, data analysis could include plotting a plant inflow time series by storm and comparing it to a rainfall time series plot for the same storm(s).

Potential sources of information for this analysis include:

- General treatment plant operating data
- POTW discharge monitoring reports (DMRs)
- Treatment plant optimization studies
- Special studies done as part of NPDES permit application
- Pretreatment program data
- Existing wet weather CSS sampling and analyses.

The permittee can potentially use National or Regional storm water data (e.g., NURP data) (U.S. EPA, 1983a) to supplement its available data, although more recent localized data are preferred. If approximate CSS flow volumes are known, approximate CSS pollutant loads can be estimated using POTW data, CSS flow volume, and assumed storm water concentration values. However, assumed constant or event mean concentration values for storm water concentrations should be used with reservation for CSOs since concentrations vary during a storm.

In order to obtain recent and reliable characterization data, the permittee may need to conduct limited sampling at locations within the CSS as well as at CSO outfalls as part of the initial system characterization. Since this limited sampling is usually less cost-effective than sampling done as part of the overall monitoring program, the permittee should fully evaluate the need for data before sampling for the initial characterization. Chapter 5 provides details on CSS monitoring procedures.

3.2.2 Mapping

The permittee should plot existing characterization data for points within the CSS as well as for CSO outfalls on the study map as appropriate. This will enable the permittee to identify areas where no data exist and areas with high concentrations of pollutants.

3.3 CHARACTERIZATION OF RECEIVING WATERS

3.3.1 Historical Data Review

The third part of the initial system characterization is to establish the status of each receiving water body impacted by CSOs. Using existing data and information, the permittee should attempt to answer the following types of questions:

- Does the receiving water body contain sensitive areas (as defined by the CSO Control Policy)?
- What are the applicable WQS and is the receiving water body currently attaining those WQS?
- Are there particular problems in the receiving water body attributable wholly or in part to CSOs?
- What are the hydraulic characteristics of the receiving water body (e.g., average/ maximum flow)?
- What other sources of pollutants in the watershed are discharging to the receiving water body?
- What is the receiving water quality upstream of the CSO outfalls?
- What are the ecologic conditions and aesthetics of the receiving water body?

The following types of receiving water data will help answer these questions:

- Applicable State WQS
- Flow characteristics
- Physiographic and bathymetric data
- Water quality data
- Sediment data
- Fisheries data
- Benthos data
- Biomonitoring results

- Ecologic data (habitat, species diversity).

Permittees may already have collected receiving water data as part of other programs or studies. For example, the NPDES permit may require receiving water sampling upstream and downstream of the treatment plant outfall or the permittee may have performed special receiving water studies as part of its NPDES permit reissuance process. Receiving water data may also be obtained through consultation with the NPDES permitting authority, EPA Regional staff, State WQS personnel, and State watershed personnel, since the Clean Water Act requires States, and EPA (when States fail to do so), to generate and maintain data on certain water bodies within their jurisdictions.

The following reports may provide information useful for characterizing a receiving water body:

- ***Section 303(d) Lists***—Under CWA section 303(d), EPA or delegated States identify and establish total maximum daily loads (TMDLs), for all waters that have not achieved water quality criteria for designated uses even after implementation of technology-based and water quality-based controls.

- ***State 304(l) Lists***—Under CWA section 304(l), EPA or States identified surface waters adversely affected by toxic and conventional pollutants from point and non-point sources, with priority given to those surface waters adversely affected by point sources of toxic pollutants. This one-time effort was completed in 1990.

- ***State 305(b) Reports***—Under CWA section 305(b), States must report biennially on the status of waters of the State with respect to water quality, including designated beneficial uses, aquatic life, and causes/sources of nonattainment.

- ***Section 319 State Assessment Reports***—Under CWA section 319, States were required to identify surface waters adversely affected by nonpoint sources of pollution, in a one time effort following enactment of the 1987 CWA Amendments.

Generally, these information sources may be obtained from EPA or State offices or may be accessed through EPA's Storage and Retrieval of U.S. Waterways Parametric Data (STORET) system, EPA's Water Quality System resident within STORET, or EPA's Water Body System (WBS). Access to EPA mainframe data bases such as STORET and WBS, however, requires user accounts and familiarity with SAS and other data base systems. Further, these data bases might not include the particular water bodies being evaluated. Therefore, the permittee should contact State officials prior to attempting to locate data on specific water bodies.

In addition, studies conducted under special programs and initiatives, enforcement actions, new permitting actions, and for other purposes may provide relevant data on receiving water flow, quality, and uses. EPA and State personnel may also generally be aware of studies conducted by other Federal organizations, such as the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the National Biological Service, and other organizations such as The Nature Conservancy and formalized volunteer groups. Thus, permittees may save considerable time and expense by consulting directly with these entities during the initial system characterization.

The receiving water characterization should also include evaluation of whether CSOs discharge to sensitive areas, which are a high priority for CSO elimination or control under the CSO Control Policy. The long-term CSO control plan should prohibit new or significantly increased overflows to sensitive areas and eliminate or relocate such overflows wherever physically possible and economically achievable. (This is discussed in more detail in *Combined Sewer Overflows – Guidance for Long-Term Control Plan*, EPA, 1995a). Therefore, the permittee should work with the NPDES permitting authority, the U.S. Fish and Wildlife Service, and relevant State agencies to determine whether particular receiving water segments may be considered sensitive under the CSO Control Policy.

In addition to reviewing existing data, the permittee may wish to conduct an observational study of the receiving water body, noting differences in depth or width, tributaries, circulation (for estuaries), point sources, suspected nonpoint sources, plant growth, and other noticeable features. This information can be used later to define segments for a receiving water model.

To supplement the observational study, the permittee may consider limited chemical or biological sampling of the receiving water. Biocriteria or indices may be used in States such as Ohio that have systems in place. Biocriteria describe the biological integrity of aquatic communities in unimpaired waters for a particular designated aquatic life use. Biocriteria can be numerical values or narrative conditions and serve as a reference point since biological communities in the unimpaired waters represent the best attainable conditions (U.S. EPA, 1991a).

3.3.2 Mapping

The permittee should include existing receiving water characterization data on the study map as appropriate. This will permit visual identification of areas for which no data exist, potential areas of concern, and potential monitoring locations. GIS mapping can be used as an aid in this process. The map could include the following:

- WQS classifications for receiving waters at discharge locations and for upstream and downstream reaches

- Location of sensitive areas such as contact recreation, drinking water intakes, endangered species habitats, sensitive biological populations or habitats

- Locations of structures, such as weirs and dams, that can affect pollutant concentrations in the receiving water

- Locations of access points, such as bridges, that make convenient sampling sites.

3.4 IDENTIFY DATA GAPS

The final task of the initial system characterization consists of identifying gaps in information and data that are essential to a basic understanding of the CSS response to rain events and the impact of CSOs on the receiving water. The following questions may help to identify data gaps that need to be addressed in the monitoring and modeling plan:

CSS Physical Characterization

- Have all CSO outfalls been identified?

- Are the drainage sub-areas delineated for each CSO outfall?

- Is sufficient information on the location, size, and characteristics of the sewers available to support more complex analysis, including hydraulic modeling?

- Is sufficient information on the location, operation, and condition of regulating structures available to construct at least a basic hydraulic simulation? (Even if a hydraulic computer model is not used, this level of knowledge is critical to understanding how the system works and for implementing the NMC.)

- Are the amount of rainfall and rainfall intensity that cause CSOs at various outfalls known?

- Are areas of surcharging in the CSS known?

- Have potential monitoring locations in the CSS been identified?

- Are there differences between POTW wet weather and dry weather operations? If so, are these clearly understood? (Enhanced POTW wet weather operation can improve capture of CSS flows significantly.)

CSS Characterization

- Are the flow and quality of CSOs known?

- Are sources of pollutant loadings known?

- Is sufficient information available on the pollutant loadings of CSOs and other sources to support an evaluation of long-term CSO control alternatives?

Receiving Water Body Characterization

- Are the hydraulic characteristics of receiving waters known, such as the average/ maximum flow of rivers and streams or the freshwater component, circulation patterns, and mixing characteristics of estuaries?

- Are locations of sensitive areas and the use classifications (e.g., A, B, SA, SB) identified on a study map?

- Have existing monitoring locations in the receiving water been identified? Have potential monitoring locations (e.g., safe, accessible points) in the receiving water been identified for areas of concern and areas where no data exist?

- Are sufficient data available to assess existing water quality problems including:

  - Erosion
  - Sediment accumulation
  - Dissolved oxygen levels
  - Bacterial problems, such as those leading to beach closures

  - Nuisance algal or aquatic plant growths
  - Damage to a fishery (e.g., shellfish beds)
  - Damage to a biological community (e.g., benthic organisms)?

- Is sufficient information available on natural background conditions that may preclude the attainment of WQS? (For example, a stream segment with a high natural organic load may have a naturally low dissolved oxygen level.)

- Is sufficient information available on other pollutant sources that may preclude the attainment of WQS?

The answers to these types of questions will support the development of goals and objectives for the monitoring plan, as described in Chapter 4.

CHAPTER 4

MONITORING AND MODELING PLAN

The CSO Control Policy specifies that permittees should immediately begin a process of characterizing their CSS, demonstrating implementation of the nine minimum controls (NMC), and developing a long-term control plan (LTCP). The NMC and the LTCP both contain elements that involve monitoring and modeling activities. The NMC include monitoring to characterize CSO impacts and the efficacy of CSO controls, while the LTCP includes elements for characterization, monitoring, and modeling of the CSS and receiving waters, evaluation and selection of CSO control alternatives, and development of a post-construction monitoring program. As discussed in Chapters 2 and 3, "monitoring" as part of the NMC involves gathering and analyzing existing data and performing field investigations, but does not generally involve sample collection and analysis or the use of complex models. Thus, the monitoring and modeling elements discussed in this chapter and subsequent chapters primarily pertain to LTCP development and implementation.

Monitoring requirements associated with LTCP development and implementation will likely be incorporated into the NPDES permit. In many cases, the permit will first require the permittee to submit a monitoring and modeling plan before conducting monitoring and modeling activities. For example, the Phase I permit may require submission of a monitoring and modeling plan as an interim deliverable during LTCP development.

For many reasons, accurate monitoring data and modeling results are important factors in making CSO control decisions. A well-developed monitoring and modeling plan is essential throughout the CSO planning process to provide useful monitoring data for system characterization, evaluation and selection of control alternatives, and post-construction compliance monitoring. Development of the plan is likely to be an iterative process, with changes made as more knowledge about the CSS and CSOs is gained. The NPDES permitting authority and the rest of the CSO planning team (i.e., State WQS personnel, State watershed personnel and EPA Regional staff) should be involved throughout this process.

This chapter describes how the permittee can develop a monitoring and modeling plan that will provide essential and accurate information about the CSS and CSOs, and the impact of CSOs on the receiving water. The chapter discusses the identification of monitoring and modeling goals and objectives and the development of a monitoring and modeling plan to ensure that those goals and objectives are met. It provides detailed discussions and examples on identifying sampling locations, frequencies, and parameters to be assessed in the CSS, CSOs, and receiving water body. In addition, it briefly discusses certain monitoring and modeling plan elements that are common to all system components being monitored. Readers should consult the appropriate EPA guidance documents (see References) for further information on monitoring topics such as chain-of-custody, sample handling, equipment, resources, and quality assurance/quality control (QA/QC) procedures.

4.1 DEVELOPMENT OF A MONITORING AND MODELING PLAN

A monitoring and modeling plan can be developed with the following steps:

Step 1: Define the short- and long-term objectives — In order to identify appropriate model inputs and facilitate well-informed decisions on CSO controls, the permittee should first formulate the short- and long-term objectives of the monitoring and modeling effort. Every activity proposed in the plan should contribute to attaining those objectives. (Section 4.1.1)

Step 2: Determine whether to use a model — The permittee should decide whether to use a model during LTCP development (and, if so, which model might be appropriate). This decision should be based on site-specific considerations (e.g., CSS characteristics and complexity, type of receiving water) and the information compiled in the initial system characterization. If a permittee decides to use a model, a modeling strategy should be developed. (Section 4.1.2)

Step 3: Identify data needed — The next step in plan development is to identify the monitoring data that are needed to meet the goals and objectives. If modeling is planned, the monitoring plan should include any additional data needed for model inputs. (Section 4.1.3)

Step 4: Identify sampling criteria (e.g., locations, frequency) — The permittee needs to evaluate and select monitoring locations within the CSS (flow monitoring and chemical analyses), CSOs (flow monitoring, chemical analyses, and potentially whole effluent toxicity testing), as well as points within the receiving water body (chemical and, potentially, biological and sediment monitoring). The permittee should also identify the frequency and duration of sampling, parameters to be sampled, sample types to be collected (e.g., grab, composite), and sample handling and preservation procedures. If modeling will be done, the monitoring plan should include any additional sampling locations, sample types, and parameters necessary to use the proposed model. If this is not feasible, the permittee may need to reevaluate the model choice and select a different or less-complex model. (Sections 4.2 to 4.6)

Step 5: Develop data management and analysis procedures — A monitoring and modeling plan also needs to specify QA/QC procedures to ensure that the collected data are reliable and a data management program to facilitate storage, use, and analysis of the data. (Section 4.7)

Step 6: Address implementation issues — Finally, the monitoring and modeling plan should address implementation issues, such as record keeping and reporting, responsible personnel, scheduling, and the equipment and resources necessary to accomplish the monitoring and modeling. (Section 4.8)

These steps are described in detail in the remainder of this chapter.

4.1.1 Goals and Objectives

The ultimate goal of a CSO control program is to implement the most cost-effective controls to reduce water quality impacts from CSOs. Monitoring and modeling will foster attainment of this goal by generating data to support decisions for selecting CSO controls. The monitoring and modeling plan should identify how data will be collected and used to meet the following goals:

- Define the CSS's hydraulic response to rainfall.
  - What level of rainfall causes CSOs?
  - Where do the CSOs occur?
  - How long do CSOs last?
  - Which structures or facilities limit the hydraulic capacity of the CSS?

- Determine CSO flows and pollutant concentrations/loadings.
  - What volume of flow is discharged?
  - What pollutants are discharged?
  - Do the flows and concentrations of pollutants vary greatly from event to event and outfall to outfall?
  - How do pollutant concentrations and loadings vary within a storm event?

- Evaluate the impacts of CSOs on receiving water quality.
  - What is the baseline quality of the receiving water?
  - What are the upstream background pollutant concentrations?
  - What are the impacts of CSOs? Are applicable WQS being met?
  - What is the contribution of pollutant loadings from other sources?
  - Is biological, sediment, or whole effluent toxicity testing necessary?

- Support model input, calibration, and verification.

- Support the review and revision, as appropriate, of WQS.
  - What data are needed to support potential revision of WQS to reflect wet weather conditions?
  - What data are needed to support a use attainability analysis?

- Support implementation and documentation of the NMC.
  - Are there dry weather overflows?
  - How can available storage in the system be maximized?
  - How can flow to the POTW be maximized?
  - How can system problem areas and bottle necks be relieved?

- Evaluate the effectiveness of the NMC.

- Evaluate and select long-term CSO control alternatives.
  - What improvements in water quality will result from proposed CSO control alternatives in the LTCP?
  - How will the CSS hydraulics and CSOs change under various control alternatives?

- How can CSO flows be relocated to less sensitive areas?

In addition to selecting and implementing long-term CSO controls, the permittee will also be required to develop and implement a post-construction compliance monitoring program. For this type of monitoring program, the goal will typically be to:

- Evaluate the effectiveness of the long-term CSO controls.
  - Are applicable WQS being met?
  - How much water quality improvement do environmental indicators show?

Besides the broad goals, a municipality may have some site-specific objectives for its monitoring program. For example, when monitoring to define the CSS's hydraulic response to rainfall, the permittee may wish to determine whether portions of the trunk lines are under-sized and whether specific portions of the combined sewer trunk lines can provide in-line storage.

4.1.2 Modeling Strategy

In developing a monitoring and modeling plan, the permittee should consider up front whether to use modeling. Modeling aids in characterizing and predicting:

- Sewer system response to storm events,
- Pollutant loading to receiving waters, and
- Impacts within the receiving waters.

Modeling also assists in formulating and testing the cause-effect relationships between storm events and receiving water impacts. This knowledge can help the permittee evaluate control alternatives and formulate an acceptable LTCP. Through the use of modeling, the permittee has a tool for predicting the effectiveness of a range of potential control alternatives. By assessing the expected outcomes of control alternatives before their implementation, the permittee can make decisions more cost efficiently. Modeling results may also be relevant to potential revisions of State WQS. The use of a model and its level of complexity affect the need for monitoring data. Thus, early in the development of a monitoring and modeling plan, the permittee should determine if modeling is needed to provide sufficient information for making CSO control decisions.

Once the model is calibrated and verified, it can be used for the following activities:

- To predict overflow occurrence, volume, and in some cases, quality, for rain events other than those which occurred during the monitoring phase. These can include a storm event of large magnitude (with a long recurrence period) or numerous storm events over an extended period of time.

- To predict the performance of portions of the CSS that have not been monitored extensively.

- To develop CSO statistics such as annual number of overflows and percent of combined sewage captured (particularly useful for municipalities pursuing the presumption approach under the CSO Control Policy).

- To optimize the sewer system performance as part of the nine minimum controls (NMC). In particular, modeling can assist in locating storage opportunities and hydraulic bottlenecks and demonstrate that system storage and flow to the POTW are maximized.

- To evaluate and optimize control alternatives, from simple controls described under the NMC (e.g., raising weir heights to increase in-line storage), to more complex controls proposed in a municipality's LTCP. The model can be used to evaluate the resulting reductions in CSO volume and frequency.

If the permittee decides to perform modeling, a modeling strategy should be developed. There are several considerations in developing an appropriate modeling strategy:

- ***Meeting the expectations of the CSO Policy***—Models should adequately meet the needs of the presumption or demonstration approach chosen by the permittee, in conjunction with the NPDES permitting authority, in LTCP development. The focus of modeling depends in part on which approach the permittee adopts. The demonstration approach can necessitate detailed simulation of receiving water impacts to show that CWA requirements will be met under selected CSO control measures. The presumption approach may involve less emphasis on receiving water modeling since it presumes that CWA requirements are met based on certain performance criteria, such as the maximum number of CSO events.

- ***Successfully simulating the physical characteristics of the CSS, pollutants, and receiving waters under study***—Models should be chosen to simulate the physical and hydraulic characteristics of the sewer system and the receiving water body, chemical and biological characteristics of the pollutants of concern, and the time and distance scales necessary to evaluate attainment of WQS. A model's governing equations and boundary conditions should match the characteristics of the water body, the pollutants of concern, and the pollutant fate and transport processes under study. A model does not necessarily need to describe the system completely in order to analyze CSO events satisfactorily. Different modeling strategies will be necessary for the different physical domains being modeled: overland storm flow, pollutant buildup/washoff, and transport to the collection system; transport within the CSS to POTW, storage or overflow; and dilution and transport in receiving waters. In most cases, simulation models appropriate for the sewer system also address pollutant buildup/washoff and overland flow. Receiving water models are typically separate from the storm water/ sewer models, although in some cases compatible interfaces are available.

- ***Meeting information needs at optimal cost***—The modeling strategy should provide answers as detailed and accurate as needed at the lowest corresponding expense and effort. Since more detailed, accurate models require greater expense and effort to use, the permittee needs to identify the point at which an increased modeling effort would provide diminishing returns. The permittee may use an incremental approach, in which simple screening models are used with initial, and usually limited, data. These results may then lead to refinements in the monitoring and modeling plan so that the appropriate data are generated for more detailed modeling.

More detailed discussions on modeling, including model selection, development, and application, are included in Chapters 7 (CSS Modeling) and 8 (Receiving Water Modeling).

4.1.3 Monitoring Data Needs

The monitoring effort necessary to address each of the identified goals will depend on a number of factors: the layout of the collection system; the quantity, quality, and variability of existing historical data; the quantity, quality, and variability of the necessary additional data; whether modeling will be done and the complexity of the model; and the available budget. In some cases, the initial characterization will yield sufficient historical data so that only limited additional monitoring will be necessary. In other cases, considerable effort may be necessary to fully investigate the characteristics of the CSS, CSOs, and receiving water. Some municipalities may choose to allocate a relatively large portion of the available budget to monitoring, while others may allocate a smaller portion. Because decisions on data needs may change as additional knowledge is obtained, the monitoring program must be a dynamic program that changes to reflect any changes in data needs.

In identifying goals and objectives, a modeling strategy, and monitoring data needs, the permittee should work with the team that will be reviewing NMC implementation and LTCP development and implementation (e.g., NPDES permitting authorities, State WQS authorities, and State watershed personnel). This coordination should begin in the initial planning stages so that appropriate goals and objectives are identified and effective monitoring and modeling approaches to meet these goals and objectives are developed. Concurrence among the review team participants during the planning stages should ensure design of a monitoring and modeling plan that is able to support sound CSO control program decisions. The proposed monitoring and modeling plan should be submitted to the review team and modified according to reviewer comments. The permittee should also coordinate the monitoring and modeling plan with other Federal and State agencies, and with other point source dischargers, especially for effects on watersheds and ambient receiving waters.

4.2 ELEMENTS OF A MONITORING AND MODELING PLAN

In addition to identifying the goals and objectives, monitoring and modeling plans should generally contain the following major elements:

- Review of Existing Data and Information (discussed in detail in Chapter 3)

  - Summary of existing data and information
  - Determination of how existing data address goals and objectives
  - Identification of data needs

- Development of Sampling Program to Address Data Needs (discussed in detail in Chapters 5 and 6)

  - Duration of monitoring program
  - Monitoring locations
  - Frequency of sampling and/or number of precipitation events to be sampled
  - Criteria for when the samples will be taken (e.g., greater than x days between precipitation events, rainfall events greater than 0.4 inches to be sampled)
  - Sampling protocols (e.g., sample types, sample containers, preservation methods)

  - Flow measurement protocols
  - Pollutants or parameters to be analyzed and/or recorded
  - Sampling and safety equipment and personnel
  - QA/QC procedures for sampling and analysis

- Discussion of Methods for Data Management and Analyses

  - Data management (e.g., type of data base)
  - Statistical methods for data analysis
  - Modeling strategy, including model(s) selected (discussed in detail in Chapters 7 and 8)
  - Use of data to support NMC implementation and LTCP development

- Implementation Plan

  - Recordkeeping and reporting
  - Personnel responsible for implementation
  - Scheduling
  - Resources (funding, personnel and equipment)
  - Health and safety issues.

The checklists in Appendix A Tables A-1 and A-2 list items that should be addressed in formulating a monitoring program. Elements in the first checklist should be part of any monitoring program and cover seven major areas: sample and field data collection, laboratory analysis, data management, data analysis, reporting, information use, and general. The second checklist applies specifically to CSO monitoring and covers three areas: mapping of the CSS and identification of monitoring locations, monitoring of CSO quantity, and monitoring of CSO quality.

Because each permittee's CSS, CSOs, and receiving water body are unique, it is not possible to recommend a generic, "one-size-fits-all" monitoring and modeling plan in this document. Rather, each permittee should design a cost-effective monitoring and modeling plan tailored to local conditions and reflecting the size of the CSS, the impacts of CSOs, and whether modeling will be performed. It should balance the costs of monitoring against the amount of data and information needed to develop, implement, and verify the effectiveness of CSO controls.

While the monitoring budget may appear large, it is often a small percentage of the total cost of controlling CSOs. Each municipality should balance the cost of monitoring against the risk of developing CSO controls based on insufficient or inaccurate data. By using the information obtained through additional monitoring or modeling, some municipalities have achieved a larger reduction in total CSO control costs than the costs for the additional monitoring or modeling.

4.2.1 Duration of Monitoring Program

The duration of the monitoring program will vary from location to location and reflect the number of storm events needed to provide the data for calibrating and validating the CSS hydraulic model (if a model is used), and evaluating CSO control alternatives and receiving water impacts. During that period (which generally may be a season or several months), storms of varying intensity, antecedent dry days, and total volume should be monitored to ensure that calculations and models represent the range of conditions experienced by the CSS.

The monitoring program should span enough storm events to develop a full understanding of pollutant loads from CSOs, including the means and variations of pollutant concentrations and the resulting effects on receiving water quality. If only a few storm events are monitored, the analysis should include appropriately conservative assumptions because of the uncertainty associated with small sample sizes. For example, if monitoring data are collected from a few storms during spring, when CSOs are generally larger and more frequent, mean pollutant concentrations may be lower due to flow dilution and diminished first flush effects. When monitoring data are collected for additional storms, including those in the summer and fall when CSOs are less frequent, the mean pollution concentrations may increase significantly. Additional samples should reduce the level of uncertainty, and allow the use of a smaller margin of safety in the analysis.

The value of additional monitoring diminishes when additional data would result in a limited change in the estimated mean and variance of a data set. The permittee should assess the value of additional data as they are collected by reviewing the change in the estimated mean and variance of contaminant concentrations. If estimated values stabilize, the need for additional data should be reassessed.

Pollutant loadings vary according to the number of days since the last storm and the intensity of previous rainfalls. Therefore, to better represent the variability of actual conditions, the monitoring program should be designed to sample storms with a variety of pre-storm conditions.

4.2.2 Sampling Protocols and Analytical Methods

The monitoring and modeling plan should describe the sampling and analytical procedures that will be used. Sample types depend on the parameter, site conditions, and the intended use of the data. Flow-weighted composites may be most appropriate for determining average loadings of pollutants to the receiving stream. Grab samples may suffice if only approximate levels of pollutants are needed or if worst-case conditions (e.g., first 15 or 30 minutes of overflow) are being assessed. In addition, grab samples should be collected for pollutant parameters that cannot be composited, such as oil and grease, pH, and bacteria. The monitoring plan should follow the sampling and analytical procedures in 40 CFR Part 136, including the use of appropriate sample containers, sample preservation methods, maximum allowable holding times, and analytical methods referencing one or more of the following:

- Test methods in Appendix A to 40 CFR Part 136 (Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater)

- Standard Methods for the Analysis of Water and Wastewater (use the most current, EPA-approved edition)

- Methods for the Chemical Analysis of Water and Wastes (EPA, 1979. EPA-600/ 4-79-020).

In some cases, other well-documented analytical protocols may be more appropriate for assessing in-stream parameters. For example, in estuarine areas, a protocol from NOAA's Status and Trends Program may provide better accuracy and precision if it reduces saltwater interferences.

For details on sampling or analysis of specific parameters, the permittee should refer to these publications. In addition, these issues are discussed in further detail in Section 5.4.1.

4.3 CSS AND CSO MONITORING

To satisfy the objectives of the CSO Control Policy, the monitoring and modeling plan should specify how the CSS and CSOs will be monitored, detailing monitoring locations, frequencies, and pollutant parameters. The plan should be coordinated with other concurrent sampling efforts (e.g., ongoing State water quality monitoring programs) to reduce sampling and monitoring costs and maximize use of available resources.

4.3.1 CSS and CSO Monitoring Locations

The monitoring and modeling plan should specify how rainfall data, flow data, and pollutant data will be collected to define the CSS's hydraulic response to rainfall and to measure CSO flows and pollutant loadings. The monitoring program should also provide background data on conditions in the CSS during dry weather conditions, if this information is not already available (see Chapter 3). Dry weather monitoring of the CSS may help identify pollutants of concern in CSOs during wet weather.

Rainfall Gage Locations

The permittee should ascertain whether additional rainfall data are necessary to supplement existing data. If so, the monitoring and modeling plan should identify where rain gages will be placed to provide data representative of the entire CSS drainage area. Gages should be spaced closely enough that location variation in storm tracking and storm intensity does not result in large errors in estimation of the rainfall within the CSS area. Recommended spacing is the subject of a variety of research papers. The *CSO Pollution Abatement Manual of Practice* (WPCF, 1989) provides the following summary of recommendations on rain gage spacing:

> *"In Canada, rainfall and collection system modelers recommend one gauge every 1 or 2 kilometers. In Britain, the Water Research Center has recommended only half that density, or one gauge every 2 to 5 kilometers. In the United States current spacing recommendations are related to thunderstorm size. The average thunderstorm is 6 to 8 kilometers in diameter...Therefore rain gauges are frequently spaced every 6 to 8 kilometers..."*

For small watersheds, rain gages may need to be placed more closely than every 6 to 8 kilometers so that sufficient data are available for analysis and calibration of any models that may be used. The monitoring and modeling plan should document the rationale for rain gage spacing.

CSS Monitoring Locations

The monitoring and modeling plan will need to identify locations within the collection system where flow and pollutant loading data will be collected. To predict the likelihood and locations of CSOs during wet weather, it is necessary to assess general flow patterns and volume in the CSS and which structures tend to limit the hydraulic capacity. This may require sampling along various trunk lines of the collection system. Flow data from existing monitors and at hydraulic controls such as pump stations and POTW headworks can also be used.

To obtain complete flow and pollutant loading data, the plan should also target portions of the collection system that are likely to receive significant pollutant loadings. The plan should identify locations where industrial users discharge into the collection system, and specify any additional monitoring that will be conducted to supplement data collected through the pretreatment program. Special consideration should be given to these areas if they are located near CSOs. See Section 4.3.3 for a discussion of the types of pollutants to be monitored.

CSO Monitoring Locations

The monitoring and modeling plan should provide for collection of flow and pollutant concentration information at as many CSO locations as possible. Small systems may be able to monitor all outfalls for each storm event studied. Others may require a tiered approach, in which only outfalls with higher flows or pollutant loadings, or discharges to sensitive areas, would warrant continuous depth and velocity flow monitoring and the use of composite samples for chemical analyses. Lower-priority outfalls, meanwhile, would be monitored with simpler techniques such as visual observation, block tests, depth measurement, overflow timers, or chalk boards (discussed in section 3.1.3) and limited chemical analyses. When multiple outfalls are located along the same interceptor, flow monitoring of selected outfalls and at one or two locations in the interceptor should suffice.

Even if a monitoring program accounts for most of the total land area or estimated runoff, monitoring other outfall locations, even with simple techniques, can provide information about problem areas. For example, at an overflow point with only 10 percent of the contributing drainage area, a malfunctioning regulator may result in discharges during dry weather or during small storms when the interceptor has remaining capacity. As a result, this overflow point may become a major contributor of flows. A simple technique such as a block test could identify this problem.

Alternatively, flow measurement equipment can be rotated between locations so that some locations are monitored for a subset of the storms studied. For example, during one storm critical outfalls could be monitored with automated flow monitoring equipment, two less-important outfalls could be monitored with portable flow meters, and the rest could be monitored using chalk boards. During a second storm, the critical outfalls could still be monitored with automated flow equipment, but the portable flow meters could be rotated to two other outfalls of secondary importance.

If it is not feasible to monitor all outfalls, the permittee should identify a specific percentage of the outfalls to be monitored based on the size of the collection system, the total number of outfalls, the number of different receiving water bodies, and potential and known impacts. The selected locations should represent the system as a whole or represent the worst-case scenario (for example, where overflows occur most frequently, have the largest pollutant loading or flow volume, or discharge to sensitive areas).

In general, monitoring locations should be distributed to achieve optimal coverage of actual overflows with a minimum number of stations. The initial system characterization should have already provided information useful in selecting and prioritizing monitoring locations, such as:

- *Drainage Area Flow Contribution*—The relative flow contributions from different drainage areas can be used to prioritize flow monitoring and chemical analysis efforts. There are several methods for estimating relative flow contributions. The land area of each outfall's sub-basin provides only an approximate estimate of the relative flow contribution because regulator operation and land use characteristics affect overflow volume. Other estimation methods, such as the rational method, account for the runoff characteristics of the upstream land area and produce relative peak flows of individual drainage areas. Flow estimation using Manning's equation (see Section 5.3.1) may produce a better estimate of the relative flow contribution by the drainage area.

- *Upstream Land Use*—During the initial sampling effort, the permittee should estimate the relative contribution of pollutant loadings from individual drainage areas. Maps developed during the initial system characterization should provide land use information that can be used to derive pollutant concentrations for the different land uses from localized data bases (based on measurements in the CSS). If local data are not available, the permittee may use regional land-use based National Urban Runoff Program (NURP) studies, although NURP data reflect only storm water and must be adjusted for the presence of sanitary sewage flows. Pollutant concentration and drainage area flow data can then be used to estimate loadings. Since pollutant concentrations can vary greatly for different land uses, monitoring locations should represent subdivisions of the drainage area which have differing land uses.

- *Location of Sensitive Areas*—Since the permittee's LTCP should give the highest priority to controlling overflows to sensitive areas, the monitoring and modeling plan should identify locations where CSOs to sensitive areas, and their impacts, will be monitored.

- *Feasibility and Safety of Using the Location*—After using the criteria above to identify which outfalls will provide the most appropriate data, the permittee should determine whether the locations are safe and accessible and identify which safety precautions are necessary. If it is not feasible or practical to monitor at the point of discharge, the permittee should select the closest downstream location that is still representative of the overflow.

Example 4-1 illustrates one approach to selecting discharge monitoring sites for a hypothetical CSS with ten outfalls. The selected outfalls—1, 4, 5, 7, and 9—discharge flow from approximately 60 percent of the total drainage area and 80 percent of the industrial area. In

1 **Example 4-1. One Approach to Selecting Discharge Monitoring Sites for a Hypothetical CSS with 10 Outfalls**

A municipality has a combined sewer area with 4,800 acres and 10 individual outfalls discharging into a large river. Exhibit 4-1 shows the characteristics of the discharge points that are potentially useful in choosing which intercepting devices to monitor. Investigators used sewer and topographic maps to determine the size of the drainage areas. Aerial photographs and information from a previous study indicated land use. Sewer maps, spot checked in the field, verified the type of regulating structure. Both the sewer map and discussions with CSS personnel provided information about safety and ease of access.

Outfalls 7 and 9 account for 33 percent of the total drainage area, and outfall 7 provides data on commercial and industrial land uses that may have relatively higher pollutant loadings. These sites pose no safety/accessibility concerns, making them desirable sampling locations.

Outfall 5 discharges in an area that is predominantly residential and includes one of the largest parks in the municipality. This park has many recreational uses, including swimming during the warmer months. Since areas used for primary contact recreation are considered sensitive areas, they are given highest priority in the permittee's LTCP under the CSO Control Policy. This outfall, which accounts for about 10 percent of the drainage area, should be monitored.

Outfall 4, which is served by a pump station, accounts for an additional 8 percent of the discharge area and includes commercial areas. A counter or timer on the pump contacts or the use of full pipe flow measurement devices usually provide an accurate measure of flow at this outfall.

Outfall 1 discharges near the north edge of town, just before the river curves at its entrance to the municipality. This outfall is located near a portion of the river that serves as a threatened species habitat and therefore is considered a sensitive area. Since sensitive areas should be given the highest priority, this outfall will be monitored. Monitoring this outfall also accounts for 13 percent of the total drainage area and a significant portion of the area with commercial land uses.

In total, these five outfalls account for approximately 64 percent of the drainage area and more than 80 percent of the industrial land use.

The remaining sites pose practical problems for monitoring. Outfall 3 is difficult to access and poses safety concerns. Outfalls 2, 6, 8, and 10 all have backwater effects, and access/safety concerns further limit monitoring opportunities.

- *Outfall 2*—Backwater effects, difficult access rating and safety concerns.
- *Outfall 3*—Residential drainage area similar to Outfall 5, but difficult access rating and safety concerns.
- *Outfall 6*—Large residential drainage area (17 percent of total) but backwater effects and access/safety concerns limit monitoring opportunities.
- *Outfall 8*—Drainage area small, but includes industrial and commercial land uses. Backwater effects and access/safety concerns limit monitoring opportunities.
- *Outfall 10*—Backwater and difficult access limit monitoring opportunities.

Exhibit 4-1. Data for Example 4-1

Outfall #	Drainage Area (acres)	Land Use: Residential %	Land Use: Industrial %	Land Use: Commercial %	Land Use: Open/Park %	Flow Regulation Device: Weir Gravity	Flow Regulation Device: Weir Backflow	Flow Regulation Device: Orifice Backwater	Flow Regulation Device: Pump Station	Access/ Safety	Sensitive Area	Potential Monitoring Location
1	695	80		20		✓					✓	Possible
2	150	50	20	30				✓		✓		No
3	560	75		5	20	✓						Possible
4	430	60	10	30					✓			Yes
5	500	90			10	✓						Possible
6	800	90		10			✓			✓		No
7	690	20	60	20		✓						Yes
8	120	40	50	10			✓			✓		No
9	1,060	80			20	✓						Yes
10	300	90			10			✓		✓		No
Total	5,305	71%	11%	10%	8%							

addition, outfalls 1 and 5 are adjacent to sensitive areas. Consequently, these five outfalls should provide sufficient in-depth coverage for the city's monitoring program. Using simplified flow and modeling techniques at outfalls 2, 3, 6, 8, and 10 can supplement the collected monitoring data and allow estimation of total system flow.

For additional guidance in prioritizing monitoring locations, permittees can consult *Combined Sewer Overflows – Guidance for Screening and Ranking* (EPA, 1995c). Although generally intended for ranking CSSs with respect to one another, the techniques in this reference may prove useful for ranking outfalls within a single system.

4.3.2 Monitoring Frequency

The permittee should monitor a sufficient number of storms to accurately predict the CSS's response to rainfall events and the characteristics of resulting CSOs. The frequency of monitoring should be based on site-specific considerations such as the overflow frequency and duration, which depend on the rainfall pattern, antecedent dry period, type of receiving water and circulation pattern or flow, ambient tide or stage of river or stream, and diurnal flow to the treatment plant. Monitoring frequency may be targeted to such factors as:

- A certain size precipitation event (e.g., 3-month, 24-hour)
- Precipitation events that result in overflows, or
- A certain number of precipitation events (e.g., monitor until five storms of a certain minimum size are sampled).

Overall, the monitoring and modeling plan should usually provide for more frequent monitoring where:

- Facilities discharge to sensitive or high-quality areas, such as waters with drinking water intakes or swimming, boating, and other recreational activities
- CSO flow volumes vary significantly from storm event to storm event.

The number of samples collected will also reflect the type of sample collected. Where possible, flow-weighted composite samples should be collected to determine the average pollutant concentration over a storm event (also known as the event mean concentration or EMC). This approach decreases the analytical cost of a program based on discrete samples. Certain parameters, such as oil and grease and bacteria, however, need to be collected by grab sample. Additionally, when the permittee needs to determine whether a pattern of pollutant concentration, such as a first-flush phenomenon, occurs during storms, the monitoring program should collect multiple samples from locations throughout a storm.

Because the pollutant loads in CSOs, the sensitivity of the receiving water to which they discharge, and the resources of permittees vary significantly, this manual does not recommend a minimum number of samples or suggest a specific expenditure level for sample collection. The permittee should carefully consider the tradeoffs involved in committing resources to a sampling program. A small number of samples may necessitate overly conservative assumptions because of high sample variability, while a larger data set might better determine pollutant concentrations and result in a more detailed analysis, enabling the permittee to optimize any investment in long-term CSO controls. On the other hand, a permittee should avoid spending large sums of money on monitoring when the additional data will not significantly enhance the permittee's understanding of CSOs and their impacts. The permittee should work closely with the NPDES permitting authority and the review team to design a monitoring program that will adequately characterize the CSS, CSO impacts on the receiving water body, and effectiveness of proposed CSO control alternatives.

4.3.3 Combined Sewage and CSO Pollutant Parameters

Chemical analyses provide information about the concentrations of pollutants carried in the combined sewage and the variability of these concentrations from outfall to outfall and storm to storm. Chemical analysis data should be used with flow data to compute pollutant loadings to receiving waters. In some cases chemical analysis data can also be used to detect the sources of pollutants in the system.

The monitoring and modeling plan should identify which parameters will be monitored. These should include pollutants with water quality criteria for the specific designated use(s) of the receiving water and pollutants key to the attainment of the designated water use(s). The NPDES permitting authority may have specific guidance regarding parameters for CSO monitoring. Parameters of concern may include:

- Indicator bacteria
- Total suspended solids (TSS)
- Biochemical oxygen demand (BOD) and dissolved oxygen (DO)
- pH
- Settleable solids
- Nutrients
- Toxic pollutants reasonably expected to be present in the CSO based on an industrial survey or tributary land use, including metals.

The monitoring and modeling plan should also include monitoring for any other pollutants for which water quality criteria are being exceeded, as well as pollutants suspected to be present in the combined sewage and those discharged in significant quantities by industrial users. For example, if the water quality criterion for zinc is being exceeded in the receiving water, zinc monitoring should be conducted in the portions of the CSS where significant industrial users discharge zinc to the collection system. POTW monitoring data and pretreatment program data on nondomestic discharges can help identify other pollutants that should be monitored. In coastal systems, measurements of sodium, chloride, total dissolved solids, or conductivity can be used to detect the presence of sea water in the CSS, which can occur because of intrusion through failed tide gates.

Not all pollutants need to be analyzed for each location sampled. For example:

- A larger list of pollutants should be analyzed for an industrial area suspected to have contaminated storm water or a large load of pollutants in its sanitary sewer.

- Bacteria should be analyzed in a CSO upstream of a beach with past bacteriological problems.

The permittee should also ensure that monitored parameters correspond to the downstream problem as well as the water quality criteria that apply in the receiving water body at the discharge pipe. For example, the downstream beach may have an *Enterococcus* standard while the water quality criterion at the discharge point might be expressed in fecal coliforms. In this case, samples should be analyzed for both parameters.

The permittee should consider collecting composite data for certain parameters on as many overflows as possible during the monitoring program. This can help establish mean pollutant concentrations for computing pollutant loads. For instance, TSS concentrations are generally important both because of potential habitat impacts and because they are associated with adsorbed toxics.

The permittee should consider initial screening-level sampling for a wide range of pollutants, and then should analyze subsequent samples only for the subset of pollutants identified in the screening. However, because pollutant concentrations in CSO discharges are highly variable, the permittee should exercise caution in removing pollutants from the analysis list.

4.4 SEPARATE STORM SEWERS

If separate storm sewers discharge to the same receiving water as CSOs, the permittee should determine pollutant loads from storm sewers as well as CSOs in order to understand relative loadings from different wet weather sources and target CSO and storm water controls appropriately. If sufficient storm water data are not available, the permittee may need to conduct separate storm sewer sampling and the monitoring and modeling plan should include storm water sampling for the pollutants being sampled in the CSS. Storm water discharges from areas suspected of having high loadings, such as high-density commercial areas or industrial parks, should have priority.

The monitoring and modeling plan should reflect storm water and other sampling programs occurring concurrently and provide for coordination with them. This will ensure that wet weather discharges and impacts are monitored and addressed in the most cost-effective, targeted manner possible.

4.5 RECEIVING WATER MONITORING

The goals of receiving water monitoring should include the following:

- Assess attainment of WQS (including designated uses)
- Establish the baseline conditions in the receiving water (chemical, biological, and physical parameters)
- Evaluate the impacts of CSOs
- Gain sufficient understanding of the receiving water to support evaluation of proposed CSO control alternatives, including any receiving water modeling that may be needed
- Support review and revision, as appropriate, of WQS.

The monitoring program should also provide background data on conditions in the receiving waters during dry weather conditions, if this information is not already available (see Chapter 3). Dry weather monitoring of the receiving water body will establish the background water quality and will determine whether water quality criteria are being met or exceeded during dry weather.

Where a permittee intends to eliminate CSOs entirely (i.e., separate its system), only limited or short-term receiving water monitoring may be necessary (depending on how long elimination of CSOs will take). It may be in the permittee's interest, however, to collect samples before separation to establish the baseline as well as after separation to evaluate the impacts of CSO elimination.

The permittee should coordinate monitoring activities closely with the NPDES permitting authority. In many cases, it may be appropriate to use a phased approach in which the receiving water monitoring program focuses initially on determining the pollutant loads from CSOs and identifying short-term water quality impacts. The information obtained from the first phase can then be used to identify additional data and analytical needs in an efficient manner. Monitoring efforts can be expanded as circumstances dictate to provide additional levels of detail, including evaluation of downstream effects and longer term effects.

The scope of the receiving water monitoring program will depend on several factors, such as the identity of the pollutants of concern, whether the receiving water will be modeled, and the relative size of the discharge. For example:

- To study dissolved oxygen (DO) dynamics, depth and flow velocity data must be collected well downstream of the CSO outfalls. DO modeling may necessitate data on the plant and algae community, the temperature, the sediment oxygen demand, and the shading of the river. Therefore, DO monitoring locations would likely span a larger area than for some other pollutants of concern.

- When the volume of the overflow is small relative to the receiving water body, as in the case of a small CSO into a large, well mixed river, the overflow may have little impact. Such a situation generally would not require extensive downstream sampling.

In developing the monitoring and modeling plan, the permittee should consider the location and impacts of non-CSO sources of pollutant loadings. As mentioned in Chapter 3, data and information regarding non-CSO sources are generally compiled and reviewed during the initial system characterization. To evaluate the impacts of CSOs on the receiving water body, the permittee should try to select monitoring locations that have limited or known effects from non-CSO sources. If the initial system characterization did not provide sufficient information to adequately determine the location of non-CSO sources, the permittee may need to conduct some monitoring to better characterize these sources.

4.5.1 Monitoring Locations

In planning where to sample, it is important to understand land uses in the drainage basin (which affect what pollutants are likely to be present) and characteristics of the receiving water body such as:

- Pollutants of concern (e.g., bacteria, dissolved oxygen, metals)
- Locations of sensitive areas
- The size of the water body
- Horizontal and vertical variability in the water body
- Degree of resolution necessary to assess attainment of WQS.

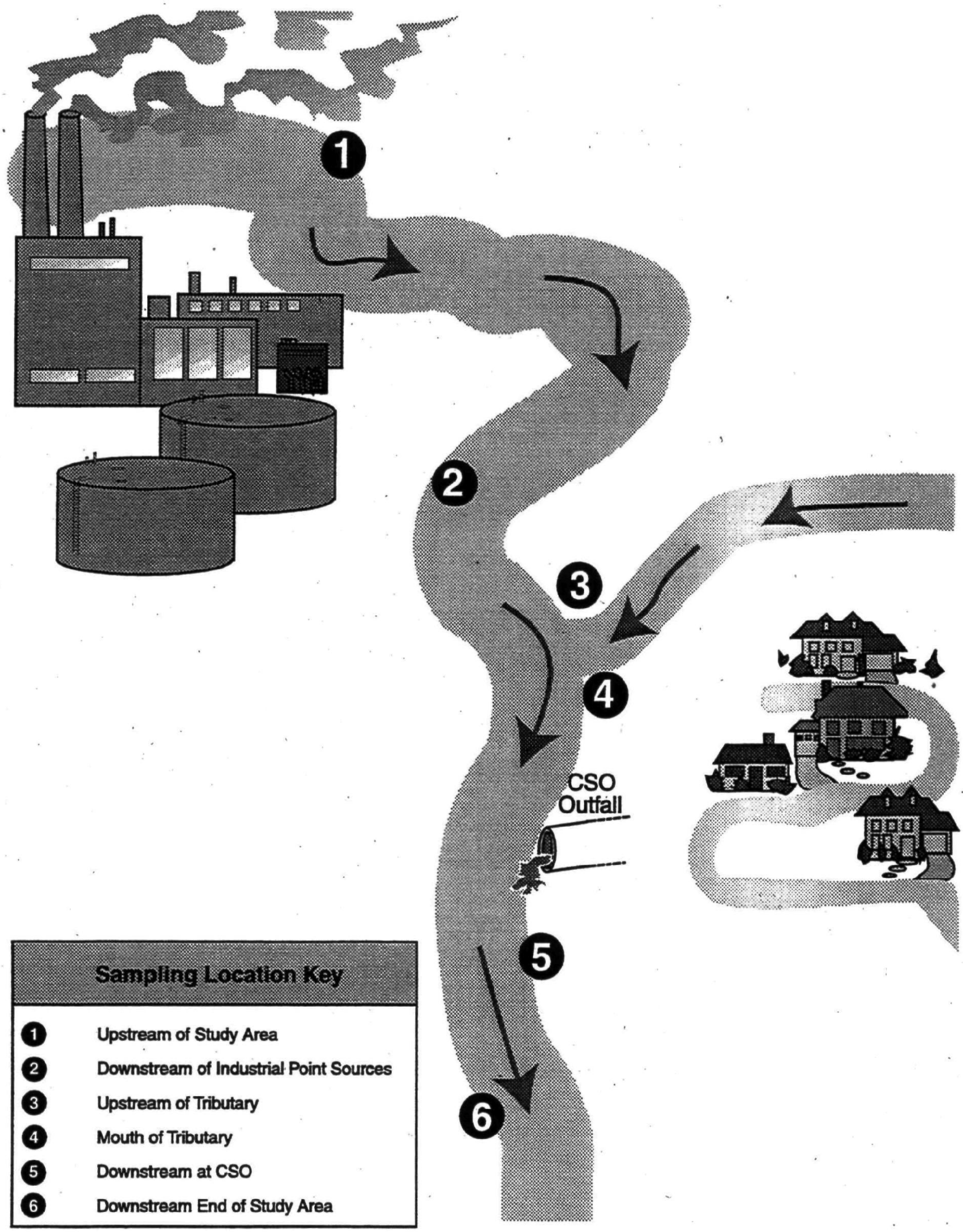
Individual monitoring stations may be located to characterize:

- Flow patterns
- Pollutant concentrations and loadings from individual sources
- Concentrations and impacts at specific locations, including sensitive areas where potential CSO impacts are of most concern, such as shellfishing zones
- Differences in concentrations between upstream and downstream sampling sites for rivers, or between inflows and outflows for lakes, reservoirs, or estuaries
- Changing conditions over time at individual sampling stations (i.e., before, during, and after a storm event)
- Differences between baseline and current conditions in CSO-impacted water bodies such as a lake, river, tributary, or bay
- Locations of non-CSO as well as CSO pollution sources.

Exhibit 4-2 illustrates how sampling locations might be distributed in a watershed to assess the effect of other sources of pollution.

The permittee should also consider making cooperative sampling arrangements where pollutants from multiple sources enter a receiving water or where several agencies share the cost of the collection system and the POTW. The identification of new monitoring locations should account for sites that may already be part of an existing monitoring system used by local or state government agencies or research organizations.

Exhibit 4-2. Monitoring Location Example



4.5.2 Monitoring Frequency, Duration, and Timing

In general, the monitoring and modeling plan should target receiving water monitoring to those seasons, flow regimes, and other critical conditions where CSOs have the greatest potential for impacts, as identified in an initial system characterization (see Chapter 3). It should specify additional monitoring as necessary to fill data gaps and to support receiving water modeling and analysis (see Tables B-2 through B-5 in Appendix B for suggested modeling parameters), or to distinguish the relative contribution of other sources to water quality impairment.

In establishing the frequency, duration, and timing of receiving water monitoring in the monitoring and modeling plan, the permittee should consider seasonal variations to determine whether measurable and significant changes occur in the receiving water body during different times of year. The monitoring and modeling plan should also enable the permittee to address issues regarding attainment of WQS, such as:

- Establishing a maximum or geometric mean coliform concentration at the point of discharge into a river or mixing zone boundary—to do this, grab samples should be taken during and immediately after discharge events in sufficient number (possibly specified in the standards) to reasonably approximate actual in-stream conditions.

- Assessing attainment of narrative standards to control nutrient load—this may call for samples collected throughout the water body and timed to examine long-term average conditions over the growing season.

- Assessing attainment of narrative standards for support of aquatic life—this may call for biological assessment in potentially impacted locations and a comparison of the data to reference sites.

Receiving water sampling designs include the following:

- ***Point-in-time*** single-event samples to obtain estimates where variation in time is not a large concern.

- ***Short-term*** intensive sampling for a predetermined period of time in order to detail patterns of change during particular events, such as CSOs. Sample collections for such studies may occur at such intervals as five minutes, one hour, or daily.

- ***Long-term*** less-intensive samples collected at regular intervals—such as weekly, monthly, quarterly, or annually—to establish ambient or background conditions or to assess seasonal patterns or general trends occurring over years.

- ***Reference site*** samples collected at separate locations for comparison with the CSO study site to determine relative changes between the locations.

- ***Near-field*** studies to sample and assess receiving waters within the immediate mixing zone of discharges. These studies can examine possible short-term toxicity impacts or long-term habitat alterations near the discharge.

- ***Far-field*** studies to sample and assess receiving waters outside the immediate vicinity of the discharge. These studies typically examine delayed impacts, including oxygen demand, nutrient-induced eutrophication, and changes in macroinvertebrate assemblages.

4.5.3 Pollutant Parameters

The monitoring and modeling plan should identify parameters of concern in the receiving water, including pollutants with water quality criteria for the specific designated use(s) of the receiving water and pollutants key to the attainment of the designated water use(s). The NPDES permitting authority may have specific requirements or guidance regarding parameters for CSO-related receiving water monitoring. These parameters may include the ones previously identified for combined sewage:

- Indicator bacteria
- TSS
- BOD and DO
- pH
- Settleable solids
- Nutrients
- Metals.

In addition, the permittee should consider the following types of monitoring prior to or concurrently with the chemical parameter analyses:

- Biological assessment (including habitat assessment)
- Sediment monitoring
- Monitoring other pollutants known or expected to be present.

Depending on the complexity of the receiving water and the analyses to be performed, the monitoring and modeling plan may need to reflect a larger list of parameters. Measuring temperature, flow, depth, and velocity, and more complex parameters such as solar radiation, light extinction, and sediment oxygen demand, can enable investigators to simulate the dynamics of the receiving water that affect basic parameters such as bacteria, BOD, and TSS (for example, a Streeter-Phelps DO analysis requires temperature, flow rate, reach length, and sediment oxygen demand). Table B-1 in the Appendix lists the data needed to perform the calculations for several dissolved oxygen, ammonia, and algal studies.

4.6 CASE STUDY

The case study in Example 4-2 outlines the monitoring aspects of a comprehensive effort to determine CSO impacts on a river and evaluate possible control alternatives. The city of South Bend, Indiana developed and implemented a monitoring program to characterize flows and pollutant loads in the CSOs and receiving water. The city then used a model to evaluate possible control alternatives.

In developing its monitoring plan, South Bend carefully selected monitoring locations that included roughly 74 percent of the area within the CSS and represented the most characteristic land uses. The city conducted its complete monitoring program at 6 of the 42 CSO outfalls and performed simpler chalk board measurements at the remaining outfalls to give some basic information on the occurrence of CSOs across the system. By using existing flow monitoring stations in the CSS, the city was able to limit the need to establish new monitoring stations.

Example 4-2. Monitoring Case Study

South Bend, Indiana

The City of South Bend, population of 109,000, has 42 combined sewer service areas covering over 14,000 acres.

Monitoring Goals

The ultimate goal of the CSO control effort was to reduce or eliminate impacts to beneficial uses of the receiving water, including recreation. The more immediate goal consisted of quantifying CSO impacts to the St. Joseph River and evaluating alternatives for cost-effective management of wet weather overflows. In order to achieve these goals, the City reviewed its existing data to determine what additional data were needed to characterize CSO impacts. The City then developed and implemented a monitoring plan to fill in these data gaps. Objectives of the monitoring plan included quantifying overflow volumes and pollutant loads in the overflows and flows and pollutant loads in the receiving water. After evaluating various analytical and modeling tools, the City decide to use the SWMM model to assist in predicting the benefits of alternative control strategies and defining problems caused by storm-related CSO discharges.

Monitoring Plan Design and Implementation

The monitoring plan was designed to focus on the 6 largest drainage areas, which were most characteristic of land uses within the CSS area and included 74 percent of that area. Monitoring all 42 outfalls was judged to be unnecessarily costly. The monitoring plan specified 8 temporary and 9 permanent flow monitoring locations along the main interceptor and in the influent and outfall structures of the 6 largest CSOs. The remaining CSO sites had chalk boards installed to determine which storms caused overflows and to help verify correct operation of monitoring equipment. Although monitoring only 15 percent of the outfalls, this plan measured flow and water quality for most of the CSS area.

The monitoring plan stipulated collecting water quality samples for both dry weather and wet weather periods. The plan specified sample collection from four CSO structures during at least five storm events. Monitored water quality parameters included nine metals, total suspended solids (TSS), BOD, CBOD (carbonaceous biochemical oxygen demand), total Kjeldahl nitrogen (TKN), ammonia, total phosphorus, total and fecal coliform bacteria, conductivity, and hardness. Periodic dry-weather grab sample collections at the interceptors were also planned.

During storm events, water quality samples were collected using 24-bottle automatic samplers at four CSO points. To quantify "first-flush" concentrations, the automatic samplers began sample collection at the start of an overflow and continued collecting samples every five minutes for the first two hours of the monitored events. A two-person crew drove between sites during each monitored event to check equipment operation and the adequacy of sample collection.

4.7 DATA MANAGEMENT AND ANALYSIS

4.7.1 Quality Assurance Programs

Since inaccurate or unreliable data may lead to faulty decisions in evaluating, selecting, and implementing CSO controls, the monitoring and modeling plan must provide for quality assurance and quality control to ensure that the data collected are precise and accurate. Quality assurance and quality control (QA/QC) procedures are necessary both in the field (during sampling) and in the laboratory to ensure that data collected in environmental monitoring programs are of known quality, useful, and reliable. Quality assurance refers to programmatic efforts to ensure the quality of monitoring and measurement data. QA programs increase confidence in the validity of the reported analytical data. Quality control, which is a subset of quality assurance, refers to the application of procedures designed to obtain prescribed standards of performance in monitoring and measurement. For example, a program describing a calibration schedule is QA, while the calibration procedures are QC.

QA/QC procedures can be divided into two categories, field procedures and laboratory procedures. Both types of QA/QC are described in the following subsections.

Field QA/QC. QA programs for sampling equipment and for field measurement procedures (for such parameters as temperature, dissolved oxygen, and pH) are necessary to ensure data of the highest quality. A field QA program should contain the following documented elements:

- The sampling and analytical methodology; special sample handling procedures; and the precision, accuracy, and detection limits of all analytical methods used.
- The basis for selection of sampling and analytical methods. Where methods do not exist, the QA plan should state how the new method will be documented, justified, and approved for use.
- Procedures for calibration and maintenance of field instruments and automatic samplers.
- Training of all personnel involved in any function affecting the data quality.

- A performance evaluation system assessing the performance of field sampling personnel in the following areas:
  - Qualifications of field personnel for a particular sampling situation
  - Determination of the best representative sampling site
  - Sampling technique including monitoring locations, the choice of grab or composite sampling, the type of automatic sampler, special handling procedures, sample preservation, and sample identification
  - Flow measurement
  - Completeness of data, data recording, processing, and reporting
  - Calibration and maintenance of field instruments and equipment
  - The use of QC samples such as duplicate, split, or spiked samples and blanks as appropriate to assess the validity of data.
- Procedures for the recording, processing, and reporting of data; procedures for review of data and invalidation of data based upon QC results.
- The amount of analyses for QC, expressed as a percentage of overall analyses, to assess the validity of data.

Sampling QC includes calibration and preventative maintenance procedures for sampling equipment, training of sampling personnel, and collection and analysis of QC samples. QC samples are used to determine the performance of sample collection techniques and should be collected when the other sampling is performed. The following sample types should be part of field QC:

- ***Duplicate Samples (Field)***—Duplicate field samples collected at selected locations provide a check for precision in sampling equipment and techniques.
- ***Equipment Blank***—An aliquot of distilled water which is taken to and opened in the field, its contents poured over or through the sample collection device, collected in a sample container, and returned to the laboratory for analysis to check sampling device cleanliness.

- ***Field/Trip Blank***—An aliquot of distilled water or solvent that is brought to the field in a sealed container and transported back to the laboratory with the sample containers for analysis in order to check for contamination from transport, shipping, or site conditions.

- ***Preservation Blank***—Adding a known amount of preservative to an aliquot of distilled water and analyzing the substance to determine the effectiveness of the preservative (i.e., whether the aliquot is contaminated).

Laboratory QA/QC. Laboratory QA/QC procedures ensure high-quality analyses through instrument calibration and the processing of control samples. **Precision** of laboratory findings refers to the reproducibility of results. In a laboratory QC program, a sample is analyzed independently, more than once using the same methods and set of conditions. The precision is estimated by comparing the measurements. **Accuracy** refers to the degree of difference between observed values and known or actual values. The accuracy of a method may be determined by analyses of samples to which known amounts of reference standards have been added.

The following techniques are useful in determining confidence in the validity of analytical data:

- ***Duplicate Samples (Laboratory)***—Samples received by the laboratory and divided into two or more portions at the laboratory, with each portion then separately and identically prepared and analyzed. These samples determine precision to assess sampling techniques and equipment.

- ***Split Samples (Field)***—Single samples split in the field and analyzed separately check for variation in laboratory method or between laboratories. Samples can be split and submitted to a single laboratory or to several laboratories.

- ***Spiked Samples (Laboratory)***—Introducing a known quantity of a substance into separate aliquots of the sample or into a volume of distilled water and analyzing for that substance provides a check of the accuracy of laboratory and analytic procedures.

- ***Reagent Blanks***—Preserving and analyzing a quantity of distilled water in the same manner as environmental water samples can indicate contamination caused by sampling and laboratory procedures.

QA/QC programs are discussed in greater detail in *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations* (EPA, 1994d) and *Industrial User Inspection And Sampling Manual For POTWs* (EPA, 1994c).

4.7.2 Data Management

Although a permittee may collect accurate and representative data through its monitoring efforts and verify the reliability of the data through QA/QC procedures, these data are of limited usefulness if they are not stored in an organized manner and analyzed properly. The permittee should develop a data management program to provide ready access to data, prevent data loss, prevent introduction of data errors, and facilitate data review and analysis. Even if a permittee intends to use a "complex" model to evaluate the impacts of CSOs and proposed CSO control alternatives, the model still requires appropriate data for input parameters, as a basis for assumptions made in the modeling process, and for model calibration and verification. Thus, the permittee needs to properly manage monitoring data and perform some review and analysis of the data regardless of the analytical tools selected.

All monitoring data should be organized and stored in a form that allows for ready access. Effective data management is necessary because the voluminous and diverse nature of the data, and the variety of individuals who can be involved in collecting, recording and entering data, can easily lead to data loss or error and severely damage the quality of monitoring programs.

Data management systems must address both managerial and technical issues. The managerial issues include data storage, data validation and verification, and data access. First, the permittee should determine if a computerized data management system will be used. The permittee should consider factors such as the volume of monitoring data (number of sampling stations, samples taken at each station, and pollutant parameters), complexity of data analysis, resources available (personnel, computer equipment, and software), and whether modeling will be performed. To enable efficient and accurate data analysis, a computerized system may be necessary for effective data management in all but the smallest watersheds. Computerized data management systems may also facilitate modeling if the data can be uploaded directly into the model rather than being reentered. Thus, if modeling will be performed, the permittee should consider compatibility with the model when selecting any computerized data management system. Technical issues related to data management systems involve the selection of appropriate computer equipment and software and the design of the data system, including data definition, data standardization, and a data dictionary.

Data quality must be rigidly controlled from the point of collection to the point of entry into the data management system. Field and laboratory personnel must carefully enter data into proper spaces on data sheets and avoid transposing numbers. To avoid transcription errors when using a computerized data management system, entries into a preliminary data base should be made from original data sheets or photocopies. As a preliminary screen for data quality, the data base/spreadsheet design should include automatic range-checking of all parameters, where values outside defined ranges are flagged and either immediately corrected or included in a follow-up review. For some parameters, it might be appropriate to include automatic checks to disallow duplicate values. Preliminary data base/spreadsheet files should be printed and verified against the original data to identify errors.

Additional data validation can include expert review of the verified data to identify possible suspicious values. In some cases, consultation with the individuals responsible for collecting or entering original data may be necessary to resolve problems. After all data are verified and validated, they can be merged into the monitoring program's master data files. For computerized systems, to prevent loss of data from computer failure at least one set of duplicate (backup) data files should be maintained.

Data analysis is discussed in Chapters 5 (CSS Monitoring) and 6 (Receiving Water Monitoring). The use of models for more complex data analysis and simulation is discussed in Chapters 7 (CSS Modeling) and 8 (Receiving Water Modeling).

4.8 IMPLEMENTATION OF MONITORING AND MODELING PLAN

During development of the monitoring and modeling plan, the permittee needs to consider implementation issues such as recordkeeping and reporting requirements, personnel responsible for carrying out each element of the plan, scheduling, and resources. Although some implementation issues cannot be fully addressed in the monitoring and modeling plan until other plan elements have evolved, they should be considered on a preliminary basis in order to ensure that the resulting plan will satisfy reporting requirements and be feasible with available resources.

4.8.1 Recordkeeping and Reporting

The monitoring and modeling plan should include a recordkeeping and reporting plan, since future permits will contain recordkeeping and reporting requirements such as progress reports on NMC and LTCP implementation and submittal of monitoring and modeling results. The recordkeeping and reporting plan should address the post-compliance monitoring program the permittee will develop as part of the LTCP.

4.8.2 Personnel Responsible for Implementation

The monitoring and modeling plan should identify the personnel that will implement the plan. In some cases, particularly in a city with a small CSS, the appropriately trained personnel available for performing the tasks specified in the monitoring and modeling plan may be very limited. By reviewing personnel and assigning tasks, the permittee will be prepared to develop an implementation schedule that will be attainable and will be able to identify resource limitations and needs (including training) early in the process.

4.8.3 Scheduling

The permittee should develop a tentative implementation schedule for the monitoring and modeling plan to ensure that elements of the plan are implemented continuously and efficiently. The schedule should be revised as necessary to reflect the review team's assessment of the plan and the evaluation of monitoring and modeling results. The schedule should address:

- Reporting and compliance dates included in the NPDES permit
- Monitoring frequencies
- Seasonal sampling schedules and dependency on rainfall patterns
- Implementation schedule for the NMC
- Coordination with other ongoing sampling programs
- Availability of resources (equipment and personnel).

4.8.4 Resources

During development of the monitoring and modeling plan, the permittee should identify equipment, personnel, and other resource needs, and may need to modify the plan after assessing the availability of these resources. For example, if the monitoring and modeling plan identifies complex modeling strategies, the permittee may need to consider modeling techniques that have more moderate data requirements. Alternatively, if the permittee does not have the resources to purchase the hardware or software needed to run a detailed model, the permittee may be able to make arrangements to use the equipment at another facility (e.g., another municipality developing a CSO control program) or at a State or Federal agency. However, if such arrangements are not possible, the permittee may need to choose a less detailed model which could lead to reduced monitoring costs.

Through a review of resources, the permittee may identify monitoring equipment needed to implement the monitoring and modeling plan. By obtaining needed equipment, such as automatic samplers, flow measuring equipment, rain gages, and safety equipment before the date when monitoring is scheduled to begin, the permittee can prevent some potential delays. The permittee may also be able to spread the costs of implementing the monitoring and modeling plan across several budget years.

CHAPTER 5

CSS MONITORING

This chapter describes techniques and equipment for monitoring rainfall and CSS flow and quality, and describes procedures for organizing and analyzing the data collected. It discusses a range of monitoring and analysis options and provides criteria for identifying appropriate options for a particular system.

5.1 THE CSO POLICY AND CSS MONITORING

The CSO Control Policy identifies several possible objectives of a CSS monitoring program:

- To gain a thorough understanding of the sewer system
- To adequately characterize the system's response to wet weather events, such as the magnitude, frequency, and duration of CSOs and the volume, concentration, and mass of pollutants discharged
- To support a mathematical model to characterize the CSS
- To support development of appropriate measures to implement the nine minimum controls (NMC)
- To support development of the long-term control plan (LTCP)
- To evaluate the expected effectiveness of the NMC and the long-term CSO controls to meet WQS.

CSS monitoring also directly supports implementation of the following NMC:

- Maximum use of the collection system for storage
- Maximization of flow to the POTW for treatment
- Control of solids and floatable materials in CSOs
- Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

CSS monitoring will also support the in-depth system characterization and post-construction compliance monitoring that are central elements in the LTCP.

This chapter outlines the steps that are critical to collection and analysis of rainfall, flow, and quality data in accordance with the CSO Control Policy.

5.2 RAINFALL DATA FOR CSS CHARACTERIZATION

Rainfall data, including both long-term rainfall records and data gathered at specific sites in the CSS, are a vital part of a CSS monitoring program. This information is necessary to analyze the CSS, calibrate and validate CSO models, and develop design conditions for predicting current and future CSOs.

This section describes how to install and use rainfall monitoring equipment to collect rainfall data and how to analyze the data gathered.

5.2.1 Rainfall Monitoring

National rainfall data are available from a number of federal and local sources, including the National Weather Service, the National Climatic Data Center (NCDC), airports, and universities (see Chapter 3). However, because rainfall conditions vary significantly over short distances, it is generally necessary to supplement national data with data from local rainfall monitoring stations.

Equipment

Two types of gages are used to measure the amount and intensity of rainfall. A standard rain gage collects the rainfall directly in a marked container and the amount of rain is measured visually. Although inexpensive, standard gages do not provide a way to record changes in storm intensity without making frequent observations during the storm.

Because wet weather flows vary with rainfall intensity, CSS monitoring programs typically use recording gages, which provide a permanent record of the rainfall amount over time. The three most common types of recording gages are:

- ***Tipping Bucket Gage***—Water caught in a collector is funneled into a two-compartment bucket. Once a known quantity of rain is collected, it is emptied into a reservoir, and the event is recorded electronically.

- ***Weighing Type Gage***—Water is weighed when it falls into a bucket placed on the platform of a spring or lever balance. The weight of the contents is recorded on a chart, showing the accumulation of precipitation.

- ***Float Recording Gage***—Rainfall is measured by the rise of a float that is placed in the collector.

A combination of standard and recording gages can be used to collect representative rainfall data more economically. If recording gages are strategically placed amid standard gages, the permittee can compare spatial variations in total rainfall at each recording gage with the surrounding standard gages. Since fewer recording gages may then be needed, money can be saved.

Equipment Installation and Operation

Rain gages are fairly easy to operate and will provide accurate data when installed and used properly. They should be located in open spaces away from the immediate shielding effects of trees or buildings. Ground installations are preferable (if vandalism is not a significant problem), although roof installations are also an option. Public buildings, such as police, fire, or public works buildings, are often used.

5.2.2 Rainfall Data Analysis

Rainfall monitoring should be synchronized with CSS flow monitoring, so rainfall characteristics can be related to the amount of runoff and CSO volume during a wet weather event and so a CSS model can be calibrated and validated. In addition, long-term rainfall data gathered from existing gages are necessary to develop appropriate design conditions for determining existing and future CSO impacts on receiving water bodies. Because precipitation can vary considerably within short distances, it is usually necessary to use data from several rain gages to estimate the average precipitation for an area.

Development of Design Conditions

The first step in rainfall characterization is to look at multiple storm events in order to develop a "design storm," which is a precipitation event with a specific characteristic used to estimate a volume of runoff or discharge of specific recurrence interval. Historic rainfall data (such as data from NOAA's National Climatic Data Center) can be used to characterize area rainfall and to estimate design conditions, as long as the data were collected close enough to the CSS's service area to reflect site conditions. Long-term rainfall data (usually extending over 30 years or more although 10 years of data are usually sufficient) from existing NCDC rain gages can be analyzed in a number of different ways to develop design storms. Common methods for characterizing rainfall include total volumes, event statistics, return period/volume curves, and intensity-duration-frequency curves. Each of these methods is described below.

Total Volumes. The National Weather Service publishes annual totals as well as deviations from the average for each rain gage in its network. Wet- and dry-year rainfalls can be defined by comparing a particular year's rainfall to the long-term average. Monthly totals and averages also can be computed in the same way to examine seasonal differences. This review of seasonal and annual rainfall totals is used to select the time period for detailed simulation modeling.

For example, 38 years of rainfall records, 1955–1992, were collected at a NOAA gage near (but not within) a CSS drainage area. These records indicate an average of 44 storm events per year, with a wide variation from year to year. To generate runoff predictions for the CSS drainage area, the STORM runoff model was calibrated and run using the 38 years of hourly rainfall data. The model predicted the number of runoff events per year, the total annual runoff, and the average overflow volume per event in inches/land area. Exhibit 5-1 ranks the years based on the number of events, inches of runoff, and average runoff per event predicted by the model. Results showed the year 1969 with both the highest number of runoff events (68) and

1

Exhibit 5-1. Ranking of Yearly Runoff Characteristics as Simulated by the Storm Model

Rank	Year	No. of Events	Year	Total Runoff (in)	Year	Avg Overflow (in./event)
1	1969	68	1969	15.1	1967	0.33
2	1984	58	1987	14.9	1991	0.31
3	1987	57	1984	14.7	1992	0.30
4	1983	56	1975	14.2	1965	0.30
5	1976	56	1974	13.1	1975	0.27
6	1989	54	1956	13.1	1955	0.27
7	1974	54	1960	12.8	1987	0.26
8	1966	54	1980	12.6	1960	0.26
9	1980	53	1983	12.5	1984	0.25
10	1956	53	1955	12.5	1979	0.25
11	1988	52	1966	12.4	1973	0.25
12	1975	52	1962	12.1	1970	0.25
13	1972	52	1992	12.1	1962	0.25
14	1957	52	1976	12.0	1956	0.25
15	1960	50	1965	12.0	1989	0.24
16	1962	49	1957	11.9	1981	0.24
17	1971	47	1970	11.7	1980	0.24
18	1970	47	1967	11.0	1974	0.24
19	1955	47	1988	10.9	1985	0.23
20	1985	45	1971	10.9	1982	0.23
21	1979	43	1979	10.7	1971	0.23
22	1968	43	1991	10.6	1966	0.23
23	1959	43	1985	10.4	1957	0.23
24	1992	41	1989	9.7	1983	0.22
25	1982	40	1982	9.1	1977	0.22
26	1965	40	1959	8.2	1969	0.22
27	1964	40	1990	8.1	1988	0.21
28	1991	34	1968	7.9	1976	0.21
29	1990	34	1981	7.6	1963	0.21
30	1978	33	1972	7.3	1986	0.20
31	1967	33	1973	7.2	1959	0.19
32	1958	32	1964	7.1	1989	0.18
33	1981	31	1977	6.7	1978	0.18
34	1977	30	1963	6.3	1968	0.18
35	1963	30	1978	6.0	1964	0.18
36	1986	29	1986	5.8	1961	0.17
37	1973	29	1961	4.8	1972	0.14
38	1961	28	1958	4.6	1958	0.14
Mean		44		10.3		0.23
Median		46		10.9		0.23

Extreme Year = 1969 Typical Year = 1970

largest total runoff volume (15.1 inches). The year 1967 had the highest predicted average overflow per event (0.33 inches).

Exhibit 5-2 lists minimum, maximum, mean, and median values for annual runoff statistics. These statistics identify typical and extreme years to select for modeling or evaluating the frequency of overflows under various control alternatives. Long-term computer simulations of the CSS using a multi-year continuous rainfall record or one-year simulations using typical or wet years are useful for assessing alternative long-term control strategies.

Exhibit 5-2. Rainfall and Runoff Parameters for Typical and Extreme Years

	No. of Events	Total Runoff (inches)	Average Overflow (in./event)
Maximum (all years)	68	15.1	0.33
1969	68	15.1	0.22
1956	53	13.1	0.25
1970	47	11.7	0.25
Mean (all years)	44	10.3	0.23
Median (all years)	46	10.9	0.23
1971	47	10.9	0.23
1988	52	10.9	0.21
1985	45	10.4	0.23
1979	43	10.7	0.25
Minimum (all years)	28	4.6	0.14

The data generated by the STORM model can be reviewed for typical or extreme years to determine the uniformity of the monthly distribution of runoff. The years 1969 and 1956 represent extreme high flows. The year 1956 had the most severe event in 38 years, with 6.0 inches of runoff in 30 hours. The years 1970 and 1985 were selected as typical years, having the most uniform distribution of rainfall throughout the year.

Event Statistics. Information may also be developed on the characteristics of individual storm events for a site. If the sequence of hourly rainfall volumes from the existing gages is grouped into separate events (i.e., each period of volume greater than zero that is preceded and followed by at least one period of zero volume would mark a separate event), then each storm event may be characterized by its duration, volume, average intensity, and the time interval between successive events. The event data can be analyzed using standard statistical procedures to determine the mean and standard deviation for each storm event, as well as probability distributions and recurrence intervals. The computer program SYNOP can be used to group the hourly rainfall values into independent rainfall events and calculate the storm characteristics and interval since the preceding storm.

Return Period/Volume Curves. The "return period" is the frequency of occurrence for a parameter (such as rainfall volume) of a given magnitude. The return period for a storm with a specific rainfall volume may be plotted as a probability distribution indicating the percent of storms with a total volume less than or equal to a given volume. For example, if approximately ten percent of the storm events historically deposit 1.5 inches of rain or more, and there are an average of 60 storm events per year, an average of 6 storm events per year would have a total volume of 1.5 inches or more, and the 1.5-inch rain event could be characterized as the "two-month storm."

Intensity-Duration-Frequency Curves. Duration can be plotted against average intensity for several constant storm return frequencies, in order to design hydraulic structures where short duration peak flows must be considered to avoid local flooding. For example, when maximizing in-system storage (under the NMC), the selected design event should ensure that backups in the collection system, which cause flooding, are avoided. Intensity-duration-frequency curves are developed by analyzing an hourly rainfall record in such a way as to compute a running sum of volumes for consecutive hours equal to the duration of interest. The set of volumes for that duration are then ranked, and based on the length in years of the record, the recurrence interval for any rank is determined. This rainfall analysis procedure is used to calculate the local value for design storms such as a 1-year, 6-hour design condition.

Local Rain Gage Data

In order to calibrate and verify runoff and water quality models, it is also necessary to analyze rainfall data for specific storm events in which CSO quality and flow sampling is occurring.

Local rain gage data can be used to assess the applicability of the long-term record of the site. For example, Exhibit 5-3 presents two months of local rainfall data from three tipping bucket gages (labelled A, B, and C in Exhibit 5-4). Comparison with NOAA data indicates that the average value of the three gages was close to the regional record with only slight variations among gages. Three events were selected for detailed water quality sampling and analysis.

Exhibit 5-3. 1993 Rainfall Data for a 5,305 Acre Drainage Area

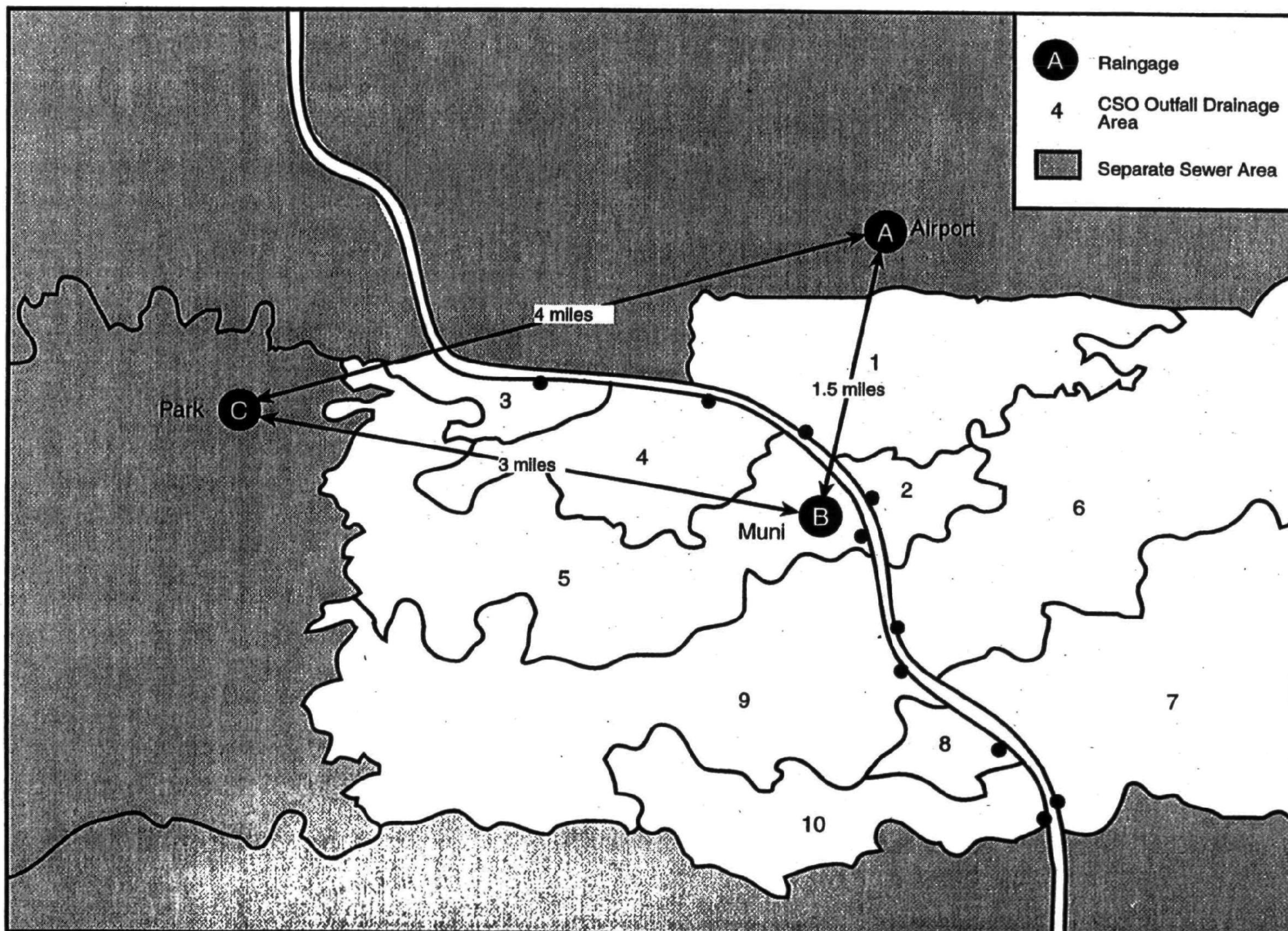
Storm Event	Date		Gage A (inches)	Gage B (inches)	Gage C (inches)	Regional Record of Rainfall (inches)	Duration (hours)	Intensity (in/hr)
1	4/6		0.58	0.58	0.62	0.59	4.8	0.12
2	4/14	M	0.22	0.17	0.19	0.19	1.5	0.13
3	4/21		0.11	0.12	0.08	0.10	1.4	0.07
4	4/28	M	0.87	1.20	1.05	1.04	2.5	0.42
5	5/5		0.12	0.18	0.12	0.14	1.5	0.09
6	5/8		0.47	0.40	0.42	0.43	9.4	0.05
7	5/11		0.50	0.45	0.45	0.47	4.5	0.10
8	5/13	M	0.44	0.31	0.22	0.32	0.8	0.40
9	5/14		0.48	0.43	0.52	0.48	4.3	0.11
	Total		**3.79**	**3.84**	**3.67**	**3.70**	**30.7**	**0.12**

M = event selected for detailed water quality monitoring

As indicated by Exhibit 5-3, storm #4 (April 28) would be particularly useful for model calibration or verification because a large amount of rain fell over a relatively short period.

In cases where local rain gages are placed near but not exactly at the locations where CSS flow and quality is being monitored, rainfall data from several nearby rain gage locations can be

Exhibit 5-4. Rain Gage Map for Example 5-1



Not to Scale

interpolated to estimate the rainfall at the sampling location. The inverse distance weighting method can be used to calculate the rainfall over a CSS sampling location in watershed 4 in Exhibit 5-4.

Inverse Distance Weighting Method

Using this method, the estimated precipitation at the sampling location is determined as a weighted average of the precipitation at the surrounding rain gages. The weights are the reciprocals of the squares of the distances between the sampling location and the rain gages. The estimated rainfall at the sampling location is calculated by summing the precipitation times the weight for each rain gage and dividing by the sum of the weights. For example, if the distance between the sampling location in watershed 4 and rain gage A is X, rain gage B is Y, and rain gage C is Z and the precipitation at each rain gage is P_A, P_B, and P_C, then the precipitation at the sampling location in watershed 4 can be estimated by:

$$P_4 = [(P_A \times \frac{1}{X^2}) + (P_B \times \frac{1}{Y^2}) + (P_C \times \frac{1}{Z^2})] / (\frac{1}{X^2} + \frac{1}{Y^2} + \frac{1}{Z^2})$$

If P_A, P_B, and P_C are 0.87, 1.20, and 1.05 inches, respectively, and X, Y, and Z are 1.0, 1.5, and 3.0 feet, respectively, then

$$P_4 = [(0.87 \times \frac{1}{(1.0)^2}) + (1.20 \times \frac{1}{(1.5)^2}) + (1.05 \times \frac{1}{(3.0)^2})] / (\frac{1}{(1.0)^2} + \frac{1}{(1.5)^2} + \frac{1}{(3.0)^2}) = 0.98 \text{ inches}$$

It may also be possible to use radar imaging data to estimate rainfall intensities at multiple locations throughout the rainfall event.

5.3 FLOW MONITORING IN THE CSS

Accurate flow monitoring is critical to understanding the hydraulic characteristics of a CSS and predicting the magnitude, frequency, and duration of CSOs. Monitoring flows in CSSs can be difficult because of surcharging, backflow, tidal flows, and the intermittent nature of overflows. Selecting the most appropriate flow monitoring technique depends on site characteristics, budget constraints, and availability of personnel. This section outlines options for measuring CSS flow and discusses how to organize and analyze the data collected.

5.3.1 Flow Monitoring Techniques

Flow measurement techniques vary greatly in complexity, expense, and accuracy. This section describes a range of manual and automated flow monitoring techniques. Exhibit 5-5 summarizes their advantages and disadvantages.

Exhibit 5-5. CSO Flow Monitoring Devices

Monitoring Method	Description	Advantages	Disadvantages
Manual Methods			
Timed Flow	Timing how long it takes to fill a container of a known size	• Simple to implement • Little equipment needed	• Labor intensive • Suitable only for low flows
Dilution Method	Injection of dye or saline solution in the system and measuring the dilution	• Accurate for instantaneous flows	• Not appropriate for continuous flow • Outside contaminants could impact results
Direct Measurement	Use of a flow meter and surveying rod to manually measure flow and depth	• Easy to collect data	• Labor intensive • Multiple measurements may be needed at a single location
Chalking Boards	Installation of a board with a chalk line which is erased to the level of highest flow	• Easy to implement	• Only rough estimate of depth measured
Bottle Boards	Installation of multiple bottles of different size where the tallest filled bottle indicates the depth of flow	• Easy to implement	• Only rough estimate of depth measured
Primary Flow			
Weir	Devices placed across the flow such that overflow occurs through a notch. Flow is determined by the depth behind the weir	• Many CSOs have existing weirs • More accurate than other manual measurements	• Cannot be used in full or nearly full pipes • Somewhat prone to. clogging and silting
Flume	Chute-like structure that allows for controlled flow	• Accurate estimate of flow • Less prone to clogging than weirs	• Not appropriate for backflow conditions • More expensive than weirs
Orifice Plate	A plate with a circular or oval opening designed to control flow	• Can measure flow in full pipes • Portable and inexpensive to operate	• Prone to solids accumulation
Depth Sensing			
Ultrasonic Sensor	Sensor mounted above the flow that measures depth with an ultrasonic signal	• Generally provide accurate measures	• May be impacted by solids or foam on flow surface
Pressure Sensor	Sensor mounted below the flow which measures the pressure exerted by the flow	• Generally provide accurate measures	• Require frequent cleaning and calibration
Bubbler Sensor	Sensor emitting a stream of bubbles and measuring the resistance to bubble formation	• Generally provide accurate measures	• Require frequent cleaning to prevent clogging
Float Sensor	Sensors using a mechanical float to measure depth	• Generally provide accurate measures	• Must be accurately calibrated prior to use and regularly checked
Velocity Meters			
Ultrasonic	Meter designed to measure velocity through a continuous pulse	• Instrument does not interfere with flow • Can be used in full pipes	• More expensive than other equipment
Electromagnetic	Meter designed to measure velocity through an electromagnetic process	• Instrument does not interfere with flow • Can be used in full pipes	• More expensive than other equipment

Manual Methods

The simplest flow monitoring techniques involve manual measurement of velocity and depth, use of bottle boards and chalking (see Example 5-1), and dye testing. Manual methods are difficult during wet weather, however, since they rely extensively on labor-intensive field efforts during storm events and do not provide an accurate, continuous flow record. Manual methods are most useful for instantaneous flow measurement, calibration of other flow measurements, and flow measurements in small systems. They are difficult to use for measuring rapidly changing flows because numerous instantaneous measurements must be taken at the proper position to correctly estimate the total flow.

Measuring Flow Depth

Primary flow devices, such as weirs, flumes, and orifice plates, control flow in a portion of pipe such that the flow's depth is proportional to its flow rate. They enable flow rate to be determined by manually or automatically measuring the depth of flow. Measurements taken with these devices are accurate in the appropriate hydraulic conditions but are not where surcharging or backflow occur. Also, the accuracy of flow calculations depends on the reliability of depth-sensing equipment, since small errors in depth measurement can result in large errors in flow rate calculation.

Depth-sensing devices can be used with pipe equations or primary flow and velocity-sensing devices to determine flow rates. They include:

- ***Ultrasonic Sensors***, which are typically mounted above the flow in a pipe or open channel and send an ultrasonic signal toward the flow. Depth computations are based on the time the reflected signal takes to return to the sensor. These sensors provide accurate depth measurements but can be affected by high suspended solid loads or foaming on the water surface.

- ***Pressure sensors***, which use transducers to sense the pressure of the water above them. They are used with a flow monitor that converts the pressure value to a depth measurement.

- ***Bubbler Sensors***, which emit a continuous stream of fine bubbles. A pressure transducer senses resistance to bubble formation, converting it to a depth value.

Example 5-1

A bottle rack is used to determine the approximate depth of overflows from a 36-inch combined sewer in an overflow manhole (Exhibit 5-6). The overflow weir for this outfall is 12 inches above the invert of the sewer, and flows below this level are routed out the bottom of the structure to the interceptor and the wastewater treatment plant (WWTP). Any flow overflowing the 12-inch weir is routed to the 42-inch outfall sewer. Attached to the manhole steps, the bottle rack approximates the flow level in the manhole by the height of the bottles that are filled. This outfall has potential for surcharging because of flow restrictions leading to the interceptor. Consequently, the bottle rack extends well above the crown of the outfall sewer. After each rainfall, a member of the monitoring team pulls the rack from the manhole, records the highest bottle filled, and returns the rack to the manhole. Exhibit 5-7 presents depth data for the nine storms listed in Exhibit 5-3.

Storm 3, which had 0.1 inch of rain in 85 minutes, was contained at the outfall with no overflow, although it did overflow at other locations. Storm 5, with an average volume of 0.14 inches and an average intensity of 0.09 in/hour, had a peak flow depth of approximately six inches above the weir crest.

It is instructive to examine the individual rain gages (located as indicated in Exhibit 5-4) and compare them to the flow depths. Rain gage A indicated that Storms 3 and 5 had similar depths and that 3 was slightly more intense. Why, then, did Storm 5 cause an overflow, while Storm 3 did not? Rain gage B, which lies nearer to the outfall, indicates 50 percent more volume and 50-percent higher intensity for storm 5. Using only rain gage A in calibrating a hydraulic model to the outfall for storms 3 and 5 could have posed a problem. Because a bottle board indicates approximate maximum flow depth, not duration or flow volume, it is not sufficient to calibrate most models.

Storms 4 and 8 caused flow depth to surcharge, or increase above the crown of the pipe. Both storms occurred during late afternoon when sanitary sewer flows are typically highest, potentially exacerbating the overflow. The surcharging pipe indicates that flow measurements will be difficult for large storms at this location. Further field investigations will be necessary to define the hydraulics of this particular outfall and intercepting device. Because of safety considerations in gaining access to this location, the monitoring team used only the bottle board during the early monitoring period. Later, the team installed a velocity meter and a series of depth probes to determine a surface profile.

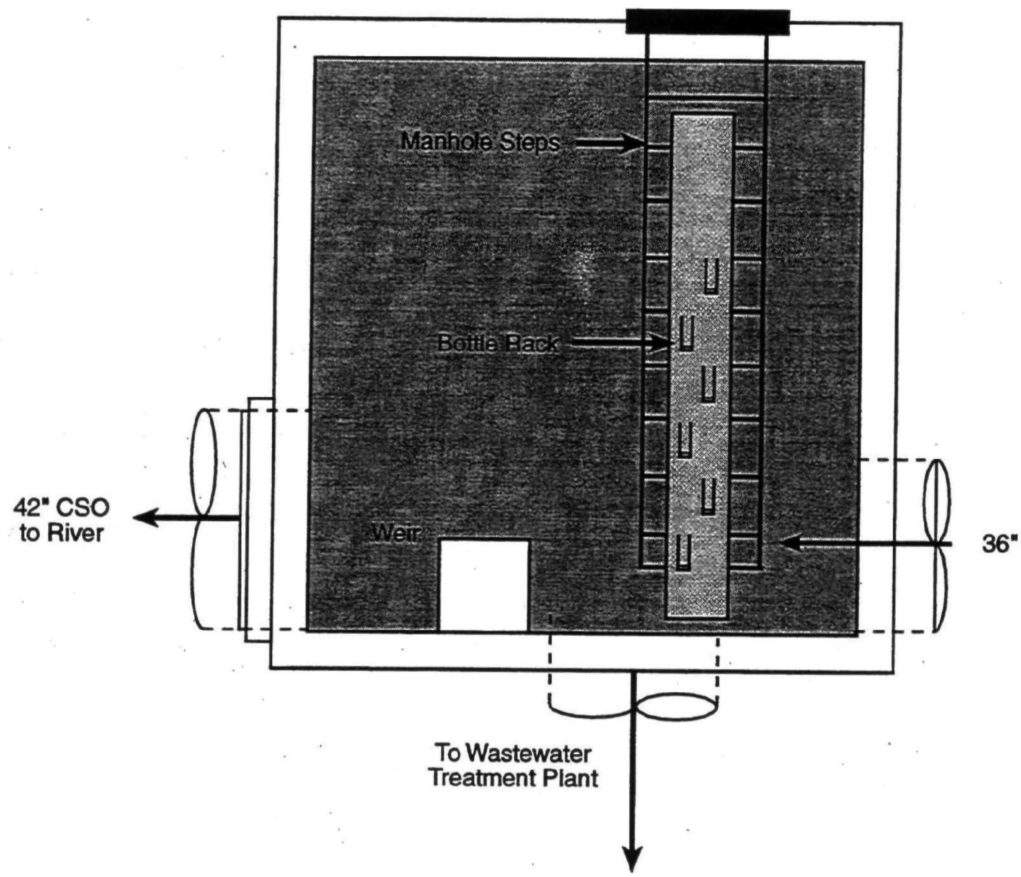
These devices provide accurate measurements. The bubble tube can clog, however, and the device itself requires frequent calibration.

- ***Float Sensors***, which sense depth using a mechanical float, often within a chamber designed to damp out surface waves. Floats can clog with grease and solid materials and are, therefore, not commonly used to sense flow in sewers.

Using depth measurement data, pipe equations can be applied to develop flow estimates. The Hazen-Williams equation, Manning equation, and similar equations can be useful for estimating flow capacity of the system and performing a preliminary flow analysis of the CSS.

Exhibit 5-6. Illustration of a Bottle Board Installation

Section



The Hazen-Williams equation is generally used for pressure conduits, while the Manning equation is usually used in open-channel situations (Viessman, 1993). The Hazen-Williams equation is:

$$V = 1.318\ C(R)^{0.63}\ (S)^{0.54}$$

where:

V = mean flow velocity
C = Hazen-Williams coefficient, based on material and age of the conduit
R = hydraulic radius
S = slope of energy gradeline (foot rise/foot run).

Exhibit 5-7. Example Outfall Bottle Rack Readings

Storm Event	Manhole Flow Level (inches)	Height of Overflow (inches)
1	21	9
2	18	6
3	12	none
4	48	36 (surcharge)
5	18	6
6	18	6
7	30	18
8	42	30 (surcharge)
9	24	12

The Manning Equation is:

$$V = (1.49/n)\,(R)^{0.666}\,(S)^{0.5}$$

where:

V = mean flow velocity
n = Manning roughness coefficient, based on type and condition of conduit
R = hydraulic radius
S = slope of energy gradeline (foot rise/foot run).

The volumetric flow rate (Q) is computed by: Q = VA where:

V = mean flow velocity
A = cross-sectional area.

Since the calculations are based on the average upstream characteristics of the pipe, personnel should measure depth at a point in the sewer where there are no bends or sudden changes in invert elevation immediately upstream. These features can introduce large errors into the flow estimate. Anomalies in sewer slope, shape, or roughness also can cause large errors (50 percent and greater) in flow measurement. However, in uniform pipes, a careful application of the formula can measure flows with an error as low as 10 to 20 percent (ISCO, 1989). The permittee can improve the accuracy of the equation somewhat by calibrating it initially, using measurements of velocity and depth to adjust slope and roughness values.

Velocity Meters

Velocity meters use ultrasonic or electromagnetic technology to sense flow velocity at a point, or in a cross section of the flow. The velocity measurement is combined with a depth value (from a depth sensor attached to the velocity meter) to compute flow volume. Velocity meters can measure flows in a wider range of locations and flow regimes than depth-sensing devices used with primary flow devices, and they are less prone to clogging. They are comparatively expensive, however, and can be inaccurate at low flows and when suspended-solid loads vary rapidly. (One type of meter combines an electromagnetic velocity sensor with a depth sensing pressure transducer in a single probe. It is useful for CSO applications because it can sense flow in surcharging and backflow conditions. This device is available as a portable model or for permanent installation.)

Measuring Pressurized Flow

Although sewage typically flows by gravity, many combined sewer systems use pumping stations or other means to pressurize their flow. Monitoring pressurized flow requires different techniques from those used to monitor gravity flows. If a station is designed to pump at a constant rate, the flow rate through the station can be estimated from the length of time the pumps are on. If a pump empties a wet well or cavern, the pumping rate can be determined by measuring the change in water level in the wet well. If the pump rate is variable, or pump monitoring time is insufficient to measure flow, then full-pipe metering is required.

Measuring Flow in Full Pipes

Full pipes can be monitored using orifices, venturis, flow nozzles, turbines, and ultrasonic, electromagnetic, and vortex shedding meters. Although most of these technologies require disassembling the piping and inserting a meter, several types of meters strap to the outside of a pipe and can be moved easily to different locations. Another measurement technique involves using two pressure transducers, one at the bottom of the pipe, and one at the top of the pipe or in the manhole just above the pipe crown. Closed pipe metering principles are discussed fully in *The Flow Measurement Engineering Handbook* (Miller, 1983). Manufacturers' literature should be consulted for installation requirements.

> **Note to reviewers:** Some of these measurement techniques may not be feasible in many systems or applications. If other techniques are more appropriate/feasible, please note them in your comments.

5.3.2 Conducting the Flow Monitoring Program

Most flow monitoring involves the use of portable, battery-operated depth and velocity sensors, which are left in place for several storm events and then moved elsewhere. For some systems, particularly small CSSs, the program may involve manual methods. In such cases, it is important to allocate the available personnel and prepare in advance for the wet weather events.

Although temporary metering installations are designed to operate automatically, they are subject to clogging in combined sewer systems and should be checked as often as possible for debris.

Some systems use permanent flow monitoring installations to collect data continuously at critical points. Permanent installations also can allow centralized control of transport system facilities to maximize storage of wastewater in the system and maximize flow to the treatment plant. The flow data recorded at the site may be recovered manually or telemetered to a central location.

To be of use in monitoring CSSs, flow metering installations should be able to measure all possible flow situations, based on local conditions. In a pipe with smooth flow characteristics, a weir or flume in combination with a depth sensor or a calibrated Manning equation may be sufficient. Difficult locations might warrant redundant metering and frequent calibration. The key to successful monitoring is combining good design and judgment with field observations, the appropriate metering technology, and a thorough meter maintenance and calibration schedule.

5.3.3 Analysis of CSS Flow Data

The CSS flow data can be evaluated to develop an understanding of the hydraulic response of the system to wet weather events and to answer the following questions for the monitored outfalls:

- Which CSO outfalls contribute the majority of the overflow volume?
- What size storm can be contained by the regulator serving each outfall? Does this containment capacity vary from storm to storm?
- *Approximately* how many overflows would occur and what would be their volume, based on a rainfall record from a different year? How many occur per year, on average, based on the long-term rainfall record?

Extrapolating from the monitored period to other periods, such as a rainfall record for a year with more storms or larger volumes, requires professional judgment and familiarity with the data. For example, as shown in Exhibit 5-8, the flow regulator serving Outfall 4 prevented overflows during Storm 3, which had 0.10 inch of rain in 1.4 hours. However, approximately half of the rainfall volume overflowed from Storm 5, which had 0.14 inch in 1.5 hours. From these data, the investigator might conclude that, depending on the short-term intensity of the storm or the antecedent moisture conditions, Outfall 4 would contain a future storm of 0.10 inches but that even slightly larger storms would cause an overflow. Also, Exhibit 5-8 indicates that a storm even as small as Storm 3 can cause overflows at the other outfalls.

Comparing the overflow volumes of different outfalls indicates which outfalls contribute the bulk of the overflow volume and, depending on loading measurements, may contribute most heavily to water quality problems. To compare the hydraulic performance of different outfalls, flows should be normalized against the drainage area and rainfall. Provided that rainfall data are representative of the area's rainfall, inches of overflow (spread over the discharge subarea) per

Exhibit 5-8. Total Overflow Volume

Storm	Rainfall Depth (R) (inches)	Duration (hours)	Outfall (and service area size, in acres)									
			#1 (659 acres)		#4 (430 acres)		#5(500 acres)		#7 (690 acres)		#9 (1,060 acres)	
			V	V/R	V	V/R	V	V/R	V	V/R	V	V/R
1	0.59	4.8	0.24	0.41	0.39	0.65	0.27	0.46	0.50	0.85	na	na
2	0.19	1.5	0.07	0.37	0.085	0.45	na	na	0.14	0.72	0.072	0.38
3	0.10	1.4	na	na	0.00	0.00	0.04	0.41	0.06	0.56	0.045	0.45
4	1.04	2.5	0.62	0.60	0.832	0.80	0.39	0.73	0.81	0.77	0.44	0.67
5	0.14	1.5	0.06	0.43	0.071	0.51	0.05	0.37	0.102	0.73	0.051	0.36
6	0.43	9.4	0.19	0.44	0.195	0.45	0.18	0.43	0.361	0.84	0.23	0.53
7	0.47	4.5	0.26	0.55	0.32	0.68	0.16	0.34	0.334	0.71	0.2	0.42
8	0.32	0.8	na	na	0.252	0.79	0.15	0.46	0.25	0.78	0.141	0.44
9	0.48	4.3	0.26	0.54	0.32	0.66	0.14	0.29	0.29	0.60	0.17	0.35
Average	0.42	3.41	0.24	0.48	0.27	0.55	0.17	0.43	0.32	0.73	0.17	0.45

V = overflow volume (inches depth when inches of overflow is spread over drainage area)
R = rainfall depth (inches)
na = no measurement available

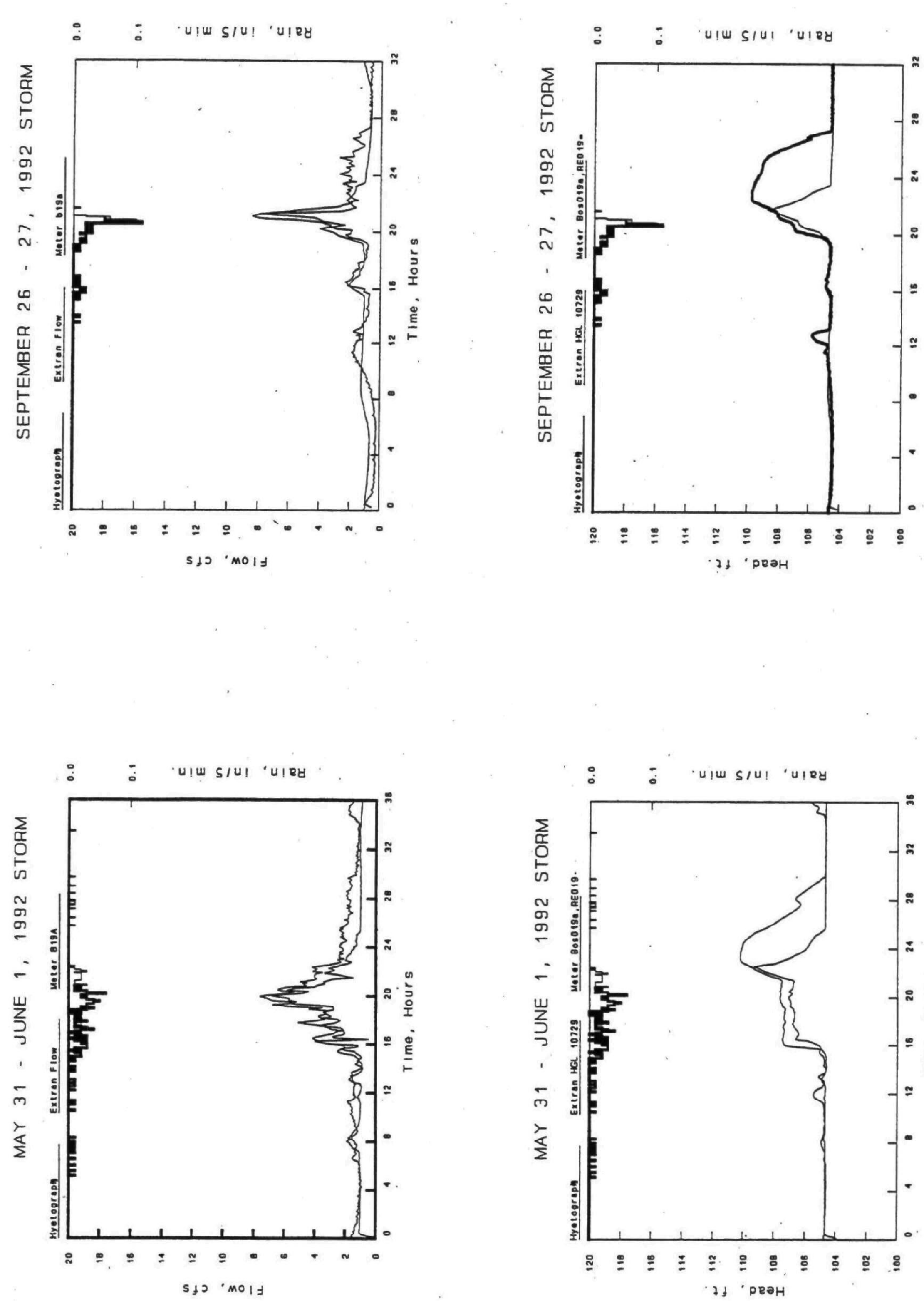
inch of rainfall constitutes a useful statistic. Exhibit 5-8 presents the overflow volumes in inches and the ratio of depth of overflow to depth of rain (V/R).

For each outfall, V/R varies with the storm depending on antecedent dry days, the time of the storm, and the maximum rainfall intensity. V/R also varies with the outfall depending on land characteristics such as its impervious portion, the hydraulic capacity upstream and downstream of the flow regulator, the operation of the flow regulator, and features that limit the rate at which water can enter the system draining to that overflow point. Because of the large number of factors affecting variations in V/R, small differences generally provide little information about overflow patterns. However, certain patterns, such as an increase in V/R over time or large differences in V/R between storms or between outfalls, may indicate design flaws, operational problems, maintenance problems, or erroneous flow measurements, or a rainfall gauge that does not represent the average depth of rain falling on the discharge subarea.

In addition to analyzing total overflow volumes for the CSOs, flow data can be used to create a plot of flow and head for a selected conduit during a storm event, as shown in Exhibit 5-9. These plots can be used to illustrate the conditions under which overflows occur at a specific outfall. They can also be used during CSS model calibration and verification (see Chapter 7).

Exhibits 5-8 and 5-9 (representing different CSS monitoring programs) illustrate some of the numerous methods available for analyzing CSO flow monitoring data. Flow data can also be used to tabulate CSO volumes and frequencies of overflows during the monitored time period and to compare the relative volumes and frequencies from different monitoring sites in the CSS. Such plotting, tabulating, and analysis of data are conducted prior to a modeling assessment as described in Chapter 7.

1 **Exhibit 5-9. Example CSS Plots of Flow and Head versus Time**



5.4 WATER QUALITY MONITORING IN THE CSS

Collecting and analyzing CSS wastewater samples is essential to characterizing an overflow and determining its impact on a receiving water body. Water quality monitoring information can be used to:

- Indicate potential exceedances of water quality criteria
- Indicate potential human health and aquatic life impacts
- Develop CSO quality models
- Assess pretreatment and pollution prevention programs as part of the NMC.

This section outlines various methods for collecting, organizing, and analyzing CSS wastewater data.

5.4.1 Quality Sampling

There are two basic aspects of wastewater quality sampling:

- Sample type (i.e., grab versus composite)
- Sample technique (i.e., manual versus automatic).

Sample type refers to the kind of sample collected—either grab or composite. Sample technique refers to the method by which a grab or composite sample is actually collected—either manually or by automatic sampler. Each of these sample types and techniques is discussed below.

Sample Types

In general, wastewater sample types fall into the following two categories:

- Grab samples
- Composite samples.

Grab Sampling. A grab sample is a discrete, individual sample collected over a period of time not greater than 15 minutes. Grab samples represent the conditions at the time the sample is taken and may not be representative of conditions at other times. Therefore, data from grab samples indicate the quality of CSS flow at a distinct point in time and do not account for variations in quality throughout a storm event. Multiple grab samples can be gathered at a station to define such variations, although costs increase due to additional labor and laboratory expenses.

Composite Sampling. A composite sample is a mixed or combined sample that is formed by combining a series of individual and discrete samples collected over a period of time, or representing more than one specific location or depth. Composite sampling provides data representing the overall quality of combined sewage averaged over a storm event. The composited sample can be collected by continuous filling of a container throughout the time period, a series of separate aliquots, or by combining individual grab samples from separate times, depths, or locations. Common types of composite samples include:

- ***Time composite samples*** - Composed of constant volume discrete sample aliquots collected at constant time intervals.

- ***Flow-weighted composite samples*** - Composed of samples combined in relation to the amount of flow observed in the period between the samples.

Flow-weighted compositing can be done in two ways:

- Collect samples at equal time intervals at a volume proportional to the flow rate (e.g., collect 100 ml of sample for every 100 gallons of flow that passed during a 10-minute interval).

- Collect samples of equal volume at varying times proportional to the flow (e.g., collect a 100 ml sample for each 100 gallons of flow irrespective of time).

The second method is preferable for sampling wet weather flows, since it results in the greatest number of samples when the flow rate is the highest. More detailed information on methods of flow weighting is presented in the *NPDES Storm Water Sampling Guidance Document* (U.S. EPA, 1992).

Sampling Methods

There are two methods of sample collection:

- ***Manual***—Each sample (whether grab or composite) or aliquot is obtained by an individual, either using equipment or by direct collection into the sample container or intermediate collection vessel.

- ***Automatic***—Sampling equipment (usually powered by battery or 120-volt power supply) is programmed to collect individual grab samples or composite samples based upon set time intervals or flow rates.

Manual and automatic sampling methods can be used to collect both grab and composite samples.

Manual Sampling. Manual samples are usually collected using a hand-held container. This method requires minimal equipment and allows field personnel to record additional observations while the sample is collected. Because of their special characteristics, certain pollutants should be collected manually. For example, fecal streptococcus, fecal coliform, and chlorine have very short holding times (i.e., 6 hours), pH and temperature need to be analyzed immediately, and oil and grease requires teflon-coated equipment to prevent adherence to the sampling equipment. Volatile compounds *must* be collected manually into the sample container according to standard procedures since these compounds will likely volatilize as a result of agitation during automatic sampler collection (APHA, 1992).

Manual sampling can be labor-intensive and expensive when the sampling program is long-term and involves many locations. Personnel must be available around the clock to sample storm events. Safety issues or hazardous conditions may affect sampling at certain locations.

Automated Sampling. Automated samplers are useful for CSS sampling because they can be pre-programmed to collect multiple discrete samples as well as single or multiple composited samples. They can collect samples on a timed basis or in proportion to flow measurement signals from a flow meter. Although these samplers require a large investment, they can reduce the amount of labor required in a sampling program and increase the reliability of flow-weighted compositing.

Automated samplers consist of a lower compartment, which holds glass or plastic sample containers and an ice well to cool samples, and an upper part, containing a microprocessor-based controller, a pump assembly, and a filling mechanism. The samplers can operate off of a battery, power pack, or electrical supply. More-expensive samplers have refrigeration equipment and require a 120-volt power supply. Many samplers can be connected to flow meters that will activate flow-weighted compositing programs, and some samplers are activated by inputs from rain gages.

Automated samplers also have limitations:

- Some pollutants cannot be sampled by automated equipment unless only approximate results are desired (e.g., oil and grease as mentioned above).

- The self-cleaning capability of most samplers provides reasonably separate samples, but some cross-contamination is unavoidable because water droplets usually remain in the tubing.

- Batteries may run down or the power supply may fail.

- Debris in the sewer, such as rags and plastic bags, can block the end of the sampling line, preventing sample collection. When the sampling line is located near a flow meter, this clogging can also cause erroneous flow measurements. Samplers and meters should be checked during storms and must be tested and serviced regularly. If no field checks are made during a storm event, data for the entire event may be lost.

Sampling Strategies

Since pollutant concentrations can vary widely during a storm event, the permittee should consider sampling strategies that include pre-storm, first flush, peak flows, recovery, and post-storm samples. For example, individual grab samples could be taken at each site during the different storm stages and analyzed. Another sampling regime the permittee can use is combining samples collected during the stages at each site:

- Pre-storm grab sample
- Composite grab samples collected during first flush
- Composite samples collected during peak flow
- Composite samples collected after peak flows
- Post-storm sample.

A third possible sampling regime could include a first flush composite taken over the first 30 minutes of discharge, followed by a second composite over the next hour of discharge, followed by a third composite for the remainder of the storm. These types of sampling regimes can better capture the varying concentrations (i.e., higher concentrations during first flush followed by declining concentrations for later discharges) that are often found in combined sewer systems.

Contaminants Requiring Special Collection Techniques

The above discussion focuses on CSS sampling for contaminants with no special collection requirements. The following contaminants have special handling requirements (as identified in 40 CFR Part 136).

- ***Bacteria***—Samples collected for bacteria analysis cannot be held for more than six hours, and most laboratories recommend that the sample be returned the same day it is collected. Automatic samplers are not appropriate for collecting bacterial samples, so they must be collected manually. Bacteria are collected directly into a sterile container or plastic bag, and care must be taken not to contaminate the sample by touching it. Often the samples are preserved with sodium thiosulfate.

- ***Volatile Organic Compounds (VOC)***—VOCs are collected directly into special glass vials. Each vial must be filled so that there is no air space into which the VOCs can volatilize and be lost.

- *Oil and Grease*—Oil and grease must be collected by grab sample using a glass jar with a teflon-coated lid. Samples are preserved by lowering the pH below 2.0 using a strong acid.

The monitoring program may also include toxicity testing, in which the acute and chronic impacts to aquatic life are determined. Procedures for toxicity testing for wet weather discharges may be found in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA, 1991a).

Sample Preparation and Handling

Sample bottles are typically supplied by the laboratory that will perform the analysis. Laboratories may provide properly cleaned sampling containers with appropriate preservatives. For most parameters, preservatives should be added to the container after the sample. To avoid hazards from fumes and spills, acids and bases should not be in containers without a sample. If preservation is by adjusting sample pH, the preserved sample should always be checked to make sure it is at the proper pH level. The laboratory will usually indicate the maximum allowed holding period for each analysis. Acceptable procedures for cleaning sample bottles, preserving their contents, and analyzing for appropriate chemicals are detailed in various methods manuals, including APHA (1992) and U.S. EPA (1979).

Water samplers, sampling hoses, and sample storage bottles should always be made of materials compatible with the pollutants being sampled. For example, when metals are the concern, bottles should not have metal components that can contaminate the samples. Similarly, when organic contaminants are the concern, bottles and caps should be made of materials not likely to leach into the sample.

Sample Volume, Preservation, and Storage. Sample volumes, preservation techniques, and maximum holding times for most parameters are specified in 40 CFR Part 136. Refrigeration of samples during and after collection at a temperature of 4°C is required for most analyses. Manual samples are usually placed in a cooler containing ice or an ice substitute. Most automated samplers have a well next to the sample bottles to hold either ice or ice substitutes.

Some expensive samplers have mechanical refrigeration equipment. Other preservation techniques include pH adjustment and chemical fixation. pH adjustment usually requires strong acids and bases, which should be handled with extreme caution.

Sample Labeling. Samples should be identified by waterproof labels containing enough information to ensure that each is unique. The information on the label should also be recorded in a sampling notebook. The label typically includes the following information:

- Name of project
- Date and time of sample collection
- Name or initials of sampler
- Analysis to be performed
- Sample ID number
- Preservative used
- Type of sample (grab, composite).

Sample Packaging and Shipping. Sometimes it is necessary to ship samples to the laboratory. Holding times should be checked prior to shipment to ensure that they will not be exceeded. While wastewater samples generally are not considered hazardous, some samples, such as those with extreme pH, will require special procedures. If the sample is shipped through a common carrier or the U.S. Postal Service, it must comply with Department of Transportation Hazardous Material Regulations (49 CFR Parts 171-177). Air shipment of samples classified as hazardous may also be covered by the Dangerous Goods Regulations (International Air Transport Association, 1996).

Samples should be sealed with chain-of-custody form seals in leak-proof bags and padded against jarring and breakage. Samples must be packed with an ice substitute to maintain a temperature of 4°C during shipment. Plastic or metal coolers make ideal shipping containers because they protect and insulate the samples. Accompanying paperwork such as the chain of custody documentation should be sealed in a waterproof bag in the shipping container.

Chain of Custody. The chain of custody form documents the changes of possession of a sample between time of collection and time of analysis. At each transfer of possession, both the relinquisher and the receiver sign and date the form in order to document transfer of the samples and to minimize opportunities for tampering. The container holding the samples can also be sealed with a signed tape or seal to document that the samples are uncompromised.

Copies of the chain of custody form should be retained by the sampler and by the laboratory. Often contract laboratories supply chain of custody forms with sample containers. The form is also useful for documenting which analyses will be performed on the samples. Forms typically contain the following information:

- Name of project and sampling locations
- Date and time that each sample is collected
- Names of sampling personnel
- Sample identification names and numbers
- Types of sample containers
- Analyses to be performed on each sample
- Additional comments on each sample
- Names of all personnel transporting the samples.

5.4.2 Analysis of Wastewater Monitoring Data

Since monitoring programs can generate large amounts of information, effective management and analysis of the data are essential. Even small-scale programs, such as those involving only a few CSS and receiving water monitoring locations, can generate an extensive amount of data. This section discusses tools for data analysis including spreadsheets, graphical presentations, and statistical analysis. (Data management is discussed in Section 4.7.2. Chapters 7 and 8 discuss more detailed data analysis during modeling.)

This section outlines an example analysis of data collected during three storms, where flow-weighted composite samples were collected and analyzed for BOD and TSS. Exhibit 5-10

Exhibit 5-10. Composite Sampling Data (mg/l)

	Storm #2		Storm #4		Storm #8		Average	
Outfall	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
1	115	340	80	200	110	240	102	260
4	96	442	94	324	120	350	103	372
5	128	356	88	274	92	288	103	306
7	92	552	82	410	71	383	82	448
9	110	402	120	96	55	522	95	340
Average	108	418	93	261	90	357	97	345

shows average concentrations for each storm at the monitored outfalls; the small sample size does not provide statistically reliable information on the expected variability of these concentrations for other events. Exhibit 5-11 shows that the mean and median for the data are similar. To determine expected values over a large sample size (i.e., more storm events), the projected mean, median, and 90th-percentile value for the data were computed assuming a lognormal distribution. (The lognormal distribution has been shown to be applicable to CSO quality (Driscoll, 1986).) If used as a basis for estimating impacts, the 90th percentile values would be more conservative than the means for BOD and TSS since only 10 percent of the actual concentrations for these pollutants should exceed the 90th-percentile values.

Exhibit 5-11. Pollutant Concentration Summary Statistics (mg/l)

	BOD	TSS
Mean	96.87	345.27
Median	94.00	350.00
Projected Mean*	97.16	352.53
Projected Median*	94.70	321.29
Projected 90th Percentile Value*	126.64	558.03

*Projected statistic from sampling population (i.e., very large data set)

Multiplying flow measurements (or estimates) by pollutant concentration values drawn from monitoring data gives the total pollutant load discharged during each storm at each outfall. Exhibit 5-12 lists pollutant loads for the three storms at each monitored outfall. As with flow data, these brief statistical summaries provide insight into the response of the system before performing more involved computer modeling. For example, the load in pounds of BOD and TSS discharged by each outfall, normalized by rainfall depth or land area, helps to identify differences in loading rates between outfalls over the long term. These loading factors can provide rough estimates of the loads from unmonitored outfalls that have land uses or impervious areas similar to the monitored area. Finally, the total load per storm helps in comparing storms and projecting storm characteristics that would produce higher or lower loads. The number of dry days and the number of days without a flushing storm affect pollutant loads, because these factors represent a period when no severe scour activity occurred in the sewer system.

Three storms can indicate trends but do not provide enough data to characterize the load of the CSS or its individual source areas. As additional data are collected during the monitoring program, estimates based on the data set become statistically more reliable because the size of the data sets increases. The additional information allows continual refinement of the permittee's knowledge of the system.

The following example, involving bacteria sampling, illustrates some additional important issues. Because automated samplers are not appropriate for collecting bacterial samples, manual grab samples were collected and analyzed for fecal coliform bacteria. During a single storm event, samples were collected from Outfall 1 at 30-minute intervals, beginning shortly after the storm started and ending with sample #6 approximately 2½ hours later (Exhibit 5-13). Peak flow occurred within the first 90 minutes. The fecal coliform concentration peaked in the first half hour and declined more than one-hundredfold to the last sample, exhibiting a "first flush" pattern. The geometric mean for these samples was 1.79×10^6 MPN/100 ml. To calculate total fecal coliform loading, flow measurements were multiplied by the corresponding grab sample concentrations at each half-hour interval. The geometric mean concentration was also multiplied by the total flow for comparative purposes. This calculation underestimates the total by a factor

1

Exhibit 5-12. Pollutant Loading Summary

		OUTFALL					
		1	4	5	7	9	TOTAL
STORM 2	Flow (MG)	1.39	0.99	na	2.55	2.07	7.00
composite	BOD (mg/l)	115	96	128	92	110	-
composite	TSS (mg/l)	340	442	356	552	402	-
load	BOD (lbs)	1,333	793	0	1,957	1,899	5,982
load	TSS (lbs)	3,941	3,649	0	11,739	6,940	26,269
STORM 4	Flow (MG)	11.67	9.72	5.31	15.09	12.64	54.43
composite	BOD (mg/l)	80	94	88	82	120	-
composite	TSS (mg/l)	200	324	274	410	96	-
load	BOD (lbs)	7,786	7,620	3,897	10,320	12,650	42,273
load	TSS (lbs)	19,466	26,265	12,134	51,599	10,120	119,584
STORM 8	Flow (MG)	na	2.95	2.00	4.68	4.07	13.70
composite	BOD (mg/l)	110	120	92	71	55	-
composite	TSS (mg/l)	240	350	288	686	522	-
load	BOD (lbs)	0	2,952	1,535	2,771	1,867	9,125
load	TSS (lbs)	0	8,611	4,804	26,775	17,719	57,909
Total Load*	BOD (lbs)	9,119	11,365	5,432	15,048	16,416	57,380
	TSS (lbs)	23,407	38,525	16,938	90,113	34,779	203,762
Area Load**	BOD	7	9	5	7	5	7
(lb/acre/storm)	TSS	18	30	17	44	11	24
Loading Rate	BOD	7,417	7,329	3,997	9,709	10,595	7,809
(lb/inch rain)	TSS	19,038	24,843	12,465	58,144	22,440	27,386

na = No flow data available. MG = millions of gallons.
load (lbs) = composite concentration (mg/l) x flow (MG) x 8.34 (conversion factor)
* For monitored storms
** Acreage data taken from Exhibit 5-8; for monitored storms (i.e., either 2 or 3)

Exhibit 5-13. Fecal Coliform Data Outfall 1, Example Storm

Sample	Fecal Coliform Concentration (No./100 ml)	CSO Flow 30 Minute Avg (cfs)	Load* (No. of Fecal Coliforms)
1	2.00 E+07	9.1	9.27 E+13
2	1.40 E+07	20.4	1.45 E+14
3	6.40 E+06	29.8	9.72 E+13
4	3.10 E+06	25.4	4.01 E+13
5	5.00 E+04	10.6	2.70 E+11
6	1.20 E+05	6.5	3.97 E+11
		Total Load	**3.76 E+14**

Geometric Mean	Mean Flow	Estimated Total Load**
1.79 E+06	17.0	**9.30 E+13**

* Load = [Concentration (No./100 ml) × Total Flow (ml)] / 100 (since concentration is for 100 ml)
Total Flow (in ml) = cfs × 1800 (# of seconds in one 30-minute interval) × 28,321 (# of ml in one cf)

** Load estimated by multiplying geometric mean bacteria by the total flow

of three, primarily because it fails to correlate the high bacteria level to the high flows. This example illustrates the value of correlating flow and concentration.

In many cases background conditions or upstream wet weather sources may provide significant pollutant loads. It is also common to have discharges from separate storm sewer systems entering the same receiving water segment as CSOs. In such cases estimation of pollutant loads from non-CSO sources is important so that loadings from these sources can be taken into account when assessing receiving water impacts from CSOs. The permittee should consider monitoring these and other non-CSO wet weather sources so that pollutant loads may be calculated. The data analysis techniques discussed in this section apply equally well to other wet weather sources, although the pollutant concentrations in such sources may differ significantly.

Single composite samples or average data may be sufficient for a preliminary estimate of pollutant loadings. Establishing an upper bound estimate for CSS pollutant loads may be necessary in order to analyze short-term impacts based on short-term pollutant concentrations in the receiving water and to develop estimates for rare events, which have not been measured. A statistical distribution, such as normal or lognormal, can be developed for the data and mean values and variations can be estimated. These concentrations can be multiplied by measured flows or an assumed design flow to generate storm loads in order to predict rare or extreme impacts. Chapters 8 and 9 discusses further how to predict receiving water impacts.

CHAPTER 6

RECEIVING WATER MONITORING

This chapter discusses techniques and equipment for receiving water monitoring, including hydraulic, water quality, sediment, and biological sampling procedures. The techniques vary in applicability and complexity, but all are generally applicable to CSO-impacted receiving waters. In collecting and analyzing receiving water monitoring data, the permittee needs to implement a quality assurance and quality control (QA/QC) program to ensure that accurate and reliable data are used for CSO planning decisions (see Section 4.7.1).

6.1 THE CSO CONTROL POLICY AND RECEIVING WATER MONITORING

The CSO Control Policy discusses characterization and monitoring of receiving water impacts as follows:

- *In order to design a CSO control plan adequate to meet the requirements of the CWA, a permittee should have a thorough understanding of its sewer system, the response of the system to various precipitation events, the characteristics of the overflows, and the water quality impacts that result from CSOs.*

- *The permittee should adequately characterize...the impacts of the CSOs on the receiving waters and their designated uses. The permittee may need to consider information on the contribution and importance of other pollution sources in order to develop a final plan designed to meet water quality standards.*

- *The permittee should develop a comprehensive, representative monitoring program that ... assesses the impact of the CSOs on the receiving waters. The monitoring program should include necessary CSO effluent and ambient in-stream monitoring and, where appropriate, other monitoring protocols such as biological assessment, toxicity testing and sediment sampling. Monitoring parameters should include, for example, oxygen demanding pollutants, nutrients, toxic pollutants, sediment contaminants, pathogens, bacteriological indicators (e.g., Enterococcus, E. Coli), and toxicity. A representative sample of overflow points can be selected that is sufficient to allow characterization of CSO discharges and their water quality impacts and to facilitate evaluation of control plan alternatives. (II.C.1)*

As discussed in Chapter 2, the permittee will use either the presumption approach or the demonstration approach in assessing attainment of WQS. Under the demonstration approach, the municipality demonstrates the adequacy of its CSO control program to attain WQS. Generally, municipalities selecting the demonstration approach will need to monitor receiving waters to show that their control programs are adequate.

The presumption approach is so named because it is based on the presumption that WQS will be met when certain performance-based criteria identified in the CSO Policy are achieved, as shown by the permittee in its LTCP. The regulatory agency is likely to request some validation of the presumption, such as receiving water quality sampling or end-of-pipe sampling of overflows combined with flow information and dilution calculations. Discussion of the different modeling considerations related to the demonstration and presumption approaches is included in Chapters 7 (CSS Modeling) and 8 (Receiving Water Quality Modeling).

6.2 RECEIVING WATER HYDRAULICS

When a CSO enters a receiving water body, it is subject to fate and transport processes that modify pollutant concentrations in the receiving water body. The impact of CSOs to receiving waters is largely determined by the hydraulics of the receiving water body and the relative magnitude of the CSO loading. Assessing receiving water hydraulics is an important first step in a receiving water study, since an understanding of how CSOs are transported and diluted is essential to characterizing their impacts on receiving waters. Awareness of large-scale and small-scale hydrodynamics can help in determining where to sample in the receiving water for the effects of CSOs. Large-scale water movement largely determines the overall transport and transformation of pollutants. Small-scale hydraulics, such as water movement near a discharge point (often called near-field), determine the initial dilution and mixing of the discharge. For example, a discharge into a wide, fast-flowing river might not mix across the river for a long distance since it will quickly be transported downstream.

6.2.1 Hydraulic Monitoring

Hydraulic monitoring involves measuring the depth and velocity of the receiving water body and its other physical characteristics (e.g., elevation, bathymetry, cross section) in order to assess transport and dilution characteristics. This may include installation of gages on either a temporary or long-term basis to determine depth and velocity variations during wet weather events. In all cases, existing mapping or a new survey of the physical characteristics of the receiving water is necessary for interpretation of the hydraulic data and understanding of the hydraulic dynamics of the receiving water. (Section 4.5 discusses receiving water sampling designs and the selection of monitoring locations.)

Identifying a suitable hydraulic monitoring method depends largely on the type and characteristics of receiving water.

Rivers and Streams

In rivers and streams, flow rate is generally a factor of the depth, width, cross-sectional area, and hydraulic geometry of the river or stream channel. Flow in rivers and streams is usually determined by measuring the stage (elevation of water above a certain base level) and relating stage to discharge with a rating curve. This relationship is developed by measuring flow velocity in the stream or river at different stages, and using velocity and the area of the stream or river channel to determine the total discharge for each stage (Bedient and Huber, 1992). For large rivers and streams, long-term flow and geometry data are often available for specific gaging stations from the USGS and the U.S. Army Corps of Engineers.

For a CSO outfall located near a USGS gage, the monitoring team can use relative watershed areas to estimate flow at the discharge site.[1] Flow information may also be available from stage measurements at bridge crossings and dams, and from studies performed by other State and Federal agencies. In the absence of such flow data, the permittee may need to install stage indicators or use current meters to collect flow measurements. Many of the CSO flow

[1]For example, the 5,000-square mile Merrimack River watershed in New Hampshire and Massachusetts has 46 USGS gages that monitor most of the larger tributaries and the main stem in several locations.

monitoring devices described in Exhibit 5-5 of Chapter 5 may apply to open channel flow in rivers and streams. The USGS (1982) and USDI (1984) have published detailed manuals on stream gaging techniques.

Estuaries and Coastal Areas

Estuaries and coastal areas are regions connecting rivers and oceans and thus represent a complex system of tides, salinity from the ocean, and upstream drainage from the river. Tidal variations and density effects from the varying levels of salinity need to be defined to determine how pollutants from CSOS are transported.

Tidal variations affect estuarine circulation patterns which, along with salinity patterns, determine how pollutant loadings entering the estuary or coastal area are dispersed. Based on velocity and salinity patterns, estuaries can be classified as one of the following types:

- ***Stratified estuaries*** have large fresh water inflows over a salt water layer. Tidal currents are not sufficient to mix the separate layers. Transport of pollutants is largely dependent on the difference in the densities of the pollutants and the receiving water.

- ***Well-mixed estuaries*** have a tidal flow much greater than the river outflow, with mixing and flow reversal sufficient to create a well-mixed water column at all depths. Pollutants tend to move with the motion of the tides and are slowly carried seaward.

- ***Partially-mixed estuaries*** have flow and stratification characteristics between the other two types and have tide-related flows much greater than river flows. Pollutant transport depends somewhat on density, but also involves significant vertical mixing.

Classification depends on the river outflow at the given time, with large river flows leading to more stratified estuaries (EPA, 1985b).

Tidal height data and current predictions, published annually by NOAA, may provide sufficient information, or it may be necessary to install a new tide gage (stage monitor) to develop data closer to the CSO-impacted area. Due to the variation of tides and winds, estuarine and coastal currents often change rapidly. It is necessary, therefore, to measure tides and currents simultaneously using continuous recording depth and velocity meters. Tidal currents can be measured with meters similar to those used for measurement of river currents, but the direction of the currents must also be recorded. Information on monitoring methods for such areas may also be found in USGS (1982) and USDI (1984).

Lakes

The hydraulic characteristics of lakes depend on several factors, including the depth, length, width, surface area, volume, basin material, surrounding ground cover, typical wind patterns, and surface inflows and outflows (including CSOs). Lakes tend to have relatively low flow-through velocities and significant vertical temperature gradients, and thus are usually not well-mixed (Thomann and Mueller, 1987). To determine how quickly pollutants are likely to be removed from a lake, it is necessary to define the flushing rate. The flushing rate depends on water inputs (inflows and precipitation) and outputs (outflows, evaporation, transpiration, and withdrawal), pollutants and their characteristics, and the degree of mixing in the lake. Mixing in lakes is primarily from the wind, temperature changes, and atmospheric pressure.

Analysis of pollutant fate and transport in lakes is often complex and generally requires the use of detailed simulation models. Some less-complex analysis can be done when simplifying assumptions, such as complete mixing in the lake, are made. To perform these analyses, parameters that need to be defined include lake volume, surface area, mean depth, and mean outflow and inflow rates. Analytical and modeling methods for lakes and the data necessary to use the methods are discussed in greater detail in Section 8.3.2 and in Thomann and Mueller (1987) and Viessman, et al. (1977).

6.2.2 Analysis of Hydraulic Data

Analysis of hydraulic data in receiving waters will allow estimation of the flow rate based on depth measurement. This analysis may involve:

- Developing stage-discharge, area-depth, or volume-depth curves for specific monitoring locations, using measured velocities to calibrate the stage-discharge relationship (methods for various types of flow monitoring stations are presented in USGS (1982) and USDI (1984))

- Pre-processing the data for input into hydraulic models

- Plotting and review of the hydraulic data

- Evaluating the data to define hydraulic characteristics, such as initial dilution, mixing, travel time, and residence time.

Plotting programs such as spreadsheets and graphics programs are useful for presenting hydraulic data. A data base, supplemented with a plotting and statistical analysis package, will typically be necessary to analyze the data and generate such information as:

- Plots of depth, velocity and flow vs. time

- Plots of depth, velocity and flow vs. distance from the outfall

- Frequency distributions of velocities and flows

- Vector components of velocities and flows

- Means, standard deviations, and other important statistical measures for depth, velocity, and flow data.

As presented later in Chapter 8, receiving water models need physical system and hydraulic data as input. Processing of input data is specific to each model. In general, however, the physical characteristics of the receiving water (slopes, locations, and temperatures) are used to develop the model computational grid. The measured hydraulic data (depths, velocities, and flows) are used to compare with model calculations for purposes of model validation.

6.3 RECEIVING WATER QUALITY

Collection and analysis of receiving water quality data are necessary when available data are not sufficient to describe water quality impacts from CSOs. This section discusses how to conduct a receiving water sampling program and analyze data for chemical quality. (Chapters

3 and 4 discuss how to identify sampling locations, sampling parameters, and sampling frequency. Section 6.4 discusses biological and sediment sampling and analysis.)

6.3.1 Water Quality Monitoring

Receiving water monitoring involves many techniques similar to CSS monitoring (see Section 5.4.1) and many of the same decisions, such as whether to collect grab or composite samples and whether to use manual or automated methods. Receiving water quality monitoring involves the parameters discussed in Section 4.5.3 as well as field measurement of parameters such as temperature and conductivity.

Sample Program Organization

Sampling receiving waters, especially large water bodies, requires careful planning and a sizable resource commitment. For example, a dye study of a large river requires careful planning regarding travel time, placement of sampling crews, points of access, and use of boats. Sampling of wet weather events is typically more complicated than for dry weather, often requiring rapid mobilization of several sampling teams on short notice, sampling throughout the night, and sampling in rainy conditions with higher-than-normal flows in the receiving water body. Time of travel between the various sampling stations may necessitate the use of additional crews if sample collection must occur at predetermined times.

Wet weather sampling requires specific and accurate weather information. Local offices of the American Meteorological Society can provide a list of Certified Consulting Meteorologists who can provide forecasting services specific to the needs of a sampling program. Radar contact can also be established for real-time observation of conditions. While these efforts represent an additional cost to the program, they may result in significant savings in costs associated with false starts and unnecessary laboratory charges.

The rainfall, darkness, and cold temperatures that often accompany wet weather field investigations can make even small tasks difficult. Contingency planning and extensive preparation can, however, minimize mishaps and help to ensure safety. Prior to field sampling, the permittee should ensure that:

- Sampling personnel are well trained and familiar with their responsibilities, as defined in the sampling plan
- Personnel use proper safety procedures
- A health and safety plan identifies the necessary emergency procedures and safety equipment
- Sample containers are assembled and bottle labels are filled out to the extent possible
- All necessary equipment is inventoried, field monitoring equipment is calibrated and tested, and equipment such as boats, motors, automobiles, and batteries are checked.

Sample Preparation and Handling

As discussed in Section 5.4.1, sample collection, preparation and handling, preservation, and storage should minimize changes in the condition of sample constituents. The standard procedures for collecting, preserving, and storing receiving water samples are the same as those for combined sewage samples and are described in 40 CFR Part 136. Procedures for cleaning sample bottles, preserving water quality samples, and analyzing for appropriate chemicals are detailed in various methods manuals, including APHA (1992) and U.S. EPA (1979). Samples should be labeled with unique identifying information and should have chain of custody forms documenting the changes of possession of the samples between time of collection and time of analysis (see Section 5.4.1).

6.3.2 Analysis of Water Quality Data

As was the case for hydraulic data, water quality data for receiving waters are analyzed by plotting and reviewing the raw data to define water quality characteristics and by processing the data for input to water quality models. Data can be analyzed and displayed using spreadsheets, databases, graphics software, and statistical packages, such as Statistical Analysis Software (SAS) and Statistical Package for Social Sciences (SPSS).

Simple receiving water analyses could include:

- Comparing receiving water quality with applicable water quality criteria to determine whether criteria are being exceeded

- Comparing sampling results from before, during, and after a wet weather event to indicate whether water quality problems are attributable to CSOs and other wet weather events

- Comparing data upstream from CSOs with data from downstream to distinguish CSO impacts.

Water quality data are also used to calibrate receiving water models (see Chapter 8). This is generally facilitated by plotting the data vs. time and/or distance to compare with model simulations. Special studies may be required to determine rate constants, such as bacteria die-off rates or suspended solids settling rates, if these values are used in the model.

6.4 RECEIVING WATER SEDIMENT AND BIOLOGICAL MONITORING

It is often difficult and expensive to identify CSO impacts during wet weather using only hydraulic and water quality sampling. As acknowledged in the CSO Control Policy, *"... data and modeling of wet weather events often do not give a clear picture of the levels of CSO controls necessary to protect WQS."* Sediment and biological monitoring may serve as cost-effective supplements or even as alternatives to water quality sampling. The following sections discuss sediment and biological sampling techniques and data analysis.

6.4.1 Sediment Sampling Techniques

Receiving water sediments are sinks for a wide variety of materials. Nutrients, metals, and organic compounds bind to suspended solids and settle to the bottom of a water body when flow velocity is insufficient to keep them in suspension. Once re-suspended through flood scouring, bioturbation, desorption, or biological uptake, free contaminants can dissolve in the water column, enter sediment-dwelling organisms, or accumulate or concentrate in fish and other aquatic organisms and subsequently be ingested by humans and other terrestrial animals.

Typically, CSOs contain suspended material that can settle out in slower-moving sections of receiving waters. Sediments can release accumulated contaminants for years after overflows have been eliminated.

Sediment samples are collected using hand or winch-operated dredges as follows:

- The device is lowered through the water column by a hand line or a winch.
- The device is then activated either by the attached line or by a weighted messenger sent down the line.
- The scoops or jaws of the device close either by weight or spring action.
- The device is retrieved to the surface.

Ideally, dredging should disturb the bottom as little as possible and collect all fine particles.[2]

Sediments can also be collected by core sampling to determine how pollutant types, concentrations, and accumulation rates have varied over time. Sediments must be physically amenable to coring, however.

To avoid sample contamination, sediments should be removed from the dredge or core sampler by scraping back layers in contact with the device and extracting sediments from the central mass of the sample. In many cases the upper-most layer of sediment will be the most contaminated and, therefore, of most interest. Sediment samples for toxicological and chemical examination should be collected following method E 1391 detailed in *Standard Guide for Conducting Sediment Toxicity Tests with Freshwater Invertebrates* (ASTM, 1991).

[2]Commonly used sediment samplers include the Ponar, Eckman, Peterson, Orange-peel, and Van Veen dredges. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters* (Klemm, 1990) has detailed descriptions of such devices.

6.4.2 Analysis of Sediment Data

CSO investigations will benefit from analysis of a range of sediment characteristics, including physical characteristics (grain size, distribution, type of sediment), chemical composition, and benthic makeup (discussed in Section 6.4.3). These characteristics should also be evaluated in sediments from upstream reference stations and sediments from non-CSO sources to facilitate comparison with sediments near the CSO outfall.

Sediment data are typically analyzed by developing grain size distributions and plotting concentrations of chemicals vs. distance. If the area of interest is two-dimensional horizontally, isopleths can be plotted showing contours of constant concentration from the CSO outfall. If vertical variations from core samples are available, concentration contours can also be plotted vs. depth. Sediment chemistry data may be statistically analyzed to compare areas that are affected by CSOs, non-CSO sources, and unaffected (background) areas. These analyses can give a longer-term view of CSO impacts than water quality monitoring.

6.4.3 Biological Sampling Techniques

Evaluation of aquatic organisms is another way to obtain information on cumulative impacts of CSOs, since resident communities of aquatic organisms integrate over time all the environmental changes that affect them.

Collection and Handling of Biological Samples

This section describes collection techniques for fish, phytoplankton, zooplankton, and benthic macroinvertebrates. Additional information is in Exhibit 6-1.

Fish. Although other aquatic organisms may be more sensitive to pollutants, fish generate the greatest public concern. Observable adverse effects from pollutants include declines of populations and tumor growth on individuals. Fish monitoring programs can identify the relative and absolute numbers of individuals of each species; the size distributions within species; growth rates; reproduction or recruitment success; the incidence of disease, parasitism, and tumors; changes in behavior; and the bioaccumulation of toxic constituents.

Exhibit 6-1. Overview of Field Biological Sampling Methods

Sample Parameter	Information Gained	Method of Collection	References
Phytoplankton Algae	· Chlorophyll a · Community structure · Primary productivity · Biomass · Density	· Plankton buckets attached to a vertical or horizontal tow net (e.g., Wisconsin style net) · Discreet depth samples using VanDorn or Kemmer bottles · Periphytometer	American Public Health Association--(APHA), 1992; American Society for Testing and Materials--(ASTM), 1991; Lind, 1985; Vollenweider, 1969; Weber, 1989; Wetzel and Likens, 1979
Limitations:	Small organisms can pass through the net, and periphytometers are only good for algae that attach to a substrate.		
Riparian and aquatic macrophytes	· Community structure · Distributions, depth & basin wide · Biomass · Density · Tissue analysis	· Usually qualitative visual assessments · Quantitative assessments use quadrant or line point methods	APHA, 1992; ASTM, 1991; Dennis and Isom, 1984; Vollenweider, 1969; Weber, 1989; Wetzel and Likens, 1979; Plafkin et al., 1989
Limitations:	Limited to the growing season for many species.		
Zooplankton	· Community structure · Distributions · Biomass · Sensitivity · Density	· Plankton buckets attached to a vertical or horizontal tow net (e.g., Wisconsin style net) · Discreet depth samples using VanDorn or Kemmer bottles	APHA, 1992; ASTM, 1991; Lind, 1985; Pennak, 1989; Weber, 1989; Wetzel and Likens, 1979
Limitations:	Small organisms can pass through the net; some zooplankton migrate vertically in the water column, therefore it is possible to miss some species.		
Benthic invertebrates	· Community structure · Biomass · Density · Distribution · Tissue analysis	· Ponar grab sampler · Eckman dredge sampler · Surber · Hess · Kick net or D-ring net · Artificial substrates	APHA, 1992; ASTM, 1991; Lind, 1985; Merritt and Cummins, 1984; Pennak, 1989; Weber, 1989; Klemm et al., 1990; Wetzel and Likens, 1979; Plafkin et al., 1989
Limitations:	Some methods are time consuming and labor intensive; some methods are depth restrictive (e.g., can only be used in shallow waters).		
Fish	· Community structure · Distributions, depth & basin wide · Biomass · Density · Bioconcentration · Fecundity	· Electroshocking · Seines · Gill nets · Trawls · Angling · Traps	APHA, 1992; ASTM, 1991; Everhart et al., 1975; Nielsen and Johnson, 1983; Plafkin et al., 1989; Schreck and Moyle, 1990; Ricker, 1975; Weber, 1989
Limitations:	Each method is biased to some degree as to the kind and size of fish collected. Some methods are designed for use in relatively shallow water.		

Common methods of sampling fish include angling, seines, gill and trap nets, and electrofishing. The references shown in Exhibit 6-1 provide guidance on methods used for collection, measurement, preservation, and analysis of fish samples.[3]

Phytoplankton. Phytoplankton are free-floating, one-celled algae. They are useful in monitoring receiving water quality because many species are highly sensitive to specific chemicals. Because phytoplankton have relatively rapid rates of growth and population-turnover (approximately 3 to 5 days during the summer season), only short-term CSO impacts can be analyzed. Laboratory analyses can provide information on the abundance of each taxon, the presence of, or changes in, populations of indicator species, and the total biomass of phytoplankton present. Lowe (1974) and VanLandingham (1982) provide useful guides to the environmental requirements and pollution tolerances of diatoms and blue-green algae, respectively.

Zooplankton. Zooplankton are free-floating aquatic protozoa and small animals. Many species are sensitive indicators of pollution. Particularly in lakes and reservoirs, zooplankton can provide information on the presence of specific toxics. Zooplankton are often collected by towing a plankton net through a measured or estimated volume of water. To calculate population density it is necessary to determine the volume of the sampling area, using a flow meter set in the mouth of the net or calculations based on the area of the net opening and the distance towed. Laboratory analyses can provide information similar to that for phytoplankton.

Benthic Macroinvertebrates. Benthic macroinvertebrates are organisms such as plecoptera (stoneflies), ephemeroptera (mayflies), and trichoptera (caddisflies) that live in and on sediments. Like plankton, benthic macroinvertebrates include useful indicator species that can

[3]Two reference works published by the American Fisheries Society are especially informative. *Fisheries Techniques* (Nielsen and Johnson, 1983) focuses mainly on field work considerations, discussing most of the sampling techniques currently practiced. The companion volume, *Methods for Fish Biology* (Schreck and Moyle, 1990), focuses primarily on methods used to analyze and assess collected fish samples. It includes material on fish growth, stress and acclimation, reproduction, behavior, population ecology, and community ecology.

provide valuable information about the presence and nature of toxics in the sediments of lakes and reservoirs.

Monitoring teams generally use dredges to sample benthic macroinvertebrates. Samples are either preserved in their entirety in polyethylene bags or other suitable containers or are washed through a fine sieve and then preserved in a suitable container (Klemm et al., 1990). The sample can be analyzed for taxa present, the total density of each taxon, relative abundance by numbers or biomass of these taxa, changes in major and indicator species populations, and the total biomass of benthic macroinvertebrates present.[4]

6.4.4 Analysis of Biological Data

Community structure can be described in terms of species diversity, richness, and evenness. Diversity is affected by colonization rates, extinction rates, competition, predation, physical disturbance, pollution, and other factors (see Crowder, 1990).

A qualitative data assessment can help determine which factors have caused measured variation in species diversity. In such an assessment, the species collected and their relative population sizes are compared with their known sensitivities to contaminants present. The tendency of species to be abundant, present, or absent relative to their tolerances or sensitivities to sediments, temperature regimes, or various chemical pollutants can indicate the most likely cause of variation in species diversity at the sampled sites.

Two cautions should be noted regarding qualitative analysis. First, different strains of the same species can sometimes have differing sensitivities to a stressor, particularly where species have undergone extensive hatchery breeding programs. Second, because listed characteristics of organisms can vary from region to region, when using lists of indicator species, it is important

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[4]Three manuals (U.S. EPA, 1983b, 1984a, 1984b) discuss the interpretation of biological monitoring data for larger bottom-living invertebrates. The *Rapid Bioassessment Protocols* (Plafkin et al., 1989) manual discusses the use of fish and macroinvertebrates as a screening method in assessing environmental integrity. *Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters* (Klemm et al., 1990) discusses analysis of qualitative and quantitative data, community metrics and pollution indicators, pollution tolerance of selected macroinvertebrates, and Hilsenhoff's family-level pollution tolerance values for aquatic arthropods.

to note whether the data were collected in the same region as the CSO study. Investigators should generally limit the use of diversity indices as general indicators of environmental effects to comparisons within the study where sampling and sample analysis methods are consistent. Investigators should contact local authorities to determine whether biological reference data can be obtained to use in the CSO study.

Rapid Bioassessment Protocols

Rapid biological assessments, using techniques such as rapid bioassessment protocols (RBPs), are a valuable and cost-effective approach to evaluating the status of aquatic systems (Plafkin et al., 1989). RBPs integrate information on biological communities with information on physical and chemical characteristics of aquatic habitats. RBPs have been successfully used to:

- Evaluate whether a stream supports designated aquatic life uses;
- Characterize the existence and severity of use impairments;
- Identify sources and causes of any use impairments;
- Evaluate the effectiveness of implemented control actions;
- Support use attainability analyses; and
- Characterize regional biotic components within ecosystems.

Typically, RBPs provide integrated evaluations that compare habitat and biological measures for studied systems to empirically-defined reference conditions (see Plafkin et al., 1989). Reference conditions are defined through systematic monitoring of one or more sites selected to represent the natural range of variation in "least disturbed" water chemistry, physical habitat, and biological conditions. A percent similarity is computed for each biological, chemical, or physical parameter measured at the study sites relative to the conditions found at the reference site(s). These percentages may be computed based on the total number of taxa found, dissolved oxygen saturation, or the embeddedness of bottom material.

Generally, where the computed percent similarity is greater than 75–80 percent of the corresponding reference condition (depending on the parameter compared), the results can indicate that conditions at the study sites are sufficiently similar to those occurring at the reference site(s). For such cases it is reasonable to conclude that the study sites' conditions are "non-impaired." In contrast, where the computed percent similarity of conditions at the study sites is less than 50 percent of the reference conditions (depending on the parameter compared), it is reasonable to conclude that conditions at those study sites are "severely impaired," relative to the reference site(s). For those sites with a percent similarity falling between these ranges, the results can indicate that conditions at the study sites are "moderately impaired" (Plafkin et al., 1989). An application of the use of RBPs in two case studies is presented in *Combined Sewer Overflows and the Multimetric Evaluation of Their Biological Effects: Case Studies in Ohio and New York* (EPA, 1996).

CHAPTER 7

COMBINED SEWER SYSTEM MODELING

This chapter discusses the use of modeling in characterizing the CSS and evaluating CSO control alternatives. It discusses how to identify the appropriate level of modeling, based on site-specific considerations, and describes the various types of available models. Because of the site-specific nature of CSSs, the varying needs for information by municipalities, and the numerous available models, *it does not recommend a specific model or modeling approach.*

7.1 THE CSO CONTROL POLICY AND CSS MODELING

The CSO Control Policy refers to modeling as a tool for characterizing a CSS and its impacts on receiving waters. It does not intend that every CSS be analyzed using complex computer models.

The CSO Control Policy describes the use of modeling as follows:

> *Modeling - Modeling of a sewer system is recognized as a valuable tool for predicting sewer system response to various wet weather events and assessing water quality impacts when evaluating different control strategies and alternatives. EPA supports the proper and effective use of models, where appropriate, in the evaluation of the nine minimum controls and the development of the long-term CSO control plan. It is also recognized that there are many models which may be used to do this. These models range from simple to complex. Having decided to use a model, the permittee should base its choice of a model on the characteristics of its sewer system, the number and location of overflow points, and the sensitivity of the receiving water body to the CSO discharges... The sophistication of the model should relate to the complexity of the system to be modeled and to the information needs associated with evaluation of CSO control options and water quality impacts.* (II.C.1.d)

The Policy also states that:

> *The permittee should adequately characterize through monitoring, modeling, and other means as appropriate, for a range of storm events, the response of its sewer system to wet weather events including the number, location and frequency of CSOs, volume, concentration and mass of pollutants discharged, and the impacts of the CSOs on the receiving waters and their designated uses.* (II.C.1)

Finally, the CSO Control Policy also states:

> *EPA believes that continuous simulation models, using historical rainfall data, may be the best way to model sewer systems, CSOs, and their impacts. Because of the iterative nature of modeling sewer systems, CSOs, and their impacts, monitoring and modeling efforts are complementary and should be coordinated.* (II.C.1.d)

The CSO Policy supports continuous simulation modeling (use of long-term rainfall records rather than records for individual storms) for several reasons. Long-term continuous rainfall records enable simulations to be based on a sequence of storms so that the additive effect of storms occurring close together can be examined. They also enable storms with a range of characteristics to be included. When a municipality uses the presumption approach, long-term simulations are appropriate because the performance criteria are based on long-term averages, which are not readily determined from design storm simulations. Continuous simulations do not require highly complex models. Models that simulate runoff without complex simulation of sewer hydraulics (e.g., STORM, SWMM RUNOFF) may be appropriate where the basic hydraulics of the system are simple.

The CSO Control Policy also states that after instituting the NMC, the permittee should assess their effectiveness and should

> *submit any information or data on the degree to which the nine minimum controls achieve compliance with water quality standards. These data and information should include results made available through monitoring and modeling activities done in conjunction with the development of the long-term CSO control plan.* (II.B)
>
> *The purpose of the system characterization, monitoring and modeling program initially is to assist the permittee in developing appropriate measures to implement the nine minimum controls and, if necessary, to support development of the long-term CSO control plan. The monitoring and modeling data also will be used to evaluate the expected effectiveness of both the nine minimum controls, and, if necessary, the long-term CSO controls, to meet WQS.* (II.C.1)

The LTCP should be based on more detailed knowledge of the CSS and its receiving waters than is necessary to implement the NMC. The LTCP should consider a reasonable range of alternatives, including various levels of controls. Hydraulic modeling may be necessary to predict how a CSS will respond to various control scenarios. A computerized model may be necessary for a complex CSS, especially one with looped networks or sections that surcharge. In simpler systems, however, basic equations (e.g., Hazen-Williams or Manning equation - see Section 5.3.1) and spreadsheet programs can be used to compute hydraulic profiles and predict the hydraulic effects of different control measures. (Verification using monitoring data becomes more important in these latter situations.)

Finally, modeling can support either the presumption or demonstration approaches of the CSO Control Policy. The *demonstration approach* requires demonstration that a control plan is adequate to meet CWA requirements. Meeting this requirement can necessitate detailed CSS modeling as an input to receiving water impact analyses. On the other hand, the *presumption approach* involves performance-based limits on the number or volumes of CSOs. This approach may require less modeling of receiving water impacts, but is acceptable only if "*the permitting authority determines that such presumption is reasonable in light of the data and analysis conducted in the characterization, monitoring, and modeling of the system and the consideration of sensitive areas . . . .*" (II.C.4.a) Therefore, the presumption approach does *not* eliminate the need to consider receiving water impacts.

7.2 MODEL SELECTION STRATEGY

This section discusses how to select a CSS model. This section does not describe all of the available CSS-related models, since other documents provide this information (see Shoemaker et al., 1992; Donigian and Huber, 1991; WPCF, 1989).

CSS modeling involves two distinct elements: hydraulics and water quality.

- Hydraulic modeling consists of predicting the flow characteristics in the CSS. These include the different flow rate components (sanitary, infiltration, and runoff), the flow velocity and depth in the interceptors, and the CSO flow rate and duration.

- Water quality modeling consists of predicting the pollutant characteristics of the combined sewage in the system, particularly at CSO outfalls and at the treatment plant. Water quality is measured in terms of bacterial counts, and concentrations of important constituents such as BOD, suspended solids, nutrients, and toxic contaminants.

Some models include both hydraulic and water quality components, while others are limited to one or the other. Although CSO projects typically involve hydraulic modeling, water quality modeling is less common, and a community may decide to rely on water quality monitoring data instead.

Several factors will dictate whether water quality modeling is appropriate. WPCF (1989) concludes that "simulation of quality parameters should only be performed when necessary and only when requisite calibration and verification data are available[...] Another option is to couple modeled hydrologic and hydraulic processes with measured quality data to simulate time series of loads and overflows." Modeling might not be justified in cases where measured water quality variations are difficult to relate to parameters such as land use, rainfall intensity, and pollutant accumulation rates. For these cases, using statistics (e.g., mean, standard deviation, etc.) of water quality parameters measured in the system can be a valid approach. One limitation of this approach, however, is that it cannot account for the implementation of best management practices such as street sweeping or the use of detention basins.

Exhibit 7-1 shows how model selection can be affected by the status of NMC implementation and LTCP development, and by whether the LTCP will be based on the presumption or demonstration approach. To avoid duplication of effort, the permittee should always consider modeling needs that will arise during later stages of LTCP development or implementation.

Nine Minimum Controls (NMC)

In this initial phase of CSO control, hydraulic modeling can be used to estimate existing CSO volume and frequency and the impacts of implementing alternative controls under the NMC. Typically, in this stage of analysis, modeling would focus more on reductions in CSO magnitude, frequency, and duration than on contaminant transport.

Long-Term Control Plan (LTCP)

EPA anticipates that hydraulic modeling will be necessary for most CSSs regardless of whether the community uses the presumption approach or demonstration approach to show that

Exhibit 7-1. Relevant CSS Hydraulic and Contaminant Transport Modeling for EPA's CSO Control Policy

	CSS Hydraulic Modeling	CSS Contaminant Transport Modeling
Nine Minimum Controls		
Demonstrate implementation of the nine minimum controls	Simple to complex models of duration and peak flows	Limited - Not usually performed
LTCP "Presumption Approach"		
Limit average number of overflows per year	Long-term continuous simulations (preferred) or design storm simulation	Limited - Not usually performed
Capture at least 85% of wet weather CS volume per year	Same	Limited - Not usually performed
Eliminate or reduce mass of pollutants equivalent to 85% capture requirement	Same	Use measured concentrations or simplified transport modeling
LTCP "Demonstration Approach"		
Demonstrate that a selected control program ... is adequate to meet the water quality based requirements of the CWA	Design storm simulations or Long-term continuous simulations	Use measured concentrations or contaminant transport simulations

its LTCP will provide for WQS attainment. Both approaches require accurate predictions of the number and volume of CSO events; under the demonstration approach, this information will help determine the amount and timing of pollutant loadings to the receiving water.

Presumption Approach. The presumption approach is likely to require hydraulic modeling to develop accurate predictions of the number and volume of CSOs. Some level of contaminant transport modeling may also be necessary to ensure that the presumption approach will not result in exceedances of water quality criteria in light of available data (loading estimates can be developed using measured concentrations or simplified screening methods, coupled with hydraulic modeling).

Demonstration Approach. Under the demonstration approach, the permittee is held to a higher level of proof, and should show that the planned controls will attain WQS unless WQS cannot be attained as a result of natural background conditions or pollution sources other than CSOs.

Therefore, CSS modeling under the demonstration approach should describe pollutant loadings to the receiving water body. Since water quality modeling in the CSS is directly linked to water quality modeling in the receiving water, the CSS model must generate sufficient data to drive the receiving water model. Further, the resolution needed for the CSS pollutant transport estimates will depend on the time resolution called for in the receiving water model, which is in turn driven by WQS. For pollutants with long response times in the receiving water (e.g., BOD and nutrients), the appropriate level of loading information is usually the total load introduced by the CSO event. For pollutants with shorter response times (e.g., bacteria, acute toxic contaminants), it may be necessary to consider the timing of the pollutant load within the course of the CSO event.

7.2.1 Selecting Hydraulic Models

Hydraulic models used for CSS simulations can be divided into three main categories:

- **Water-budget models** based on Soil Conservation Service (SCS) runoff curve numbers,[1] runoff coefficients, or other similar method for the generation of flow. These models can estimate runoff flows influent to the sewer system and, to a lesser degree, flows at different points in the system. Water-budget models do not actually simulate flow in the CSS, however, and therefore do not predict such parameters as the flow depth, which frequently control the occurrence of CSOs. (The RUNOFF block of EPA's Storm Water Management Model (SWMM) is an example of a water-budget model.)

[1]SCS runoff curves were developed based on field studies measuring runoff amounts from different soil cover combinations. The appropriate runoff curve is determined from antecedent moisture condition and the type of soil. (Viessman, et al., 1977)

- **Models based on the kinematic wave approximation** of the full hydrodynamic equations.[2] These models can predict flow depths, and therefore overflows, in systems which are not subject to surcharging or back-ups (backwater effects). (The TRANSPORT block of SWMM is an example.)

- **Complete, dynamic models** are based on the full hydrodynamic equations and can simulate surcharging, backwaters or looped systems. (The EXTRAN block of SWMM is an example.)

Exhibit 7-2 summarizes the strengths and limitations of these three classes of models. Section 7.3 discusses available hydraulic models.

The simpler models were developed to support rapid evaluations of CSSs. They require little input data, are relatively easy to use, and require less computer time than complete models. These features, however, are becoming less relevant as complete models with user-friendly pre- and post-processors are now widely available. Advances in computer technology render run time a secondary issue for all but the largest of applications. Thus, complete and complex models can often be used with as much ease and as little data as simple models.

Criteria for the selection of a CSS hydraulic model include:

1. **Ability to accurately represent CSS's hydraulic behavior.** The hydraulic model should be selected with the above limitations in mind. For example, a complete dynamic model may be appropriate if CSOs are due to back-ups or surcharging. Since models differ in their ability to deal with such factors as conduit cross-section shapes, special structures, pump station controls, tides simulation, and automatic regulators, these features in a CSS may guide the choice of one model over another.

2. **Extent of Monitoring.** Monitoring usually cannot cover an entire CSS, particularly a large CSS. A dynamic model is more reliable for predicting the behavior of unmonitored overflows, since all the hydraulic features controlling the overflow can

[2]Flow, which is caused by the motion of waves, can be described by the hydraulic routing technique. This technique is based on the simultaneous solution of the continuity equation and the momentum equation for varying flow. Under certain conditions, these hydrodynamic equations can be simplified to a one-dimensional continuity equation and a uniform flow equation (in place of the full momentum equation). This is referred to as the kinematic wave approximation (discharge is simply a function of depth). (Bedient and Huber, 1992)

Exhibit 7-2. Characteristics of RUNOFF, TRANSPORT, and EXTRAN Blocks of the EPA Storm Water Management Model (SWMM)[1]

Characteristics	Blocks		
	RUNOFF	TRANSPORT	EXTRAN
1. Hydraulic simulation method	Nonlinear reservoir, cascade of conduits	Kinematic wave, cascade of conduits	Complete equations, conduit networks
2. Relative computational expense for identical network schematizations	Low	Moderate	High
3. Attenuation of hydrograph peaks	Yes	Yes	Yes
4. Time displacement of hydrograph peaks	Weak	Yes	Yes
5. In-conduit storage	Yes	Yes	Yes
6. Backwater or downstream control effects	No	No[2]	Yes
7. Flow reversal	No	No	Yes
8. Surcharge	Weak	Weak	Yes
9. Pressure flow	No	No	Yes
10. Branching tree network	Yes	Yes	Yes
11. Network with looped connections	No	No	No
12. Number of preprogrammed conduit shapes	3	16	8
13. Alternative hydraulic elements (e.g., pumps, weirs, regulators)	No	Yes	Yes
14. Dry-weather flow and infiltration generation (base flow)	No	Yes	Yes
15. Pollution simulation method	Yes	Yes	No
16. Solids scour-deposition	No	Yes	No
17. User input of hydrographs/ pollutographs	No	Yes	Yes

[1] After Huber and Dickinson, 1988.
[2] Backwater may be simulated as a horizontal water surface behind a storage element.

be simulated. In some cases, however, estimates of overflow at unmonitored locations can be made based on monitoring in comparable areas (i.e., areas with similar geographic features like elevation), based on V/R ratios (see Section 5.3.3) and drainage basin characteristics.

3. **Need for long-term simulations.** Long-term simulations are desirable to predict the average annual number of CSOs, volumes, and loadings upon which the presumption approach is based. For large systems, long-term simulations using a detailed dynamic model often require lengthy computer run times.

4. **Need to assess water quality in CSS.** If CSS water quality simulations are needed, the hydraulic model should also be capable of simulating water quality.

5. **Need to assess water quality in receiving waters.** The pollutants of concern and the nature of the receiving water affect the resolution of the CSO data needed for the water quality analyses. For example, analyses of bacteria will typically require hourly rather than daily loading data, and the hydraulic model must be capable of providing this resolution.

6. **Ability to assess the effects of control alternatives.** If control alternatives involve relieving downstream back-ups or surcharging, correct simulation may require use of a dynamic model.

7. **Use of the presumption or demonstration approach.** Some permittees using the first presumption approach option—no more than four overflow events per year—can estimate the number of overflow events fairly accurately by calculating the probability of exceeding storage and treatment capacity. Other permittees may need to account for transient flow peaks, requiring accurate flow routing. The other two presumption approach options—percent volume capture and pollutant load capture—generally require some analysis of the timing and peaking of flows, so that a hydraulic simulation approach may be needed.

   If a permittee is using the demonstration approach, receiving water modeling is necessary, and the pollutant transport time step for receiving water modeling may influence the time step for CSS quality modeling. This in turn will constrain the time resolution for CSS hydraulic modeling. If the permittee uses the demonstration approach, more sophisticated modeling approaches will probably be necessary.

8. **Ease of use and cost.** As mentioned above, simple models tend to be easier to use than complete dynamic models, although user-friendly dynamic models now exist. These, however, are generally commercial models and cost more than public domain models. Another option is to use commercial pre- and post-processors (or shells) designed to facilitate the use of public domain models such as SWMM. They can provide graphically-oriented, menu-driven data entry and extensive results plotting capabilities at a cost lower than that of complete dynamic models.

Another issue related to ease of use is *robustness*—i.e., a model's lack of propensity to become unstable. Instabilities are uncontrolled oscillations of the model results which are due to the approximations made in the numerical solution of the basic differential equations. Instabilities tend to occur primarily in fully dynamic models, and are caused by many factors, including attempts to simulate short conduits. Resolving model instabilities can be time-consuming and may require extensive experience with the model. Commercial models tend to be more robust than public domain models.

7.2.2 Selecting Water Quality Models

CSS water quality models can be divided into the following categories:

- ***Land Use Loading Models***—These models provide pollutant loadings as a function of the distribution of land uses in the watershed. Generally, these models attribute to each land use a concentration for each water quality parameter, and calculate overall runoff quality as a weighted sum of these concentrations. Pollutant concentrations for the different land uses can be derived from localized data bases or the Nationwide Urban Runoff Program (NURP) studies. Local data are usually preferable to NURP data since local data are generally more recent and site-specific.

- ***Statistical Methods***—A more sophisticated version of the previous method, statistical methods attempt to formulate a derived frequency distribution for Event Mean Concentrations (EMCs). EMCs are defined as the total mass of a pollutant discharged during an event divided by the total discharge volume. NURP documents discuss the use of statistical methods to characterize CSO quality in detail (Hydroscience, Inc., 1979) and in summary form (U.S. EPA, 1983a).

- ***Build-Up/Washoff Models***—These models simulate the basic processes that control runoff quality, accounting for such factors as time periods between events, rainfall intensity, and best management practices. They require calibration.

Few models address the potentially important role of chemical reactions and transformations within the CSS. Calibration is difficult because pollutant loading into the CSS is never known exactly.

The permittee should consider the following criteria when selecting a CSS water quality model:

1. **Needs of the receiving water quality simulation.** The time scale of the water quality simulation in the CSS, and the degree of sophistication of the model, depends partly on the needs of the receiving water quality simulation (if implemented) and, ultimately, on the level of detail required to demonstrate compliance with the CWA. If it is only necessary to estimate average annual loading to the receiving water, then detailed hourly or sub-hourly simulation of combined sewage quality generally will not be necessary. As noted above, there are many cases where it is appropriate to combine sophisticated hydraulic modeling with approximate quality modeling.

2. **Ability to assess control and best management practice (BMP) alternatives.** When the control alternatives under assessment include specific BMPs or control technologies, the quality model should be sophisticated enough to estimate the effects of these alternatives.

3. **Ability to accurately represent significant characteristics of pollutants of concern.** The pollutants involved in CSS quality simulation can be roughly grouped as bacteria, BOD, nutrients, sediments and sediment-associated pollutants, and toxic contaminants. Most water quality models are designed to handle sediments and nutrients, but not all can model additional pollutants. In some cases and for some pollutants, this limitation can be circumvented by using a sediment potency factor, which relates mass of a given pollutant to sediment transport.

4. **Capability for Pollutant Routing.** Another concern is the model's capability for pollutant routing—i.e., its capacity to account for variability in pollutant concentrations during storm events. Many models translate source availability and CSO quantity to pollutant loading without taking separate account of the timing of pollutant delivery due to transport through the CSS. Many systems deliver the highest concentrations of pollutants in the rising limb of the storm flow (the "first flush" effect). If the CSO loading for such systems is modeled using overflow quantity and average concentrations, inaccuracies will result, particularly if the "first flush" is effectively captured by the POTW or storage.

5. **Expense and Ease of Use.** Sophisticated water quality models can be expensive to calibrate and will generally be more difficult to use. If a simpler model is applicable to the situation and can be properly calibrated, it may be sufficient.

7.3 AVAILABLE MODELS

Exhibits 7-3 and 7-4 summarize several hydraulic and water quality models, respectively, that have been developed by EPA and the Army Corps of Engineers and are available in the public domain. An increasing number of high-quality commercial models and pre/post-processors is also available, either as custom-developed software or as more user-friendly, enhanced models based on popular public domain software.[3] Several of the available commercial models and pre/post processors are listed in Exhibit 7-5. This listing is provided to assist potential users; it is not meant to endorse any particular model or imply that models not listed are not acceptable.

These exhibits summarize some important technical criteria, and can be used as a preliminary guide. However, to evaluate the use of a specific model in a particular situation the permittee should refer to the more detailed reviews and major references listed in Exhibits 7-3 and 7-4. Both Shoemaker et al. (1992) and Donigian and Huber (1991) provide preliminary evaluations of the functional criteria, including an indication of the cost of implementation and data requirements.

7.4 USING A CSS MODEL

7.4.1 Developing the Model

Until recently the modeler had to compromise between the level of detail in a model, the mode in which it was run (complex vs. simple), and the time period for the simulation (event vs. continuous). As computer technology continues to improve, limitations in computing power are becoming less of a factor in determining the appropriate level of modeling complexity. In some cases, where detail is not required, a simplified model may save time spent filling the data requirements of the model, preparing files, and doing the model runs. Shoemaker et al. (1992,

[3]The commercial packages have not been reviewed by EPA and they are subject to continued evolution and change, like all commercial software. A recent listing of some available models is found in Mao (1992). Other recent developments in sewer and runoff models include models linked to geographic information systems (GIS), computer-aided design (CAD) systems, and receiving water models such as WASP.

Exhibit 7-3. CSS Hydraulic Models (Public Domain)

Model Name	Characteristics				
	Hydraulic Time Scales	**Hydraulic Simulation Type**	**Assess Control Alternatives**	**Key to Reviews**	**Major References**
EPA Statistical[1]	Annual, Event	Runoff Coefficient	No	1,2,3	Hydroscience, 1979 Driscoll et al., 1990
The Simple Method	Annual, Event	Runoff Coefficient	No	1	Schueler, 1987
USGS Regression Method	Annual, Event	Regression	No	1,2	Driver & Tasker, 1988
SLAMM	Continuous -Daily	Water Balance	Limited	1	Pitt, 1986
P8-UCM	Continuous -Hourly	Curve Number	Advanced	1	Palmstrom & Walker, 1990
Auto-Q-ILLUDAS	Continuous -Hourly	Water Balance	Limited	1,3	Terstriep et al., 1990
STORM	Continuous -Hourly	Runoff Coeff./ Curve Number	Limited	1,2,3	HEC, 1977
DR3M-QUAL	Continuous -Sub-hourly	Kinematic Wave	Advanced	1,2,3	Alley & Smith, 1982a & 1982b
HSPF	Continuous -Sub-hourly	Kinematic Wave	Moderate[2]	1,2,3	Johanson et al., 1984
SWMM	Continuous -Sub-hourly	Kinematic & Dynamic Wave	Advanced	1,2,3	Huber & Dickinson, 1988; Roesner et al., 1988

Notes:
1 Reviewed as "FHWA" by Shoemaker et al., 1992
2 Can be used for assessment of control alternatives, but not designed to readily implement that function.

Key to Reviews:
1 Shoemaker et al., 1992.
2 Donigian and Huber, 1991.
3 WPCF, 1989.

1 **Exhibit 7-4. CSS Water Quality Models (Public Domain)**

Model Name	Characteristics				
	Quality Time Scales	Pollutant Types	Pollutant Routing - Transport	Pollutant Routing - Transformation	BMP Evaluation
EPA Statistical[1]	Annual	S, N, O	no	no	low
The Simple Method	Annual	S, N, O	no	no	low
USGS Regression Method	Annual	S, N, O	no	no	no
Watershed	Annual	S, N, O	no	no	medium
GWLF	Continuous - Daily	S, N	low	no	low
SLAMM	Continuous - Daily	S, N, O	medium	no	medium
P8-UCM	Event	N, O	low	no	high
Auto-Q-ILLUDAS	Continuous - Hourly	S, N, O	medium	no	medium
STORM	Continuous - Hourly	S, N, O	no	no	medium
DR3M-QUAL	Continuous - Sub-hourly	S, N[2]	high	no	medium
HSPF	Continuous - Sub-hourly	S, N, O	high	high	high
SWMM	Continuous - Sub-hourly	S, N[2]	low[3]	low	high

Notes: 1 Reviewed as "FHWA" by Shoemaker et al. 1992
2 Other constituents can be modeled by assumption of a sediment potency fraction.
3 Low rating from Shoemaker et al. for "weak" quality simulations may not be fully justified relative to the strength of other models.

Key to Pollutant Type: S - Sediment N - Nutrients O - Other

Exhibit 7-5. Commercial CSS Models

Package Name*	Capabilities			Contact
	Pre/Post-Processor	Hydraulic	Water Quality	
XP-SWMM	Graphical User Interface and Post-processor for SWMM	Dynamic	In Development*	XP Software Tampa, Florida 813-886-7724/800-883-3487
Hydra	Yes	Dynamic	No	Pizer, Inc. Seattle, Wash. 206-634-2808/800-222-5332
Eagle Point Hydrology Series	Yes	Dynamic	No	Eagle Point 800-678-6565
Mouse	Yes	Dynamic	Yes	Danish Hydraulic Institute 011-45-42 86 79 51
HydroWorks	Yes	Dynamic	In Development	Wallingford Software, England 011-44 0 1491 82 47 77
PC-SWMM	Menu-driven interface for SWMM	No	No	Computational Hydraulics Guelph, ON (519) 767-0197
MTVE	For SWMM EXTRAN & RUNOFF	No	No	10Brooks Software (313) 761-1511
SWMMDuet	SWMM/GIS Interface	No	No	Delaware Dept. of Natural Resources (302) 739-3451

* as of April 1995

Tables 7-9) provides a tabular summary of the main input data and output information for each of the models presented in Exhibits 7-3 and 7-4.

The level of discretization (i.e., coarse vs. fine scale) determines how accurately the geometry of the CSS and the land characteristics of the drainage basin are described. At a very coarse level of discretization, the CSS is a black box with lumped parameters and primarily CSOs are simulated (e.g., using the STORM model). A more complex approach might be to simulate the larger pipes of the CSS, but to lump the characteristics of the smaller portions of the CSS. Another intermediate level of complexity is to simulate the interceptor since it is the limiting component in the CSS for controlling overflows. Much can be learned about system behavior by simulating interceptor hydraulics in response to surface runoff. More complex simulations would include increasing levels of detail about the system.

In determining the appropriate level of discretization, the modeler must ask:

- What is the benefit of a finer level of detail?
- What is the penalty (in accuracy) in not modeling a portion of the system?

For systems that are controlled hydraulically at their downstream ends, it may only be necessary to model the larger downstream portion of the CSS. If flows are limited due to surcharging in upstream areas, however, a simulation neglecting the upstream portion of the CSS would over-estimate flows in the system. In some cases it is difficult to determine ahead of time what the appropriate level of detail is. In these cases, the modeler can take an incremental approach, determining the value of additional complexity or data added at each step. Exhibit 7-6, for example, compares a simulation based on 5 subcatchments (coarse discretization) and a simulation based on 12 subcatchments (finer discretization) with observed values. Only marginal improvement is observable when subcatchments are increased from 5 to 12. The modeler should probably conclude that even finer discretization (say, 15 subcatchments) would provide little additional value.

7.4.2 Calibrating and Validating the Model

A model general enough to fit a variety of situations typically needs to be adjusted to the characteristics of a particular site and situation. Model calibration and validation are used to "fine-tune" a model to a specific need and then to demonstrate the credibility of the simulation results. Using an uncalibrated model may be acceptable for screening purposes, but without supporting evidence the uncalibrated result may not be accurate. To use model simulation results for evaluating control alternatives, the model must be reliable.

Calibration is the process of using a set of input data and then comparing the results to actual measurements of the system. For example, a CSS hydraulic model used to simulate

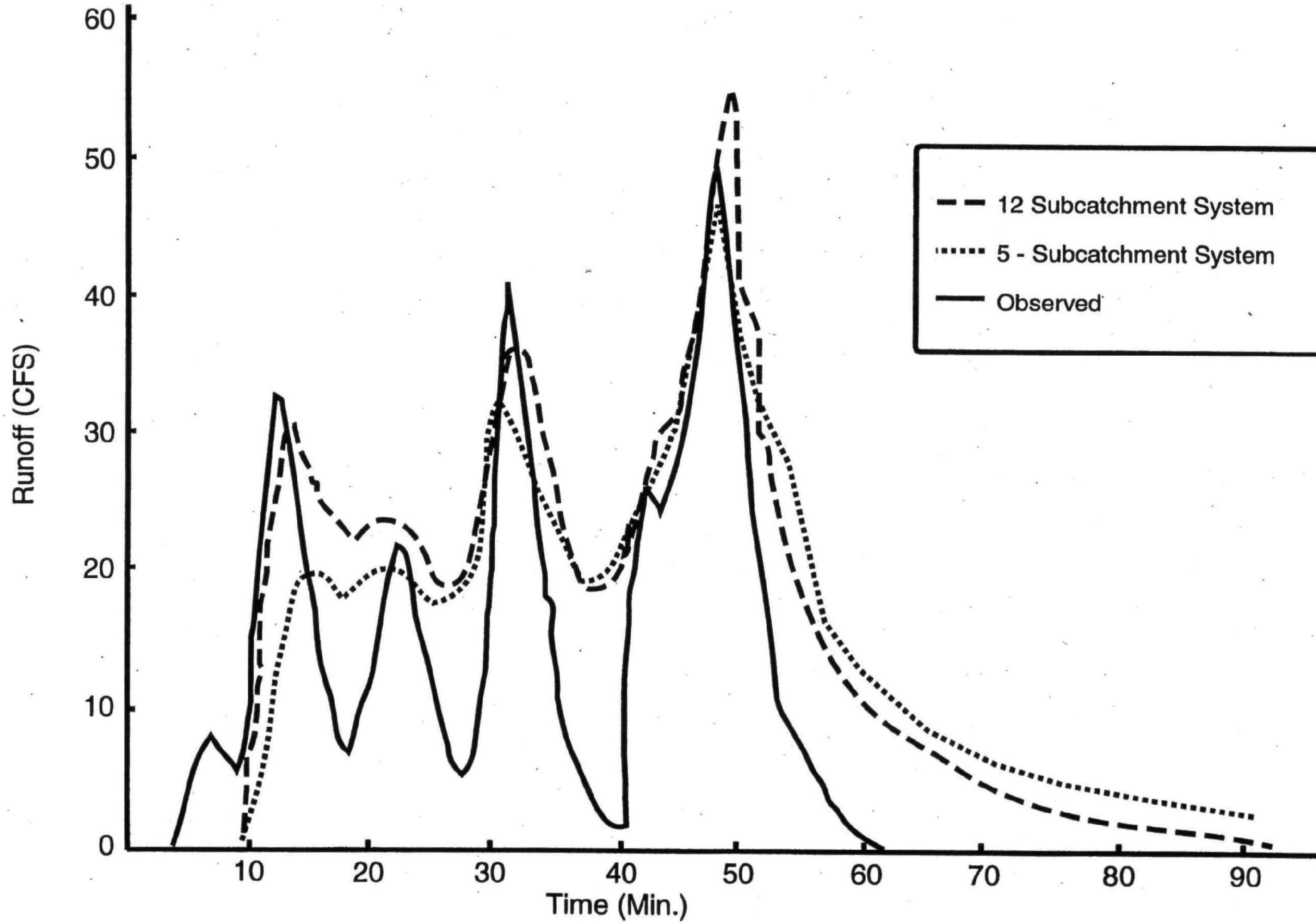


Exhibit 7-6. Levels of Discretization

overflows is calibrated by running the model using measured rainfall data to simulate attributes of CSO overflows, such as volume, depth, and timing. The model results are then compared to actual measurements of the overflows. The modeler then adjusts parameters such as the Manning roughness coefficient or the percent imperviousness of subcatchments and runs the model a second time, again comparing the results to observations. Initial calibration runs often point to features of the system which may not have been evident based on the available maps. For example, a connection or bypass may have been installed without being reflected on available maps. The modeler repeats this procedure until satisfied that the model produces reasonable simulations of the overflows. Calibration is usually performed on more than one storm, to ensure appropriate performance for a range of conditions. Example model calibration plots of flow and depth during storm events are shown in Exhibit 5-9.

Validation is the process of testing the calibrated model using one or more independent data sets. In the case of the hydraulic simulation, the model is run without any further adjustment using independent set(s) of rainfall data. Then the results are compared to the field measurements collected concurrently with these rainfall data. If the results are suitably close, the model is considered to be validated. The modeler can then use the model with other sets of rainfall data or at other outfalls. If validation fails, the modeler must recalibrate the model and validate it again using a third independent data set. If the model fails a validation test, the next test must use a new data set. (Re-using a data set from a previous validation test does not constitute a fair test, because the modeler has already adjusted model parameters to better the fit of the model to the data.) Validation is important because it assesses whether the model retains its generality: that is, a model that has been adjusted extensively to match a particular storm might lose its ability to predict the effects of other storms.

The availability of adequate calibration data places constraints on which models are appropriate. Simplified models in which many system features are aggregated require more calibration than detailed models which simulate every component of the system.

When identifying the time period for conducting CSS flow monitoring, the permittee should consider the effect of using larger data sets. *The CSO Control Manual* (U.S. EPA, 1993) states that "an adequate number of storm events (usually 5 to 10) should be monitored and used in the calibration." The monitoring period should indeed cover at least that many storms, but calibration and validation are frequently done with 2 to 3 storms each.

EPA's *Compendium of Watershed-Scale Models for TMDL Development* (Shoemaker et al., 1992) includes the following comments on calibration and validation:

> *Most models are more accurate when applied in a relative rather than an absolute manner. Model output data concerning the relative contribution...to overall pollutant loads is more reliable than an absolute prediction of the impacts of one control alternative viewed alone. When examining model output . . . it is important to note three factors that may influence the model output and produce unreasonable data. First, suspect data may result from calibration or verification data that are insufficient or inappropriately applied. Second, any given model, including detailed models, may not represent enough detail to adequately describe existing conditions and generate reliable output. Finally, modelers should remember that all models have limitations and the selected model may not be capable of simulating desired conditions. Model results must therefore be interpreted within the limitations of their testing and their range of application. Inadequate model calibration and verification can result in spurious model results, particularly when used for absolute predictions. Data limitations may require that model results be used only for relative comparisons.*

Common practice employs both judgment and graphical analysis to assess a model's adequacy. However, statistical evaluation can provide a more rigorous and less subjective approach to validation (see Reckhow et al., 1990, for a discussion of statistical evaluation of water-quality models).

Nix (1990) suggests the following general sequence for the calibration of CSS models:

1. **Identify the important model algorithms and parameters.** A combination of sensitivity analysis and study of model algorithms can determine which parameters are most important for calibration of a given model-site pairing.

2. **Classify model parameters** to determine the degree to which they can be directly measured, or, alternatively, are conceptual parameters not susceptible to direct measurement. For instance, a parameter such as area is usually easily defined, and thus not varied in calibration, while parameters that are both important to model performance and not susceptible to direct measurement (e.g., percent imperviousness) will be the primary adjustment factors for calibration.

3. **Calibrate the model(s) first for the representation of overflow volume.**

4. After obtaining a reasonable representation of event overflow volume, **calibrate to reproduce the timing and peak flow (hydrograph shape) of overflows.**

5. Finally, **calibrate the quality parameters** only after an acceptable quantity simulation has been obtained.

Section 7.5 describes an example of CSS modeling, including commentary on calibration and simulation accuracy.

7.4.3 Performing the Modeling Analysis

Once a model has been calibrated and validated, it can be run for either long-term simulations (i.e., continuous simulation) or for single events (usually a set of design storms).

- **Long-term simulations** can account for the sequencing of the rainfall in the record, and the effect of having storms immediately follow each other. Such simulations are therefore useful for assessing the long-term performance of the system under the presumption approach. If possible, continuous simulation models should be calibrated using continuous data. Calibration with single events is also possible, but antecedent conditions must be taken into account. As the speed of desktop computers increases, modelers will be able to perform long-term continuous simulations with higher and higher levels of detail.

- **Single event simulations** are useful for developing an understanding of the system (including the causes of CSOs) and for the formulation of control measures, and can be used for calibrating models.

Although increased computer capabilities enable continuous simulations with greater levels of detail, continuous simulation of very large systems can have some drawbacks:

- The model may generate such a large amount of data, that data analysis and interpretation are difficult, and

- Limitations in the accuracy of hydrologic input data (due to the inability to perform a continuous simulation of spatially variable rainfall over a large catchment area) may lead to an inaccurate time series of hydraulic conditions within the interceptor.

7.4.4 Modeling Results

Model Output

The most basic type of model output is text files in which the model input is repeated and the results are tabulated. These can include flow and depth versus time in selected conduits and junctions, as well as other information such as which conduits are surcharging. The model output may include an overall system mass balance with such measures as the runoff volume entering the system, the volume leaving the system at the downstream boundaries, the volume lost due to flooding, and the change of volume in storage. The model output can also measure the mass balance accuracy of the model run, which may provide indications that problems, such as instabilities (see Section 7.2.1), occurred.

Most models also produce plot files, which are easier to evaluate than text files. Output data from plot files can be plotted using spreadsheet software or commercial post-processors, which are available for several public-domain models (particularly SWMM). Commercial models typically include extensive post-processing capabilities, allowing the user to plot flow or depth versus time at any point in the system or to plot hydraulic profiles versus time along any set of conduits.

Interpretation of Results

Simulation models predict CSO volumes, pollutant concentrations, and other variables at a resolution that depends on the model structure, model implementation, and the resolution of the input data. Because the ultimate purpose of modeling is generally to assess the CSO controls needed to provide for the attainment of WQS, the model's space and time resolution should match that of the applicable WQS. (For instance, the State WQS may include a criterion that a one-hour average concentration not exceed a given concentration more than once every 3 years on average.) Spatial averaging may be represented by a concentration averaged over a receiving water mixing zone, or implicitly by the specification of monitoring locations to establish whether the instream criteria can be met. In any case, the permittee should note whether the model predictions use the same averaging scales as the relevant water quality criteria. When used for continuous rather than event simulation, as suggested by the CSO Control Policy, simulation models provide output that can be analyzed to predict water quality criteria exceedances and the frequency of such exceedances.

In interpreting model results, the permittee needs to be aware that modeling usually will not provide exact predictions of system performance measures such as overflow volumes or exceedances of water quality criteria. With sufficient effort, permittees often can obtain a high degree of accuracy in modeling the hydraulic response of a CSS, but results of modeling pollutant buildup/washoff, transport in the CSS, and fate in receiving waters are considerably less accurate. Achieving a high degree of accuracy is more difficult in a continuous simulation because of the difficulty of specifying continually changing boundary conditions for the model parameters.

In model interpretation, the permittee should remember the following:

- Model predictions are only as accurate as the user's understanding and knowledge of the system being modeled and the model being used,
- Model predictions are no better than the quality of the calibration and validation exercise and the quality of the data used in the exercise, and
- Model predictions are only estimates of the response of the system to rainfall events.

Model Accuracy and Reliability

Since decisions are based on model predictions, permittees need to understand the uncertainty associated with the model prediction. For instance, a model for a CSO event of a given volume may predict a coliform count of 350 MPN/100 ml in the overflow, well below the hypothetical water quality criterion of 400 MPN/100 ml. However, the model prediction is not exact, as observation of an event of that volume would readily show. Consequently, additional information specifying how much variability to expect around the "most likely" prediction of 350 is useful. Obviously, the interpretation of this prediction differs, depending on whether the answer is "likely between 340 and 360" or "likely between 200 and 2000."

Evaluating these issues involves the closely related concepts of model accuracy and reliability. "Accuracy" is a measure of the agreement between the model predictions and observations. "Reliability" is a measure of confidence in model predictions for a specific set of conditions and for a specified confidence level. For example, for a simple mean estimation, the accuracy could be measured by the sample standard deviation, while the reliability of the prediction (the sample mean in this case) could be evaluated at the 95 percent confidence level as plus or minus approximately two standard deviations around the mean.

Modeling as part of LTCP development enables the permittee to demonstrate that a given control option is "likely" to result in compliance with the requirements of the CWA and attainment of applicable WQS, including protection of designated uses. During LTCP development, the permittee will justify that a proposed level of control will be adequate to provide for the attainment of WQS. Therefore, the permittee should be prepared to estimate and document the accuracy and reliability of model predictions.

An evaluation of model accuracy and reliability is particularly important for the analysis of wet-weather episodic loading, such as CSOs. Whether water quality criteria involve a defined duration (averaging period) and frequency of excursion, as average monthly and maximum daily values, or as a maximum concentration for a given design stream flow (e.g., 7Q10), duration and frequency are included either directly or implicitly. Estimating duration and frequency of excursion requires knowledge of model reliability, and the duration and frequency of the storm events serving as a basis for the model.

Available techniques for quantifying uncertainties in modeling studies include sensitivity analysis, first-order error analysis, and Monte Carlo simulations. Sensitivity analysis is the simplest and most commonly used technique in water quality modeling (U.S. EPA, 1995g). Sensitivity analysis is used to assess the impact of the uncertainty of one or more input variables on the simulated output variables. First-order analysis is used in a manner similar to sensitivity analysis where input variables are assumed to be independent, and the model is assumed to respond linearly to the input variables. In addition to estimating the change of an output variable with respect to an input variable, first-order error analysis also provides an estimate of the output variance. Monte Carlo simulation, a more complex technique, is a numerical procedure where an input variable is defined to have a certain probability density function (pdf). Before each model run, an input variable is randomly selected from each predefined pdf. By combining the results of several model runs, a pdf can be developed for the output variable which is useful in predicting overall model results. The number of model runs is extremely large as compared to the number of runs typically done for sensitivity or first-order error analysis.

The main input variables for simulating the impact of CSO loadings are properties of the mean rainfall event (storm event depth, duration, intensity, and interval between events), CSO concentrations of specific pollutants, design flow of the receiving water body, and its background concentrations. The output consists of an assessment of the water quality impact in terms of duration and frequency of exceedances of water quality criteria. Pollutant concentrations are the main "uncertain" (sensitive) input variables and can be varied over a range of reasonable values to asses their impact on the resulting water quality. Uncertainty analysis can improve management decisions and provide insight into the need for any additional data collection to refine the estimated loads. For instance, if a small change in a pollutant concentration results in an extremely large variation in the prediction of water quality, it may be appropriate to allocate resources to more accurately estimate the CSO pollutant concentration used in the model.

7.5 EXAMPLE SWMM MODEL APPLICATION

This section applies the Storm Water Management Model (SWMM) to a single drainage area from the example CSS drainage area presented in Chapters 4 and 5. While some of the details of the application are particular to the SWMM model, most of the explanation is applicable to a range of hydraulic models. The TRANSPORT block of the SWMM model was chosen for the flow routing because the hydraulics in the system did not include extensive surcharging, and the system engineers felt that a dynamic hydraulic model such as SWMM EXTRAN was not needed to accurately predict the number and volume of CSOs.

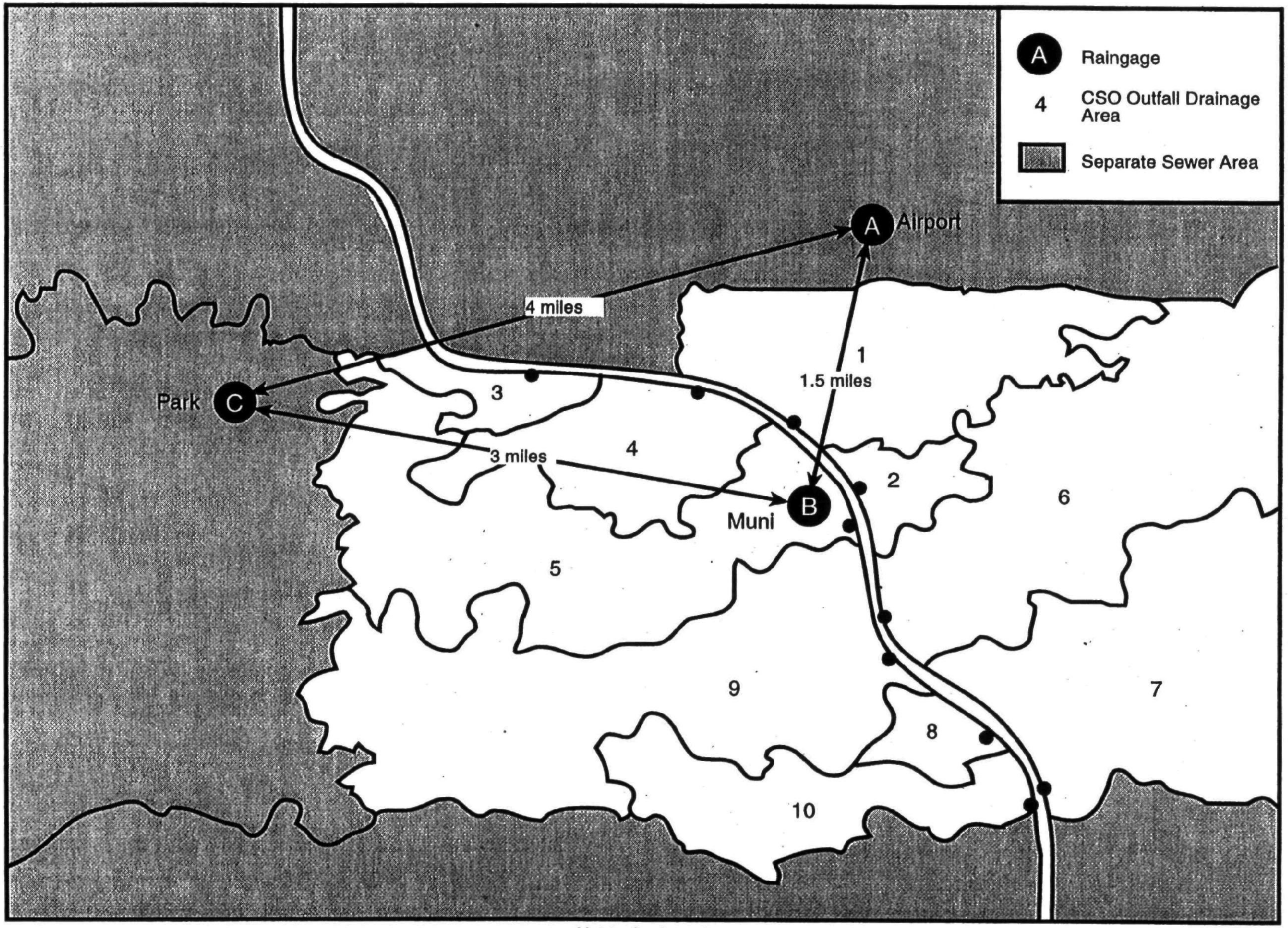
7.5.1 Data Requirements

The first step in model application is defining the limits of the combined sewer service area, and delineating subareas draining to each outfall (see Exhibit 7-7). This can be accomplished using a sewer system map, a topographic map, and aerial photographs as necessary. The modeler next must decide what portions of the system to model based on their contributions to CSOs (as illustrated in Example 4-1). The next step is to divide selected portions of the CSS and drainage area into segments and translate drainage area and sewer data into model parameters. This process, referred to as discretization, begins with the identification of drainage boundaries, the location of major sewer inlets using sewer maps, and the selection of channels and pipes to be represented in the model. The drainage area is then further divided into subareas, each of which contributes to the nodes of the simulated network. The modeler must consider the tradeoff between a coarse model that simulates only the largest structures in the CSS, and a fine-scale model that considers nearly every portion of the CSS. A coarse model requires less detailed knowledge of the system, less model development time, and less computer time. The coarse model, however, leaves out details of the system such as small pipes and structures in the upstream end of the CSS. Flow in systems that are limited by upstream structures and flow capacities will not be simulated accurately.

Where pipe capacities limit the amount of flow leaving a drainage area or delivered to the wastewater treatment plant, the flow routing features of the model should be used to simulate channels and pipes in those areas of concern. The level of detail should be consistent with the minimum desired level of flow routing resolution. For example, information cannot be obtained about upstream storage when the upstream conduits and their subcatchments are not simulated. Further, sufficient detail needs to be provided to allow control options within the system to be evaluated for different areas.

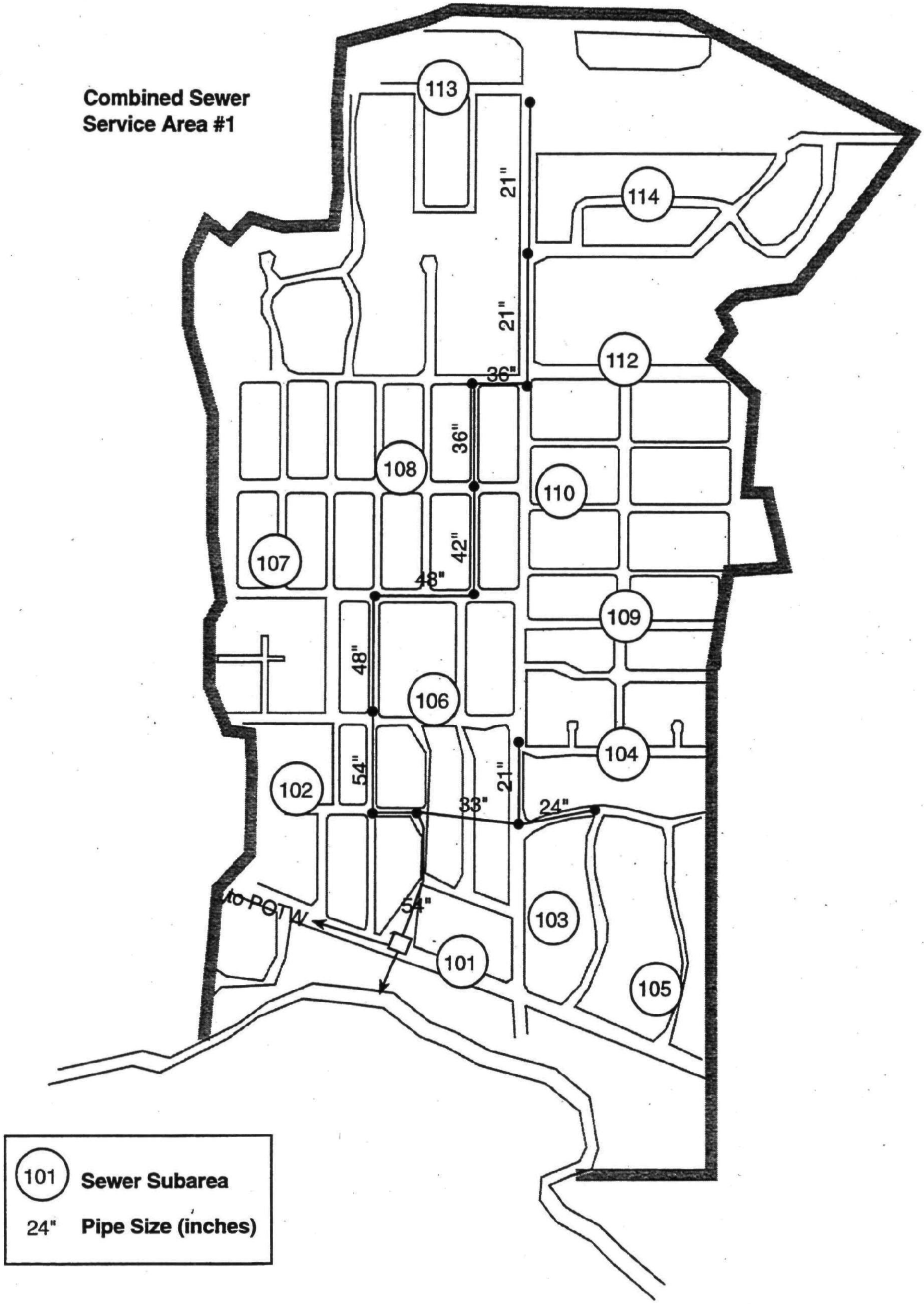
In this example, the modeled network is carried to points where the sewers branch into pipes smaller than 21 inches. From these points upstream, the system isn't directly modeled. Instead, runoff from the upstream area is estimated and routed into the 21-inch pipes. Exhibit 7-8 presents the modeled sewer lines and the subareas tributary to those lines for service area 1.

Exhibit 7-7. Drainage Area Map



Not to Scale

1 **Exhibit 7-8. Sewer Network and Subareas**



7.5.2 SWMM Blocks

RUNOFF block. The RUNOFF block of SWMM generates surface runoff and pollutant loads in response to precipitation input and modeled surface pollutant accumulations. The main data inputs for the RUNOFF block are:

- subcatchment width
- subcatchment area
- subcatchment imperviousness
- subcatchment ground slope
- Manning's roughness coefficient for impervious and pervious areas
- impervious and pervious area depression storage
- infiltration parameters.

The main RUNOFF block data inputs (by subcatchment area number) for the example are shown in Exhibit 7-9. The subcatchment area is measured directly from maps and the width is generally taken as the physical width of overland flow. Selection of subcatchment width is more subjective when the subcatchment is not roughly rectangular, symmetrical and uniform. Slopes are taken from topographic maps, and determinations of imperviousness, infiltration parameters, ground slope, Manning's roughness coefficients, and depression storage parameters are based on field observations and aerial photographs.

The RUNOFF block data file is set up to generate an interface file that transfers hydrographs generated by the RUNOFF block to subsequent SWMM blocks for further processing. In this example, the data generated in the RUNOFF block are processed by the TRANSPORT block.

TRANSPORT block. The TRANSPORT Block is typically used to route flows and pollutant loads through the sewer system. TRANSPORT also allows for the introduction of dry weather sanitary and infiltration flow to the system. The main TRANSPORT block inputs by

Exhibit 7-9. SWMM Runoff Block Input Parameters (SWMM H1 Card)

Sub Area No.	Inlet No. (manhole)	Width (ft.)	Area (ac.)	Imperv %	Slope (ft./ft.)	Manning (n)		Depression Stor.		Infiltration		
						Imperv.	Perv.	Imperv.	Perv.	Max Rate (in./hr.)	Min Rate (in./hr.)	Decay Rate (1/sec.)
101	125	3216	25.1	55	.0060	0.015	0.2	0	0.3	1	0.1	0.001
102	126	4114	34.0	35	.0060	0.015	0.2	0	0.3	1	0.1	0.001
103	126	3468	20.7	28	.0125	0.015	0.2	0	0.3	1	0.1	0.001
104	127	4080	28.1	55	.0100	0.015	0.2	0	0.3	1	0.1	0.001
105	128	5140	47.2	22	.0001	0.015	0.2	0	0.3	1	0.1	0.001
106	129	3407	21.9	31	.0040	0.015	0.2	0	0.3	1	0.1	0.001
107	130	7596	27.9	46	.0001	.0150	0.2	0	0.3	1	0.1	0.001
108	130	5614	23.2	38	.0001	0.015	0.2	0	0.3	1	0.1	0.001
109	131	8581	39.4	35	.0170	0.015	0.2	0	0.3	1	0.1	0.001
110	132	5026	20.0	75	.0100	0.015	0.2	0	0.3	1	0.1	0.001
111	133	5445	35.0	17	.0200	0.015	0.2	0	0.3	1	0.1	0.001
112	133	2505	29.9	59	.0140	0.015	0.2	0	0.3	1	0.1	0.001
113	134	7504	37.9	39	.0125	0.015	0.2	0	0.3	1	0.1	0.001
114	135	5610	74.7	29	.0001	0.015	0.2	0	0.3	1	0.1	0.001
115	136	10069	220.0	37	.0100	0.015	0.2	0	0.3	1	0.1	0.001

1

Exhibit 7-10. SWMM Transport Block Input Parameters (SWMM E1 Card)

SEWER ELEMENT DATA								
ELEMENT NO.	UPSTREAM ELEMENT NO. 1	UPSTREAM ELEMENT NO. 2	UPSTREAM ELEMENT NO. 3	ELEMENT TYPE	LENGTH (ft) [for pipe element] INFLOW (cfs) [for manhole]	PIPE DIMENSION (ft)	PIPE SLOPE (ft/100 ft)	MANNING PIPE ROUGHNESS (n)
125	175	0	0	manhole	0.087	0	0	0
175	126	0	0	sewer pipe	1000	0.45	0.5	0.014
126	176	177	0	manhole	0.188	0	0	0
177	150	0	0	sewer pipe	840	2.75	0.28	0.014
150	178	179	0	manhole	0	0	0	0
178	127	0	0	sewer pipe	390	1.75	0.39	0.014
127	0	0	0	manhole	0.097	0	0	0
179	128	0	0	sewer pipe	651	2.0	0.34	0.014
128	0	0	0	manhole	0.163	0	0	0
176	129	0	0	sewer pipe	733	4.5	0.07	0.014
129	180	0	0	manhole	0.076	0	0	0
180	130	0	0	sewer pipe	841	4.0	0.16	0.014
130	181	0	0	manhole	0.176	0	0	0
181	131	0	0	sewer pipe	620	4.0	0.09	0.014
131	182	0	0	manhole	0.136	0	0	0
182	132	0	0	sewer pipe	727	3.5	0.12	0.014
132	183	0	0	manhole	0.103	0	0	0
183	133	0	0	sewer pipe	771	3	0.16	0.014
133	184	0	0	manhole	0.221	0	0	0
184	134	0	0	sewer pipe	1110	2.75	0.13	0.014
134	185	0	0	manhole	0.258	0	0	0
185	135	0	0	sewer pipe	1007	1.75	0.4	0.014
135	0	0	0	manhole	0.131	0	0	0

element number are presented in Exhibit 7-10. The exhibit specifies the number and type of each element (including upstream elements), the element length (for pipe elements), and inflow (for manholes).

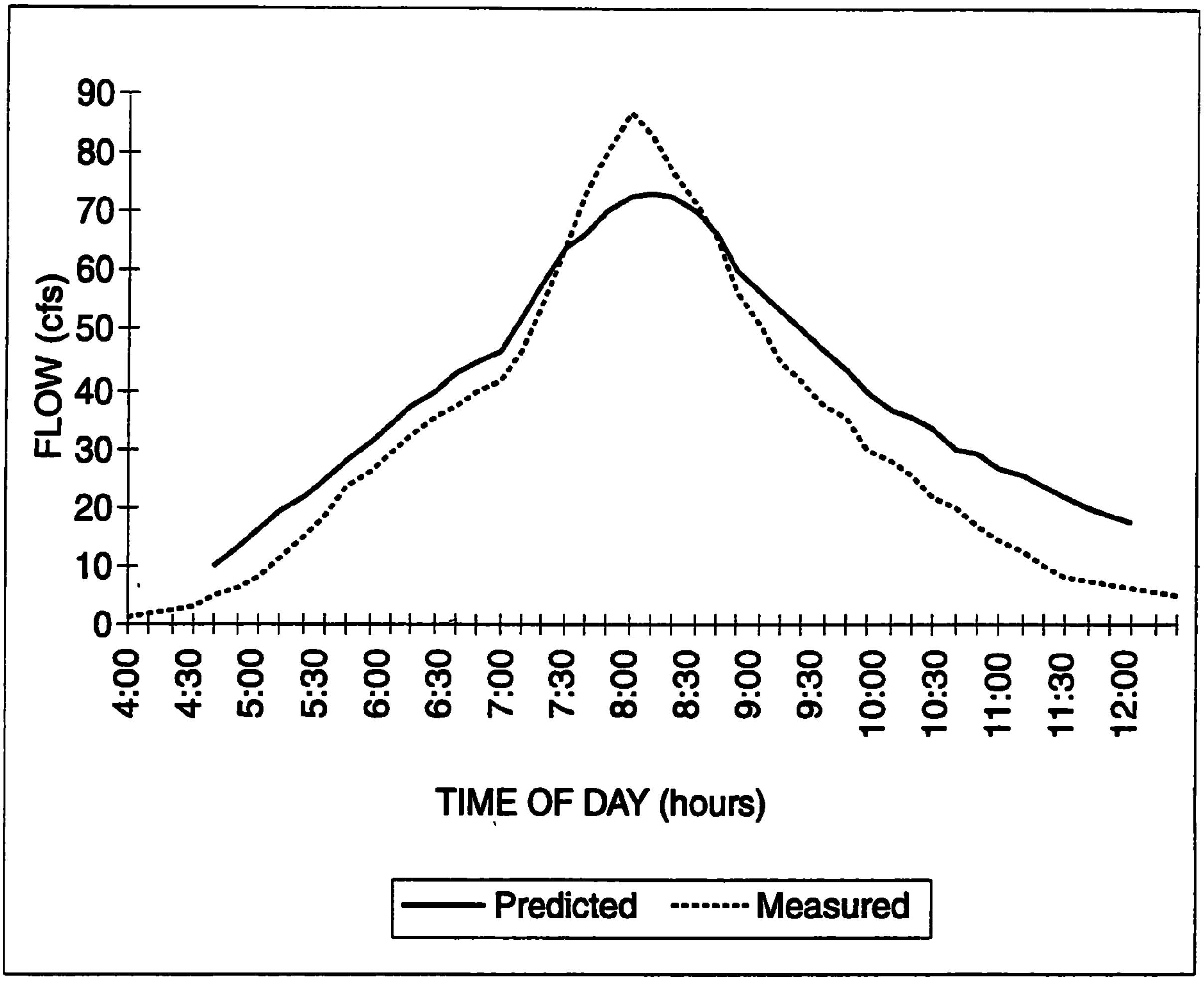
The inflow parameter allows for introduction of dry-weather (sanitary) flow to the system. Dry-weather flow is typically distributed proportional to area served. Here it is set to 0.0035 cfs per acre. If the records are available, this parameter can be refined by multiplying the per-capita wastewater flow (typically available from the wastewater treatment plant or latest facilities plan) by the average population density calculated from census figures and sewer service area maps.

7.5.3 Model Calibration and Application

The output hydrograph for element (manhole) 125 from the TRANSPORT block is presented as Exhibit 7-11, with the measured flow for the event plotted for comparison. The peak flow, shape of the hydrograph, and the total volume of overflow for this calibration run are very close to the measured values.

The SWMM model is applied to monitored drainage areas within the CSS using available monitoring data to calibrate the hydraulic portions of the program to monitored areas. For outfalls that are not monitored, parameters are adjusted based on similar monitored areas and on flow depths or flow determinations obtained from the initial system characterization (see Chapter 3). Once the entire CSS drainage area is modeled and the SWMM model calibrated, the model then needs to be validated. It can then be used to predict the performance of the system for either single events (actual or design) or for a continuous rainfall record. Recall that it is desirable to calibrate the model to a continuous sequence of storms if is to be applied to a continuous rainfall record. Individual storms related to monitored events can be run to calculate the total volume of overflow for the system. Peak flow values from the SWMM hydrographs can be used for preliminary sizing of conveyance facilities that may be needed to alleviate restrictions.

Exhibit 7-11. Flow Hydrograph



To predict the number of overflows that will occur per year, the calibrated model can either be run in a continuous mode or for design storm events. In the continuous mode the model can be run using the long-term rainfall record (preferable where the data are available), or for a shorter period of time (say, for a typical or extreme year from the example discussed throughout Chapter 5). While the event mode is useful for some design tasks and for estimating hourly loading for a fine-scale receiving water model, the continuous mode is preferable for evaluating the number of overflows under the presumption approach. In this example, a continuous simulation based on the 38-year rainfall record predicted between 12 and 32 overflow events per year. The average—22 overflow events per year—is used for comparison with the 4-event-per-year criterion in the presumption approach. (Note that only one outfall in the system needs to overflow to trigger the definition of "CSO event" under the presumption approach.)

Based on model results, system modifications were recommended as part of NMC implementation. After the NMC are in place, the model will be rerun to assess improvement and the need for additional controls.

7.5.4 SWMM Quality Modeling

Once the SWMM model has been hydraulically calibrated, it can be used to predict pollutant concentrations in the overflow. The summary of the flow-weighted concentrations output by the model can then be compared to composite values of actual samples taken during the course of the overflow. Plots of individual concentrations versus time (pollutographs) can also be used to match the variation in concentration of a pollutant during the course of the overflow. First flush effects can also be observed from the model output if buildup/washoff is used.

Model Results

Exhibit 7-12 presents the BOD and total solids output of the SWMM model for the example storm. Note that the modeled concentrations of both pollutants follow a similar pattern throughout the overflow with little if any first flush concentration predicted in the early part of the overflow. The initial loads assigned within the model for this calibrated example were 70 pounds per acre for BOD and 1,000 pounds per acre for total solids. This model was previously calibrated using monitoring data.

Predicted and observed values for BOD and total solids concentrations are presented in Exhibit 7-13. The observed concentrations are from analyses of composite samples collected in an automated field sampler for this storm. The modeled values give an approximate, but not precise, estimate of the parameters. While some studies have resulted in closer predictions, this discrepancy between predicted and observed pollutant values is not uncommon.

Exhibit 7-12. Pollutographs

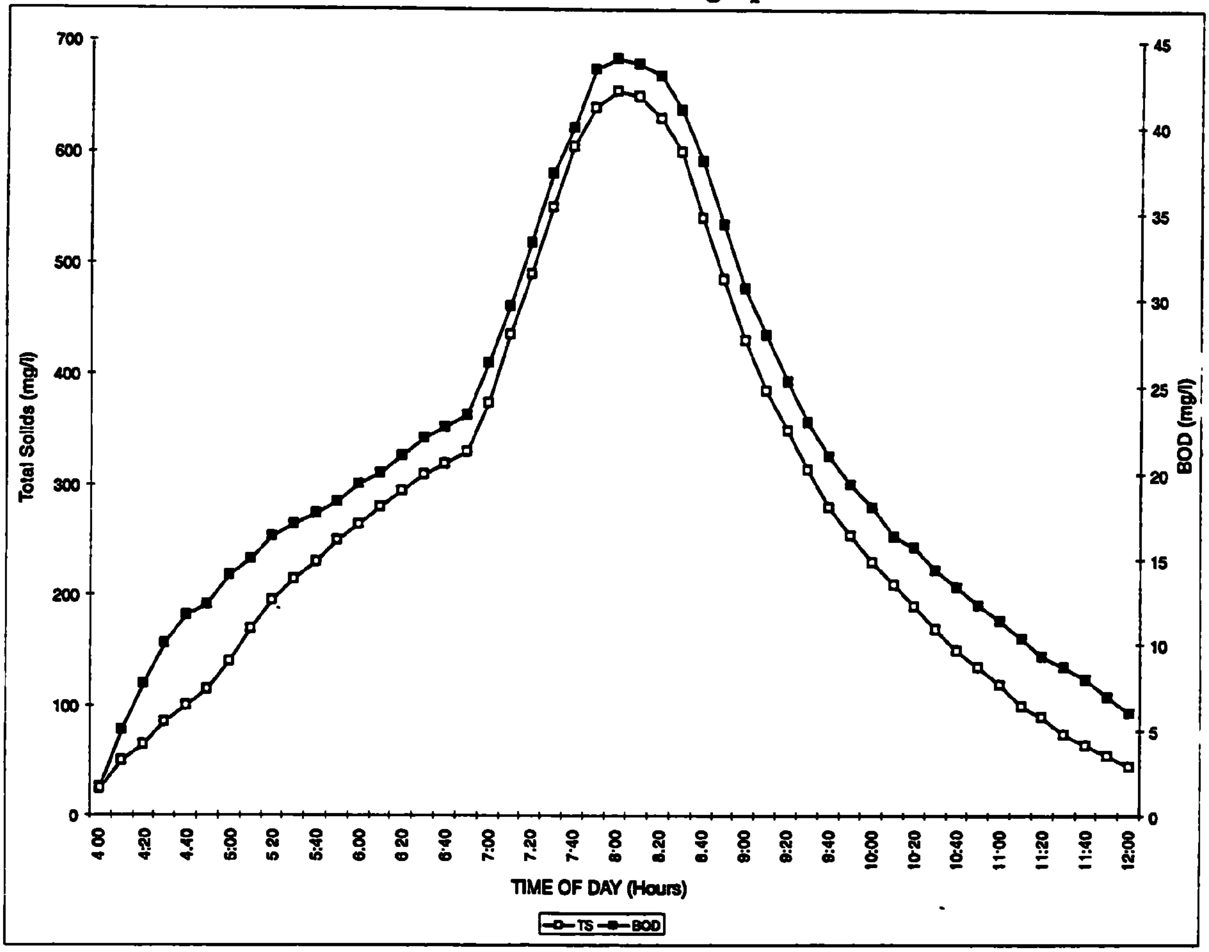


Exhibit 7-13. Predicted and Observed Pollutant Concentrations

	Predicted		Observed	
	BOD	TS	BOD	TS
Flow-weighted concentration (mg/l)	31.4	420	94	300

The modeling in this example would be useful for evaluating the CSS performance against the four-overflow-event-per-year criterion in the presumption approach. It could also be used to evaluate the performance of simple controls. If further analysis is required, more complex modeling may be necessary.

CHAPTER 8

RECEIVING WATER MODELING

This chapter discusses the use of receiving water modeling in evaluating CSO impacts to receiving waters. It introduces simplified techniques, such as dilution and decay equations, and more complex computer models, such as QUAL2EU and WASP. This chapter uses the term "modeling" broadly to refer to a range of receiving water simulation techniques.

8.1 THE CSO POLICY AND RECEIVING WATER MODELING

Under the CSO Control Policy a permittee should develop an LTCP that provides for attainment of WQS using either the demonstration approach or presumption approach. Under the demonstration approach, the permittee documents that the selected CSO control measures will provide for the attainment of WQS, including designated uses in the receiving water. Receiving water modeling may be necessary to characterize the impact of CSOs on receiving water quality and to predict the improvements which would result from different CSO control measures. The presumption approach does not explicitly call for analysis of receiving water impacts. However, because the presumption approach may not be used when the permitting authority determines that it will not result in compliance with CWA requirements, the permittee may need to use screening-level models to show receiving water impacts.

In many cases, CSOs discharge to receiving waters that are water quality-limited and receive pollutant loadings from other sources, including nonpoint sources and other permitted point sources. The CSO Control Policy states that the permittee should characterize "the impacts of the CSOs and other pollution sources on the receiving waters and their designated uses." Under the demonstration approach, "where WQS and designated uses are not met in part because of natural background conditions or pollution sources other than CSOs, a total maximum daily load, including a wasteload allocation and a load allocation, or other means should be used to apportion pollutant loads."

Established under Section 303(d) of the CWA, the TMDL process assesses point and nonpoint pollution sources that together may contribute to a water body's impairment. This process relies on receiving water models.

An important initial decision—which water quality parameters should be modeled—should be based on data from receiving water monitoring. CSOs affect several receiving water quality parameters. Since the impact on one parameter is frequently much greater than on others, relieving this main impact will likely also relieve the others. For example, if a CSO causes exceedances of bacteria standards by several hundred-fold, as well as moderate dissolved oxygen depressions, solving the bacterial problem will likely solve the dissolved oxygen problem and so it may be sufficient to monitor bacteria only. Reducing the scope of modeling in this fashion may substantially reduce its cost.

8.2 MODEL SELECTION STRATEGY

A receiving water model should be selected according to the following factors:

- The type and physical characteristics of the receiving water body. Rivers, estuaries, coastal areas, and lakes typically require different models.

- The water quality parameters to be modeled. These may include bacteria, dissolved oxygen, suspended solids, toxics, and nutrients. These parameters are affected by different processes (e.g., die-off for bacteria, settling for solids, biodegradation for DO, adsorption for metals) with different time scales (e.g., hours for bacterial die-off, days for biodegradation) and different kinetics. The time scale in turn affects the distance over which the receiving water is modeled (e.g., a few hundred feet for bacteria to a few miles for dissolved oxygen).

- The number and geographical distribution of discharge points and the need to simulate sources other than CSOs.

The rest of Section 8.2 discusses some important considerations for hydrodynamic and water quality modeling, and how they affect the selection and use of a model.

The main purpose of a receiving water model for CSO analyses is to predict receiving water quality under different receiving water conditions and loadings. The flow conditions, or hydrodynamics, of the receiving water are an important factor in determining the effects of CSOs on receiving water quality. For simple cases, hydrodynamic conditions can be determined from the receiving water monitoring program; otherwise a hydrodynamic model may be necessary to characterize flow conditions.

Hydrodynamic and water quality models are either *steady-state* or *transient*. Steady-state models assume that conditions do not change over time, while transient models can simulate time-varying conditions. Flexibility exists in the choice of model types; generally, either a steady-state or transient water quality simulation can be done regardless of whether flow conditions are steady-state or transient.

8.2.1 Hydrodynamic Models

A hydrodynamic model provides the flow conditions, characterized by the water depth and velocity, for which water quality must be predicted. The following factors should be considered for different water body types:

- *Rivers*—The flow in rivers is generally unidirectional (except for localized eddies or other flow features) and the stream velocity and depth are a function of the flow rate. For relatively large rivers, the flow rate may not increase significantly due to wet weather discharges, and a constant flow can be used as a first approximation. This constant flow can be a specified low flow or a flow typical of a season or month. When the increase of river flow is important, it can be estimated by adding together all upstream flow inputs or by doing a transient flow simulation. The degree of refinement required also depends on the time scale of the water quality parameters of interest. For example, a constant river flow may suffice for bacterial simulations since die-off is relatively rapid. For dissolved oxygen, the time variations in river flow rate may be important and need to be considered.

- *Estuaries*—CSO impacts in estuaries are affected by tidal variations of velocity and depth (including possible reversal of current direction) and by possible salinity stratification. Tidal fluctuations can be assessed by measuring velocity and depth variations over a tide cycle or by using a one- or two-dimensional model. Toxics with relatively small mixing zones can be analyzed using steady currents corresponding to different times during the tidal cycle, but this may require using a computed circulation pattern from a model.

- *Coastal Areas*—CSO impacts in coastal areas are also affected by tidal fluctuations. The discussion on estuaries generally applies to coastal areas, but, because the areas are not channelized, two-dimensional or even three-dimensional models may be necessary.

- *Lakes*—CSO impacts in lakes are affected by wind (which usually accompanies wet weather) and thermal stratification. Wind-driven currents can be monitored directly or simulated using a hydrodynamic model (to properly simulate wind-driven currents, the model may need to cover the entire lake). Thermal stratification can generally be measured directly.

Because the same basic hydrodynamic equations apply (momentum and continuity)[1], the major models for receiving waters can typically simulate more than one type of receiving water body. Ultimately, three factors dictate whether a model can be used for a particular hydraulic regime. One factor is whether it provides a one-, two-, or three-dimensional simulation. A second is the model's ability to handle specific boundary conditions, such as tidal boundaries.

A third factor is whether the model assumes steady-state conditions or allows for time-varying pollutant loading. In general, steady-state loading models cannot accurately model CSO problems that require analysis of far-field effects. However, in some instances a steady-load model can estimate the maximum potential effect, particularly in systems where the transport of constituents is dominated by the main flow of the water body, rather than local velocity gradients. For example, by assuming a constant source and following the peak discharge plug of water downstream, the steady-load model QUAL2EU can determine the maximum downstream effects of conventional pollutants. The result is a compromise that approximates the expected impact but neglects the effects of longitudinal dispersion in moderating the concentration peak as it moves downstream. However, QUAL2EU cannot give an accurate estimate of the duration of excursions above WQS.

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[1]The momentum equation describes the motion of the receiving water, while the continuity equation is a flow balance relationship (i.e., total inflows to the receiving water less total outflows is equal to the change in receiving water volume).

8.2.2 Water Quality Models

The frequency and duration of CSOs are important determinants of receiving water impacts and need to be considered in determining appropriate time scales for modeling. CSO loads are typically delivered in short pulses during storm events. Selection of appropriate time scales for modeling receiving water impacts resulting from a pulsed CSO loading depends upon the time and space scales necessary to evaluate the WQS. If analysis requires determining the concentration of a toxic at the edge of a relatively small mixing zone, a steady-state mixing zone model may be satisfactory. When using a steady-state mixing zone model in this way, the modeler should apply appropriately conservative assumptions about instream flows during CSO events. For pollutants such as oxygen demand, which can have impacts lasting several days and extending several miles downstream of the discharge point, it may be warranted to incorporate the pulsed nature of the loading. Assuming a constant loading is much simpler (and less costly) to model; however, it is conservative (i.e., leads to impacts larger than expected). For pollutants such as nutrients where the response time of the receiving water body may be slow, simulating only the average loading rate may suffice.

Receiving water models vary from simple estimations to complex software packages. The choice of model should reflect site conditions. If the pulsed load and receiving water characteristics are adequately represented, simple estimations may be appropriate for the analysis of CSO impacts. To demonstrate compliance with the CWA, the permittee may not need to know precisely where in the receiving water excursions above WQS will occur. Rather, the permittee needs to know the maximum pollutant concentrations and the likelihood that excursions above the WQS can occur at any point within the water body. However, since CSOs impacting sensitive areas are given a higher priority under the CSO policy, simulation models for receiving waters with sensitive areas may need to use short time scales (e.g., hourly pollutant loads), and have high resolution (e.g., several hundred yards or less) to specifically assess impacts to sensitive areas.

8.3 AVAILABLE MODELS

Receiving water models cover a wide variety of physical and chemical situations, and, like CSS models, vary in complexity. EPA has produced extensive guidance on receiving water modeling as part of the Waste Load Allocation (WLA) guidance series. These models, however, tend to concentrate on continuous sources and thus may not be the most suitable for CSOs. A recent summary of EPA-supported models including receiving water models is provided in Ambrose et al. (1988). This guidance does not provide a complete catalogue of available receiving water models. Rather, it describes simplified techniques and provides a brief overview of relevant EPA-supported receiving water models.

8.3.1 Simplified Analyses

In many cases, detailed receiving water simulation may not be necessary. Use of dilution and mixing zone calculations or simulation with simple spreadsheet models will be sufficient to assess the magnitude of potential impacts or evaluate the relative merits of various control options.

Many of the simpler approaches to receiving water evaluation make assumptions of steady flow and steady or gradually varying loading. These assumptions may be appropriate if an-order-of-magnitude estimate or an upper bound of the impacts are required. The latter is obtained by using conservative parameters such as peak loading and low current speed. If WQS attainment is predicted under realistic worst case assumptions, more complex simulations may not be needed.

8.3.2 Model Types

The following sections discuss the simulation of different water quality parameters in rivers, lakes and estuaries.

RIVERS

Bacteria and Toxics. Bacteria and toxic contaminants are primarily a concern in the immediate vicinity of CSO outfalls. They are controlled by lateral mixing, advection, and decay processes such as die-off (for bacteria) and settling or vaporization (for toxics). When stream flow is small relative to CSO flow, lateral mixing may occur rapidly and a one-dimensional model may be appropriate. Initial estimates can be made using a steady-state approach that neglects the time-varying nature of the CSO. In this case, concentrations downstream of a CSO are given by:

$$C_x = \frac{Q_u C_u + Q_e C_e}{Q_s} e^{\frac{-KX}{u}}$$

where:	C_x	=	max pollutant concentration at distance X from the outfall
	C_e	=	pollutant concentration in effluent
	C_u	=	pollutant concentration upstream from discharge
	Q_e	=	effluent flow
	Q_u	=	stream flow upstream of discharge
	Q_s	=	stream flow downstream of discharge ($Q_u + Q_e$)
	X	=	distance from outfall
	u	=	stream flow velocity
	K	=	decay rate (die-off rate for bacteria, settling velocity divided by stream depth for settling, vaporization rate divided by stream depth for vaporization)

For CSOs in large rivers, lateral mixing may occur over large distances and bacterial counts or toxics concentrations on the same shore as the discharge can be calculated using the following expression, as a conservative estimate (U.S. EPA, 1991a):

$$C_x = \frac{C_e Q_e W}{Q_s \sqrt{\frac{\pi D_y X}{u}}}$$

where:	D_y	=	lateral dispersion coefficient
	W	=	stream width

This equation is conservative because it neglects any discharge-induced mixing. Simulating over the correlated probability distributions of C_e, Q_e, Q_s and Q_u can provide an estimate of the frequency of WQS exceedances at a specific distance from the outfall. The method requires the estimation of a lateral dispersion coefficient, which can be measured in dye studies or by methods described in *Mixing in Inland and Coastal Waters* (Fischer et al., 1979). Fischer's methods calculate the lateral dispersion coefficient D_y as follows:

$$D_y = 0.6\ du^* \pm 50\%$$

where: d = water depth at the specified flow
u^* = shear velocity

In turn, the following equation estimates shear velocity:

$$u^* = (gds)^{1/2}$$

where: g = acceleration due to gravity
s = slope of channel
d = water depth

EPA (1991a) advocates the use of three modeling techniques for assessing toxic discharges: continuous simulation, Monte Carlo simulation, and lognormal probability modeling. These methods approximate the complete probability distributions of receiving water concentrations, in accordance with the recommended frequency-duration format for water quality. The model DYNTOX (LimnoTech, 1985) is specially designed for lognormal probability analysis of toxics in rivers. The WLA series by Delos et al. (1984) and U.S. EPA (1991a) address the transport of toxics and heavy metals in rivers.

Note to reviewers: Would it be helpful to add a description here of continuous and Monte Carlo simulations and logonormal probability modeling, or should that be left to the referenced documents?

Oxygen Demand/Dissolved Oxygen. The time scales and distances affecting DO processes are greater than for bacteria and toxics. Lateral mixing therefore results in approximately uniform conditions over the river cross section and one-dimensional models are usually appropriate for simulation. The WLA guidance (U.S. EPA, 1994) discusses the effects of steady and dynamic DO loads, and provides guidelines for modeling impacts of steady-state sources. Simple spreadsheet models such as STREAMDO IV (Zander and Love, 1990) have recently become available for DO analysis.

In general, screening analyses using classical steady-state equations can examine DO impacts to rivers as a result of episodic loads. This approach assumes plug flow, which in turn allows an assumption of constant loading averaged over the volume of the plug (Freedman and Marr, 1990). This approach does not consider longitudinal diffusion from the plug, making it a conservative approach. The plug flow analysis should correlate with the duration of the CSO. For example, a plug flow simulation of a 2-hour CSO event would result in a downstream DO sag that would also last for 2 hours. Given the plug flow assumption, the classic Streeter-Phelps equation can estimate the DO concentration downstream:

$$D = D_o e^{-K_a t} + \frac{W}{Q}\left(\frac{K_d}{K_a - K_r}\right)\left[e^{-K_r t} - e^{-K_a t}\right]$$

where:	D	=	dissolved oxygen deficit downstream (M/V)
	D_0	=	initial dissolved oxygen deficit (M/V)
	K_a	=	atmospheric re-aeration rate (1/T)
	t	=	time of passage from source to downstream location (T)
	W	=	total pollutant loading rate (M/T)
	Q	=	total river flow (V/T)
	K_d	=	BOD deoxygenation rate (1/T)
	K_r	=	BOD loss rate (1/T)

This method can address the joint effects of multiple steady sources through the technique of superposition (Exhibit 8-1). However, it cannot address multiple sources that change over time, nor can it address the effects of river morphology. When such issues are important, more sophisticated modeling techniques are necessary.

Nutrients/Eutrophication. Nutrient discharges affect river eutrophication over time scales of several days to several weeks. Nutrient/eutrophication analysis considers the relationship between nutrients and algal growth. Analysis of nutrient impacts in rivers is complex

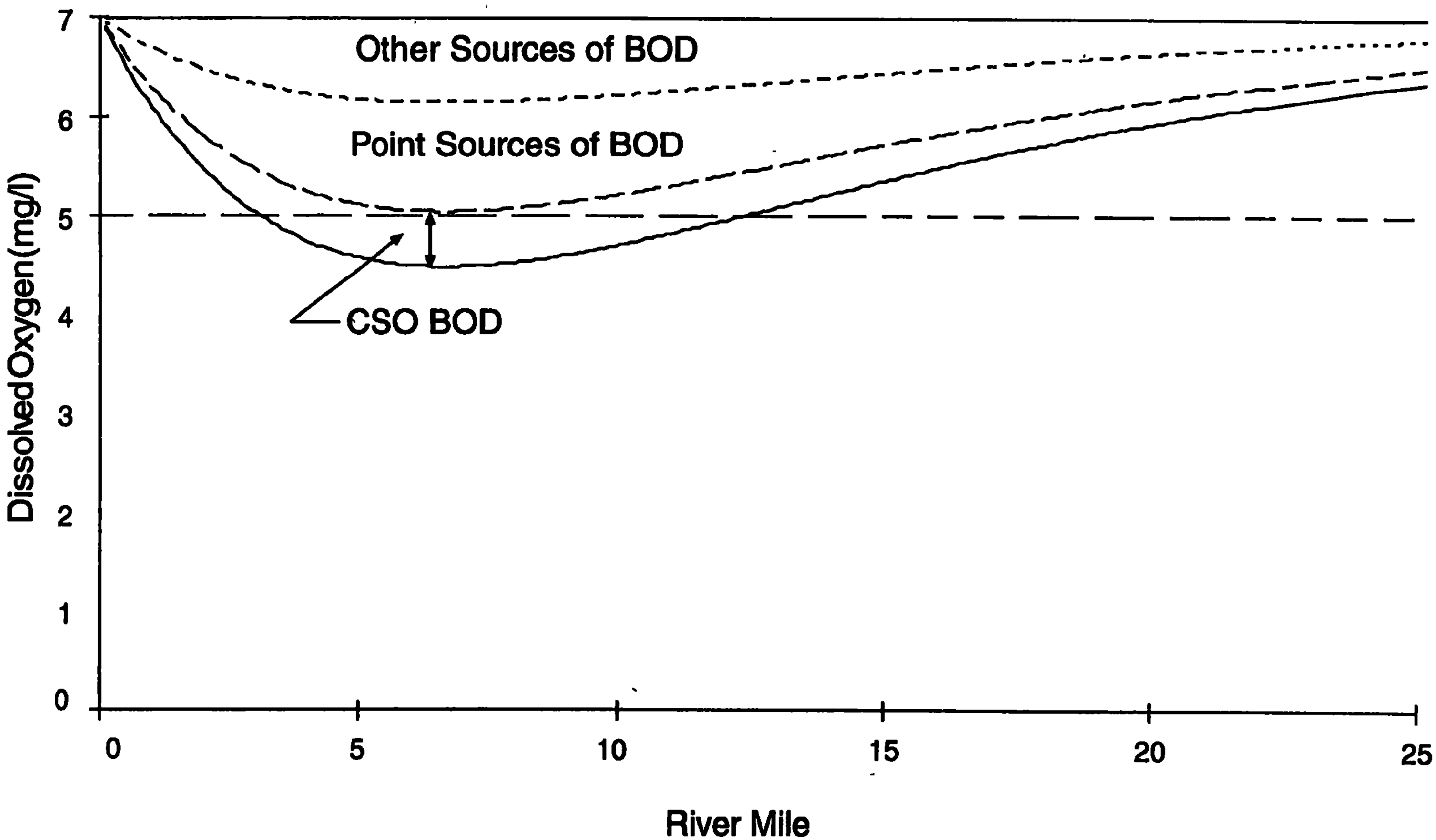


Exhibit 8-1. Dissolved Oxygen Superposition Analysis

because nutrients and planktonic algae[2], which are free-floating one-celled algae, usually move through the system rapidly.

The current WLA guidance (U.S. EPA, 1995g) considers only planktonic algae (rather than all aquatic plants) and discusses nutrient/eutrophication in rivers primarily as a component in computing DO. The guidance applies to narrative criteria that limit nuisance plant growth in large, slowly flowing rivers.

LAKES

Bacteria and Toxics. Mixing zone analysis can often be used to assess attainment of WQS for bacteria and toxics in lakes. For a small lake in which the effluent mixes rapidly, the concentration response is given by (Freedman and Marr, 1990):

$$C=\frac{M}{V}e^{(-K-\frac{Q}{V})t}$$

where:

M	=	mass loading (M)
Q	=	flow (L^3/T)
K	=	decay rate (1/T)
V	=	lake volume (L^3)
t	=	time (T)
C	=	concentration (M/L^3)

For an incompletely-mixed lake, however, a complex simulation model is generally necessary to estimate transient impacts from slug loads. The EPA WLA guidance series contains a manual (Hydroqual, Inc., 1986) on chemical models for lakes and impoundments. This guidance, which is also applicable to bacteria, describes simple and complex models and presents criteria for selecting models and model parameters.

Oxygen Demand/Dissolved Oxygen. Simple analytical approximations can model oxygen demand and DO in cases where DO mixing occurs quickly relative to depletion by

[2]Aquatic plants can be divided into those that move freely with the water (planktonic aquatic plants) and those that are attached or rooted in place.

COD/BOD. Where lateral mixing occurs rapidly but vertical temperature stratification exists, DO concentration can be addressed for a two-layer stratified lake under the following simplifying assumptions (from Thomann and Mueller, 1987):

- The horizontal area is constant with depth
- Inflow occurs only to the surface layer
- Photosynthesis occurs only in the surface layer
- Respiration occurs at the same rate throughout the lake
- The lake is at steady-state.

With these severe restrictions, the solution is given by:

$$c_1 = \left(\frac{q}{K_L+q}\right)c_o + \left(\frac{K_L}{K_L+q}\right)c_s + \frac{pH_1 - RH - S_B}{K_L+q} - \frac{K_{d1}H_1L_1 - K_{d2}H_2L_2}{K_L+q}$$

and

$$c_2 = c_1 - \left(\frac{S_B + RH_2 - K_{d2}H_2L_2}{E/H_i}\right)$$

where the subscripts 1 and 2 refer to the epilimnion (top layer) and hypolimnion (lower layer) respectively, and variables without subscripts refer to the whole lake, and where:

q	=	Outflow rate (L/T)
K_L	=	DO transfer rate at lake surface (L/T)
c	=	DO concentration (M/L^3)
c_o, c_s	=	Initial and saturation dissolved oxygen concentrations (M/L^3)
p	=	Gross photosynthetic production of DO (m/L^3-T)
H	=	Depth (L)
H_i	=	$H/2$ when $H_1 = H_2$ and H_1 when $H_2 >> H_1$ (L)
R	=	Phytoplankton DO respiration (M/L^3-T)
S_B	=	Sediment oxygen demand (M/L^2-T)
K_d	=	Deoxygenation coefficient (1/T)
L	=	Steady-state CBOD concentration in water column (M/L^3), = W/{Q+K_rV}, where W is the mass loading rate, Q is the rate of flow through the lake, V is the volume, and K_r is the net loss rate.
E	=	Dispersion coefficient (L^2/T)

Because this analysis assumes steady-state loading and because measuring some of the parameters proves difficult, the method may only have limited application to CSOs.

In many cases, complex simulation models are necessary to analyze DO in lakes. These are either specialized lake models or flexible models, such as EUTROWASP, that are designed to address issues specific to lakes. Some modelers have been successful in modeling thermally stratified lakes with one or two dimensional river models (e.g., QUAL2EU) that assume the river bottom is the thermocline.

Nutrient/Eutrophication Impacts. For lakes, simple analytic equations often can analyze end-of-pipe impacts and whole-lake impacts. However, evaluating mixing phenomena in a lake frequently requires a complex computer model (Freedman and Marr, 1990). Simple analytical methods can be applied to lake nutrient/eutrophication impacts in situations where the CSOs mix across the lake area within the time scale required to obtain a significant response in the algal population. In most lakes, phosphorus is considered to be the limiting nutrient for nuisance algal impacts and eutrophication. Mancini et al. (1983) and Thomann and Mueller (1987) have developed a procedure for calculating the allowable surface loading rate. The following steps are drawn from this procedure:

Step 1. Estimate the lake volume, surface area, and mean depth.

Step 2. Estimate the mean annual outflow rate. Where urban areas draining to the lake constitute a significant fraction of the total drainage area, flow estimates from urban runoff and CSOs should be included in the hydrologic balance around the lake. For lakes with large surface areas, the estimate should include surface precipitation and evaporation.

Step 3. Determine the average annual total phosphorus loading due to all sources, including all tributary inflows, municipal and industrial sources, distributed urban and rural runoff, and atmospheric inputs. *Technical Guidance Manual for Performing Waste Load Allocation* (Mancini et al., 1983) discusses techniques for estimating these loadings.

Step 4. For total phosphorus, assign a net sedimentation loss rate that is consistent with a local data base.

Step 5. Select trophic state objectives of either total phosphorus or chlorophyll-*a* consistent with local experience. Calculate the value of the allowable phosphorus areal loading, W', from:

$$W' = a\bar{z}\left(\frac{Q}{V} + v_s\right)$$

where:

- W' is the allowable areal surface loading rate (M/L^2-T)
- a is the trophic state objective concentration of total phosphorus or chlorophyll-*a* (M/L^3),
- Q is outflow (L^3/T),
- V is lake volume (L^3),
- $\bar{z}$ is mean depth (L), and
- v_s is the net sedimentation velocity (L/T).

Step 6. Compare the total areal loading determined in Step 3 to the value of W' obtained in Step 5.

Additional approaches are discussed in Rechkow and Chapra (1983b).

ESTUARIES

Unlike rivers, estuaries are tidal. When averaged on the basis of tidal cycles, pollutant transport in narrow, vertically mixed estuaries with dominant longitudinal flow is similar to that in rivers. However, due to tidal reversals of flow, a narrow estuary may have a much larger effective dispersion coefficient since shifting tides may cause greater lateral dispersion. In such a system, the modeler can apply approximate or screening models used for rivers, provided that an appropriate tidal dispersion coefficient has been calculated. In wider estuaries, tides and winds often result in complex flow patterns and river-based models would be inappropriate. WLA guidance for estuaries is provided in several EPA manuals (Ambrose et al., 1990a; Ambrose et al., 1990b; Jirka, 1992; Freedman et al., 1992).

In addition to their tidal component, many estuaries are characterized by salinity-based stratification. Stratified estuaries have the horizontal mixing due to advection and dispersion that is associated with rivers and the vertical stratification characteristic of lakes.

In complex estuaries, accurate analysis of far-field CSO impacts—such as nutrients/eutrophication, DO, and impacts on particular sensitive areas—typically requires complex simulation models. Simpler analyses are sometimes possible by treating the averaged effects of tidal and wind-induced circulation and mixing as temporally constant parameters. This approach may require extensive site-specific calibration.

Near-field mixing zone analysis in estuaries also presents special problems, because of the role of buoyancy differences in mixing. Jirka (1992) discusses mixing-zone modeling for estuaries.

8.3.3 EPA-Supported Models

EPA's Center for Exposure Assessment Modeling (CEAM) maintains a distribution center for water quality models and related data bases (Exhibit 8-2). CEAM-supported models relevant to modeling impacts to receiving water include QUAL2EU, WASP, HSPF, EXAMSII, CORMIX, and MINTEQ.

QUAL2EU is a one-dimensional model for rivers. It assumes steady-state flow and loading but allows simulation of diurnal variations in temperature or algal photosynthesis and respiration. QUAL2EU simulates temperature, bacteria, BOD, DO, ammonia, nitrate, nitrite, organic nitrogen, phosphate, organic phosphorus, algae, and additional conservative substances.[3] Because it assumes steady flow and pollutant loading, its applicability to CSOs is limited. However, the model can use steady loading rates to generate worst-case projections for CSOs to rivers. The model has pre and post-processors for performing uncertainty and sensitivity analyses.

Additionally, in certain cases, experienced users may be able to use the model to simulate non-steady pollutant loadings under steady flow conditions by establishing certain initial conditions or by dynamically varying climatic conditions. If used in this way, the QUAL2EU

[3]A conservative substance is one that does not undergo any chemical or biological transformation or degradation in a given ecosystem. (EPA, 1995g)

Exhibit 8-2. EPA CEAM Supported Receiving Water Models

Applicability to Hydraulic Regimes and Pollutant Type

Model	Rivers & Streams			Lakes & Impoundments			Estuaries			Near Field Mixing
	Nutrients	Oxygen	Other	Nutrients	Oxygen	Other	Nutrients	Oxygen	Other	
QUAL2EU	✓	✓	✓							
WASP5	✓	✓	✓	✓	✓	✓	✓	✓	✓	
HSPF	✓	✓	✓							
EXAMSII			✓			✓			✓	
DYNTOX			✓							
CORMIX	Near-field mixing model for all water body types									✓
MINTEQ	Equilibrium metal speciation model									

Key Characteristics and References

Model	Pollutant Loading Type	Transport Dimensionality	Current Version	Key References
QUAL2EU	Steady	1-D	3.22	Brown & Barnwell, 1987
WASP5	Dynamic	Quasi-2/3-D (link-node)	5.10	Ambrose, et al., 1988
HSPF	Dynamic (Integrated)	1-D	10.11	Johanson, et al., 1984
EXAMSII	Dynamic	User input (quasi 3-D)	2.96	Burns, et al., 1982
CORMIX	Steady (near field)	Quasi-3-D (zonal)	2.10	Doneker & Jirka, 1990
MINTEQ	Steady	None	3.11	Brown & Allison, 1987

model should be considered a screening tool since the model was not designed to simulate dynamic quality conditions.

WASP5 is a quasi-two-dimensional or quasi-three-dimensional water quality model applicable to rivers, estuaries, and many lakes. It has a link-node formulation, which simulates storage at the nodes and transport along the links. The links represent a one-dimensional solution of the advection dispersion equation, although quasi-two-dimensional or quasi-three-dimensional simulations are possible if nodes are connected to multiple links. The model also simulates limited sediment processes. It includes the time-varying processes of advection, dispersion, point and nonpoint mass loading, and boundary exchanges. WASP5 can be used in two modes: EUTRO5 for nutrient and eutrophication analysis and TOXI5 for analysis of toxic pollutants and metals. WASP is essentially a pollutant fate and transport model; transport can be driven by the WASP companion hydrodynamic model, DYNHYD, which simulates transient hydrodynamics (including tidal estuaries) or by using it with another hydrodynamic model.

HSPF is a comprehensive hydrologic and water quality simulation package which can simulate both CSSs and receiving waters for conventional and toxic organic pollutants. It simulates channels (such as rivers) on a one-dimensional basis and completely-mixed waters (such as reservoirs) as zero-dimensional. HSPF simulates three sediment types: sand, silt and clay. It can also simulate an organic pollutant and transformation products of that pollutant.

EXAMSII can rapidly evaluate the fate, transport, and exposure concentrations of steady discharges of synthetic organic chemicals to aquatic systems. A recent upgrade of the model considers seasonal variations in transport and time-varying chemical loadings, making it quasi-dynamic. The user must specify transport fields to the model.

CORMIX is an expert system for mixing zone analysis. It can simulate submerged or surface, buoyant or non-buoyant discharges into stratified or unstratified receiving waters, with emphasis on the geometry and dilution characteristics of the initial mixing zone. The model uses a zone approach, in which a flow classification scheme determines which near-field mixing processes to model.

MINTEQ determines geochemical equilibrium for priority pollutant metals. Not a transport model, MINTEQ provides a means for modeling metal partitioning in discharges. The model usually must be run in connection with another fate and transport model, such as those described above. It provides only steady-state predictions.

8.3.4 Other Models

EPA CEAM or other government agencies also support the following additional models:[4]

MICHRIV (Richardson et al., 1983) is a one-dimensional steady-state model for simulating the transport of contaminants in the water column and bed sediments in streams and non-tidal rivers.

SERATRA (Onishi and Wise, 1982) is a two-dimensional vertical plane model for the transport of contaminants and sediments in rivers.

CE-QUAL-W2 is a reservoir and narrow estuary hydrodynamics and water quality model developed by the Waterways Experiment Station of the U.S. Army Corps of Engineers in Vicksburg, Mississippi. The model provides dynamic two-dimensional (longitudinal and vertical) simulations. It accounts for density effects on flow as a function of the water temperature, salinity and suspended solids concentration. CE-QUAL-W2 can simulate up to 21 water quality parameters in addition to temperature, including one passive tracer (e.g., dye), total dissolved solids (TDS), coliform bacteria, inorganic suspended solids, algal/nutrient/DO dynamics (11 parameters), alkalinity, pH and carbonate species (4 parameters).

Another model relevant to assessing impacts to receiving water is **DYNTOX**. DYNTOX is a one-dimensional, probabilistic toxicity dilution model for transport in rivers. It provides continuous Monte Carlo or lognormal probability simulations that can be used to analyze the

[4] McKeon and Segna (1987), Ambrose et al. (1988) and Hinson and Basta (1982) have reviewed some of these models.

frequency and duration of ambient toxic concentrations resulting from a waste discharge. The model considers dilution and net first-order loss, but not sorption and benthic exchange.

8.4 USING A RECEIVING WATER MODEL

As was the case for CSS models (see Section 7.4), receiving water modeling involves development of the model, calibration and validation, performing the simulation, and interpreting the results.

8.4.1 Developing the Model

Specific data needs for receiving water models depend upon the hydraulic regime and model employed. For specific input data requirements, the permittee should refer to the documentation for individual models, the relevant sections of the WLA guidance, or to texts such as *Principles of Surface Water Quality Modeling and Control* (Thomann and Mueller, 1987). Tables B-2 through B-5 in Appendix B contain general tables of data inputs to receiving water models.

8.4.2 Calibrating and Validating the Model

Like CSS models, receiving water models need to be calibrated and validated. The model should be run to simulate events for which receiving water hydraulic and quality monitoring were actually conducted, and the model results should be compared to the measurements. Generally, receiving water models are calibrated and validated first for receiving water hydraulics and then for water quality. Receiving water models typically cannot be calibrated to the same degree of accuracy as CSS models because:

- Pollutant loading inputs typically are estimates rather than precisely known values.

- Since three-dimensional receiving water models are still not commonly used for CSO projects, receiving water models involve spatial averaging (over the depth, width or cross-section). Thus, model results are not directly comparable with measurements, unless the measurements also have sufficient spacial resolution to allow comparable averaging.

- Loadings from non-CSO sources, such as storm water, upstream boundaries, point sources, and atmospheric deposition often are not accurately known.

- Receiving water hydrodynamics are affected by numerous factors which are difficult to account for. Those include fluctuating winds, large scale eddies, and density effects.

Although these factors make model calibration challenging, they also underscore the need for calibration to ensure that the model reasonably reflects receiving water data.

8.4.3 Performing the Modeling Analysis

Receiving water modeling can involve single events or long-term simulations. Single event simulations are usually favored when using complex models, since these model require larger amounts of input data and take significantly longer to run. However, advances in computer technology keep pushing the limits of what can practically be achieved. Long-term simulations can predict water quality impacts on an annual basis.

Although a general goal is to predict the number of water quality criteria exceedances, models can evaluate exceedances using different measures, such as hours of exceedance at beaches or other critical points, acre-hours of exceedance, and mile-hours of exceedance along a shore. These provide a more refined measure of the water quality impacts of CSOs and of the expected effectiveness of different control measures.

Commonly, CSO loadings are simulated separately in order to gage CSO impacts relative to other sources. This procedure is appropriate because the equations which govern receiving water quality are linear and, consequently, effects are additive.

8.4.4 Modeling Results

By means of averages over space and time, simulation models predict CSO volumes, pollutant concentrations, and other variables of interest. The extent of this averaging depends on the model structure, how the model is applied, and the resolution of the input data. The model's space and time resolution should match that of the necessary analysis. For instance, the applicable WQS may be expressed as a 1-hour average concentration not to exceed a given concentration more than once every 3 years on average. Spatial averaging may be represented by a concentration averaged over a receiving water mixing zone, or implicitly by the specification of monitoring locations to establish compliance with instream criteria. In any case, the permittee should note whether the model predictions use the same averaging scales required in the permit or relevant WQS.

When used for continuous rather than event simulation, as suggested by the CSO Control Policy, simulation model results can predict the frequency of exceedances of water quality criteria. Probabilistic models, such as the Monte Carlo simulation, also can make such predictions. In probabilistic models the simulation is made over the probability distribution of precipitation and other forcing functions (e.g., temperature, point sources, flow). In either case, modelers can analyze the output for water quality criteria exceedances and the frequency of such exceedances.

The key result of receiving water modeling is the prediction of future conditions, due to implementation of CSO control alternatives. In most cases, CSO control decisions will have to be supported by model predictions of the pollutant load reductions necessary to achieve water quality standards. In the receiving waters, critical or design water quality conditions might be periods of low flows and high temperature that are impacted by wet weather events. These periods are established based on a review of available data. Flow, temperature, and other variables for these periods then form the basis of future condition analysis.

It is useful to assess the sensitivity of model results to variations and changes in parameters, rate constants, and coefficients. Such a sensitivity analysis can determine the key parameters, rate constants, and coefficients which merit particular attention in evaluating CSO control alternatives. The modeling approach should accurately represent features that are fully understood, and sensitivity analysis should be used to evaluate the significance of factors that are not as clearly defined. (See Section 7.4.4 for additional discussion of sensitivity analysis.)

CHAPTER 9

ASSESSING RECEIVING WATER IMPACTS AND ATTAINMENT OF WATER QUALITY STANDARDS

This chapter focuses on the link between CSOs and the attainment of WQS in a water body. As discussed in previous chapters, permittees can consider a variety of methods to analyze the performance of the CSS and the response of a water body to pollutant loads. Permittees can use these methods to estimate the water quality impacts of a proposed CSO control program and evaluate whether it is adequate to meet CWA requirements.

Under the CSO Control Policy, permittees need to develop a long-term control plan (LTCP) that provides for WQS attainment using either the presumption approach or the demonstration approach. This chapter focuses primarily on issues related to the demonstration approach since this approach requires the permittee to adequately demonstrate that the selected CSO controls will provide for the attainment of WQS. As mentioned in Chapter 8, the presumption approach does not explicitly call for analysis of receiving water impacts and thus generally involves less complex modeling.

Modeling time-varying wet weather sources such as CSOs is more complex than modeling more traditional point sources. Typically, point-source modeling assumes constant pollutant loading to a receiving water body under critical, steady-state conditions—such as minimum seven-consecutive-day average stream flow occurring once every ten years (i.e., 7Q10). Wet weather loads occur in pulses, however, and often have their peak impacts under conditions other than low-flow situations. A receiving water model must therefore accommodate the short-term variability of pollutant concentrations and flow volume in the discharge as well as the dynamic conditions in the receiving water body.

CSO loads can be incorporated into receiving water models using either a steady-state or a dynamic approach. A steady-state model can be used to obtain an approximate solution using, for example, average loads for a design storm. A dynamic approach, on the other hand, incorporates time-varying loads and simulates the time-varying response of the water body. The steady-state approximation uses conservative assumptions and sacrifices accuracy but typically requires less cost and effort. A dynamic model requires greater resources but may result in a more cost-effective CSO control plan, since it avoids conservative assumptions.

Generally, the modeler should use the simplest approach that is appropriate for local conditions. For example, a steady-state model may be appropriate in a receiving water that is relatively insensitive to short-term variations in load rate. (For instance, the response time of lakes and coastal embayments to some pollutant loadings may be measured in weeks to years, and the response time of large rivers to oxygen demand may be measured in days (Donigian and Huber, 1991).) Steady-state models are also useful for estimating the dilution of pollutants, such as acute toxins or bacteria, close to the point of release.

9.1 IDENTIFYING RELEVANT WATER QUALITY STANDARDS

If a permittee uses the demonstration approach, the permittee should prove that its selected CSO controls will ensure that WQS are met. The CSO Control Policy states that:

> *The permittee should demonstrate...*
>
> *i. the planned control program is adequate to meet WQS and protect designated uses, unless WQS or uses cannot be met as a result of natural background conditions or pollution sources other than CSOs;*
>
> *ii. the CSO discharges remaining after implementation of the planned control program will not preclude the attainment of WQS or the receiving waters' designated uses, or contribute to their impairment. Where WQS and designated uses are not met in part because of natural background conditions or pollution sources other than CSOs...* (II.C.4.b)

The first step in analyzing CSO impacts on receiving water consists of defining the pollutants or stressors of concern and any corresponding WQS applicable to the receiving water. CSOs are distinguished from storm water loadings by the increased levels of such pollutants as bacteria, oxygen-demanding wastes, and certain nutrients. In some cases, toxic pollutants entering the CSS from industrial sources may be pollutants of concern in CSOs.

State WQS include designated uses and numerical and narrative criteria. Since CSO controls must ultimately provide for attainment of WQS, the analysis of CSO control alternatives should be tailored to the applicable WQS. For example, if the WQS specifies daily average concentrations, the analysis should address daily averages. Many water bodies have narrative criteria such as a requirement to limit nutrient loads to an amount that does not produce a "nuisance" growth of algae, or the prevention of solids and floatables build-up. In such cases, the permittee could consider developing a site-specific, interim numeric performance standard that would result in meeting the narrative criterion.

EPA has developed water quality criteria to assist States in developing their numerical standards and to assist in interpreting narrative standards (EPA, 1991a). EPA recommends that water quality criteria for the protection of aquatic life have a magnitude-duration-frequency format, which requires that the concentration of a given constituent not exceed a critical value more than once in a given return period:

- ***Magnitude***—The concentration of a pollutant, or pollutant parameter such as toxicity, that is allowable.

- ***Duration***—The averaging period, which is the period of time over which the in-stream concentration is averaged for comparison with criteria concentrations. This specification limits the duration of concentrations above the criteria.

- ***Frequency***—How often criteria can be exceeded.

A magnitude-duration-frequency criteria statement directly addresses protection of the water body by expressing the acceptable likelihood of excursions above the WQS. Although this approach appears useful, it requires estimation of long-term average rates of excursion above WQS.

Many States rely instead on the concept of design flows, such as 7Q10. Evaluating compliance at a design low flow of specified recurrence is a simple way to approximate the average duration and frequency of excursions above the WQS. A single design flow, however, is not necessarily the best choice for wet-weather flows, which are unlikely to occur simultaneously with critical low-flow conditions. Consequently, a design flow-based control strategy may be overly conservative.

The statistical form of the relevant WQS is important in determining an appropriate model framework. Does the permittee need to calculate a long-term average, a worst case maximum, or an actual time sequence of the number of water quality excursions? An approach that gives a reasonable estimate of the average may not prove useful for estimating an upper bound. In some cases, such as State standards for indicator bacteria, water quality criteria will be expressed as both a short-term maximum (or upper percentile) and a long-term average component.

9.2 OPTIONS FOR DEMONSTRATING COMPLIANCE

Receiving water impacts can be analyzed at varying levels of complexity, but all approaches attempt to answer the same question: *Using a prediction of the frequency and volume of CSO events and the pollutant loads delivered by these events, can WQS in the receiving water body be attained with a reasonable level of assurance?*

Any of the following types of analyses, arranged in order of increasing complexity, can be used to answer this question:

- ***Design Flow Analysis***—This approach analyzes the impacts of CSOs under the assumption that they occur at a design condition (e.g., 7Q10 low flow prior to addition of the flow from the CSS). The CSO is added as a steady-state load. If WQS can be attained under such a design condition, with the CSO treated as a steady source, WQS are likely to be attained for the actual wet weather conditions. This approach is conservative in two respects: (1) it does not account for the short-term pulsed nature of CSOs, and (2) it does not account for increased receiving water flow during wet weather.

- ***Design Flow Frequency Analysis***—Where the WQS is expressed in terms of frequency and duration, the frequency of occurrence of CSOs can be included in the analysis. The design flow approach can then be refined by determining critical design conditions that can reasonably be expected to take place concurrently with CSOs. For instance, if CSO events occur primarily in one season, the analysis can include critical flows and other conditions appropriate to that season, rather than the 7Q10.

- *Statistical Analysis*—Whereas the previous two approaches rely on conservative design conditions, a statistical analysis can be used to consider the range of flows that may occur together with CSO events. This analysis more accurately reflects the frequency of excursions of WQS.

- *Watershed Simulation*—A statistical analysis does not consider the dynamic relationship between CSOs and receiving water flows. For example, both the CSO and receiving water flows increase during wet weather, providing additional dilution capacity. Demonstrating the availability of this additional capacity, however, requires a model that includes the responses of both the sewershed and its receiving water to the rainfall events. Dynamic watershed simulations may be carried out for single storm events or continuously for multiple storm events.

The permittee should consider the tradeoffs between simpler and more complex types of receiving water analysis. A more complex approach, although more costly, can generally provide more precise analysis using less conservative assumptions. This may result in a more tailored, cost-effective CSO control strategy.

Additional discussion on data assessment for determining support of WQS can be found in *Guidelines for the Preparation of the 1996 State Water Quality Assessments (305(b) Reports)* (EPA, 1995f).

9.3 EXAMPLES OF RECEIVING WATER ANALYSIS

This section presents three examples to illustrate key points for CSO receiving water impact analysis. The examples focus on (1) establishing the link between model results and demonstrating the attainment of WQS, and (2) the uses of receiving water models at different levels of complexity, from design flow analysis to dynamic continuous simulation.

The first example shows how design flow analysis or more sophisticated methods can be used to analyze bacteria loads to a river from a single CSO event. The second example, which is more complex, involves bacterial loads to an estuary. The third example illustrates how BOD loads from a CSS contribute to dissolved oxygen depletion.

9.3.1 Example 1: Bacterial Loads to a River

This example involves a CSS in a small northeastern city that overflows relatively frequently and contributes to WQS excursions. CSOs are the only pollutant source, and only a single water quality criterion—for fecal coliform—applies. The use classification for this receiving water body is primary and secondary contact recreation. The city has planned several engineering improvements to its CSS and wishes to assess the water quality impacts of those improvements.

Exhibit 9-1 is a map of key features in this example.

In this example, dilution calculations may suffice to predict whether the water quality criterion is likely to be attained during a given CSO event. This is because:

(1) Mixing zones are allowed in this State, so the water quality criterion must be met at the edge of the mixing zone. If the criterion is met at that point, it will also be met at points farther away.

(2) Die-off will reduce the numbers of bacteria as distance from the discharge/mixing zone increases.

(3) Since the river flows constantly in one direction, bacterial concentrations do not accumulate or combine loads from several days of release.

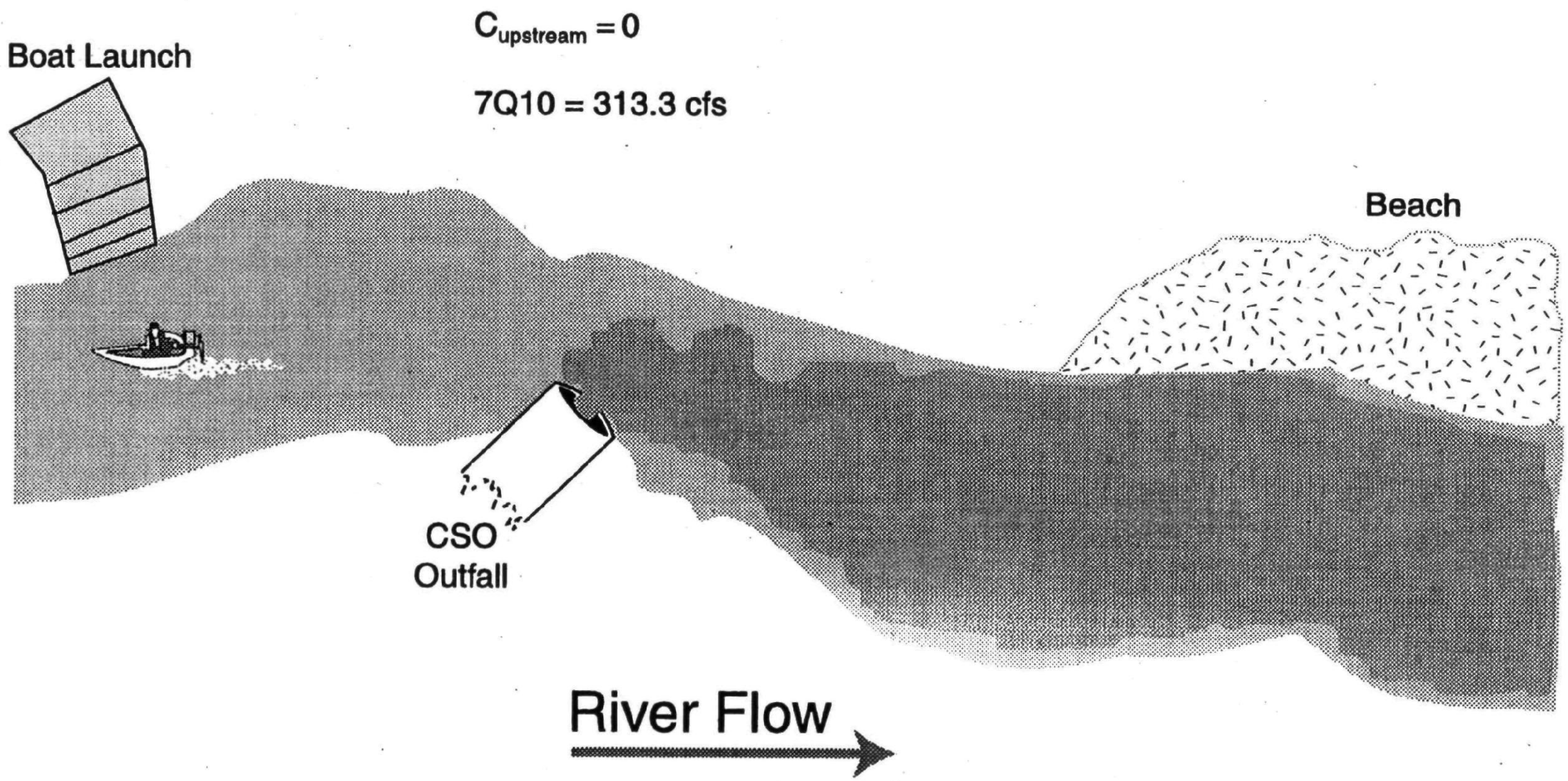
To illustrate the various levels of receiving water analysis, this example assumes that the magnitude and timing of CSOs, based on controls instituted to date, can be predicted precisely and that the long-term average characteristics of the CSS will remain constant. The predictions for the next 31 years include the following (Exhibit 9-2):

(1) The system should experience a total of 238 overflow events, an average of 7.7 per year.

(2) The largest discharge is approximately 1.1 million cubic feet, but most of the CSOs are less than 200,000 cubic feet.

(3) The maximum number of CSOs in any one month is 18.

Exhibit 9-1. Map for Example 1



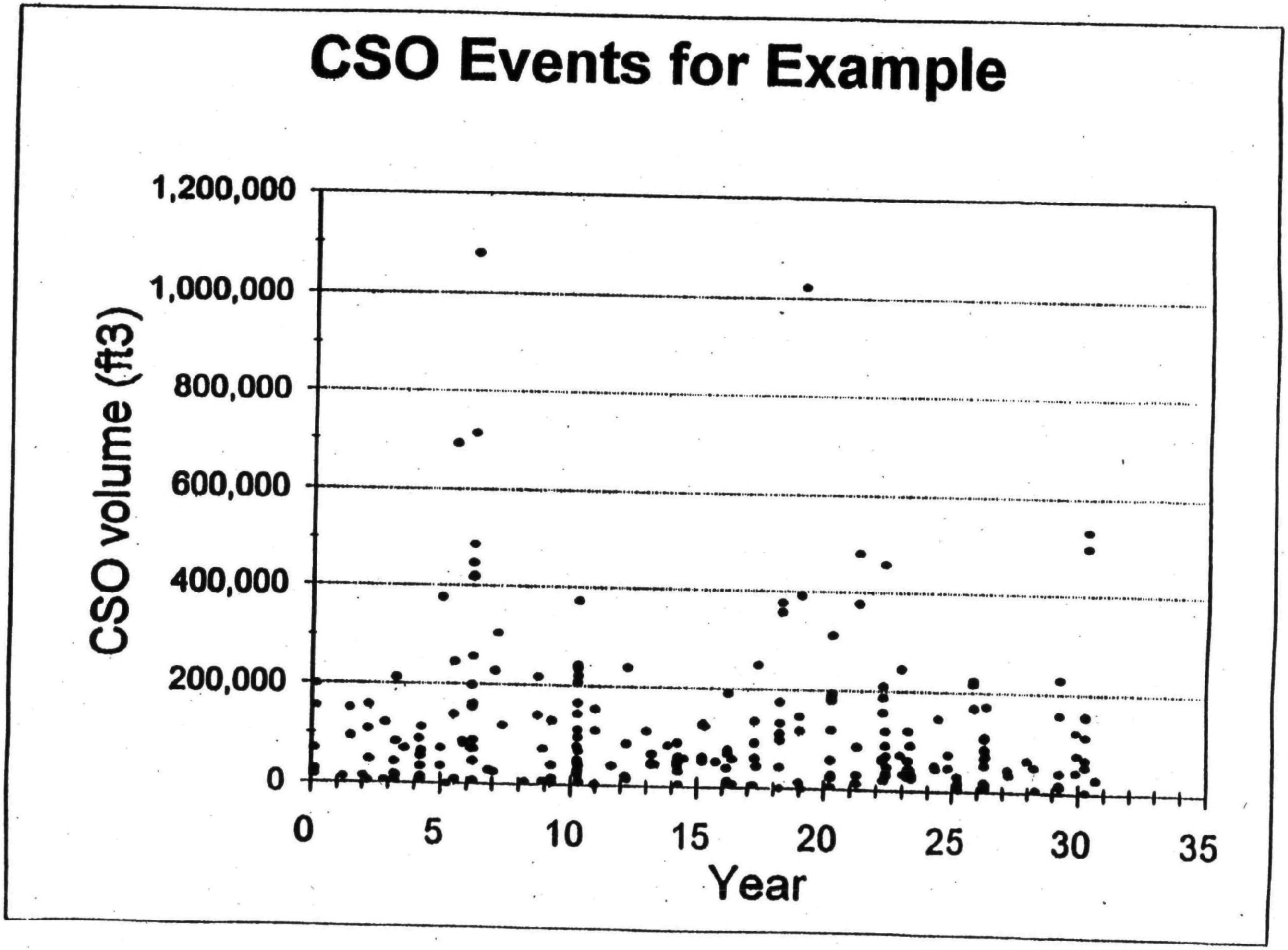


Exhibit 9-2. CSO Events for Example 1

(4) During that month, the maximum receiving water concentration resulting from CSOs exceeds 6,000 MPN/100 ml. Even in this "worst-case" month, however, the geometric mean is 400 MPN/100 ml, based on 30 daily samples and assuming a background concentration of 100.

At least one CSO event occurs in each calendar month, although 69 percent of the events occur in March and April when snowmelt increases flow in the CSS. Because river flow is lower in summer and fall, the rarer summer and fall CSOs may cause greater impact in the receiving water. For simplicity, assume that background fecal coliform levels are close to zero, and that CSOs are the only significant source of fecal coliforms in the river.

Water Quality Standards

Water quality criteria for fecal coliforms differ from State to State, but typically specify a 30-day geometric mean or median and a certain small percentage of tests performed within a 30-day period that are not to exceed a particular upper value. In this case, the applicable water quality criterion for fecal coliforms specifies that:

(1) The geometric mean for any 30-day period not exceed 400 MPN ("most probable number") per 100 ml, and

(2) Not more than 10 percent of samples taken during any 30-day period exceed 1,000 MPN per 100 ml.[1]

The water quality criterion does not specify an instantaneous maximum count for this use classification.

It is comparatively simple to assess how the first component—the geometric mean of 400 MPN/100 ml—applies.[2] In this case, CSOs occur only occasionally. In the worst-case month, which had 18 CSOs, the geometric mean is still only 400 MPN/100 ml based on 30 daily

[1]Most Probable Number (MPN) of organisms present is an estimate of the average density of fecal coliforms in a sample, based on certain probability formulas.

[2]The geometric mean, which is defined as the antilog of the average of the logs of the data, typically approximates the median or midpoint of the data.

samples. It is therefore extremely unlikely that the geometric mean concentration standard of 400 MPN/100 ml will be violated in any other month.

In general, the second component of the water quality criterion—a percentile (or maximum) standard—will prove more restrictive for CSOs. A CSS that overflows less than 10 percent of the time (fewer than 3 days per month) could be expected to meet a not-more-than-10-percent requirement, *on average*. This CSS could meet such a requirement if loads from other sources were well below 1000 MPN/100 ml and the CSS discharged to a flowing river system, where bacteria do not accumulate from day to day. Further, an actual overflow event may not result in an excursion above the 1000 MPN/100 ml criterion *if* the flow in the receiving water is sufficiently large. The permittee, however, must demonstrate that the occurrence of a 30-day period when CSOs result in non-attainment of the WQS more than 10-percent of the time is *extremely unlikely*. This means that the analysis must consider both the likelihood of occurrence of overflow events and the dilution capacity of the receiving water at the time of an overflow. The following sections demonstrate various ways to make this determination.

Design Flow Analysis

Design flow analysis is the simplest but not necessarily the most appropriate approach. This approach uses conservatively low receiving water flow to represent the minimum reasonable dilution capacity. If the effects of all CSO events would not prevent the attainment of the standard under these stringent conditions, the permittee has clearly demonstrated that the applicable WQS should be attained. In cases where nonattainment is indicated, however, the necessary reductions to reach attainment may be unreasonably high since CSOs are unlikely to occur at the same time as design low flows.

The CSO outfall in this example is at a bend in the river where mixing is rapid. Therefore, the loads are considered fully mixed through the cross-section of flow. The concentration in the receiving water is determined by a simple mass balance equation,

$$C_{RW} = \frac{C_{CSO}Q_{CSO} + C_U Q_U}{Q_{CSO} + Q_U}$$

where C represents concentration and Q flow (in any consistent units). The subscripts RW, CSO, and U refer to "receiving water," "combined sewer overflow," and "upstream," respectively.

For the design flow analysis, upstream volume Q_U is set to a low flow of specified recurrence and receiving water concentration C_{RW} is set equal to the water quality criterion. In this example, upstream volume Q_U is set at the 7Q10 flow. The 7Q10 flow is commonly used for steady-state wasteload analyses; although it has a 10-year recurrence and is much more stringent than the not-more-than-10-percent requirement of the standard, this conservatism ensures that excursions of the standard will indeed occur only rarely.

The 7Q10 flow in this river is 313.3 cfs, so upstream volume Q_U is set to 313.3. Since background (upstream) fecal coliform concentrations are negligible, C_U is set to 0. The WQS stipulates that not more than 10 percent of samples taken during any 30-day period exceed 1,000 MPN/100 ml; thus receiving water concentration C_{RW} is set at 1000. Given 7Q10 flow in the receiving water (and assuming a negligible fecal coliform contribution from upstream), the mass balance equation may be rearranged to express the CSO concentration that just meets the standard, in terms of the CSO flow volume:

$$C_{CSO}=\frac{C_{RW}(Q_{CSO}+Q_U)-C_UQ_U}{Q_{CSO}}=\frac{1000(Q_{CSO}+313.3)-C_U313.3}{Q_{CSO}}$$

The equation treats both the concentration and flow from the CSO as variables, unlike a standard wasteload allocation for a point source, where flow is usually considered constant. For a given CSO concentration, the capacity of the receiving water increases as increased CSO volume provides additional dilution capacity. Therefore, the relationship between allowable concentration and CSO flow is not linear. As a result, the necessary levels of control on CSOs are not represented by a single point, but rather by a set of combinations of concentration and flow that meet the water quality criterion.

Exhibit 9-3 displays a line that represents combinations of CSO concentration and CSO flow that just meet the WQS at 7Q10 flow. The region below the line represents potential control strategies. For instance, for CSO flows below 0.05 cfs (0.03 MGD), the WQS would be met at design low flow provided that the concentration in the CSO remained below 6.3×10^6 MPN/100 ml. At a CSO flow of 6 cfs, however, the concentration would need to be below 0.053×10^6 MPN/100 ml.

The typical concentration of fecal coliforms in CSOs is approximately 2×10^6 MPN/100 ml. With upstream concentration C_U equal to zero, the mass balance equation is:

$$2{,}000{,}000 = \frac{C_{RW}(Q_{CSO}+Q_U)-C_U Q_U}{Q_{CSO}} = \frac{1000(Q_{CSO}+313.3)-0x313.3}{Q_{CSO}}$$

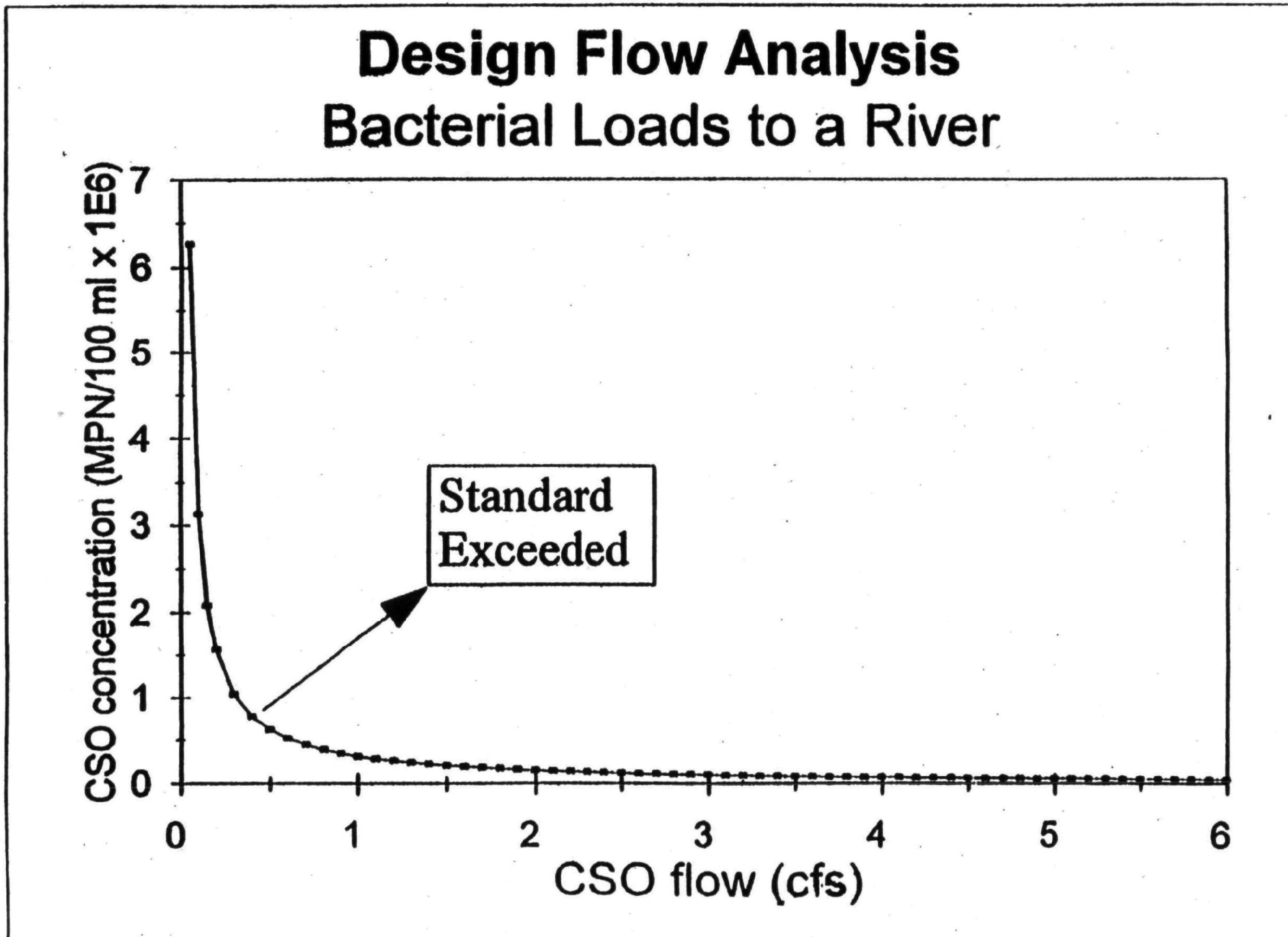
Solving for Q_{CSO}, we find that a CSO flow less than 0.157 cfs would be necessary to attain water quality criteria. Therefore, demonstrating attainment of the water quality criteria via a design low flow analysis would be difficult.

The design low flow analysis is conservative because CSOs typically occur when the receiving water is responding to precipitation and higher-than-normal dilution capability is available. Further, while CSOs may occur during design low flows, these co-occurrences will be much rarer than the occurrence of the low flows themselves. Therefore, the use of the design low flow protects to a more stringent level than indicated since dilution effects are likely to be greater.

Design Flow Frequency Analysis

This approach differs from design flow analysis in that it also considers the probability of exceeding WQS at a given flow. Although still simple, this approach better tailors the level of CSO control to the WQS. The major difference between CSOs and steady-state sources is that CSOs occur intermittently, providing no load on most days but large loads on an occasional basis. The not-more-than-10-percent criterion can be attained by assuring that not more than 3

Exhibit 9-3. Design Flow Analysis



days in a 30-day period experience CSOs, or—more precisely—not more than 3 days have CSOs with a pollutant loading above a critical amount.

The Poisson distribution is the statistical distribution commonly used to describe the number of discrete random events, such as precipitation or CSOs, occurring within a given time period.[3] To meet the not-more-than-10-percent criterion, the probability of four or more CSO events occurring within a 30-day period needs to be acceptably low, such as less than 5 percent (i.e., the probability that exactly zero, one, two, or three events occur within 30 days must be greater than 95 percent). Achieving this result entails setting the cumulative Poisson distribution for z = 0 to 3 events to 0.95, as follows:

$$P[z=(0,1,2,3)]=\sum_{z=0}^{3}\frac{e^{-v}v^{z}}{z!}=0.95$$

where the parameter v is the average number of events in 30 days. Solving this equation yields a value of v that is predicted to result in a less than 5-percent chance of experiencing more than 3 events in a month. The resulting estimate is v = 1.37 events per month, equivalent to 16.62 events per year. At a 99-percent confidence level (1% probability of more than 3 events), v = 0.822, or 9.86 events per year.

Over the 31 years, 238 CSO events occur, giving an average of 0.64 events per month. Although this number is less than the value of v determined above, the permittee has not actually demonstrated that the WQS will be attained. This is because CSO events are unevenly distributed throughout the year: over 31 years, only one CSO has occurred in August but 96 have occurred in April. Box 9-1 shows the average numbers by month.

[3] More information on the use of Poisson distributions may be found in *Environmental Statistics and Data Analysis* (Ott, 1995).

Since most CSOs occur in spring, the probability of a water quality criterion exceedance needs to be calculated on a month-by-month rather than annual average basis. Here, reducing the relatively high number of overflows in April should result in attainment of the criterion in other months. A control plan that reduces the April average from 3.1 (the current number) to 1.37 (as calculated above) should result in the attainment of the water quality criterion in other months as well.

Box 9-1. Average Number of CSOs per Month in Example

Jan	0.32
Feb	0.16
Mar	2.23
Apr	3.10
May	0.52
Jun	0.13
Jul	0.19
Aug	0.03
Sep	0.13
Oct	0.13
Nov	0.32
Dec	0.42

Additional refinements can focus more specifically on eliminating only those CSO events predicted to exceed WQS at actual receiving water flow. Not all of the April events result in such excursions; many are very small. Further, the dilution capacity of the receiving water tends to be high during the spring. Therefore, the analysis can be refined by considering a design flow appropriate to the month in question and then counting only those CSO events predicted to result in excursions above WQS at this flow.

Box 9-1 indicates that only March and April exceed the number of overflows per month indicated by the Poisson analysis (v = 1.37 at 95% confidence level). The 7Q10 flow for these months is 440 cfs. Using this higher receiving water flow, almost 10 percent of the March-April CSO events would not cause exceedance of the 1,000 MPN/100 ml standard, leaving an April recurrence of 2.87 per month (almost 10 percent less than 3.1). More importantly, the resulting table of predicted receiving water concentrations can be analyzed to determine the percentage reduction in CSO volume needed to meet the standard. Engineering improvements that result in a reduction to approximately 11 percent of current CSO volume would be predicted to limit CSO-caused WQS excursions to the desired Poisson frequency.

The design flow frequency analysis gives results that are doubly conservative, because the analysis assumes low flow at the same time that it imposes a low probability of exceeding the standard at that low flow. This approach, then, pays a price for its simplicity, by requiring highly conservative assumptions. A less restrictive analysis would need information on the probability distribution of receiving water flows likely to occur during CSO events.

Statistical Analysis

The next level considers not only design low flows, but the whole range of flows experienced during a month. Although CSOs are more likely when receiving water flow is high, CSO events do not always have increased dilution capacity available. Clearly, however, CSOs will experience at least the typical range of dilution capacities. Therefore, holding the probability of excursions to a specified low frequency entails analyzing the impacts of CSOs across the possible range of receiving water flows, and not only design low flows.

This example assumes that the permittee has a predictive model of CSO volumes and concentrations and adequate knowledge of the expected distribution of flows based on 20 or more years of daily gage data. In short, the permittee knows the loads and the range of available dilution capacity but not the frequency with which a particular load will correspond to a particular dilution capacity. A Monte Carlo simulation can readily address this type of problem, and is used with the April CSO series.[4]

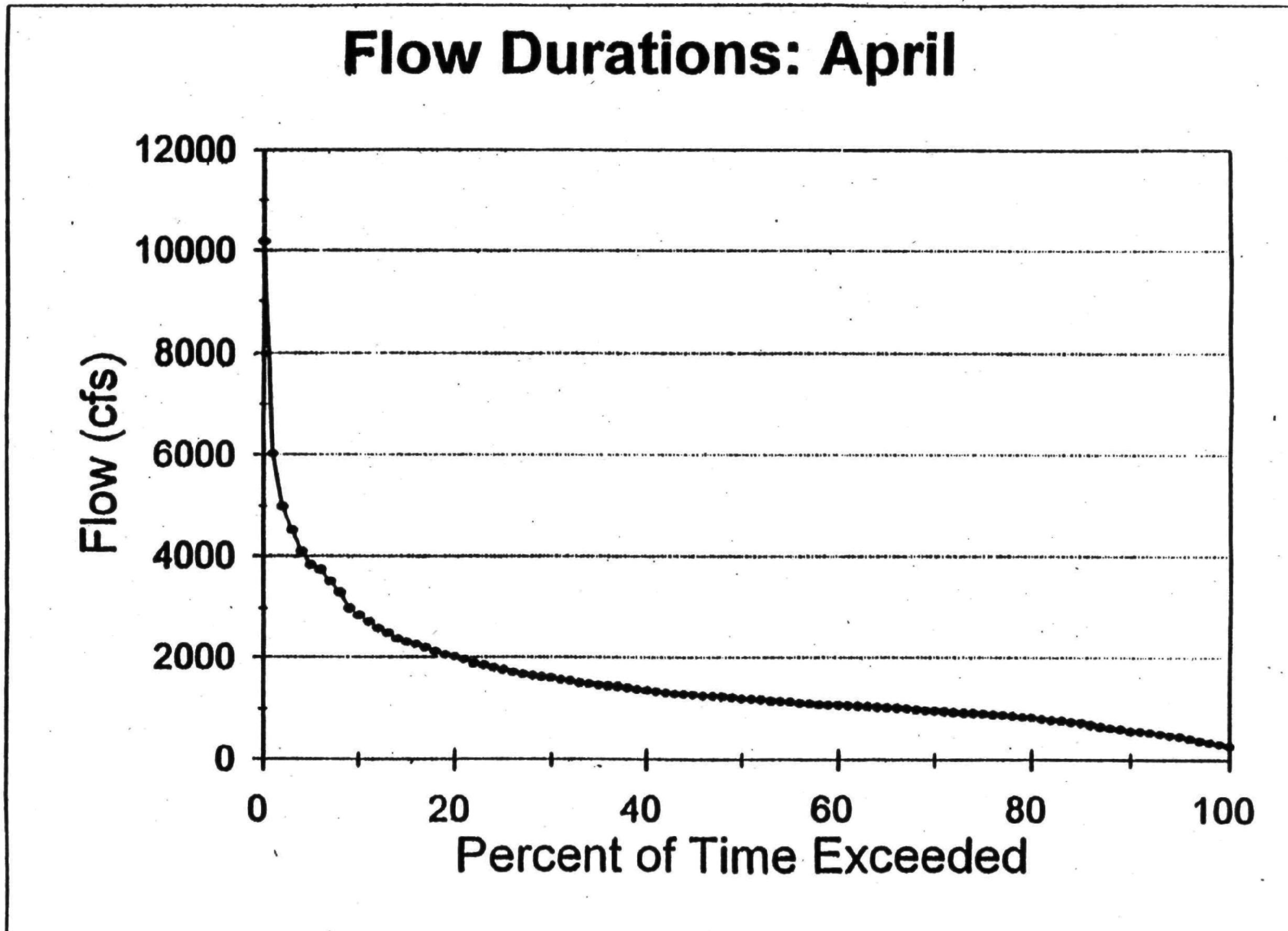
The April receiving water flows are summarized by a flow-duration curve, which indicates the percent of time a given flow is exceeded (Exhibit 9-4). The distribution of flows is asymmetrical, with a few large outliers. Daily flows typically are lognormally distributed. April's flows are lognormal with mean natural log of 7.09 (1,200 cfs)[5], and standard deviation of 0.46.

---

[4]The Monte Carlo approach describes statistically the components of the calculation procedure or model that are subject to uncertainty. The model (in this case, the simple dilution calculation) is run repeatedly, and each time the uncertain parameter, such as the receiving water flow, is randomly drawn from an appropriate statistical distribution. As more and more random trials are run, the resulting predictions build up an empirical approximation of the distribution of receiving water concentrations that would result if the CSO series were repeated over a very long series of natural flows. The Monte Carlo analysis can often be performed using a spreadsheet. The resulting distribution can then be used for analyzing control strategies.

[5]For a lognormal distribution, the mean is equal to the natural log of the median of the data (7.09 = ln (median)). Therefore, the median April flow = $e^{7.09}$ = 1200 cfs.

Exhibit 9-4. Flow Duration Curve



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The 31 years of CSS data include 96 April overflow events. In the Monte Carlo simulation these 96 events were matched with randomly selected receiving water flows from the April flow distribution, for a total of 342 Aprils of simulated data. The number of events in which the 1,000 MPN/100 ml standard would be exceeded was then calculated, and the count for the month tabulated.

Exhibit 9-5 shows the results. Of the 342 Aprils simulated, 122 had zero excursions of the standard attributable to the CSS. The maximum number of predicted excursions in any April was 17. The average number for the month was 2.45, which, as expected, is less than the 2.87 average determined in the design flow frequency analysis since that analysis assumed a conservatively low receiving water flow. However, this average still exceeds the desired Poisson frequency of 1.37.

This analysis more closely approaches the actual pattern of water quality excursions caused by the CSS. The objective implied by the WQS is three or fewer excursions per month. In Exhibit 9-5, the right-hand axis gives the cumulative frequency of excursions, expressed on a zero-to-one scale. Of the 342 simulated Aprils, over 75 percent were predicted to have three or fewer excursions, leaving 25 percent predicted to have four or more. Note that the 11 simulated Aprils with either 16 or 17 excursions all result from the same month of CSS data, corresponding to an abnormally wet period. The permittee may wish to explore whether these data are representative of expected future conditions.

Once set up, the Monte Carlo simulation readily evaluates potential control strategies. For instance, a control strategy with the goal of a 20-percent reduction in CSO flow and a 30-percent reduction in coliform levels would raise to 82 the percentage predicted to meet the water quality criterion. Although the Monte Carlo analysis introduces a realistic distribution of flows, it may still result in an overly conservative analysis for how CSOs correlate with receiving water flows, since it involves using a distribution, such as lognormal, which at best approximates the true distribution of flows. A more exact analysis needs accurate information about the relationship between CSO flows and loads and receiving water dilution capacity.

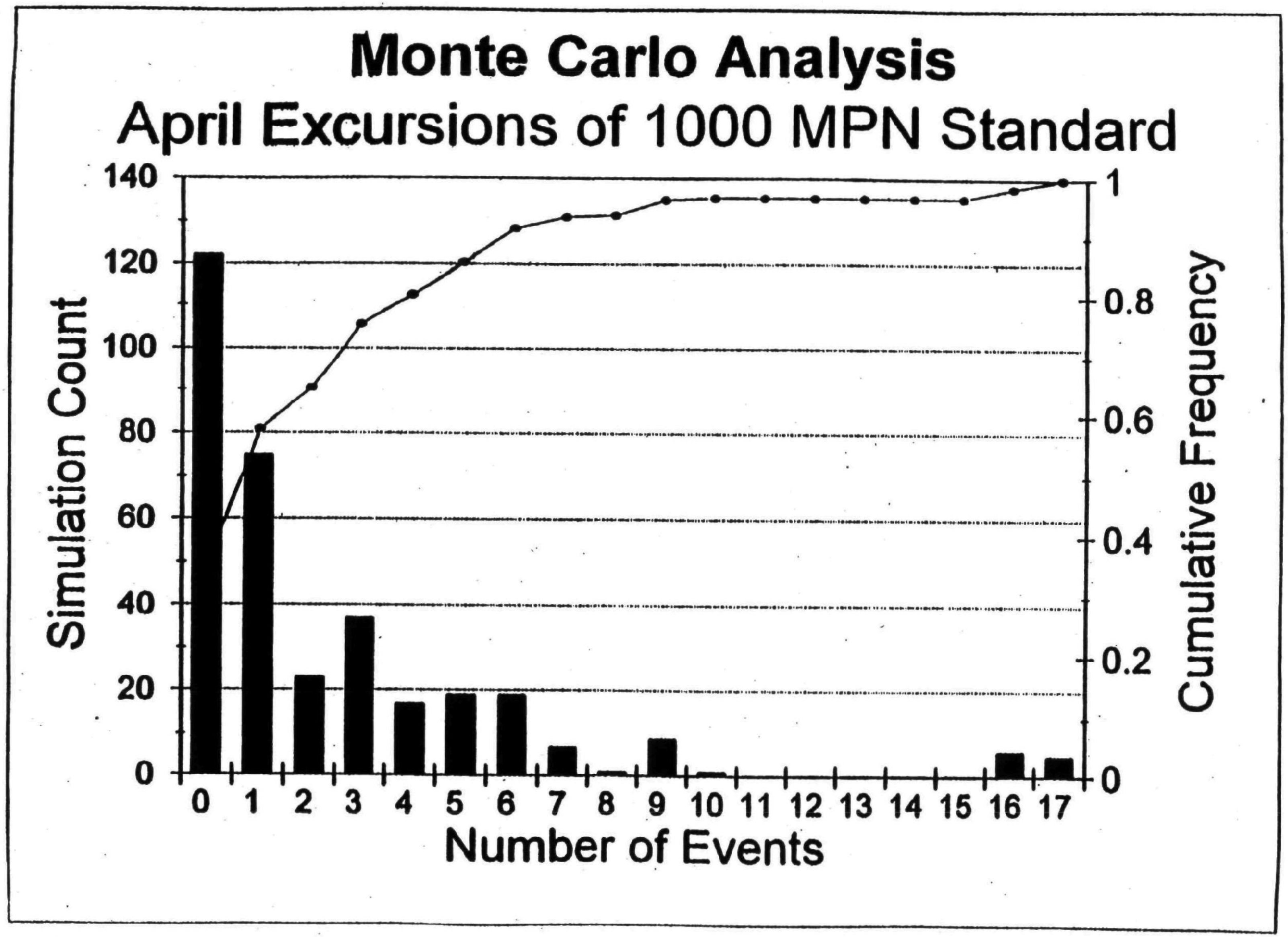


Exhibit 9-5. Expected Exceedances of Water Quality Criterion

Watershed Simulation

The most precise approach may be a dynamic simulation of both the CSS and the receiving water. This approach uses the same time series of precipitation to drive both the CSS/CSO model and the receiving water model. In cases where a dynamic simulation of the entire watershed would be prohibitively expensive, and where sufficient flow and precipitation records are available, the permittee may combine measured upstream flows and a simulation of local rainfall-runoff to represent the receiving water portion of the simulation.

As above, receiving water modeling entails an extremely simple dilution calculation. Determining the data for the dilution calculation by simulating dilution capacity or flows, and the analysis of the data, introduce complexity. This analysis uses a model that accurately predicts the available dilution capacity corresponding to each CSO event. Such a model accurately represents the actual coliform counts in the receiving water and enables the permittee to determine which events exceed the standard of 1,000 MPN/100 ml.

Exhibit 9-6 presents the results as the count of CSO events by month which result in receiving water concentrations greater than or equal to 1,000 MPN/100 ml. For 31 years of data, only three individual months are predicted to have more than three (greater than 10%) days in excess of the standard. Consequently, excursions above the monthly percentile goal occur only about 0.8 percent of the time. Further, the return period for years with exceedances of this standard is 31/3 = 10.3 years. Although the CSS produces relatively frequent overflows, the rate of actual water quality problems is quite low. Exhibit 9-7, which plots CSO volumes versus receiving water flow volume, illustrates why water quality problems remain rare. This figure shows that all the CSO events have occurred when the receiving water is at flow above 7Q10. Furthermore, most of the large CSO discharges are associated with receiving water flows well above low flow. Although this excess dilution capacity reduces the effect of the CSO pollutant loads, demonstrating compliance also necessitates careful documentation of the degree of correlation.

Of course, no simulation represents reality perfectly. Further, the precipitation series or rainfall-runoff relations on which the model is based are likely to change with time. Therefore,

Exhibit 9-6. Excursions of Water Quality Criterion by Month

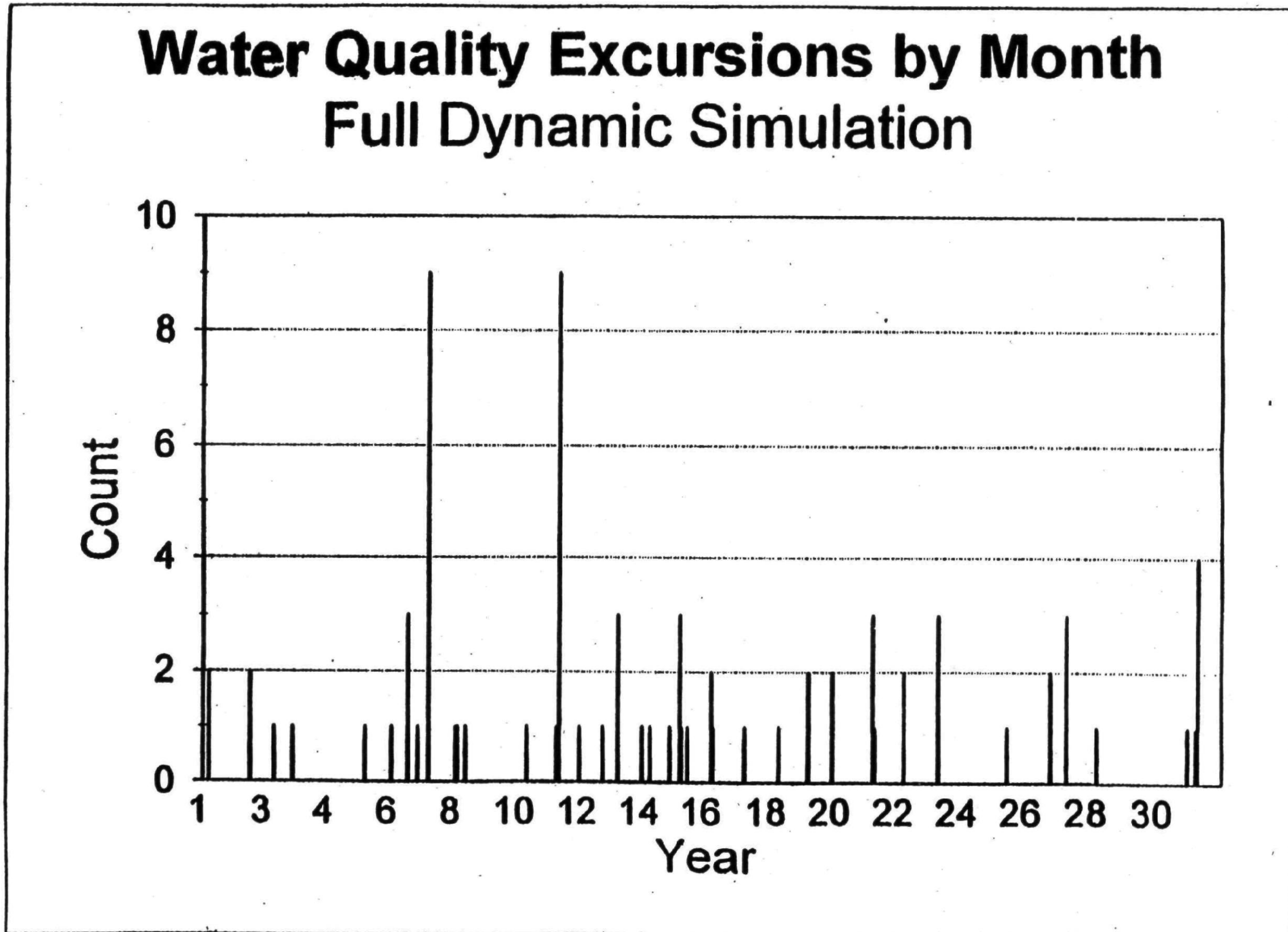
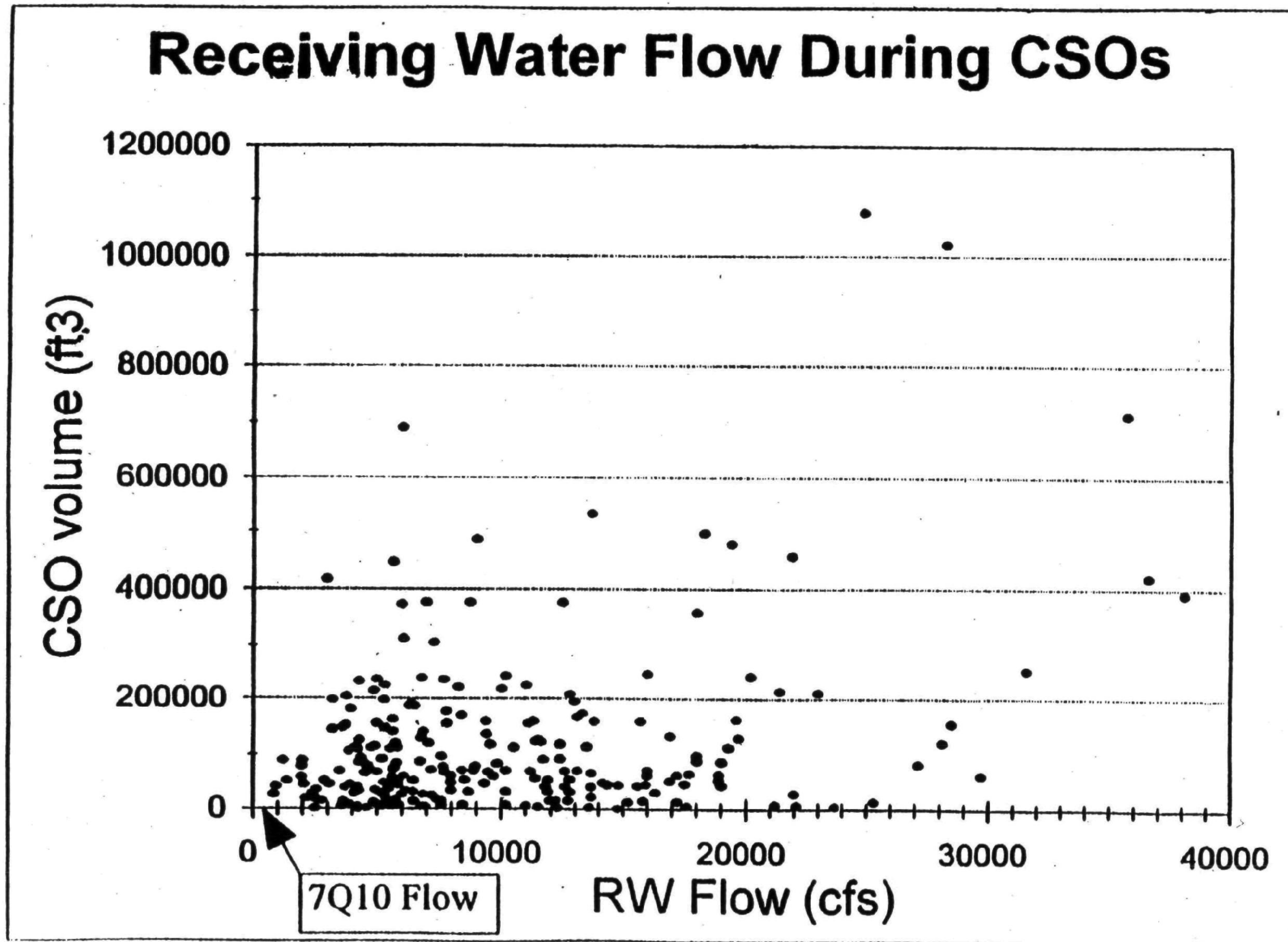


Exhibit 9-7. Receiving Water Flow During CSOs



an analysis of the uncertainty present in predictions should accompany any predictions based on continuous simulation modeling. A long-term control plan justified by the demonstration approach should include a margin of safety that reflects the degree of uncertainty in the modeling effort.

9.3.2 Example 2: Bacterial Loads to an Estuary

In the previous example, a simple dilution calculation sufficed to calculate impact in the receiving water body, since compliance was evaluated at the point of mixing and the concentration of pollutants decreased as they moved away from the source area.

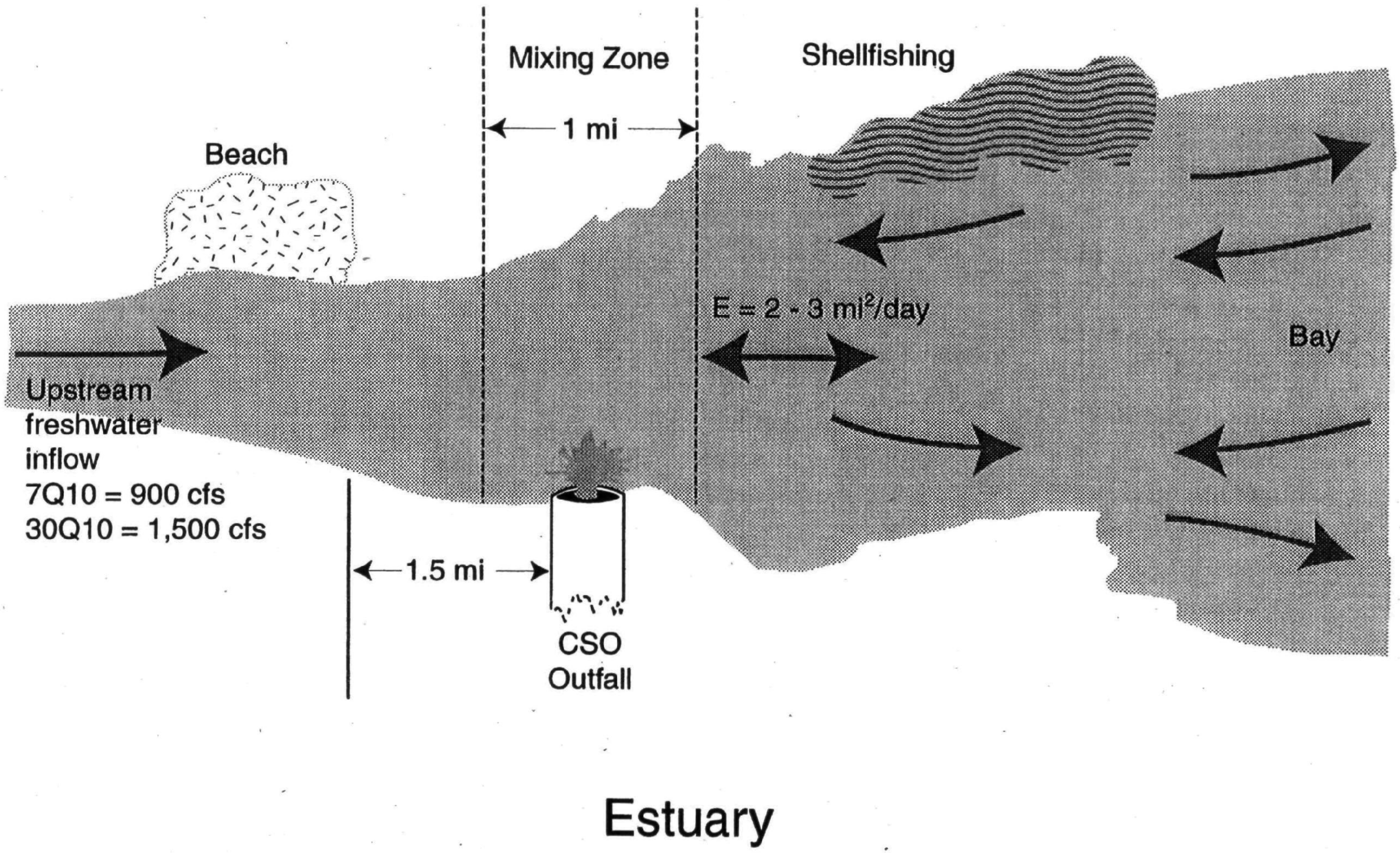
The second example, involving bacterial WQS in a tidal estuary, is more complex. Like the previous example, it evaluates the frequency of excursions of WQS, but modeling the fate of bacteria in the receiving water is more complicated. This is because estuaries are typically both advective and dispersive in nature (that is, contaminants are dispersed as a result of freshwater flow-through as well as tidal mixing). The tidal component can move contaminants both up- and down-estuary from the source. As a result, observed bacterial concentrations depend not only on current releases but also on previous days' releases. This example introduces another complication: the receiving water includes shellfish beds and public beaches with more restrictive bacterial standards. Exhibit 9-8 is a map of the estuary, indicating direction of tidal flow, mixing zone, and location of sensitive areas.

As in the previous example, WQS for fecal coliform are expressed as a geometric mean of 400 MPN/100 ml and not more than 10 percent of samples in a 30-day period above 1,000 MPN/100 ml. The shellfishing and bathing areas have more restrictive WQS, specifying that the 30-day geometric mean of fecal coliform counts not exceed 200 MPN/100 ml on a minimum of five samples and that not more than 20 percent of samples exceed 400 MPN/100 ml.

Design Condition Analysis

As in the previous example, the simplest level of analysis considers conservative design conditions. For an estuary, however, other processes need to be considered:

Exhibit 9-8. Map for Example 2



(1) This estuary is not strongly stratified near the source, so unstratified critical dilution conditions apply.[6]

(2) Further from the CSO discharge, it is necessary to evaluate the combination of reasonable flows and diffusion coefficients that produces the maximum impact by combining relatively high dispersion rates and relatively low dilution rates.

(3) Design conditions should also include temperature and salinity, both of which influence the coliform die-off rate.

This example uses an analytical model for one-dimensional estuarine advection and dispersion . Selected data are presented in Box 9-2. This solution is based on the assumption of an infinitely long estuary of constant area and is useful for estuaries that are sufficiently long to approach steady state near the outfall. The ratio KE/U_2, referred to as the estuary number, strongly controls the character of the solution. The estuary number reflects the relative importance of dispersive and advective fluxes. As this number approaches zero, advection predominates and transport in the estuary becomes increasingly similar to river transport. In this estuary, the ratio is approximately 1.5, indicating relatively strong tidal mixing with significant transport up-estuary.

Box 9-2. Assumptions for Estuarine CSO Example

Upstream Flows		
7Q10	=	900 cfs
U (7Q10)	=	1.5 mi/day
30Q10	=	1,500 cfs
U (30Q10)	=	2.5 mi/day
Estuary		
A	=	10,000 ft^2
E	=	2-3 mi^2/day
T	=	27°C
K	=	1.11/day
Unstratified		
CSO		
C	=	1 x 10^6 coliforms/100 ml
Q_e	=	0.1 MGD as maximum average per month, 2 MGD as daily maximum

[6]Recommendations for design ("critical dilution") conditions in estuaries are provided in U.S. EPA (1991b):

> In estuaries without stratification, the critical dilution condition includes a combination of low-water slack at spring tide for the estuary and design low flow for river inflow. In estuaries with stratification, a site-specific analysis of a period of minimum stratification and a period of maximum stratification, both at low-water slack, should be made to evaluate which one results in the lowest dilution....

The geometric mean requirement of the water quality criterion is taken as an average condition over time for scoping; that is, the 30-day time frame for this analysis is assumed to be sufficiently long to allow the variability in the load, as well as tidal cycles, to be averaged out. The scoping thus assumes a steady load in terms of an average over time. An advection-dispersion solution can again be used in this case. Results of the scoping analysis based on the one-dimensional advection-dispersion solution are shown in Exhibit 9-9. A mixing zone of 0.5 mile up-estuary and down-estuary of the outfall is allowed. The beach location, 1.5 miles up-estuary of the outfall, is of particular concern. The model was applied for a variety of conditions, including freshwater flows at 7Q10 and 30Q10 levels and loads at the estimated event maximum daily average load and expected maximum 30-day average load. Because the answer depends on the value assigned to the dispersion coefficient, sensitivity of the answer to dispersion coefficients ranging from 2 mi^2/day to 3 mi^2/day, representing the expected range for the part of the estuary near the outfall, was examined.

It is most appropriate to compare the geometric mean criteria to the 30Q10 upstream flow and average load (as the standard is written as a 30-day average), and the percentile standards to the 7Q10 upstream flow and event maximum load. Scoping indicates that the CSOs may cause the short-term criterion to be exceeded at the mixing zone boundaries and are likely to cause impairment at the up-estuary beach. Increasing the estimate of the dispersion coefficient increases the estimated concentration at the beach, reflecting increased up-estuary "smearing" of the contaminant plume, which illustrates that the minimum mixing power may not be a reasonable design condition for evaluating maximum impacts at points away from the outfall. WQS excursions at the beach are likely to occur only at low upstream flows, while the combination of average loads and 30Q10 freshwater flows is not predicted to cause impairment. In evaluating impacts at the beach, recall that scoping was conducted using a one-dimensional model, which averages a cross-section. If the average is correctly estimated, impacts at a specific point (e.g., the beach) may still differ from the average. Concentrations at the beach may be higher or lower than the cross-sectional average, depending on tidal circulation patterns.

The design condition analysis identifies instantaneous concentrations at the down-estuary boundary of the mixing zone and the beach as potential compliance problems. It also predicts

Exhibit 9-9. Steady State Predictions of Fecal Coliform Count (MPN/100ml)

Flow.	Upstream: 900 cfs (7Q10)		Upstream: 1,500 cfs (30Q10)			
Load:	Event Maximum Load				Average Load	
Dispersion:	E = 2 mi^2/day	E = 3 mi^2/day	E = 2 mi^2/day	E = 3 mi^2/day	E = 2 mi^2/day	E = 2 mi^2/day
Mixing Zone, Upstream	838	821	596	651	30	33
Mixing Zone, Downstream	1212	1050	1102	981	35	49
Beach	252	333	123	207	6	10

excursions at average flow conditions and suggests that additional controls are needed. Numerical experiments with the design condition scoping model suggest that a target 25-percent reduction in CSO flow volume would provide for the attainment of WQS.

Design Flow Frequency Analysis

The design condition analysis addresses the question of whether there is a potential for excursions of WQS. It does not address the frequency of excursions. The frequency of excursions depends on (1) the frequency and magnitude of CSO events, and (2) the dilution capacity of the receiving water body at the time of discharge (note that, in the estuary, the range of dilution capacities (on a daily basis) is less extreme than in the river, because the tidal influence is always present, regardless of the level of upstream flows). To obtain an upper-bound (conservative) estimate of the frequency of excursions, an analysis of the monthly or seasonal frequency of CSO events should be combined with a design dilution capacity appropriate to that month. A simple analysis of the frequency of CSO events on a monthly or seasonal basis is combined with a design dilution capacity appropriate to that month to obtain an upper-bound (conservative) estimate of the frequency of excursions of the WQS.

Statistical Analysis

The design flow analyses of the previous two sections contain a number of conservative simplifying assumptions:

(1) They assume a steady (rather than intermittent) source

(2) They assume a design minimum dilution capability for the estuary

(3) They do not account for many of the real-world complexities of estuarine mixing

(4) They do not account for the effects of temperature and salinity on bacterial die-off.

The scoping analysis can be improved by considering a full distribution of probable upstream flows in a Monte Carlo simulation. The expected range of hydrodynamic dispersion coefficients could also be incorporated into the analysis.

Watershed Simulation

Building a realistic model of contaminant distribution and transport in estuaries is typically resource-intensive and demanding. A watershed simulation may, however, be needed to demonstrate compliance for some systems where the results of conservative design flow analyses are unclear. Detailed guidance on the selection and use of estuarine models is provided in EPA's Wasteload Allocation series, Book III, Parts 1-4.

9.3.3 Example 3: BOD Loads

The third example concerns BOD and depletion of DO, another important water quality concern for many CSSs. Unlike bacterial loads, BOD impacts are usually highest downstream of the discharge and occur some time after the discharge has occurred.

The CSS in an older industrial city has experienced frequent overflow events. The CSOs discharge to a moderate-sized coastal plain river, which also receives point-source loads upstream. In the reach below the CSS discharge, the river's 7Q10 flow is 194 cfs, with a depth of 5 feet and a velocity of 0.17 ft/s. Above the city, velocities range from 0.2 to 0.3 ft/s at 7Q10 flow. A major industrial point source of BOD lies 18 miles upstream (Box 9-3). Other minor BOD loads enter via tributaries.

The river reach below the city has a designated use of supporting a warm water fishery. For this designation, State criteria for DO are a 30-day mean of 7.0 mg/l and a 1-day minimum of 5.0 mg/l. The State also requires that WLAs for BOD be calculated on the basis of the 1-day minimum DO standard calculated at 7Q10 flow and the maximum average monthly temperature. The 5.0 mg/l criterion is not expressed in a frequency-duration format; the 1-day minimum is a fixed value, but evaluation in terms of an extreme low flow of specified recurrence implicitly assigns an acceptable frequency of recurrence to DO 1-day average concentrations less than 5.0 mg/l. (The State criterion for DO is thus hydrologically based and is roughly equivalent to maintaining an acceptable frequency of biologically based excursions of the water quality criteria for ambient DO).

> **Box 9-3. Assumptions for BOD Example**
>
> CSO Discharge (at maximum load)
> - BOD_5 = 200 mg/l
> - $CBODU/BOD_5$ = 2.0
> - NBOD = 0 mg/l
> - Q_e = 4 MGD
>
> Point Source Effluent Upstream
> - Distance Upstream = 18 mi
> - BOD_5 = 93 mg/l
> - $CBODU/BOD_5$ = 2.5
> - NBOD = 0 mg/l
> - Q_e = 5 MGD
>
> Reaction Parameters
> - $T = 27°C$
> - $K_a = [12.9 \times U^{1/2}/H^{3/2}] \times (1.024)^{(T-20)}$
> - where U = avg stream velocity (ft/s)
> - and H = average depth (ft)
> - $K_d = K_r = 0.3 \times (1.047)^{(T-20)}$
> - SOD (below CSS) = 0.3 mg/l-day
> - SOD (elsewhere) = 0
>
> Upstream Background
> - BODU = 1 mg/l
> - DOD = 1 mg/l

Design Condition Analysis

A conservative assessment of impacts from the CSS can be established by combining a reasonable worst-case load (the maximum design storm with a 10-year recurrence interval) with extreme receiving water design conditions. Limited monitoring data and studies of other CSO problems suggested that a reasonable worst-case estimate was a 1-day CSO volume of 4 MGD, with an average BOD5 concentration of 200 mg/l.

As described in Chapter 8, initial scoping was carried out using a simple, steady-state DO model (see Section 8.3.2, Rivers Oxygen Demand/Dissolved Oxygen subsection)[7]. The initial scoping assumes the presence of the upstream point source and the estimated worst-case CSO load. All BOD_5 was initially assumed to be CBOD and fully available to the dissolved phase. Sediment oxygen demand (SOD), known to play a role in the reach below the CSS, was estimated at 0.3 mg/l-day . No SOD was assumed for other reaches as a qualitative balance to the assumption that no BOD load is lost to settling.

Results of the scoping model application are shown in Exhibit 9-10, which shows the interaction of the point source, CSO, and minor steady sources to the river. The exhibit combines two worst-case conditions: high flow from the episodic source and low (7Q10) flow in the receiving water. Under these conditions, the maximum DO deficit is expected to occur 7.5 miles downstream of the CSO, with predicted DO concentrations as low as 3.9 mg/l. Under such conditions, the CSO flow is approximately 25 percent of total flow in the river.

Design Flow Frequency Analysis

The State criterion called for a one-day minimum DO concentration of 5 mg/l , calculated at design low flow conditions for steady sources. Use of the 7Q10 design flow was interpreted as implying that an approximately once-in-three year excursion of the standard, on average, was acceptable (U.S. EPA, 1991a).[8] As in the previous examples, the rate of occurrence of CSOs provides an upper bound on the frequency of WQS excursions attributable to CSOs. In this case, however, the once-in-three-years excursion frequency cannot be attained through CSO control alone. Instead, the co-occurrence of CSOs and receiving water flows must be examined.

To accommodate this relationship, the design flow model can be modified to assess the dependence of DO concentrations on upstream flow during maximum likely loading from the

[7] Similar DO analysis is discussed in Thomann and Mueller (1987).

[8] The average frequency of excursions is intended to provide an average period of time during which aquatic communities recover from the effects of the excursion and function normally before another excursion. Based on case studies, a three year return internal was determined to be appropriate. The three year return internal was linked to the 7Q10 flow since this flow is generally used as a critical low flow condition.

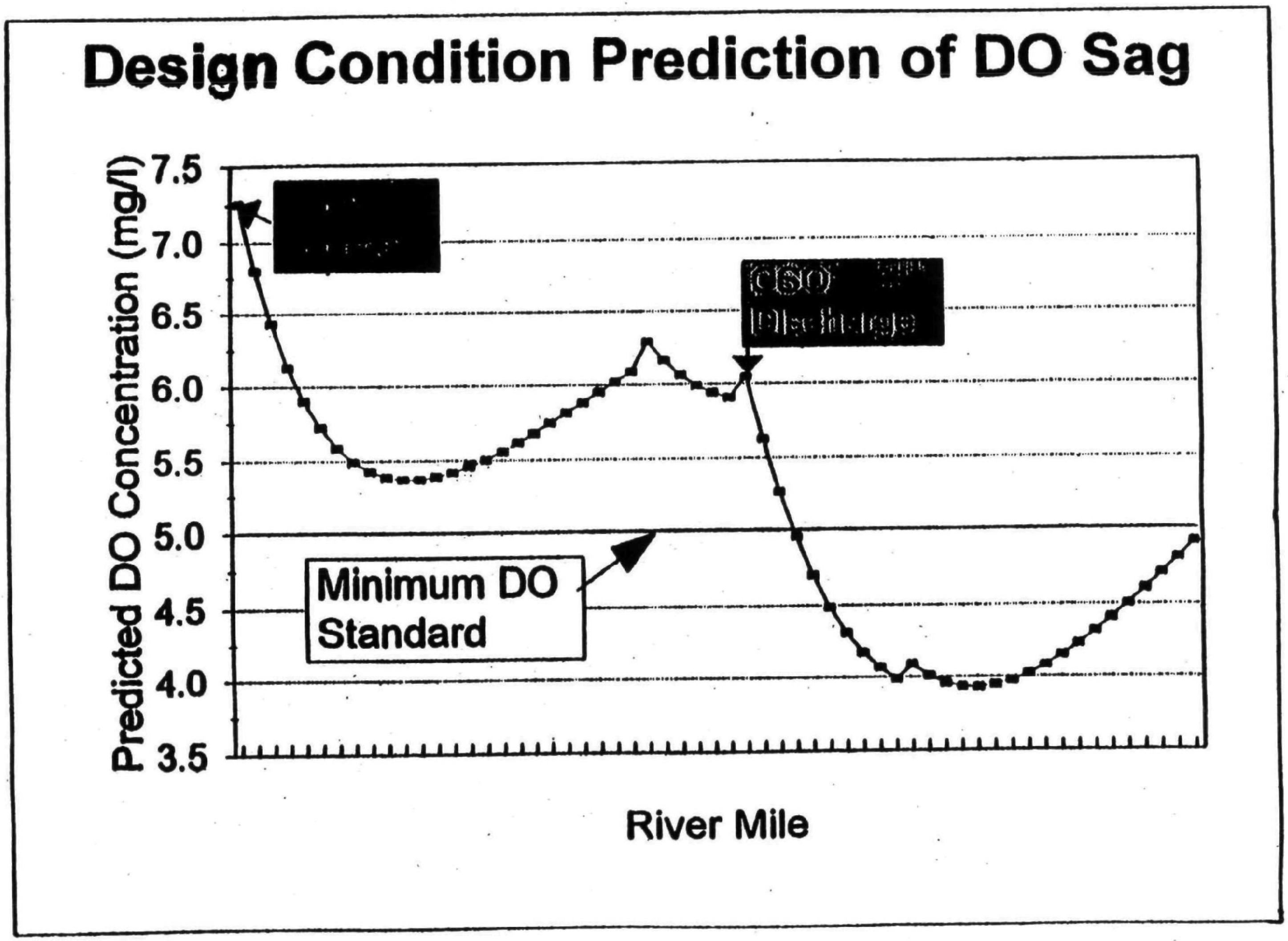


Exhibit 9-10. Design Condition Prediction of DO Sag

CSO. Design flow was simulated using the worst-case CSO flow over a variety of concurrent upstream flows, since upstream flows affect both the dilution capacity of the river and the velocity of flow and reaeration rate. As shown in Exhibit 9-11, the estimated DO concentrations depend strongly on upstream flow. Note that WQS are predicted to be attained if the upstream flow is greater than about 510 cfs. A flow less than 510 cfs occurs about five times per year, on average, in this segment of the river.

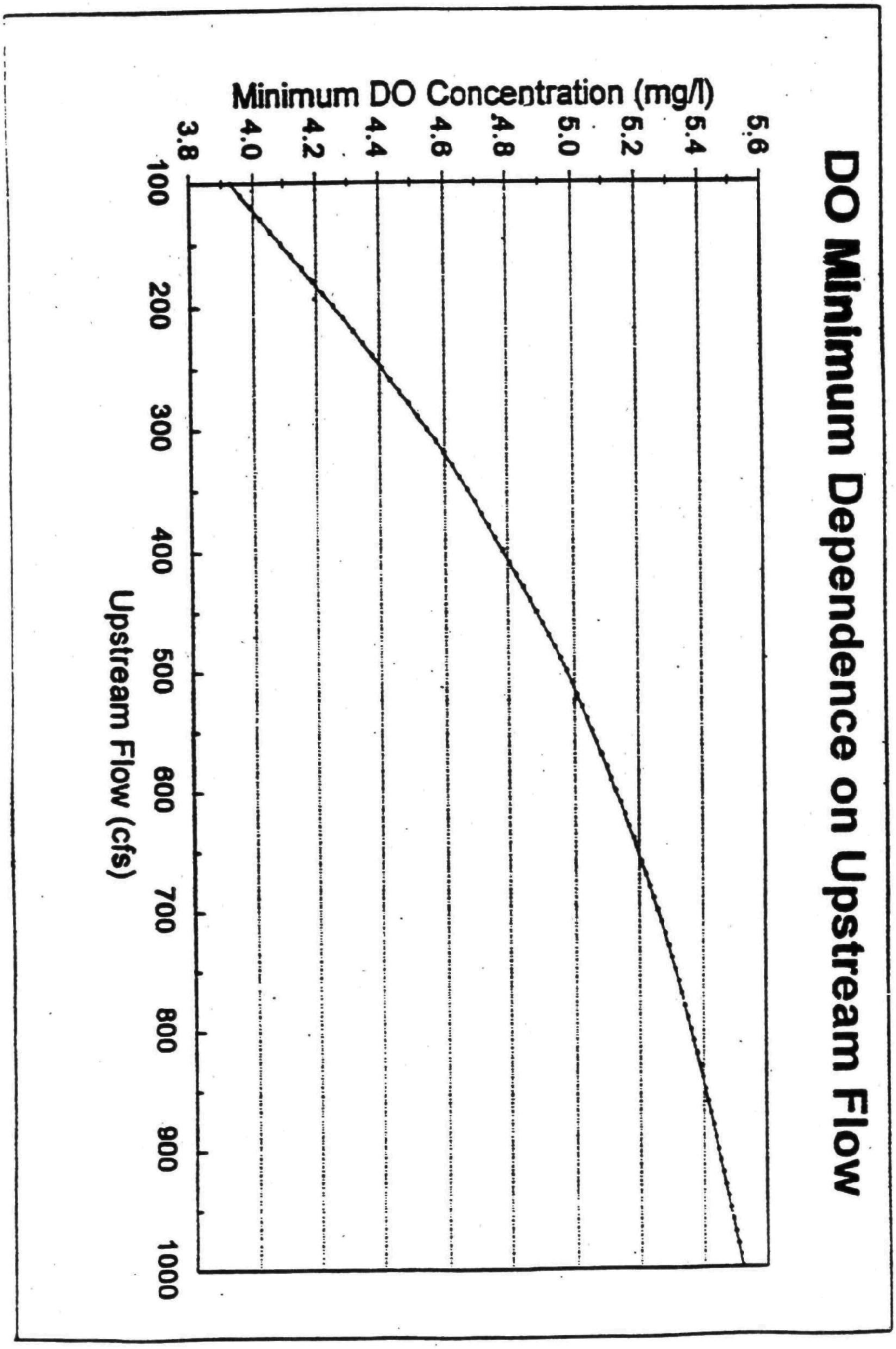
The target rate of WQS excursions is one in three years. An upper bound for the actual long-term average rate of excursions can be established as the probability that flow is less than 510 cfs in the river multiplied by the probability that a CSO occurs:

$$P_{exc}=p(Q<510cfs)f_{CSO}$$

where P_{exc} is the probability of a WQS excursion on any given day and f_{cso} is the fraction of days in the year on which CSO discharges occur, on average. Since the goal for excursions is once every three years, P_{exc} is set at 1/(3 × 365), or .000913. Since a flow less than 510 cfs occurs five times per year, p(Q<510) is 5/365, or .0137. Substituting these values into the equation yields f_{cso} = .000913/.0137 = 0.067. This implies that up to 24 CSOs per year will meet the long-term average goal for DO WQS excursions, even under the highly conservative assumption that all CSOs provide the reasonable maximum BOD load.

An important caveat, however, is that no other significant wet weather sources are assumed to be present in the river. In most real rivers, major precipitation events also produce BOD loads from urban storm water, agriculture, etc. Where such loads are present, conservative assumptions regarding these additional sources need to be incorporated into the scoping level frequency analysis.

As with the other examples, further refinement in the analysis can be attained by examining the statistical behavior of the CSO and receiving water flows in more detail. Finally, 1 Exhibit 9-11. Relationship Between DO Concentration and Upstream Flow



dynamic continuous simulation models could be used to provide a more realistic estimate of the actual time series of DO concentrations resulting from CSOs.

9.4 SUMMARY

As illustrated in the preceding examples, no one method is appropriate for a particular CSS or for all CSSs: the method should be appropriate for the receiving water problem, and a complex dynamic simulation is not always necessary. The municipality (in cooperation with the NPDES authority) needs to balance effort spent in analysis with the level of accuracy required. However, as the first example illustrated, as additional effort is invested assumptions can usually be refined to better reflect the actual situation.

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A. Annotated References on Monitoring

In addition to the monitoring guidance provided in the above sections, many documents contain information useful in designing a monitoring program for CSO controls. This section briefly highlights information from these documents.

- The Water Environment Federation's *Combined Sewer Overflow Pollution Abatement Manual of Practice* No. FD-17 (WPCF 1989) includes discussions on establishing planning objectives for characterizing receiving waters, their aquatic life, and meteorologic conditions; identifying critical events; evaluating system load characteristics; selecting analytic methods; mapping the system; developing the sampling plan; selecting field sampling procedures; monitoring CSS and environmental flow; and modeling.

- *Design of Water-Quality Monitoring Systems* (Ward et al. 1990) includes insightful discussions on the design of monitoring plans, the essential role of statistics, frameworks for designing water-quality information systems, quantification of information, data analysis, and the documentation of monitoring plans. This reference also includes four case studies of large-scale and long-term monitoring programs.

- *NPDES Storm Water Sampling Guidance Document*, EPA 833-B-92-001, (EPA 1992) details EPA's requirements for monitoring storm water discharges. When such monitoring is required as a condition of a CSS's NPDES permit, monitoring efforts for CSO control should be coordinated with this required monitoring effort in order to maximize data collection efficiencies and minimize monitoring costs.

- *A Statistical Method for Assessment of Urban Stormwater Loads, Impacts, and Controls*, EPA 440/3-79-023, (Driscoll et al. 1979) discusses approaches for defining the purpose of monitoring programs; monitoring rainfall; using rainfall data to project and evaluate impacts; selecting monitoring sites; characterizing drainage basins; determining study periods, sampling frequencies, and sampling intervals during storms; selecting sampling procedures and sampling parameters; understanding special considerations for monitoring receiving waters; and using continuous monitoring. It also provides an extensive literature compilation regarding storm water and CSO monitoring.

- *Data Collection and Instrumentation in Urban Stormwater Hydrology* (Jennings 1982) reviews data and instrumentation needs for urban storm water hydrology. This reference considers monitoring strategy design and the collection and use of data to characterize rainfall, other meteorological characteristics, streamflows, receiving water biologies and chemistries, and land use.

- *Use of Field Data in Urban Drainage Planning* (Geiger 1986) describes rainfall-runoff processes and data collection constraints, the need to match data collection to study objectives, the use of data in urban drainage planning, the application and verification of models used in urban drainage planning, the validity of the design storm concept, the reliability of storm water simulations, and the real-time use of monitoring data in control and sewer system operation.

- "Water Body Survey and Assessment Guidance For Conducting Use Attainability Analyses (UAA)" (EPA. 1983a. In *Water Quality Standards Handbook.*). The UAA concepts discussed in this Handbook include useful field sampling methods, modeling, and interpretation approaches in three Technical Support Documents for flowing waters, estuaries, and lakes (EPA 1983b, 1984a, and 1984b).

- Several guidance documents that discuss or pertain to EPA's Waste Load Allocation (WLA) process also provide useful information on a wide range of topics that are potentially valuable when planning monitoring programs for CSO control:

  - *Guidance for State Water Monitoring and Waste Load Allocation Programs* (EPA, 1985) includes a chapter on monitoring for water-quality-based controls. It discusses the process of collecting and analyzing effluent and ambient monitoring data in establishing water-quality standards and EPA's responsibilities in this process.

  - *Handbook—Stream Sampling for Waste Load Allocation Applications* (Mills et al. 1986) addresses sampling considerations for acquiring data on stream geometry, hydrology, meteorology, water quality, and plug flows. It also reviews sampling considerations for gathering data to meet various modeling needs.

  - "Nutrient/Eutrophication Impacts," Chapter 2 of *Technical Guidance Manual for Performing Waste Load Allocations, Book IV: Lakes and Impoundments*, (Mancini et al. 1983) primarily emphasizes modeling considerations. However, this chapter also provides useful introductions to approaches for estimating loading rates to standing water systems and needs for monitoring data to support modeling efforts.

  - *Technical Guidance Manual for Performing Waste Load Allocations, Book III: Estuaries, Part 2: Application of Estuarine Waste Load Allocation Models* (Martin et al. 1990) includes a chapter on monitoring protocols for calibrating and validating estuarine WLA models. It reviews the types of data needed, frequency of collection, spatial coverage, and quality assurance.

  - *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water* (Mills et al. 1985a, b) presents a broad array of modeling and data management approaches for assessing aquatic fates of toxic organic substances, waste-load calculations, rivers and streams, impoundments, estuaries, and ground waters.

APPENDIX A

Table A-1
Checklist of Considerations for Documenting Monitoring Program Designs and Implementation (expanded from Ward et al., 1990);

Sample and Field Data Collection

Pre-Sampling Preparations

- __ Selecting personnel and identifying responsibilities
- __ Training personnel in safety, confined space entry, and verifying health-care (first-aid and wet-weather training, CPR, safety guides,, currency of vaccinations etc.)
- __ Preparing site access and obtaining legal consents
- __ Acquiring necessary scientific sampling or collecting permits
- __ Developing formats for field sampling logs and diaries
- __ Training personnel in pre-sampling procedures (e.g., purging sample lines, instrument calibration)
- __ Checking equipment availability, acquisition, and maintenance
- __ Scheduling sample collection (random? regular? same-time-of-day?)
- __ Preparing pre-sampling checklist

Sampling Procedures

- __ Procedures documentation
- __ Staff qualifications and training
- __ Sampling protocols
- __ Quality-control procedures (equipment checks, replicates, splits, etc.)
- __ Required sample containers
- __ Sample numbers and labeling
- __ Sample preservation (e.g, "on ice" or chemical preservative)
- __ Sample transport (delivery to laboratory)
- __ Sample storage requirements
- __ Sample tracking and chain-of-custody procedures
- __ Quality control or quality assurance
- __ Field measurements
- __ Field log and diary entries
- __ Sample custody and audit records

Post-Sample Follow Up

- __ Filing sample logs and diaries
- __ Cleaning and maintaining equipment
- __ Disposing chemical wastes properly
- __ Reviewing documentation and audit reports

Table A-1 (continued)
Checklist of Considerations for Documenting Monitoring Program Designs and Implementation (expanded from Ward et al., 1990);

Laboratory Analysis

Pre-Sample Analysis Preparations
- __ Verifying use of proper analytical methods
- __ Scheduling analyses
- __ Verifying sample number
- __ Defining a recording system for sample results
- __ Applying a system to track each sample through the lab
- __ Maintaining and calibrating equipment
- __ Preparing quality control solutions

Sample Analysis
- __ Sample analysis methods and protocols
- __ Use of reference samples, duplicates, blanks, etc.
- __ Quality control and quality assurance compliance
- __ Sample archiving
- __ Proper disposal of chemical wastes
- __ Full documentation in bench sheets

Data Record Verification
- __ Coding sheets, data loggers
- __ Data verification procedures and compliance with project plan
- __ Verifying analysis of splits within data quality objectives
- __ Assigning data-quality indicators and explanations

Data Management

- __ Selecting appropriate hardware and software
- __ Documenting data-entry practices and data validation (e.g., entry-range limits, duplicate entry checking)
- __ Data tracking
- __ Defining characteristics of data achieving system
- __ Developing data-exchange protocols
- __ Formatting data for general availability

Data Analysis

- __ Selecting software
- __ Handling missing data and non-detects
- __ Identifying and using data outliers
- __ Planning graphical procedures (e.g., scatter plots, notched-box and whisker)
- __ Parametric statistical procedures
- __ Non-parametric statistical procedures
- __ Trend analysis procedures
- __ Multivariate procedures
- __ Quality-control checks on statistical analyses

Table A-1 (continued)
Checklist of Considerations for Documenting Monitoring Program Designs and Implementation (expanded from Ward et al., 1990);

Reporting

__ Scheduling reports—timing, frequency, and lag times following sampling
__ Designing report contents and formats
__ Designing planned tables and graphics
__ Assigning report sign-off responsibility(ies)
__ Determining report distribution recipients and availability
__ Planning use of paper and electronic formats
__ Presentations

Information Use

__ Identifying and applying decision or trigger values, resulting action
__ Implementing construction, control, and/or monitoring design alternatives
__ Planning public-release procedures

General

__ Contingencies
__ Follow-up procedures
__ Data management.
__ Data analysis.
__ Reporting.
__ Information use.

Table A-2
Checklist for Reviewing CSO Control Monitoring Plans

CSO Drainage and Sewer System Map

__ up-to-date
__ shows "as-built" sewer system
__ drainage areas with land use information indicated
__ location of major industrial sewer users indicated
__ location of all direct discharge points indicated, including all related CSO, POTW, storm water, and industrial discharges into the receiving water
__ bypass points distinguished from CSOs points with locations indicated
__ locations of CSO quantity and quality monitoring sites indicated
__ receiving waters identified
__ designated and existing uses of receiving waters indicated
__ areas of historical use impairment indicated

CSO Overflow Quantity

__ number of storms to be monitored
__ number of CSO outfalls to be monitored
__ sampling points include major CSOs
__ POTW influent flow to be monitored
__ method of flow measurement adequate
__ frequency of flow measurement during each storm event
__ storm statistics to be reported—mean, maximum, duration
__ storm statistics to be reported for all storms during the study period

CSO Overflow Quality

__ number of storms to be monitored
__ number of CSO outfalls to be monitored
__ sampling points include major CSOs
__ POTW influent quality to be monitored
__ drainage areas representative of entire drainage area for land use and sewer users
__ number of storm events to be monitored
__ method and frequency of sampling
__ parameters to be analyzed
__ detection limits adequate
__ toxicity test conducted
__ receiving water(s) to be sampled
__ aesthetics monitored

APPENDIX B

Table B-1
Data Requirements for Hand-Calculation Techniques Described in WLA Guidance Documents and Screening Manual (Mills et al.) For Analysis of Conventional Pollutants

Data Requirements	Streeter-Phelps DO Analyses-[a]	NH3 Toxicity Calculations-[b]	Algal Predictions Without Nutrient Limitations-[c]	Algal Predictions With Nutrient Limitations-[c]	Algal Effects on Daily Average DO-[c]	Algal Effects on Diurnal DO-[c]
Hydraulic and Geometric Data						
Flow Rates	x	x	x	x	x	x
Velocity	x	x	x	x	x	x
Depth	x	x	x	x	x	x
Cross-sectional area	x	x	x	x	x	x
Reach length	x	x	x	x	x	x
Constituent Concentrations-						
DO	x					
CBOD, NBOD	x					
NH3		x				
Temperature	x	x	x	x	x	x
Inorganic P			x	x	x	x
Inorganic N			x	x	x	x
Chlorophyll a			x	x	x	x
pH		x				
DO/BOD Parameters						
Restoration rate coefficient	x				x	x
Sediment Oxygen Demand	x					
CBOD decay rate	x					
CBOD removal rate	x					
NBOD decay rate	x					
NH3 oxidation rate		x			x	x
Oxygen per unit chlorophyll a						
Algal oxygen production rate	x					
Algal oxygen respiration rate	x					

Table B-1 (Continued)
Data Requirements for Hand-Calculation Techniques Described in WLA Guidance Documents and Screening Manual (Mills et. al.) For Analysis of Conventional Pollutants

Data Requirements	Streeter-Phelps DO Analyses-[a]	NH3 Toxicity Calculations-[b]	Algal Predictions Without Nutrient Limitations-[c]	Algal Predictions With Nutrient Limitations-[c]	Algal Effects on Daily Average DO-[c]	Algal Effects on Diurnal DO-[c]
Phytoplankton Parameters						
Maximum growth rate			x	x	x	x
Respiration rate			x	x	x	x
Settling velocity			x	x	x	x
Saturated light intensity			x	x	x	x
Phosphorous half-saturation constant				x	x	x
Nitrogen half-saturation constant				x	x	x
Phosphorous to chlorophyll ratio			x	x	x	x
Nitrogen to chlorophyll ratio			x	x	x	x
Light Parameters						
Daily solar radiation			x	x	x	x
Photo period			x	x	x	x
Light extinction coefficient			x	x	x	x

[a] Streeter-Phelps DO calculations are described in Chapter 1 of Book II of the WLA guidance documents (Table 1-1) and the Screening Manual (Mills et. al.).

[b] Ammonia toxicity calculations are described in Chapter 1 of Book II of the WLA guidance documents.

[c] Algal predictions and their effects on DO are discussed in Chapter 2 of Book II of the WLA guidance documents.

[d] Flow rates are needed for the river and all point sources at various points to define nonpoint flow.

[e] Constituent concentrations are needed at the upstream boundary and all point sources.

[f] Chlorophyll a concentrations are also needed at the downstream end if the reach to estimate net growth rates.

Table B-2
Model Input Parameters for Qual-2E

Input Parameter	Variable by Reach	Input Parameter	Variable by Reach	Variable with Time
Dissolved Oxygen Parameters		*Nonconservative Constituent Parameters*		
Reservation rate coefficients	Yes	Decay rate		
O2 consumption per unit of NH3 oxidation				
O2 consumption per unit of NO2 oxidation		*Meteorological Data*		
O2 production per unit photosynthesis		Solar radiation		Yes
O2 consumption per unit respiration		Cloud cover		Yes
Sediment oxygen demand	Yes	Dry bulb temperature		Yes
		Wet bulb temperature		Yes
Carbonaceous BOD Parameters		Wind speed		Yes
CBOD decay rate	Yes	Barometric pressure		Yes
CBOD settling rate	Yes	Elevation		
		Dust attenuation coefficient		
Organic Nitrogen		Evaporation coefficient		
Hydrolize to ammonia	Yes			
		Stream Geometry Data		
Ammonia Parameters		Cross-sectional area vs. depth	Yes	
Ammonia oxidation rate	Yes	Reach length	Yes	
Benthic source rate	Yes			
		Hydraulic Data (Stage-flow Curve Option)		
Nitrite Parameters		Coefficient for stage-flow equation	Yes	
Nitrite oxidation rate	Yes	Exponent for stage-flow equation	Yes	
		Coefficient for velocity-flow equation	Yes	
Nitrate Parameters		Exponent for velocity-flow equation	Yes	
None				
		Hydraulic Data (Manning's Equation Option)		
Organic Phosphorous		Manning's n	Yes	
Transformed to diss. p	Yes	Bottom width of channel	Yes	
		Side slopes of channel	Yes	
Phosphate Parameters		Channel slope	Yes	
Benthic source rate	Yes			
		Flow Data		
Phytoplankton Parameters		Upstream boundaries	Yes	

Table B-2 (continued)
Model Input Parameters for Qual-2E

Input Parameter	Variable by Reach	Input Parameter	Variable by Reach	Variable with Time
Maximum growth rate		Tributary inflows	Yes	
Respiration rate		Point sources	Yes	
Settling rate	Yes	Nonpoint sources	Yes	
Nitrogen half-saturation constant		Diversions	Yes	
Phosphorous half-saturation constant				
Light half-saturation constant		*Constituent Concentrations*		
Light extinction coefficient	Yes	Initial conditions	Yes	
Ratio of chlorophyll a to algal biomass	Yes	Upstream boundaries		Yes
Nitrogen fraction of algal biomass		Tributary inflows	Yes	
Phosphorous fraction of algal biomass		Point sources	Yes	
		Nonpoint sources	Yes	
Coliform Parameters				
Die-off rate	Yes			

Table B-3
Comparison of Qual-II With Other Conventional Pollutant Models Used in Waste Load Allocations [Adapted from (11)]

Model	Temporal Variability: Water Quality	Temporal Variability: Hydraulics	Variable Loading Rated	Types of Loads	Spatial Dimensions	Water Body	Water Quality Parameters Model	Process Simulated: Chemical/Biological	Process Simulated: Physical
DOSAG-I	Steady-state	Steady-state	No	multiple point source	1-D	stream network	DO, CBOD, NBOD, conservative	1st-order decay of NBOD, CBOD, coupled DO	dilution, advection, reservation
SNSIM	Steady-state	Steady-state	No	Multiple point sources & nonpoint sources	1-D	stream network	DO, CBOD, NBOD, conservative	1st-order decay of NBOD, CBOD, coupled DO, benthic demand (s), photosynthesis (s)	dilution, advection, reservation
QUAL-II	Steady-state or dynamic	Steady-state	No	multiple point sources & nonpoint sources	1-D	stream network	DO, CBOD, temperature, ammonia, nitrate, nitrite, algae, phosphate, coliforms, non-conservative substances, three conservative substances	1st-order decay of NBOD, CBOD, coupled DO, benthic demand (s), CBOD settling (s), nutrient-algal cycle	dilution advection, reservation, heat balance
RECEIV-II	Dynamic	Dynamic	Yes	multiple point sources	1-D or 2-D	stream network or well-mixed estuary	DO, CBOC, ammonia, nitrate, nitrite, total nitrogen, phosphate, coliforms, algae, salinity, one metal ion	1st-order decay of NBOD, CBOD, coupled DO, benthic demand (s), CBOD settling (s), nutrient-algal cycle	dilution, advection, reservation

(s) = specified

Table B-4
Methods for Determining Coefficient Values in Dissolved Oxygen and Eutrophication Models

Model Parameter	Symbol	Method Determination
Dissolved Oxygen Parameters		
Reaeration rate coefficient	K_s	Compute as a function of depth and velocity using an appropriate formula, or measure in field using tracer techniques.
O_2 consumption per unit of NH3 oxidation	a1	Constant fixed by biochemical stoichiometry
O_2 consumption per unit NO2 oxidation	a2	Constant fixed by biochemical stoichiometry
O_2 production per unit photosynthesis	a3	Literature values, model calibration and measurement by light to dark bottles and chambers.
O_2consumption per unit respiration	a4	Literature values and model calibration .
Sediment oxygen demand	K_{SOD}	In situ measurement and model calibration.
Carbonaceous BOD Parameters		
CBOD decay rate	K_d	Plot CBOD measurements on semi-log paper or measure in laboratory.
CBOD settling rate	K_s	Plot CBOD measurements on semi-log paper and estimate from steep part of curve.
Ammonia Parameters		
Ammonia oxidation rate .	K_{N1}	Plot TKN measurements and NO_3+NO_2 measurements on semi-log paper.
Benthic source rate	K_{BEN}	Model calibration.
Nitrite Parameters		
Nitrite oxidation rate	K_{N2}	Use literature values and calibration, since this rate is much faster than the ammonia oxidation rate.
Phosphate Parameters		
Benthic source rate	K_{BEP}	Model calibration.

Table B-4 (Continued)
Methods for Determining Coefficient Values in Dissolved Oxygen and Eutrophication Models

Model Parameter	Symbol	Method Determination
Phytoplankton Parameters		
Growth rate	μ	Literature values and model calibration, or measure in field using light-dark bottle techniques.
Respiration rate	r	Literature values and model calibration, or measure in field using light-dark bottle techniques.
Settling rate	V_s	Literature and model calibration.
Nitrogen fraction of algal biomass	a5, a6, a7	Literature values and model calibration or laboratory determinations from field samples.
Phosphorous fraction of algal biomass	a8, a9	Literature values and model calibration or laboratory determinations from field samples.
Half-saturation constants for nutrients	K_n, K_p	Literature values and model calibration.
Saturating light intensity or half-saturation constant for light	I_s or K_L	Literature values and model calibration.

Note: Literature values for model coefficients are available in ref. (18, 19, 20)

Table B-5
Summary of Data Requirements for Screening Approach for Metals in Rivers

Data	Calculation Methodology Where Data are Used*	Remarks
Hydraulic Data		
1. Rivers:		
• River flow rate, Q	D, R, S, L	An accurate estimation of flow rate is very important because of dilution considerations. Measure or obtain from USGS gage.
• Cross-sectional area, A	D, R, S	
• Water depth, h	D, R, S, L	The average water depth is cross-sectional area divided by the surface width.
• Reach lengths, x	R, S	
• Stream velocity, U	R, S	The required velocity is distance divided by travel time. It can be approximated by Q/A only when A is representative of the reach being studied.
2. Lakes:		
• Hydraulic residence time, T	L	Hydraulic residence times of lakes can vary seasonally as the flow rates through the lakes change.
• Mean depth, H	L	Lake residence times and depths are used to predict settling of absorbed metals in lakes.
Source data		
1. Background		
• Metal concentrations, C_t	D, R, S, L	Background concentrations should generally not be set to zero without justification.
• Boundary flow rates, Q_u	D, R, S, L	
• Boundary suspended solids, Su	D, R, S, L	One important reason for determining suspended solids concentrations is to determine the dissolved concentration, C, of metals based on C_T, S, and K_p. However, if C is known along with C_T and S, this information can be used to find K_p.
• Silt, clay fraction of suspended solids	L	
• Locations	D, R, S, L	
2. Point Sources		
• Locations	D, R, S, L	
• Flow rate, Q_w	D, R, S, L	
• Metal concentration, C_{tw}	D, R, S, L	
• Suspended solids, S_w	D, R, S, L	

Table B-5 (continued)
Summary of Data Requirements for Screening Approach for Metals in Rivers

Bed Data		
• Depth of contamination		For the screening analysis, the depth of contamination is most useful during a period of prolonged scour when metal is being input into the water column from the bed.
• Porosity of sediments, n		
• Density of solids in sediments (e.g.,2.7 for sand) u_s		
• Metal concentration in bed during prolonged scour period, C_2		
Derived Parameters		
• Partition coefficient, K_p	All	The partition coefficient is a very important parameter. Site-specific determination is preferable.
• Settling velocity, w_s	S,L	This parameter is derived based on suspended solids vs. distance profile.
• Resuspension velocity, W_{rs}	R	This parameter is derived based on suspended solids vs. distance profile.
Equilibrium Modeling		
• Water quality characterization of river:	E	Equilibrium modeling is required only if predominant metal species and estimated solubility controls are needed.
• pH		
• Suspended solids		
• Conductivity		
• Temperature		
• Hardness		Water quality criteria for many metals are keyed to hardness, and allowable concentrations increase with increasing hardness.
• Total organic carbon		
• Other major cations and anions		

*D- Dilution (includes total dissolved and adsorbed phase concentration predictions)

R- dilution and resuspension

S-dilution and settling

L- lake