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Combined Sewer Overflows

Guidance For Monitoring And Modeling

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COMBINED SEWER OVERFLOWS

GUIDANCE FOR MONITORING AND MODELING

Office of Wastewater Management
U.S. Environmental Protection Agency
Washington, DC 20460

January 1999

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

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OFFICE OF
WATER

MEMORANDUM

SUBJECT: Combined Sewer Overflows: Guidance for Monitoring and Modeling

FROM: Michael B. Cook, Director
Office of Wastewater Management (4203)

TO: Interested Parties

I am pleased to provide you with the Environmental Protection Agency's (EPA) guidance document on the monitoring and modeling of combined sewer overflows (CSO) and their impacts on receiving waters. This is the seventh in a series of guidance manuals that EPA prepared to support implementation of the 1994 Combined Sewer Overflow Control Policy.

This manual presents a set of guidelines that provide flexibility for a municipality to develop a site-specific strategy for characterizing its combined sewer system operations and impacts and for developing and implementing a long-term CSO control plan. It is **not** a "how-to" manual defining how many samples to collect or which flow metering technologies to use.

EPA used a peer-review process and solicited comments from CSO stakeholders and the general public. The EPA identified the Water Environment Research Foundation (WERF) and two technical experts to provide technical and scientific peer review. WERF convened a panel of its technical experts to review the document. The peer reviewers and the other reviewers submitted detailed comments and recommendations. EPA will make available to interested parties a "response-to-comments" document detailing how it addressed comments received during the peer review and the public comment period. I am very grateful to the peer reviewers and the other individuals and organizations who participated in preparation and review. I believe that this manual will assist municipalities as they develop and implement long-term CSO control plans to meet the requirements of the Clean Water Act and the objectives of the EPA's CSO Control Policy.

If you have any questions on the manual or its distribution, please contact Tim Dwyer in the Office of Wastewater Management at (202) 260-6064. Mr. Dwyer's e-mail address is *dwyer.tim@epa.gov.*

ACKNOWLEDGMENTS

The U.S. Environmental Protection Agency (EPA) wants to thank the Cities of Columbus, Georgia; South Bend, Indiana; and Indianapolis, Indiana for allowing EPA to use their experiences in monitoring and modeling as case studies for this manual. The experiences of these cities provide excellent examples of the monitoring and modeling process associated with developing and implementing combined sewer overflow (CSO) control programs. EPA believes that use of case studies greatly enhances the value of the document.

EPA also acknowledges the peer reviewers who kindly donated their time and knowledge to improving the technical and scientific discussions in this manual. The peer reviewers were David Dilks, Limno-Tech, Inc.; Raymond M. Wright, Ph.D., P.E., University of Rhode Island; and John Marr, Limno-Tech, Inc., who reviewed it on behalf of the Water Environment Research Foundation.

Finally, EPA thanks those individuals and organizations that took the time and energy to review and submit comments as part of the public review process. They are to be commended for their perseverance and dedication to a long and arduous task.

EPA believes that the peer review process and the public comments greatly improved the technical and scientific aspects of the manual. We hope that users will find the information in the manual useful as they develop and implement CSO control plans.

Assistance in developing this manual was provided to EPA under contract number 68-C4-0034.

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

BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BAT	Best Available Technology Economically Achievable
BCT	Best Conventional Pollutant Control Technology
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
BPJ	Best Professional Judgment
CAD	Computer Aided Design
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
DO	Dissolved Oxygen
EMAP	Environmental Monitoring and Assessment Program
EMC	Event Mean Concentration
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
IDF	Intensity Duration Frequency
I/I	Infiltration/Inflow
LA	Load Allocation
LTCP	Long-Term Control Plan
MPN	Most Probable Number
NCDC	National Climatic Data Center
NMC	Nine Minimum Controls
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NURP	Nationwide Urban Runoff Program
PDF	Probability Density Function
O&M	Operation 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 Survey
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
UAA	Use Attainability Analysis
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
WLA	Wasteload Allocation
WQS	Water Quality Standard(s)

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Combined sewer systems (CSSs) are 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 950 communities nationwide, most of them 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.

CSOs contain many types of contaminants, including pathogens, oxygen-demanding pollutants, suspended solids, nutrients, toxics, and floatable matter. Their presence in CSOs and the volume of the flows 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 is partly due to the difficulty in quantifying CSO impacts on receiving water quality and the site-specific variability in the volume, frequency, and characteristics of CSOs. In addition, the financial considerations for communities with CSOs can be significant. The U.S. Environmental Protection Agency (EPA) estimates the CSO abatement costs for the 950 communities served by CSSs to be approximately $45 billion based on results from the 1996 Clean Water Needs Survey.

To address these challenges, EPA 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 of 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 attention, it failed to resolve 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, 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 l-l 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 l-l. 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

NMC = nine minimum controls
LTCP = long-term control plan
WQS = water quality standards

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 - Guidancefor Long-Term Control Plan* (U.S. EPA, 1995a) (EPA 832-B-95-002)
- *Combined Sewer Overflows - Guidance for Nine Minimum Controls* (U.S. EPA, 1995b) (EPA 832-B-95-003)
- *Combined Sewer Overflows - Guidance for Screening and Ranking* (U.S. EPA, 1995c) (EPA 832-B-95-004)
- *Combined Sewer Overflows - Guidance for Funding Options* (U.S. EPA, 1995d) (EPA 832-B-95-007)
- *Combined Sewer Overflows - Guidance for Permit Writers* (U.S. EPA, 1995e) (EPA 832-B-95-008)
- *Combined Sewer Overflows - Guidance for Financial Capability Assessment and Schedule Development* (U.S. EPA, 1997) (EPA 832-B-97-004).

EPA has printed a limited number of copies of each guidance document and has made them available through several sources:

- EPA's Water Resource Center (202-260-7786)
- National Small Flows Clearinghouse (800-624-8301 or http://www.estd.wvu.edu/nsfc/)
- National Technical Information Service (NTIS) (800-553-6847 or http://www.ntis.gov)
- Educational Resources Information Center (ERIC) (800-276-0462 or http://www.aspensys.com/eric/catalog/)
- State environmental offices
- EPA Regional Offices.

Electronic copies of some of the guidance documents are also available on EPA's Office of Water Internet site (http://www.epa.gov/ow/).

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. 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 controlplan. 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:

- Chapter 2 - Introduction To Monitoring and Modeling
- Chapter 3 - Initial System Characterization-Existing Data Analysis and Field Investigation
- Chapter 4 - Monitoring and Modeling Plan
- Chapter 5 - CSS Monitoring
- Chapter 6 - Receiving Water Monitoring
- Chapter 7 - CSS Modeling
- Chapter 8 - Receiving Water Modeling
- Chapter 9 - 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 CSO Control Policy. Thoughtful development and implementation of a monitoring and modeling plan will support the selection and implementation of cost-effective CSO controls and an assessment of their improvements 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 combined sewer systems (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 characterize their CSSs, demonstrate implementation of the nine minimum controls (NMC), and 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 a long-term control plan (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 of the CSO Control Policy, 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 at a minimum include 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 solid 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 was expected by January 1, 1997. EPA's guidance document Combined Sewer *Overflows - Guidance for Nine Minimum Controls* (U.S. 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 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 water quality standards (WQS) are currently being attained for both wet weather and dry weather
- Developing a record of overflow occurrences (number, volume, frequency, and duration)
- Compiling existing information on water quality impacts associated with CSOs (e.g., beach closings, evidence of floatables wash-up, fish kills, sediment accumulation, and the frequency, duration, and magnitude of instream WQS violations).

Monitoring as part of the NMC is not intended to be extensive or costly. It should entail collection of existing information from relevant agencies about the CSS, CSOs, the receiving water body, and pollutant sources discharging to the same receiving waters, as well as preliminary investigation activities such as field inspections and simple measurements using chalk boards, bottle boards, and block tests. The collected information and data 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 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 and identify opportunities to mitigate the impacts of nondomestic discharges during wet weather.

- ***Control of solid andfloatable 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 two approaches are discussed in more detail below and in Chapters 7 through 9.

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 sufficient data are available, or can be collected, 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 permitting authority 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.

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 andprotect 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."* (Section II.C.4.b of the CSO Control Policy)

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 meets certain performance-based criteria. 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 capturedfor treatment under paragraph ii...* " (Section 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. Considerations for using both the presumption approach and the demonstration approach are discussed in *Combined Sewer Overflows - Guidance for Long Term Control Plan* (U.S. EPA, 1995a).

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 CSS
- Public participation
- Consideration of sensitive areas
- Evaluation of alternatives
- Cost/performance considerations
- Operational plan
- Maximization of treatment at the POTW
- Implementation schedule
- Post-construction compliance monitoring program.

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

Characterization, monitoring, and modeling of the CSS

The first step in developing an LTCP involves characterization, monitoring, and modeling of the CSS. 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 ofpollutants 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. "* (Section II.C.1)

Characterization, monitoring, and modeling of the CSS can be broken into the following elements:

1. Examination of 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 and available data on flow, capacity, and water quality for the collection system, treatment plant, and receiving water. This analysis, as well as information from field inspections and simple measurements, provides 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), other pollution sources discharging to the receiving water (e.g., direct industrial discharges, POTWs, storm water discharges), and background/upstream pollution sources (e.g., agricultural or other nonpoint source runoff).

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 existing 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 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* (U.S. 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 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 (best available technology economically achievable/best conventional pollutant control technology), which at a minimum should include the NMC, 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 two 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 other 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 a 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.

The 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 Control 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 LTCPs, they may have an opportunity to pursue a coordinated and cooperative approach to CSO control planning.

The sources of watershed pollution and impairment, in addition to CSOs, are varied and include other point source discharges, discharges from storm drains, overland runoff, habitat destruction, land use activities (such as agriculture and construction), erosion, and septic systems and landfills. A watershed-based approach to LTCP development allows for the site-specific determination of the relative impacts of CSOs and other pollution sources. The flows and loads from the pollutant sources are estimated using available site-specific data and modeling. In addition to locally available data, potential data sources include:

- ***BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) -*** Combines a geographic information system (GIS), national watershed data, and environmental assessment and modeling tools to facilitate watershed and water quality analysis. Additional information is available at http://www.epa.gov/OST/BASINS/. (U.S. EPA, 1997a)

- ***EMAP (Environmental Monitoring and Assessment Program)*** - Contains data on a limited set of estuaries, surface waters, and coastal bays, as well as some information on landscape characteristics and land use. EPA's EMAP Internet site (http://www.epa.gov/emap/) also contains links to additional sources of environmental data.

- ***NAWQA (National Water-Quality Assessment) Program*** - Contains information on the status and trends in the quality of 60 U.S. river basins and aquifers. Information on the NAWQA Program can be obtained from the U.S. Geological Survey (703-648-5716) or from the USGS Internet site (http://wwwrvares.er.usgs.gov/nawqa/).

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 allocations for point sources and load allocations for nonpoint sources, may be necessary to apportion loads among dischargers. Several publications provide TMDL and wasteload allocation guidance (U.S. EPA, 1995g; U.S. EPA, 1991b; Mills et al., 1986; Mancini et al., 1983; Martin et al., 1990; Mills et al., 1985a,b). 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. BASINS (U.S. EPA, 1997a) also supports the development of TMDLs.

EPA's Office of Water is committed to supporting States that want to implement a comprehensive statewide watershed management approach. EPA has convened a Watershed Management Policy Committee, consisting of senior managers, to oversee the reorientation of all EPA water programs to support watershed approaches.

Of particular importance to CSO control planning and management is the *NPDES Watershed Strategy* (U.S. EPA, 1994e). This strategy outlines national objectives and implementation activities to integrate the NPDES program into the broader watershed protection approach. The Strategy also supports the development of statewide basin management as part of an overall watershed management approach. Statewide basin management is an overall framework for integrating and coordinating water resource management efforts basin-by-basin throughout an entire State. This will result in development and implementation of basin management plans that meet stated environmental goals.

The *Clean Water Action Plan*, issued jointly by EPA and the U.S. Department of Agriculture, calls for States to issue unified watershed assessments by October, 1998 (U.S. EPA/USDA, 1998). Assessments identify degraded watersheds needing restoration, watersheds needing preventive action to sustain water quality, and pristine or sensitive watersheds on Federal lands needing additional protection. The *Clean Water Action Plan* identifies mechanisms for States and tribes to coordinate with Federal agencies to prioritize watershed restoration and protection efforts. Additional information is available at http://www.cleanwater.gov/.

Use of the comprehensive watershed approach during long-term CSO planning will promote a more cost-effective program for achieving WQS in a watershed. LTCP development using the watershed approach is discussed further in *Combined Sewer Overflows - Guidance for Long-Term Control Plan* (U.S. EPA, 1995a).

2.3 MEASURES OF SUCCESS

Before developing a monitoring plan for characterizing the CSS and determining post-construction compliance, the permittee should identify 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, such as the number of inspections

- ***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 receiving water body, such as trends in dissolved oxygen levels, sediment oxygen demand, and solids and fecal coliform concentrations

- ***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.

Measures of success for a CSO control program should typically 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 the occurrence and effects of CSOs. Municipalities and NPDES permitting authorities should agree early in the planning stages on the data and information that will be used to measure success. These measures of success may need to be adapted as a municipality gains additional information during its system characterization. (Measures of success for the CSO program are discussed in *Combined Sewer Overflows-Guidance for Long-Term Control Plan* (U.S. 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 CSOs. 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

Section 301 of the CWA and NPDES regulations at 40 CFR 122.44 require the establishment of both technology-based and water quality-based effluent limitations:

- ***Technology-based requirements.*** Section 301 of the CWA requires effluent reductions based on various degrees of control technology for all discharges of pollutants. NPDES regulations at 40 CFR 122.44(a) require that technology-based effluent limitations be established for pollutants of concern discharged by point sources that will be regulated under an NPDES permit. Under the CSO Control Policy, permittees are expected to implement technology-based controls including, at a minimum, the NMC.

- ***Water quality-based requirements.*** Section 301(b)(1)(C) of the CWA and NPDES regulations at 40 CFR 122.44(d) require that NPDES permits contain water quality-based effluent limitations for all discharges that cause, contribute to, or have the potential to cause an exceedance of a numeric or narrative WQS. As described in the CSO Control Policy, Phase I permits should at least require that the permittee immediately comply with applicable narrative WQS, while sufficient data may not be available at this point to evaluate the need for numeric effluent limits. For Phase II permits, the CSO Control Policy recommends that permits contain water quality-based effluent limits expressed as numeric performance standards (e.g., number of overflow events per year) for the selected CSO controls. If sufficient data are available, numeric water quality-based effluent limitations should be developed and included in Phase II permits.

The development of permit limits and conditions for CSO permittees is described in greater detail in *Combined Sewer Overflows - Guidance for Permit Writers* (U.S. EPA, 1995e).

Since CSO controls must ultimately provide for the attainment of WQS, the analysis of CSO control alternatives should be tailored to the applicable WQS. 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. In identifying applicable WQS, the permittee and the permitting and WQS authorities should consider whether revisions to WQS are appropriate for wet weather conditions in the receiving water.

Review 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 information gained from LTCP development can then be used to support any efforts to revise WQS. (The identification of applicable WQS and methods for assessing attainment of WQS are discussed in Chapter 9).

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* (U.S. 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 (U.S. EPA, 1994; U.S. EPA, 1984a; U.S. EPA, 1984b; U.S. EPA, 1983b).

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 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) and NMC and LTCP implementation (in a Phase II permit)
- Determine, in coordination with the permittee and appropriate State and Federal agencies, whether the permittee needs to consider any sensitive areas in developing a monitoring and modeling plan
- 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
- Decide if the presumption approach is applicable based on the data and analysis conducted in the characterization, monitoring, and modeling of the system and the consideration of any sensitive areas

- 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 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.

- Develop appropriate monitoring requirements for post-construction compliance monitoring to assess attainment of WQS and the effectiveness of CSO controls (in a Phase II permit and ongoing).

- Assist in the review and possible revision of WQS.

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 where necessary

- 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 lead to the selection of long-term CSO controls. The public participation effort might involve public meetings at key points during the system characterization phase of LTCP development. Input from the public, obtained during the early phases of the planning process, will enable a municipality to better develop an outreach program that reaches a broad base of citizens. In addition to public meetings, municipalities can obtain input from telephone surveys, community leader interviews, and workshops. Each of these activities can give the municipality a better understanding of the public perspective on local water quality issues and sewer system problems, the amount of public concern about CSOs in particular, and public willingness to participate in efforts to control CSOs.

CHAPTER 3

INITIAL SYSTEM CHARACTERIZATION - EXISTING DATA ANALYSIS AND FIELD INVESTIGATION

As explained in Chapter 2, the development of a long-term control plan (LTCP) requires a thorough characterization of the combined sewer system (CSS). Accurate information on CSS design, CSS responses to wet weather, pollutant 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 waters and help focus the monitoring and modeling plan.

The primary objectives of the existing data analysis and field investigation 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 any known CSO impacts on receiving waters
- To identify the data that still need to be collected through the monitoring and modeling program
- To assist in implementation and documentation of the nine minimum controls (NMC).

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. Implementation of the NMC, which was expected by January, 1997, should have enabled permittees to compile a substantial amount of information on their CSSs. In addition, studies by EPA, State agencies, or other organizations may provide substantial information and data for the receiving water characterization.

This chapter describes the following activities in the initial system characterization:

- ***Physical Characterization of CSS-*** identification and description of all functional elements of the CSS and sources discharging into the CSS, 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 and pollutant characteristics of CSOs.

- ***Characterization of Receiving Waters-*** identification of the designated uses and current status of the receiving waters affected by CSOs, water quality assessment 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) when reviewing the results from the initial system characterization and in preparation for developing 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 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 (including existing flow data for both wet weather and dry weather). 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, manhole locations for monitoring access, catch basin locations, and pipe shapes and materials. Sewer maps may also show curb/surface drainage, roof connections, pipe age, and ongoing roadway construction projects and their influence on storm flow. Many cities have also used Geographic Information Systems (GIS) to develop maps of their 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 lo-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 Photograph-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. Wastewater treatment plants may also collect their own rainfall data or maintain records of rainfall data from a local weather station.

  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. For calibration and validation of hydraulic models (see Section 7.4), it is important to use rainfall data collected from within or in very close proximity to the drainage area.

National rainfall data are available from the National Weather Service, which operates thousands of weather monitoring stations throughout the country. Rainfall data for some areas are available on the Internet (the National Weather Service home page can be found at http://www.nws.noaa.gov/). The local municipality, airports, universities, or other State or Federal facilities can also provide rainfall data. The National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC), 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. Some NCDC data are also available on the Internet (NCDC's home page can be found at http://www.ncdc.noaa.gov/). 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. 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 also be available from:

- GIS databases
- Treatment plant upgrade reports
- CSS flow records (for both dry weather and wet weather)
- Treatment plant and pump station flow and performance records
- Design specifications
- Infiltration/inflow (I/I) studies
- Sewer system evaluation surveys (SSES)
- Storm water master plans

- Storm water utility records and reports
- Section 208 areawide waste treatment plans
- Section 201 facility plans
- Local property taxation records
- Federal and State highway maps and plans
- County/city planning and zoning agencies.

The availability of these sources of information varies widely among permittees. Collection system operation 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 CSO. 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 planning further investigative efforts and logistics. The map should be modified as necessary to reflect additional CSS and receiving water information (such as the locations of other point source discharges to the receiving water, the location of sensitive areas, and planned or existing monitoring locations), when these become available.

The completed map should include the following information:

- Delineation of contributing CSS drainage areas (including topography)
- General land uses (e.g., residential, commercial, industrial) and degree of imperviousness
- POTW and interceptor network

- Trunk sewer and interceptor sewer locations and sizes
- Diversion structures (e.g., gates, weirs)
- CSO outfalls (including the presence of backflow gates)
- Access points (e.g., manholes safely accessible considering traffic and pipe depth; flat, open areas accessible for sampling)
- Pump stations
- River crossings
- Rain gages
- Existing monitoring locations (CSS, CSO, storm water, other point and nonpoint sources, and receiving water)
- USGS gage stations
- Receiving water bodies
- Soil types
- Ground water flow
- Outlying separate sanitary sewer areas draining to the CSS (where applicable)
- Other point source discharges such as industrial discharges and separate storm water system discharges
- Existing industrial and municipal treatment facilities
- Existing non-domestic discharges to the CSS.

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 GIS approach can be used. Some advanced sewer models can draw information directly from CAD tiles, eliminating the duplication of entering data into the model. A municipality's planning department may be a useful source for the hardware, software, and data needed for such mapping efforts.

3.1.3 System Field Investigation

Before developing a monitoring and modeling program, the permittee should supplement historical CSS information 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. Field inspections should address all areas of the CSS, including the pipe network, flow diversion structures, CSO outfalls, pump stations, manholes, and catch basins.

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 and possible causes of the overflows (e.g., diversion structures set too low)
- Identify locations of CSO outfalls (and whether they are submerged)
- Identify non-standard engineering or construction practices (e.g., irregularly-designed regulators, use of atypical materials)
- Examine the general conditions and operability of flow regulating equipment (e.g., weirs, gates)
- Identify areas in need of maintenance, repair, or replacement
- Identify areas that are curbed, areas where roof downspouts are directly connected to the CSS, and impervious areas.

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. WPCF (1989) describes in-line inspection methods in detail and provides additional useful information for system evaluations.

The field investigation may also involve preliminary collection of both dry weather and wet weather flow and depth data, which can support the CSS flow monitoring and modeling activities later in the CSO control planning process. Preliminary CSS flow and depth estimates can begin to 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)? How much flow is being discharged during dry weather?
- Do surcharging or backwater effects occur in intercepting devices or flow diversion structures?
- How deep are the maximum flows at the flow diversion structures? Would alteration of a diversion structure affect whether a CSO occurs?

A variety of simple flow measurement techniques can help answer these questions prior to development and implementation of a monitoring and modeling plan. These include:

- ***Chalk Board-*** A chalk board is a simple depth-measuring device, generally placed in a manhole. It is 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.
- ***Chalk Spraying-*** A sprayer is used to blow chalk into a CSO structure. Passing sewer flow washes away the chalk, indicating approximate flow depth since spraying.
- ***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 be a useful component of the NMC for monitoring to characterize CSO impacts and the efficacy of CSO controls. The permittee should discuss this with the permitting authority. In some limited cases, automated continuous flow monitoring may be used. These techniques and other CSS monitoring techniques are discussed in Chapter 5.

3.1.4 Preliminary CSS Hydraulic Analysis

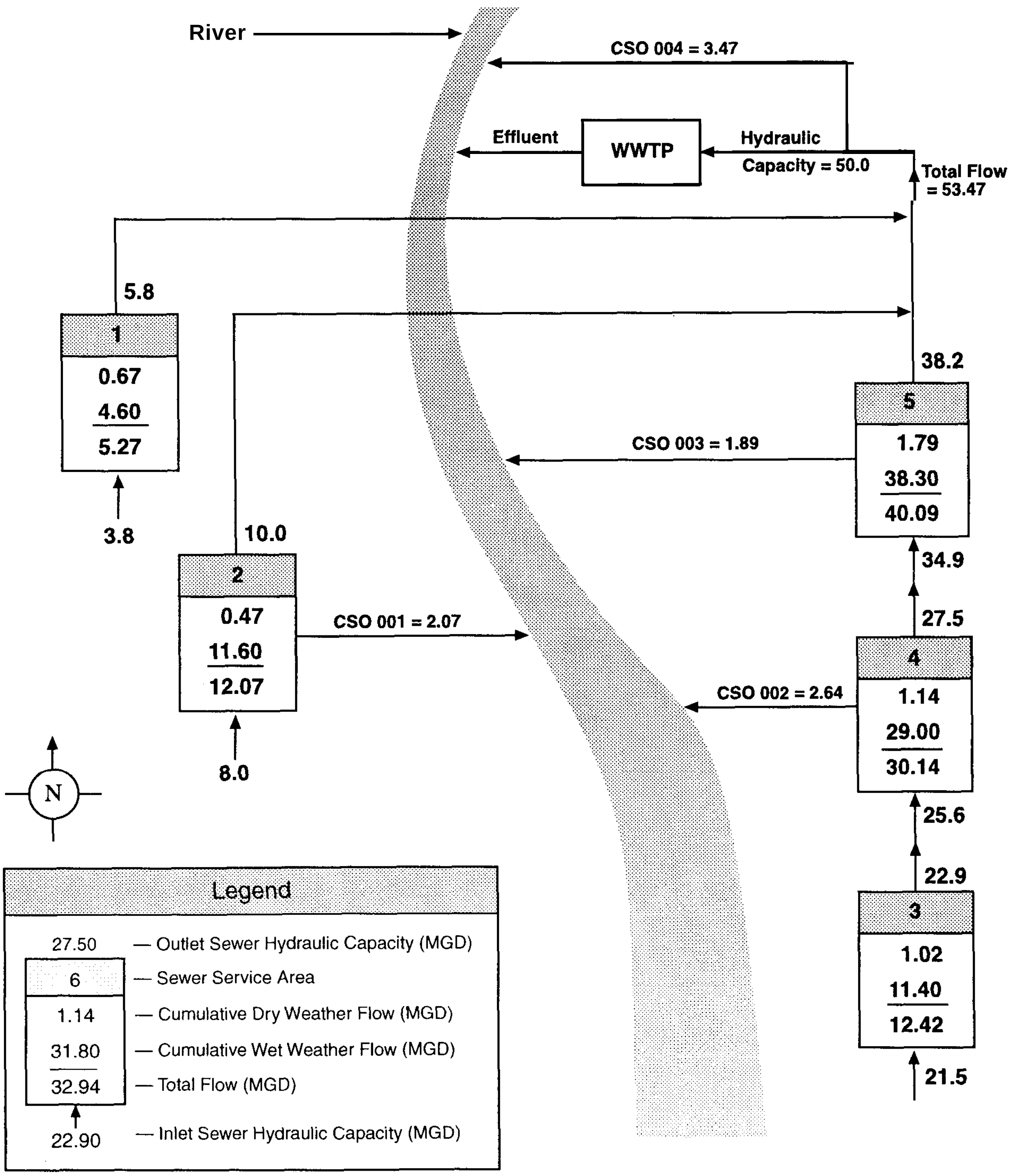
The physical characterization of the CSS should include a flow balance, using a schematic diagram of the collection system. Exhibit 3-1 provides an example of a basic flow balance diagram. It shows expected wet weather and dry weather flows through each service area, and the likely flows at each CSO based on sewer hydraulic capacities. The diagram can be expanded to include additional detail, such as breaking down the cumulative flows at each regulator to show schematically where the flows are entering the system. This can sometimes reveal local bottlenecks that may be resolved by relocating the connection to a downstream portion of the system where there is greater capacity.

The following steps can be used to develop a flow balance diagram or conduct a similar flow analysis:

- Section the collection system into a series of basins of small enough area to characterize the major collection system elements, differing land uses, receiving streams, and other characteristics that may become important during the development of a monitoring and modeling plan. These basins will likely be refined as work progresses.

- Establish the hydraulic capacity of each element of the system. For a preliminary analysis, this can be done using the unsurcharged capacity of the system, based on pipe size and slope, pump station capacity, and a knowledge of bottlenecks in the system.

Exhibit 3-1. Basic 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.

- For each basin, develop a dry weather estimate of flow delivered to the system. This can be done in a preliminary way by using total dry weather flow to the treatment plant, disaggregated to each basin using population. Care should be taken where significant differences in infiltration are suspected.

- For each basin, develop an estimate of wet weather inflow and wet weather-induced infiltration. This estimate should be based on a consistent storm or return frequency in each basin. (Flow monitoring in the CSS, including rainfall and runoff assessment, is discussed in Chapter 5.)

- Display these data in a manner that aids data analysis, such as in a flow balance diagram (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.

The preliminary hydraulic analysis, together with other physical characterization activities, will be useful in designing the CSS monitoring program and identifying areas that should receive greater attention in developing the monitoring and modeling plan. This preliminary analysis can help in identifying likely CSOs, the magnitude of rainfall that causes CSOs, estimated CSO volumes, and potential control points. 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 assessments will support decisions on what pollutants should be monitored and where. This is discussed in detail in Chapter 4.

The POTW's records can provide influent pollutant and flow data for both dry weather and wet weather conditions. Such data can be analyzed to answer questions like:

- 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, BOD, and metals at the plant during wet weather flow?
- 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(s) and comparing it to a rainfall time series plot for the same storm(s). In some cases, the permittee may also be able to use POTW data to identify which portions of the CSS are contributing significant pollutant loadings.

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 an NPDES permit application
- Pretreatment program data
- Collection system data gathered during NMC implementation
- Existing wet weather CSS sampling and analyses
- Facilities plans and designs.

The permittee can potentially use national or regional storm water data (e.g., Nationwide Urban Runoff Program (NURP) data[1]) (US. 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, such as NURP data, should be used with some reservation for CSOs since concentrations vary during a storm and from storm to 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 selected 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 such data as part of the initial characterization. Chapter 5 provides details on CSS monitoring procedures.

3.2.2 Mapping

The permittee should plot existing pollutant characterization data on the study map for points within the CSS as well as for CSO outfalls. This will highlight 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 and working with the NPDES and water quality standards (WQS) authorities, the permittee should attempt to answer the following types of questions:

[1] Some NURP data may no longer be useful due to changed conditions (e.g., lead data might not apply since control programs have been in place for many years). The permittee should contact the permitting authority to determine the applicability of NURP data.

- Does the receiving water body contain sensitive areas (as defined by the CSO Control Policy)?

- What are the applicable WQS? Is the receiving water body currently attaining WQS, including designated uses?

- 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 flow, tidal characteristics, instream flow regulations for dams and withdrawals)?

- What other dry and wet weather sources of pollutants in the watershed are discharging to the receiving water body? What quantity of pollutants is being discharged by these sources?

- What is the receiving water quality upstream of the CSO outfalls?

- What are the ecologic and aesthetic conditions of the receiving water body?

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

- Applicable State WQS
- USGS and other flow data (including tide charts)
- Physiographic and bathymetric data
- Water quality data
- Sediment data
- Fisheries data
- Biomonitoring results
- Ecologic data (habitat, species diversity)
- Operational data (hydropower records).

The permittee may already have collected receiving water data as part of other programs or studies. For example, the NPDES permit may require 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. The CWA requires States 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:

- ***State 303(d) Lists***- Under CWA section 303(d), States and authorized Tribes identify, and establish total maximum daily loads (TMDLs) for, all waters that do not meet WQS even after implementation of technology-based effluent limitations and any more stringent effluent limitations or other pollution control requirements.[2]

- ***State 304(l) Lists***- CWA section 304(l) required States to identify surface waters adversely affected by toxic and conventional pollutants from point and non-point sources, with priority given to waters adversely affected by point sources of toxic pollutants.[3] This one-time effort was completed in 1990. EPA recommends that the permittee discuss with the permitting authority data on toxic "hot spots" identified under this requirement.

- ***State 305(b) Reports***- Under CWA section 305(b), States must submit a water quality assessment report to EPA every two years.

- ***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, permittees may retrieve this information at EPA or State offices, 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). Since these data bases might not include the particular water bodies being evaluated, the permittee should contact State officials prior to seeking the data.

[2] EPA recommends that the permittee discuss with the permitting authority the status of existing TMDL reports and the schedule for doing new TMDLs for the CSO-impacted receiving water bodies.

[3] These lists are not complete for some locations, so the lists should be discussed with State WQS staff before they are used extensively.

In addition, studies conducted under enforcement actions, new permitting actions, and special programs and initiatives may provide relevant data on receiving water flow, quality, and uses. BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) contains water quality monitoring data and data on point sources and land use (US. EPA, 1997a). EPA's EMAP (Environmental Monitoring and Assessment Program) contains data on a limited number of receiving waters and the EMAP Internet site (http://www.epa.gov/emap/) provides links to other sources of environmental data (including STORET). EPA and State personnel may have information on studies conducted by other Federal organizations, such as the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, USGS, and the National Biological Service, and other organizations such as The Nature Conservancy and formalized volunteer groups. For example, USGS's National Water-Quality Assessment (NAWQA) Program contains water quality information on 60 U.S. river basins and aquifers.[4] The permittee may save considerable time and expense by consulting directly with these entities during the initial system characterization.

The receiving water characterization should also include an evaluation of whether CSOs discharge to sensitive areas, which are a high priority under the CSO Control Policy.[5] The LTCP 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,* U.S. EPA, 1995a). 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

[4] Information on the NAWQA program is available from USGS (703-648-5716) and the USGS Internet site (http://wwwrvares.er.usgs.gov/nawqa/).

[5] Sensitive areas, as discussed in the CSO Policy, are defined by the NPDES authority but include Outstanding National Resource Waters, National Marine Sanctuaries, waters with threatened or endangered species and their habitat, waters with primary contact recreation, public drinking water intakes or their designated protection areas, and shellfish beds.

estuaries), point sources, suspected nonpoint sources, plant growth, riparian zones, 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, 1991 a). A limitation of biocriteria is that they normally do not take into account wet weather conditions unique to urban streams, such as runoff from highly impervious areas.

3.3.2 Mapping

The permittee should plot existing receiving water characterization data on the study map. 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. In addition to the elements listed in Section 3.1.2 and 3.2.2, the map could include the following:

- WQS classifications for receiving waters at discharge locations and for upstream and downstream reaches, and an indication of whether receiving waters are tidal or non-tidal
- Location of sensitive areas such as downstream beaches, other public access areas, drinking water intakes, endangered species habitats, sensitive biological populations or habitats, and shellfishing areas
- Locations of structures, such as weirs and dams, that can affect pollutant concentrations in the receiving water
- Locations of access points, such as bridges, dams, and existing monitoring stations (such as USGS stations), that make convenient sampling sites.

3.4 IDENTIFY DATA GAPS

The final task in the initial system characterization is to identify gaps in information that is essential to a basic understanding of the CSS's 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:

Physical Characterization of CSS

- Have all CSO outfalls been identified? (Has the permittee taken all reasonable steps to identify outfalls-e.g., reviewing maps, conducting inspections, looking at citizen complaints?)
- 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 (as needed)?
- 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 minimum amount of rainfall and minimum rainfall intensity that cause CSOs at various outfalls known?
- Are the areas of chronic 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? (Improved wet weather operation can increase capture of CSS flows significantly.)

Characterization of Combined Sewage and CSOs

- Are the flow and pollutant concentrations of CSOs for a range of storm conditions known?
- Are the sources of CSS pollutants known?

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

Characterization of Receiving Waters

- Are the hydraulic characteristics of receiving waters known, such as the average/ maximum/minimum (7Q10) flow of rivers and streams or the freshwater component, circulation patterns, and mixing characteristics of estuaries?

- Are locations of sensitive areas and designated uses 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 and the potential for future water quality problems, including information on:

  - Streambank erosion
  - Sediment accumulation
  - Dissolved oxygen levels
  - Bacterial problems, such as those leading to beach closures
  - Toxicity (metals)
  - Nuisance algal or aquatic plant growths
  - Damage to a fishery (e.g., shellfish beds)
  - Damage to a biological community (e.g., benthic organisms)
  - Floatables or other aesthetic concerns?

- 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 (e.g., agricultural sources, other nonpoint sources, and municipal and industrial point sources, including those upstream) 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

Under the CSO Control Policy, the permittee should begin immediately to characterize its combined sewer system (CSS), document implementation of the nine minimum controls (NMC), and develop 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 sampling 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.

The NPDES permit is likely to contain requirements for monitoring necessary to develop and implement an LTCP. In many cases, the permit will first require the permittee to submit a monitoring and modeling plan. For example, the Phase I permit may require submission of a monitoring and modeling plan as an interim deliverable during LTCP development.

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 permittee should aggressively seek to involve the NPDES permitting authority, as well as State water quality standards (WQS) personnel, State watershed personnel, and EPA Regional staff, throughout this process.

This chapter describes how the permittee can develop a monitoring and modeling plan that provides 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 achieve those goals and objectives. It provides detailed discussions and examples on identifying sampling locations, frequencies, and parameters to be assessed. 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 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 wet weather impacts and make sound 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. (Step 1 is discussed in Section 4.1.1.)

Step 2: Decide whether to use ***a model*** - The permittee should decide whether to use a model during LTCP development (and, if so, which model to use). 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, the monitoring and modeling plan should include a modeling strategy. (Section 4.1.2)

Step 3: Identify data needed - The permittee should identify the monitoring data 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 should identify monitoring locations within the CSS, which CSOs to monitor, and sampling points within the receiving water body. The permittee must also determine the frequency and duration of sampling, parameters to be sampled, appropriate sample types to be collected (e.g., grab, composite), and proper sample handling and preservation procedures. If a model will be used, the monitoring plan should include any additional sampling locations, sample types, and parameters necessary to adequately support 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 4.7)

Step 5: Develop data management and analysis procedures - A monitoring and modeling plan also needs to specify QA/QC procedures and a data management program to facilitate storage, use, and analysis of the data. (Section 4.8)

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 4.9)

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 cost-effective controls to reduce water quality impacts from CSOs and provide for compliance with CWA requirements, including attainment of WQS. 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 a use attainability analysis?
  - What data are needed to support potential revision of WQS to reflect wet weather conditions?

- Evaluate the effectiveness of the NMC.
  - Have any dry weather overflows been eliminated?
  - Has wet weather flow to the POTW increased (if additional plant capacity was available)?
  - Has the level of rainfall needed to cause CSOs increased?

- 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 CSO frequency and duration change under various control alternatives?
  - What is the best combination of control technologies across the system?
  - Can CSO flows to sensitive areas be eliminated? If not, can they 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?
  - Do the measures of success (see Section 2.3) indicate reductions in CSOs and their effects?

Besides the broad goals, a municipality may have some site-specific objectives for its monitoring program. For example, a permittee that is considering sewer separation as a CSO control alternative may wish to assess the likely impacts of increased storm water loads on receiving waters.

The permittee should distinguish between short-term and long-term monitoring objectives. Determining the length of short-term and long-term planning horizons will depend in part on how much CSO control is already in place.

4.1.2 Modeling Strategy

In developing a monitoring and modeling plan, the permittee should consider up front whether to use modeling. If a permittee has a relatively simple system with a limited number of outfalls, the use of flow balance diagrams and similar analyses may be sufficient and modeling may not be necessary. For more complex systems, modeling can help characterize and predict:

- Sewer system response to wet weather
- Pollutant loading to receiving waters
- Impacts within the receiving waters
- Relative impacts attributable to CSOs and other pollutant sources.

Modeling also assists in formulating and testing the cause-effect relationships between wet weather events and receiving water impacts. This knowledge can help the permittee evaluate control alternatives and formulate an acceptable LTCP. Modeling enables the permittee to predict the effectiveness of a range of potential control alternatives. By assessing the expected outcomes of control alternatives before their implementation, the permittee can make more cost-effective decisions. Modeling results may also be relevant to reviewing and revising State WQS. Since the use of a model and its level of complexity affect the need for monitoring data, the permittee should determine early on whether modeling is needed to provide sufficient information for making CSO control decisions.

Once a model is calibrated and verified, it can be used to:

- Predict CSO occurrence, volume, and in some cases, pollutant characteristics, for rain events other than those that 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.

- Predict the wet weather performance of portions of the CSS that have not been monitored extensively.

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

- Optimize sewer system performance as part of the 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.

- Evaluate and optimize control alternatives, from simple controls described under the NMC (such as raising weir heights to increase in-line storage) to more complex controls proposed in the LTCP. The model can be used to evaluate the resulting reductions in CSO volume and frequency.

- To predict the number and duration of WQS exceedances in areas of interest (such as beaches or other sensitive areas).

- To evaluate water quality improvements likely to result from implementation of different CSO controls or combinations of CSO controls.

If the permittee decides to model, the monitoring and modeling plan should include a modeling strategy. There are several considerations in developing an appropriate modeling strategy:

- ***Meeting the expectations of the CSO Policy-*** The focus of modeling depends in part on whether the permittee adopts the presumption or demonstration approach under the CSO Policy. For some communities, 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 not involve as much receiving water modeling since it presumes that CWA requirements are met based on certain performance criteria, such as the maximum number of CSO events or the percent capture of flows entering the system during a wet weather event.

- ***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 CSS and the receiving water body, characteristics of the pollutants of concern, and the time and distance scales necessary to evaluate attainment of WQS. Receiving waters should be modeled whenever there is significant uncertainty over the importance of CSO loads as compared to other sources. A model's governing equations and boundary conditions should match the characteristics of the CSS, receiving water body, and 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 the POTW, storage facility, or CSO; 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 identify modeling activities that provide answers as detailed and accurate as needed at the lowest corresponding expense and effort. Since more detailed, accurate models are more difficult and expensive 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, initially using simple screening models with 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. Another option is to use a simpler CSS model for the whole system and selectively apply a more complex sewer model to portions of the system to answer specific design questions.

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 goal will depend on a number of factors: the layout of the collection system; the quantity, quality, and variability of the existing historical data and the necessary additional data; whether modeling will be done and, if so, the complexity of the selected 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 waters. Some municipalities may choose to allocate a relatively large portion of the available budget to monitoring, while others may allocate less. Because data needs may change as additional knowledge is obtained, the monitoring program must be a dynamic program that evolves to reflect any changes in data needs.

In identifying goals and objectives, developing a modeling strategy, and identifying 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 will support sound CSO control program decisions. The proposed plan should be submitted to the review team and modified as necessary. 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, the monitoring and modeling plan should generally contain the following major elements:

- Review of Existing Data and Information (discussed in Chapter 3)
  - Summary of existing data and information
  - Determination of how existing data meet goals and objectives
  - Identification of data gaps and deficiencies

- Development of Sampling Program to Address Data Needs (discussed in Chapters 4-6)
  - Duration of monitoring program
  - Monitoring locations
  - Frequency of sampling and number of wet weather events to be sampled
  - Criteria for when the samples will be taken (e.g., greater than x days between events, rainfall events greater than 0.4 inches to be sampled)
  - Strategy for determining when to initiate wet weather monitoring
  - 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
  - Procedures for validating, tracking, and reporting sampling results

- Discussion of Methods for Data Management and Analyses (discussed in Chapters 4-9)
  - Data management (e.g., type of data base)
  - Statistical methods for data analysis
  - Modeling strategy, including model(s) selected (discussed in Chapters 7 and 8)
  - Use of data to support NMC implementation and LTCP development

- Implementation Plan (discussed in Section 4.9, and Chapters 5 and 6)
  - Recordkeeping and reporting
  - Personnel responsible for implementation
  - Scheduling
  - Resources (funding, personnel, and equipment)
  - Health and safety issues.

The checklists in Appendix A, Tables A-l 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 volume, and monitoring of CSO quality.

As noted earlier, development of a monitoring and modeling plan is generally an iterative process. The permittee should update the plan as a result of feedback from the NPDES permitting authority and the rest of the CSO planning team, and as more knowledge about the CSS and CSOs is gained.

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 a monitoring and modeling budget may initially seem large, it is often a small percentage of the total cost of CSO control. Each municipality should balance the cost of monitoring and modeling against the risk of developing ineffective or unnecessary CSO controls based on insufficient or inaccurate data. The information obtained from additional monitoring and modeling may very well be offset by the reduction in total CSO costs.

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), the permittee should monitor storms of varying intensity, antecedent dry days, and total volume to ensure that calculations and models represent the range of conditions experienced by the CSS.

The monitoring program should span enough storm events to enable the permittee to fully understand the pollutant loads from CSOs, including the means and variations of pollutant concentrations and the resulting effects on receiving water quality. If the permittee monitors only a few storm events, 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 dilution from snowmelt and heavier rainfall 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 how the estimated mean and variance of contaminant concentrations changes over time. If estimated values stabilize (i.e., the mean and variance show almost no change as additional monitoring results are added to the data set), 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 pollutant levels 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 cornposited, 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:

- Approved methods referenced in 40 CFR 136.3, Tables 1A through 1E
- 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 (U.S. 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.

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, including 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. Careful selection of monitoring locations can minimize the number of monitors and monitoring stations needed.

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 wet weather events 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. In general, rainfall should be monitored if CSO flow and quality are being measured since areas often do not have routine rainfall monitoring data of sufficient detail. In such cases 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 model calibration. The monitoring and modeling plan should document the rationale for rain gage spacing. Additional gages can provide valuable information for CSS analysis and modeling and are usually a relatively inexpensive investment.

CSS Monitoring Locations

The monitoring and modeling plan will need to identify where in the collection system 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 identify 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 operating records for hydraulic controls such as pump stations and POTW headworks can also be used. Some calculations may be necessary to obtain flow data. For example, pump station operating records may consist of pump run times and capacities, which can be used to calculate flow.

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 industrial pretreatment program. The plan should give special consideration to these areas when they are located near CSO outfalls. Section 4.3.3 discusses the types of pollutants to be monitored.

CSO Monitoring Locations

The monitoring and modeling plan should provide for flow and pollutant monitoring for a representative range of land uses and basin sizes and at as many CSO outfalls as possible. Small systems may be able to monitor all outfalls for each storm event studied, but large systems may need a tiered approach in which only outfalls with higher flows or pollutant loadings receive the full range of measurements. Discharges to sensitive areas would warrant continuous 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 several 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 the permittee could monitor critical outfalls with automated flow monitoring equipment, two less-important outfalls with portable flow meters, and the others using chalk boards. During a second storm, the permittee could still monitor critical outfalls with automated flow equipment but rotate the portable flow meters to two other outfalls of secondary importance. However, since variability is usually greater from storm to storm than from site to site, it is generally preferable to measure more storms at a set of representative sampling sites than to rotate between all CSO locations.

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). If a representative set of CSO locations is selected for monitoring, the results can be more easily extrapolated to non-monitored areas in the system.

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 and pollutant monitoring 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[1], 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 drainage area.

- ***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 and industrial wastewater. 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 with differing land uses.

[1] The rational method is described in Schwab, et al., 1981.

- ***Location of Sensitive Areas-*** Since the 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 above criteria to identify which outfalls will provide the most useful 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 upstream or 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 more than 60 percent of the total drainage area and 70 percent of the industrial area. Outfalls 1 and 5 are adjacent to sensitive areas. These five outfalls should provide sufficient in-depth coverage for the city's monitoring program. Simplified flow and modeling techniques at outfalls 2, 3,6, 8, and 10 can supplement the collected monitoring data and allow estimation of total CSS flow.

Combined Sewer Overflows - Guidance for Screening and Ranking (U.S. EPA, 1995c) provides additional guidance on prioritizing monitoring locations. 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 CSO 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.

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 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. 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 monitoring at outfall 7 would provide 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 8 percent of the discharge area and includes commercial areas. At this outfall, a counter or timer on the pump contacts or the use of full pipe flow measurement devices usually provides an accurate measure of flow.

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 70 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 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				Flow Regulation Device				Access/ Safety Concerns	Sensitive Area	Potential Monitoring Location
		Residential	Industrial	Commercial	Open/Park	Weir Gravity	Weir Backflow	Orifice Backwater	Pump Station			
1	695	80%		20%		✓					✓	Yes
2	150	50%	20%	30%				✓		✓		No
3	560	75%		5%	20%	✓						Yes
4	430	60%	10%	30%					✓			Yes
5	500	90%			10%	✓					✓	Yes
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%	10%	11%	8%							

Monitoring frequency may be targeted to such factors as:

- Wet weather events that result in overflows
- A certain number of precipitation events (e.g., monitor until five storms are sampled-each storm may need to meet a certain minimum size)
- A certain size precipitation event (e.g., 3-month, 24-hour).

A range of storm sizes should be sampled, if possible, to characterize the CSS response for the variety of storm conditions that can occur. These data can be useful for long-term simulations. Section 4.6 discusses a strategy for determining whether to monitor a particular wet weather event. Overall, more frequency monitoring is warranted where:

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

The number of samples collected will also reflect the type of sample collected. Where possible, the permittee should collect flow-weighted composite samples 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, have limited holding times and must be collected by grab sample (see discussion in Section 5.4.1). Also, 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 several samples from the same locations throughout a storm.

permittee should carefully consider the tradeoffs involved in committing resources to a sampling program. A small number of samples may necessitate more conservative assumptions or result in more uncertain assumptions because of high sample variability. 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, CSO impacts, and design of CSO controls. 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

The monitoring and modeling plan should state how the permittee will determine the concentrations of pollutants carried in the combined sewage and the variability of these concentrations during a storm, from outfall to outfall, and from storm to storm. Pollutant concentration data should be used with flow data to compute pollutant loadings to receiving waters. In some cases such 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. The NPDES permitting authority may have specific guidance regarding parameters for CSO monitoring. Parameters of concern may include:

- Flow (volume and flow rate)
- Indicator bacteria[2]
- Total suspended solids (TSS)

[2] Concentrations of bacteria in CSOs may be fairly consistent over time (around 10^6 MPN/100 ml for fecal coliform). If sampling yields consistent results over time, the permittee may find that additional bacteria sampling is not informative. Concentration data could be combined with flow data to determine bacteria loadings.

- 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 typically present in storm water, such as zinc, lead, copper, and arsenic (U.S. EPA, 1983a).[3]

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 should be monitored in the portions of the CSS where industrial users discharge zinc to the collection system. POTW monitoring data and industrial 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 may be the result 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 or drinking water supply with past bacteriological problems, while it may not be necessary to analyze for metals or other toxics.

[3] The permittee should consider sampling both dissolved and total recoverable metals. The dissolved portion is more immediately bioavailable, but does not account for metals that are held in solids. Since CSOs generally contain elevated levels of suspended solids, which can release metals over time, sampling for total metals is important for evaluating CSOs and their impacts.

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. Collecting some discrete TSS samples can also be useful, particularly for evaluating the existence of first flush.

The permittee should consider initial screening-level sampling for a wide range of pollutants if sufficient information is not available to initially identify the parameters of concern. The permittee can then 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 are significant contributors to the same receiving water as CSOs,[4] the permittee should determine pollutant loads from storm sewers as well as CSOs. This information is needed to define the 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 sample separate storm sewers 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. Storm water discharges from highways can be another major source of pollutants,

[4] The potential significance of storm water discharges can often be assessed by looking at land uses and the relative sizes of discharges.

particularly solids, oil and grease, and trace metals. For guidance on characterizing and monitoring urban runoff, permittees can refer to EPA's *NPDES Storm Water Sampling Guidance Document* (U.S. EPA, 1992) and the *Guide for Collection, Analysis, and Use of Urban Storm Water Data* (Alley, 1977).

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 their impacts are monitored and addressed in a cost-effective, targeted manner. Many communities operate their storm water programs under a different department or authority from their sewer program. Whenever possible, similar activities within these different organizations should be coordinated on a watershed basis.

4.5 RECEIVING WATER MONITORING

The goals of receiving water monitoring should include the following:

- Assess attainment of WQS (including designated uses)
- Define the baseline conditions in the receiving water (chemical, biological, and physical parameters)
- Assess the relative 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 the 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 helps define 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 useful, 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 CSO. 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 require 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.[5] 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 other sources of pollutant loadings. As mentioned in Chapter 3, information on these sources is 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 these other sources, If the initial system

[5] In areas where the receiving water is used for swimming, the dilution needs to be at least 10,000 to 1 for bacteria.

characterization did not provide sufficient information to adequately determine the location of these sources, the permittee may need to conduct some monitoring to better characterize them.

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
- 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 such as shellfishing zones and recreational areas
- Differences in concentrations between upstream and downstream sampling sites for rivers, or between inflows and outflows for lakes, reservoirs, or estuaries
- Changing conditions at individual sampling stations before, during, and after storm events
- Differences between baseline and current conditions in receiving water bodies
- Locations of point and nonpoint pollution sources.

In selecting monitoring locations, the permittee needs to consider physical logistics (e.g., whether the water is navigable, if bridges are available from which to sample) and crew safety.

Exhibit 4-2 illustrates how sampling locations might be distributed in a watershed to assess the effect of other sources of pollution. If monitoring is conducted at the potential sampling locations (labeled 1-6 in Exhibit 4-2), the results from the different locations could be compared to provide a relative measure of the pollutant contributions from each source.

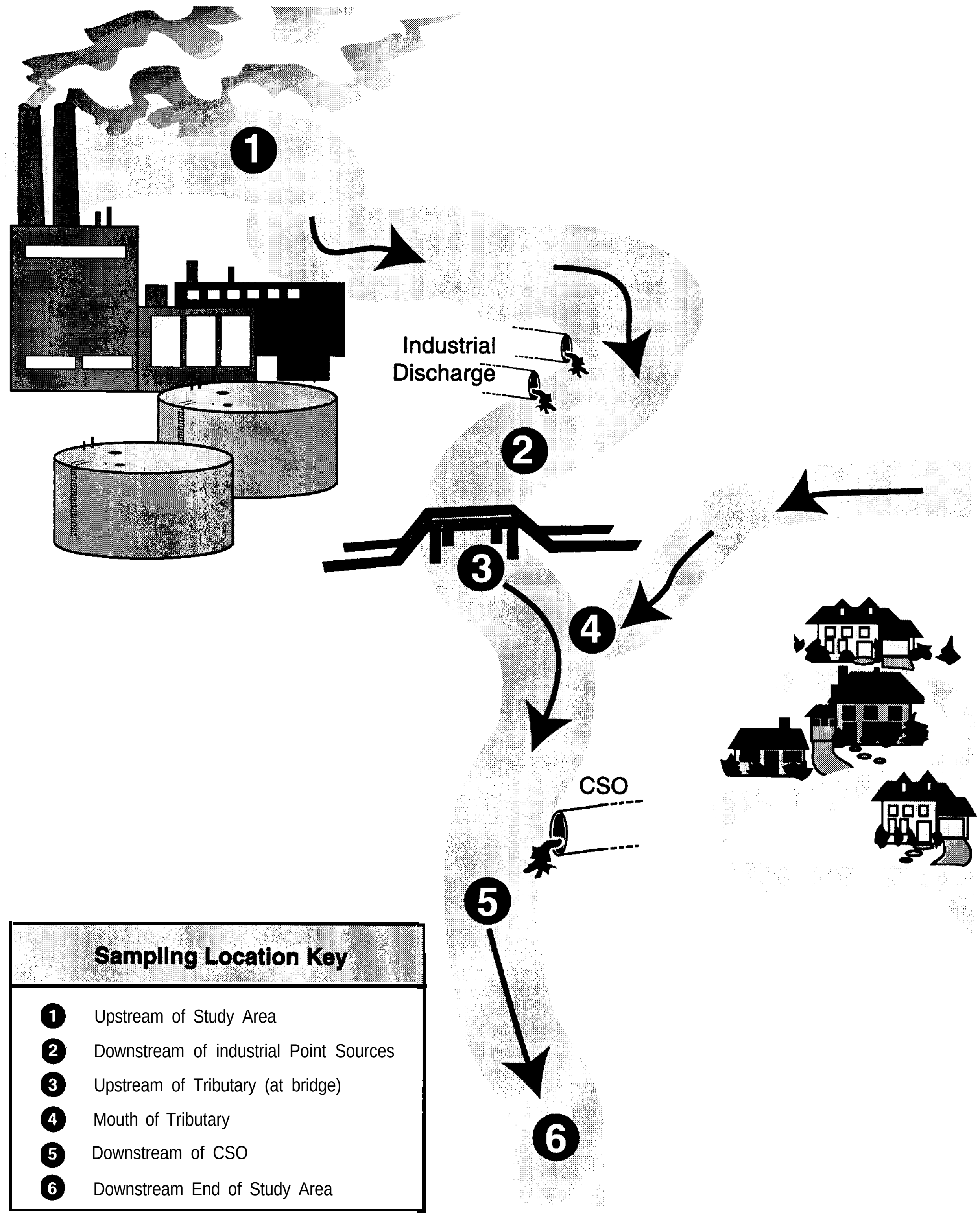
The permittee should also consider making cooperative sampling arrangements when pollutants from multiple sources enter a receiving water or when several agencies share the cost of the collection system and the POTW. The identification of new monitoring locations should account for sites that may already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

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 potential modeling parameters), or to determine 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 and uses during

Exhibit 4-2. Receiving Water Monitoring Location Example



different times of year. The monitoring and modeling plan should also enable the permittee to address issues regarding attainment of WQS, such as:

- Assessing attainment of WQS for recreation: This may require determination of a maximum or geometric mean coliform concentration at the point of discharge into a river or mixing zone boundary. This requires grab samples during and immediately after discharge events in sufficient number (possibly specified in the WQS) to reasonably approximate actual in-stream conditions.

- Assessing attainment of WQS for nutrients: 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 WQS for aquatic life support: This may call for biological assessment in potentially affected 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 intervals such 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 CSOs. These studies can examine possible short-term toxicity impacts or long-term habitat alterations near the CSO.

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

Section 4.6 discusses a strategy for determining whether to initiate monitoring for a particular wet weather event.

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 designated use(s) of the receiving water. The NPDES 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 (see Section 4.3.3):

- Indicator bacteria
- TSS
- BOD and DO
- pH
- Settleable solids
- Nutrients
- Metals (dissolved and total recoverable) and other toxics.

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

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

Monitoring should focus on the parameters of concern. In many cases, the principal concern will be pathogens, represented by fecal coliform.

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.[6] Table B-1 in Appendix B lists the data needed to perform the calculations for several dissolved oxygen, ammonia, and algal studies. Indirect indicators, such as beach closings, fish advisories, stream bank erosion, and the appearance of floatables, may also provide a relative measure of the impacts of CSOs.

4.6 CRITERIA FOR INITIATING MONITORING OF WET WEATHER EVENTS

The monitoring program should include enough storm events to enable the permittee to predict the CSS's response to rainfall events, the characteristics of resulting CSOs, and the extent of impacts on receiving waters (as discussed in Sections 4.2.1, 4.3.2, and 4.5.2). By developing a strategy for determining which storm events are most appropriate for wet weather monitoring, the permittee can collect the needed data while limiting the number of times the sampling crew is mobilized and the number of sampling events. This can result in significant savings in personnel, equipment, and laboratory costs.

The following list (ORSANCO, 1998) contains key elements to consider in determining whether to initiate monitoring for a wet weather event:

- Identifying local site conditions
  - Establish the amount and intensity of precipitation needed to initiate CSOs
  - Characterize seasonal stream conditions (flow, stage, and velocity)
  - Characterize historical climatic patterns
- Setting criteria for monitoring activities
  - Establish minimum amount of precipitation and duration to trigger event monitoring
  - Focus on frontal storms instead of thunderstorms

[6] For example, a Streeter-Phelps DO analysis requires temperature, flow rate, reach length, and sediment oxygen demand.

  - Identify time periods contained within the monitoring schedule that may not be representative of the system (holiday weekends) and avoid monitoring during those periods

- Identify local rain gage networks

  - Airports
  - Municipalities

- Identify monitoring contact personnel

  - Laboratory managers
  - Consultant crew leaders
  - Municipality crew leaders

- Identify weather sources

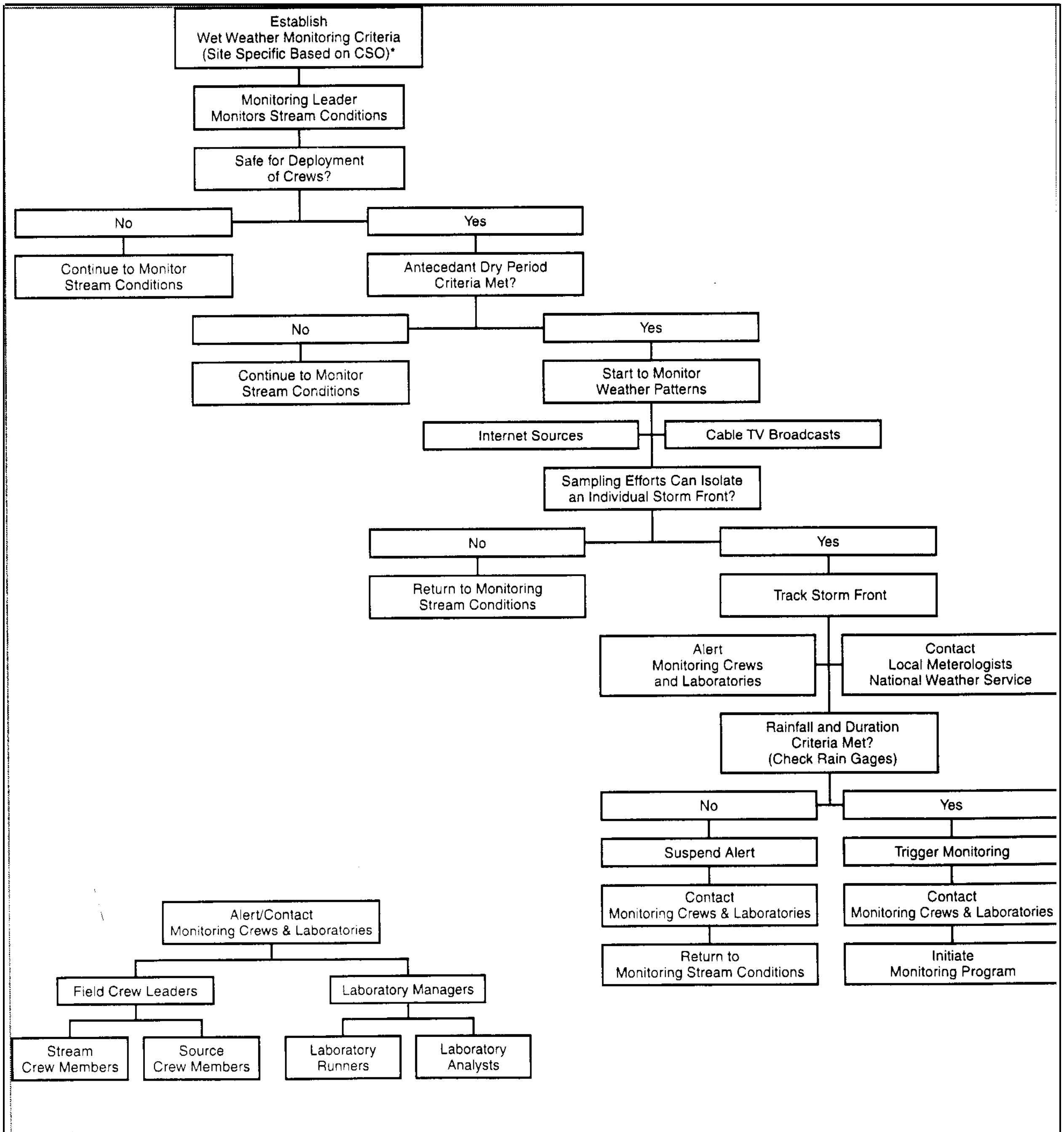
  - Local meteorologist
  - National Weather Service
    - Contact at regional forecast office
    - NOAA weather radio broadcast
  - Cable TV broadcasts
    - Local radar
    - Weather Channel
  - Internet sites
    - Local television network sites
    - National weather information sites

- Storm tracking

  - The monitoring leader tracks weather conditions and stream conditions
  - The monitoring leader notifies all monitoring contact personnel of potential events when:
    - Stream conditions are acceptable
    - Monitoring criteria may be met
  - The monitoring leader initiates monitoring following the flowchart.

The flowchart in Exhibit 4-3 provides an example of how to apply these elements (ORSANCO, 1998).

Exhibit 4-3. Decision Flowchart for Initiating a Wet Weather Monitoring Event



* Since the amount and intensity of precipitation needed to initiate an overflow and the physical conditions may vary significantly from CSO to CSO, the permittee may need to establish different monitoring criteria for different CSOs.

4.7 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 chalking 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.

4.8 DATA MANAGEMENT AND ANALYSIS

4.8.1 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 have the required precision and accuracy. 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. The implementation of a vigorous QA/QC program can also reduce monitoring expenses. For example, a QA/QC program for flow monitoring may help prevent the need for resampling due to meter fouling or loss of calibration.

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 on uses of the receiving water, the St. Joseph River. The more immediate goal consisted of quantifying CSO impacts to the St. Joseph River and evaluating alternatives for cost-effective CSO control. To achieve these goals, the City reviewed its existing data to determine what additionaldata were needed to characterize CSO impacts. The City then developed and implemented a sampling and flow 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 decided to use the SWMM model to assist in predicting the benefits of alternative control strategies and defining problems caused by CSOs.

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 interior surface of each non-monitored CSO diversion structure was chalked to determine which storms caused overflows; after each storm, the depth to which the chalk disappeared was recorded. Although the plan included monitoring only 14 percent of the outfalls, it measured flow and water quality for most of the CSS area and covered a representative range of land uses and basins. Flow monitoring data were used to calibrate the SWMM model.

The monitoring plan described water quality sampling procedures for both dry weather and wet weather periods. The plan specified sample collection from four CSO structures during at least five storm events representing a range of storm sizes. For the CSOs, 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 the four CSO points. To quantify “fist-flush” concentrations, the automatic samplers began collecting samples at the start of an overflow event 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.

River samples were taken from eight bridges along the St. Joseph River during and after three storms. Six bridges are located within South Bend, and two are located just downstream in Michigan. River samples were analyzed to determine the impacts of CSOs on the St. Joseph River and to calibrate and verify the river model for dissolved oxygen, E. coli, and fecal coliform.

Example 4-2. Monitoring; Case Study (Continued)

River samples were collected concurrently from the eight bridges every four hours. Four people sampled the eight bridges. One person collected samples from two adjacent bridges within 30 minutes, Samples were collected at the center of each bridge at the same location where the City collects its monthly river samples. At least two sets of samples were collected before the storm to establish the baseline condition and the river was sampled for at least 48 hours after onset of the storm to allow the river to return to its baseline condition.

Hourly rainfall data were collected from a network of five rain gages located in the drainage basins.

Results of the Sampling and Flow Monitoring Program

Results from the sampling and monitoring program for three storms during summer and early fall of 1991 indicated little or no impact on dissolved oxygen in the St. Joseph River, Large pulses in river bacteria counts (E. coli and fecal coliform) were observed during the storms. Bacteria counts returned to baseline values within 48 hours after the onset of each storm, Wet weather CSO sampling results showed a “first flush” effect in three of the four sampled CSO structures. The fourth structure did not exhibit a “first flush” effect, probably because of a high biochemical oxygen demand (BOD) loading at the upstream end of the trunk sewer to the structure. Wet weather CSO sampling results also showed that the soluble metal concentrations were much lower than the particulate metal concentrations.

The objective of the CSO control program is to solve real pollution problems and improve the river water quality for specific uses. Based on the results of the monitoring program, bacteria reduction in the river during wet weather has been the primary focus; A cost-performance curve was developed, using bacteria reduction as the performance measure; to select the most cost-effective alternative and level of CSO control.

For an additional case study on CSO and receiving water monitoring, see Chapter 2 of *Combined Sewer Overflows - Guidance for Long-Term Control Plan* (EPA, 1995a).

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

QC.

QA/QC procedures can be divided into two categories:
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 are of the appropriate quality. A field QA program should contain the following documented elements:

- The sampling and analytical method; 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.
- Sample tracking procedures (labeling, transport, and chain of custody).
- Procedures for calibration and maintenance of field instruments and automatic samplers during both dry and wet weather flows.
- The organization structure, including assignment of decision-making and other responsibilities for field operations.
- Training of all personnel involved in any function affecting 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 and tracking procedures
  - 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 recording, processing, and reporting data; procedures for use of non-detects/results-below-detection in averaging or other statistical summaries (e.g., substituting one-half the detection level for results of non-detect at the lowest standard used); 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 the homogeneity of the water 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.

- ***Trip Blank*** **-** An aliquout of deionized/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 deionized/distilled water and analyzing the substance to determine whether the preservative is contaminated.

The permittee should also consider analyzing a sample of blank water to ensure that the water is free of contaminants.

Laboratory QA/QC. Laboratory QA/QC procedures ensure analyses of known and documented quality through instrument calibration and the processing of samples. **Precision** of laboratory findings refers to the reproducibility of results. In a laboratory QC program, a sample is independently analyzed more than once, using the same methods and set of conditions. The precision is estimated by the variability between repeated measurements. **Accuracy** refers to the degree of difference between observed values and known or true values. The accuracy of a method may be determined by analyzing 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 assess precision and evaluate 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 laboratory blank 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* (U.S. EPA, 1994d) and *Industrial User Inspection And Sampling Manual For POTWs* (U.S. EPA 1994c).

4.8.2 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, when 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).

4.9 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.

4.9.1 Recordkeeping and Reporting

The monitoring and modeling plan includes 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 addresses the post-compliance monitoring program the permittee will develop as part of the LTCP.

4.9.2 Personnel Responsible for Implementation

The monitoring and modeling plan identities 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.

4.9.3 Scheduling

The monitoring and modeling plan has a tentative implementation schedule to ensure that elements of the plan are implemented continuously and efficiently. The schedule can 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).

4.9.4 Resources

The monitoring and modeling plan identifies equipment, personnel, and other resource needs. If modeling will be conducted, resource needs include a copy of the model and the equipment and technical expertise to use the model. The plan may need to be modified after assessing the availability of these resources. For example, if the monitoring and modeling plan identifies complex modeling strategies, resource limitations may require the permittee 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.

CHAPTER 5

CSS MONITORING

This chapter describes how to monitor rainfall, combined sewer system (CSS) flow, and CSS water 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.

5.1 THE CSO CONTROL POLICY AND CSS MONITORING

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

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

CSS monitoring also directly supports implementation of the following elements of the nine minimum controls (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 water quality data in accordance with the CSO Control Policy.

5.2 RAINFALL DATA FOR CSS CHARACTERIZATION

Rainfall data 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. Rainfall data should include long-term rainfall records and data gathered at specific sites throughout the CSS.

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

5.2.1 Rainfall Monitoring

The permittee's rainfall data will probably include both **national** and **local** data. 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). Because rainfall conditions vary over short distances, the permittee will probably need to supplement national data with data from local rainfall monitoring stations. Wastewater treatment plants may already collect and maintain local rainfall data. If sufficient local rainfall data are not available, the permittee may need to install rain gages. Where possible, the permittee should place gages in every monitored CSO basin because of the high spatial variability of rainfall.

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 unless frequent observations are made 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.

It is possible to save money by using a combination of standard and recording gages. Placing recording gages strategically amid standard gages makes it possible to compare spatial variations in total rainfall at each recording gage with the surrounding standard gages.

Equipment Installation and Operation

Rain gages are fairly easy to operate and provide accurate data when installed and used properly. Some installation recommendations are as follows:

- Gages should be located in open spaces away from the immediate shielding effects of trees or buildings.
- Gages should be installed at ground level (if vandalism is not a problem) or on a rooftop.
- Police, fire, public works, or other public buildings are desirable installation sites.

5.2.2 Rainfall Data Analysis

The permittee should synchronize rainfall monitoring with CSS flow monitoring, so that rainfall characteristics can be related to the amount of runoff and CSO volume and 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

Using rainfall data for planning purposes involves development of a “design storm.” A design storm is a precipitation event with a specific characteristic that can be used to estimate a volume of runoff or discharge of specific recurrence interval. Design conditions can be estimated if historic rainfall data (such as data from NOAA’s National Climatic Data Center) exist that:

- Extend over a sufficient period of time (30 or more years is preferable; 10 is usually acceptable); and
- Were collected close enough to the CSS’s service area to reflect conditions within that area.

Common methods for characterizing rainfall include total volumes, event statistics, return period/volume curves, and intensity-duration-frequency curves. These are described below.

Total Volumes. The National Weather Service publishes annual, monthly, and daily rainfall totals, as well as averages and deviations from the average, for each rain gage in its network. The time period for detailed simulation modeling can be selected by:

- Identifying wet- and dry-year rainfalls by comparing a particular year’s rainfall to the long-term average; and
- Identifying seasonal differences by calculating monthly totals and averages.

Simple hydraulic models can be used to predict total volumes of runoff, which can be used to identify typical rainfall years and the variations across years. 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 (HEC, 1977) 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 had both the highest number of runoff events (68) and 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 the modeled runoff predictions based on the data in Exhibit 5-1 for the example site. These statistics identify typical and extreme years to select for modeling or predicting 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.

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 over the 38-year evaluation period, 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.

For some systems, the permittee may be able to identify typical years and analyze variations by reviewing the rainfall record manually. In these cases, it may not be necessary to use a simple hydraulic model to analyze rainfall data.

Exhibit 5-l. 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

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

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 (Driscoll, et al., 1990) 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." Return periods are discussed in *Hydrology and Floodplain Analysis* (Bedient and Huber, 1992).

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 (IDF) curves are developed by analyzing an hourly rainfall record so as as to compute a running sum of volumes for consecutive hours equal to the duration of interest. The 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 procedure is used to calculate the local value for design storms such as a 1 -year, 6-hour design condition. Development and use of IDF curves is discussed in *Hydrology and Floodplain Analysis* (Bedient and Huber, *1992)* and the *Water Resources Handbook* (Mays, 1996).

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 are sampled.

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 six weeks of local rainfall data from three tipping bucket gages (labeled A, B, and C in Exhibit 5-4). Comparison with regional rainfall records indicates that the average value of the three gages was close to the regional record with only slight variations among gages.

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

Storm events 2, 4, and 8 were selected for detailed water quality sampling and analysis. Subsequent analyses of CSS flow and CSS water quality data for this example are discussed in Sections 5.3.3 and 5.4.2, respectively.

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 interpolated to estimate the rainfall at the sampling location. The inverse distance weighting method (see box on next page) can be used to calculate the rainfall over a CSS sampling location in watershed 4 in Exhibit 5-4.

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

Inverse Distance Weighting Method

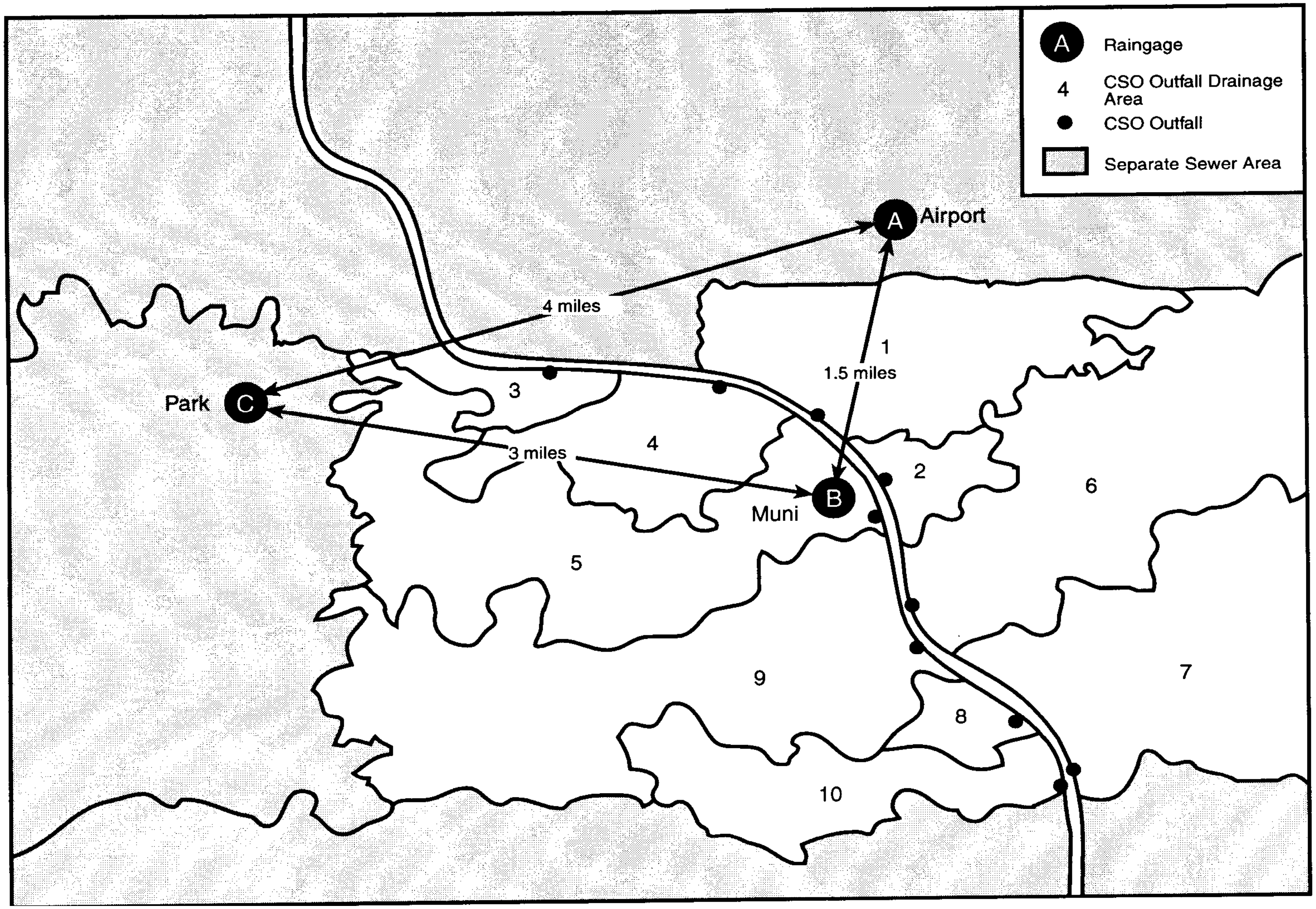
Using this method, the estimated precipitation at the sampling location is calculated as the weighted average of the precipitation at the surrounding rain gages. The weights are the reciprocals of the squares of the distances between the sampling location and the rain gages. The estimated rainfall at the sampling location is calculated by summing the precipitation times the weight for each rain gage and dividing by the sum of the u-eights. For example, if the distance between the sampling location in watershed 4 and ram 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 1.5, 1.0, and 2.5 miles, respectively, then

$$P_4 = [(0.87 \times \frac{1}{(1.5)^2}) + (1.20 \times \frac{1}{(1.0)^2}) + (1.05 \times \frac{1}{(2.5)^2})] \;/\; (\frac{1}{(1.5)^2} + \frac{1}{(1.0)^2} + \frac{1}{(2.5)^2}) = 1.09 \text{ inches}$$

Exhibit 5-4. Rain Gage Map for Data Presented in Exhibit 5-3



Not to Scale

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.

Manual Methods

The simplest flow monitoring techniques include 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 the 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 accurate 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

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 affect 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 and Chalking Boards	Blowing chalk into a CSO structure, or installation of a board with a chalk line. The chalk is erased to the level of highest flow	• Easy to implement	• Provides only a rough estimate of depth
Bottle Boards	Installation of multiple bottles at different heights where the highest filled bottle indicates the depth of flow	• Easy to implement	• Provides only a rough estimate of depth
Primary Flow			
Weir	Device placed across the flow such that overflow occurs through a notch. Flow is determined by the depth behind the weir	• Many CSOs have an existing weir • 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 that emits a stream of bubbles and measures 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 for fouling
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

flow rate calculation. Monitoring devices need to be resistant to fouling and clogging because of the large amounts of grit and debris in a CSS.

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. 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.

Example 5-1. Flow Monitoring

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. 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 gaming access to this location, the monitoring team used only the bottle board during the early monitoring period. Later, the team instailed a velocity meter and a series of depth probes to determine a surface profile.

Exhibit 5-6. Illustration of a Bottle Board Installation

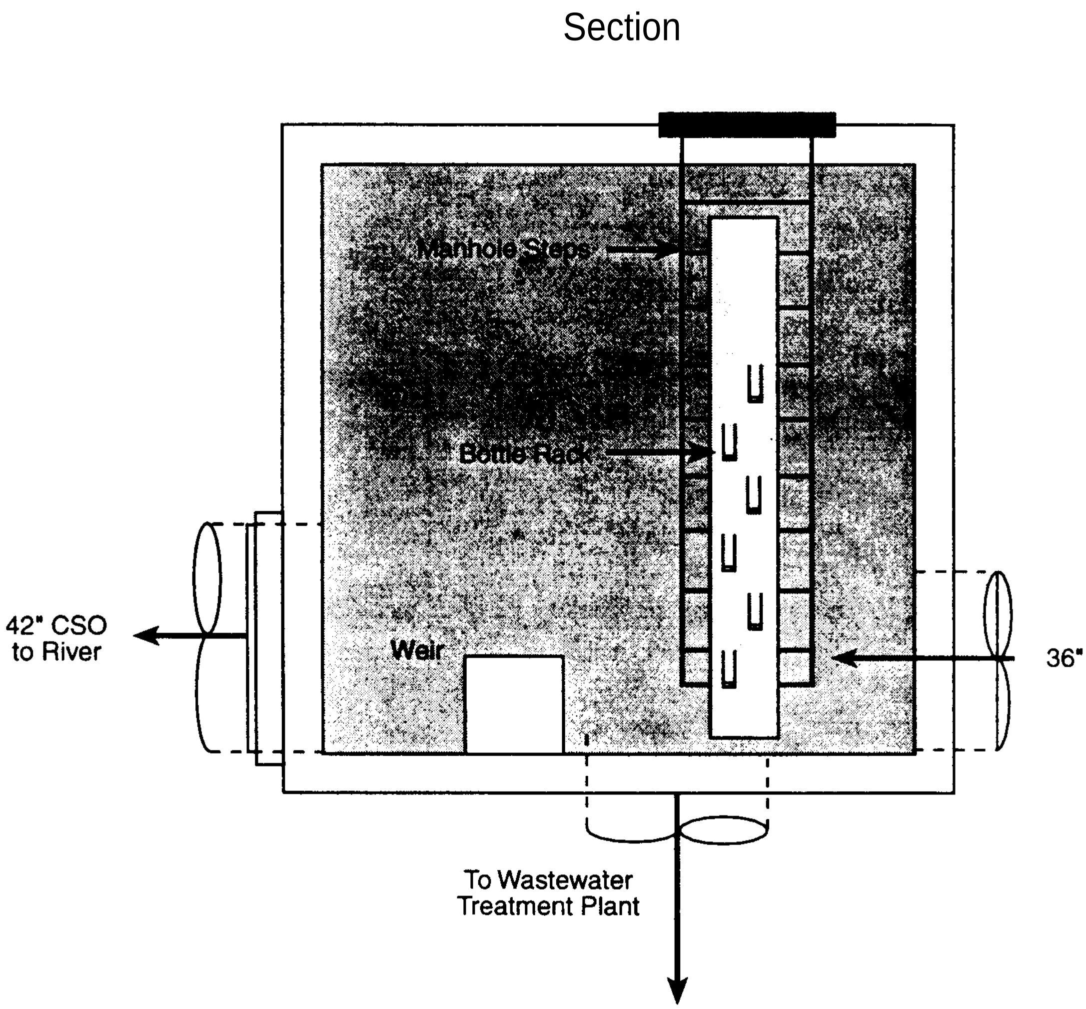


Exhibit 5-7. Example Outfall Bottle Rack Readings

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

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. 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 (ratio of rise to run).

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 (ratio of rise to run).

The volumetric flow rate (Q) is computed by:

$$Q = V\,A$$

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, sudden changes in invert elevation, or manholes 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 these formulas 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 CSSs 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.

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 monitoring 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 CSSs 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? What rainfall amount is needed to initiate overflow? 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.

Exhibit 5-8. Total Overflow Volume

Storm	Rainfall Depth (R) (inches)	Duration (hours)	Outfall (and service area size, in acres)									
			#l (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

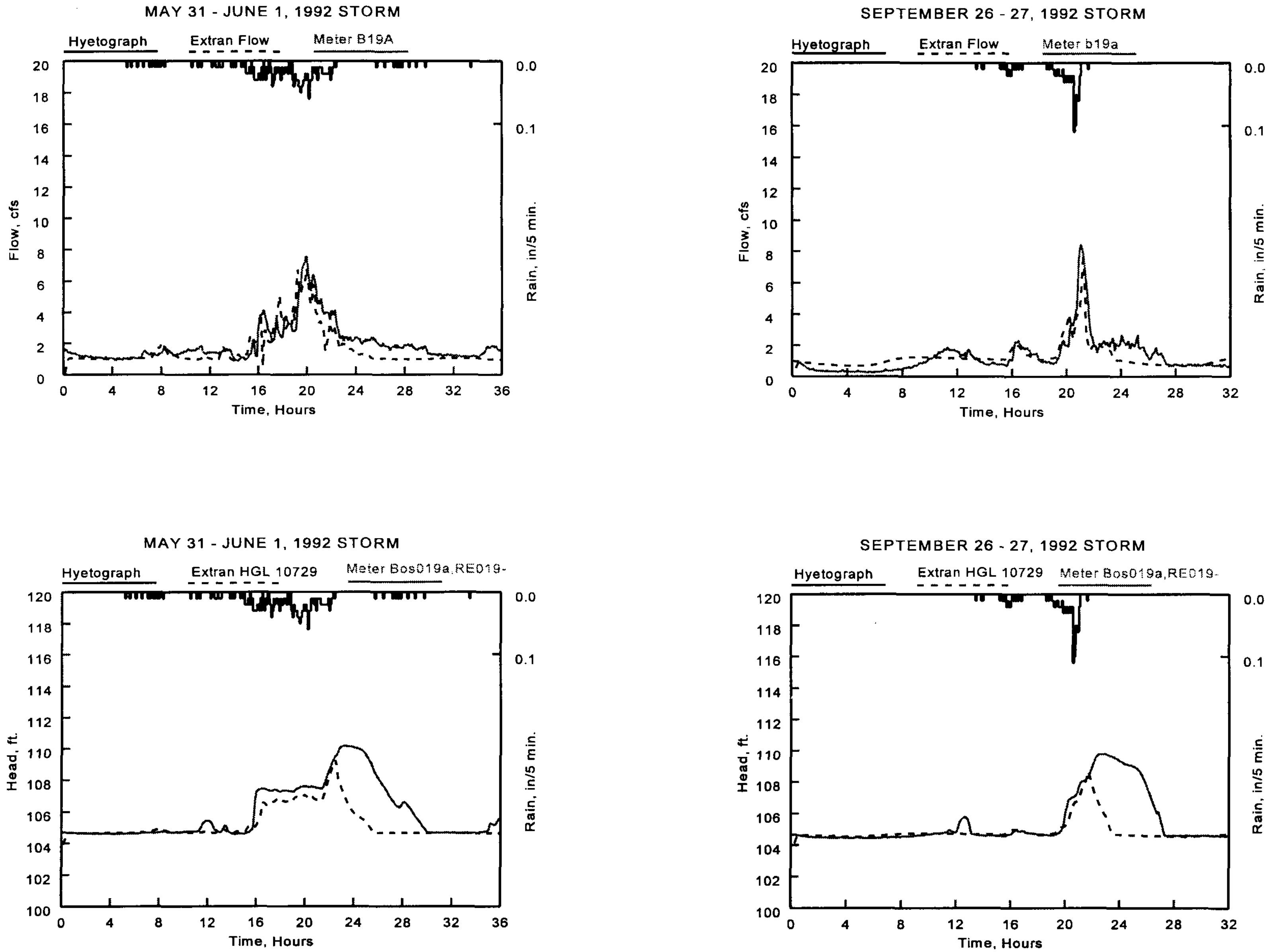
Comparing the overflow volumes of different outfalls indicates which outfalls contribute the bulk of the overflow volume and, depending on loading measurements, may contribute most heavily to water quality problems. To compare the hydraulic performance of different outfalls, flows should be normalized 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 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 the number of 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 gage that does not represent the average depth of rain falling on the discharge subarea.

In addition to supporting an analysis of CSO volume, 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. Additional methods include plotting regressions of overflow volume and rainfall to interpret monitoring data and identify locations that will cause difficulty in calibrating a model. For this type of regression, the y-intercept defines the rainfall needed to cause an overflow and the slope roughly defines the gross runoff coefficient for the basin. Flow data can also be used to tabulate CSO volumes and frequencies during the monitored time period and to compare the relative volumes and frequencies from different

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



monitoring sites in the CSS. Data are plotted, tabulated, and analyzed prior to a modeling assessment (described in Chapter 7).

5.4 WASTEWATER 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. Wastewater 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. Sampling during wet weather events involves some factors that are not a significant concern during dry weather. These additional considerations are discussed in the section on sample program organization for receiving water quality monitoring (Section 6.3.1).

5.4.1 Water Quality Sampling

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 maximum of 15 minutes. Grab samples represent the conditions at the time the sample is taken 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 formed by combining 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 continuously filling a container throughout the time period, collecting a series of separate aliquots, or combining individual grab samples from separate times, depths, or locations. Common types of composite samples include:

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

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

Flow-weighted cornpositing 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 lo-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).

Grab and composite samples can be collected using either of two **sample methods:** manual and automatic.

Manual Sampling. Manual samples are usually collected by an individual 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 can adhere to the sampling equipment and cause inaccurate measurements. Volatile compounds *must* be collected manually 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 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 automated samplers require a large investment, they can reduce the amount of labor required in a sampling program and increase the reliability of flow-weighted cornpositing.

Automated samplers have 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 cornpositing programs, and some samplers are activated by inputs from rain gages.

Automated samplers also have limitations:

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

- The sample nozzles of many automatic samplers do not have the velocity capabilities necessary for picking up the sand and gravel in untreated CSO flows.

Sampling Strategies

In developing a sampling strategy, the permittee should consider the timing of samples and sampling intervals (i.e., duration of time between the collection of samples). Since pollutant concentrations can vary widely during a storm event, the permittee should consider sampling strategies that include pre-storm, first flush, peak flow, recovery, and post-storm samples. For example, the permittee could take individual grab samples at each site during the different storm stages. Another sampling regime the permittee can use is taking a series of samples during the stages at each site:

- Pre-storm grab sample
- Composite samples collected during first flush
- Composite samples collected during peak flow
- Composite samples collected after peak flows
- Post-storm grab 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. To characterize first flush, a sample should be collected as close to the beginning of the CSO event as feasible. Appropriate sampling intervals depend on such factors as drainage area sizes, slopes, land uses, and percent imperviousness.

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*** - Because samples collected for bacteria analysis cannot be held for more than six hours, they must be collected manually. Bacteria samples are collected directly into a sterile container or plastic bag, and it is important not to contaminate the sample by touching it. Often the samples are preserved with sodium thiosulfate.

- ***Volatile Organic Compounds (VOCs)*** - Samples analyzed for 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*** - Samples analyzed for 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.

- ***Dissolved Metals*** - Samples collected for dissolved metals analysis must be filtered immediately after sample collection and before preservation.

The monitoring program may also include toxicity testing, in which the acute and chronic impacts to aquatic life are determined. Toxicity testing procedures for wet weather discharges are 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 involves adjusting sample pH, the preserved sample should always be checked to make sure it is at the proper pH level. The maximum allowed holding period for each analysis is specified in Table II of 40 CFR Part 136. 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 sampling for metals, bottles should not have metal components that can contaminate the samples. Similarly, bottles and caps used for organic samples 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
- Sample location
- 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, require special procedures. Samples shipped through a common carrier or the U.S. Postal Service 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.

The sampler and the laboratory should retain copies of the chain-of-custody form. Contract laboratories often 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 was 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 4.8.2. 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 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. To estimate pollutant concentrations for a large set of storm events, expected values can be calculated by assuming a lognormal distribution. (The lognormal distribution has been shown to be applicable to CSO quality (Driscoll, 1986).) Exhibit 5-11 shows that the mean and median for the data are similar and are within typical ranges for CSO quality. The mean and median for the sampling data can be used with a lognormal distribution to compute the expected mean, median, and 90th-percentile value for a large data set of many storm events. 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.

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 any more involved computer modeling is performed. For example, the load in pounds of BOD and TSS discharged at each outfall, normalized to account for differences in rainfall depth or land area at each outfall, helps to identify differences in loading rates across outfalls over the long term. These loading factors can provide rough estimates of the loads from unmonitored outfalls that have land

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

Outfall	Storm #2		Storm #4		Storm #8		Average	
	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

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

	BOD	TSS
Mean	96.87	345.27
Median	94.00	350.00
Expected Mean*	97.16	352.53
Expected Median*	94.70	321.29
Expected 90th Percentile Value*	126.64	558.03
Typical CSO Characteristics[1]	60 - 220	270 - 550

*Projected statistic from sampling population (i.e., very large data set)
[1]Metcalf & Eddy, Inc., 1991.

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. Pollutant loads are affected by the number of dry days and the number of days without a flushing storm 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

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)

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 example shown in Exhibit 5-13, involving bacteria sampling, illustrates the value of correlating flow and concentration data. 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. Peak flow occurred within the first 90 minutes. The fecal coliform concentration peaked in the first half hour and declined nearly one-hundredfold to the last sample, exhibiting a "first flush" pattern. The average concentration was 3.14×10^6 MPN/100 ml. To calculate total fecal coliform loading, flow measurements were multiplied by the corresponding grab sample concentrations at each half-hour interval, as shown in the right-hand column. The average concentration was also multiplied by the total flow for comparative purposes. This second calculation (1.79×10^{14} MPN) overestimates the total loading, primarily because it fails to correlate the decreasing bacteria level to the changing flows.

In many cases background conditions or upstream wet weather sources, such as separate storm sewer systems, may provide significant pollutant loads. Where possible, the permittee should try to assess loadings from non-CSO sources in order to fully characterize the receiving water impacts from CSOs. In some cases, these other sources may be outside the permittee's jurisdiction. If the permittee cannot obtain existing monitoring data on these sources, the permittee should consider monitoring these sources or entering into an agreement to have the appropriate party conduct the monitoring. 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.

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

Sample	Fecal Coliform Concentration (No./100 ml)*	CSO Flow 30 Minute Avg (cfs)	Load for 30 Minute Interval** (No. of Fecal Coliforms)
1	9.20×10^6	9.6	4.50×10^{13}
2	6.44×10^6	20.4	6.70×10^{13}
3	1.80×10^6	28.8	2.64×10^{13}
4	8.90×10^5	24.4	1.10×10^{13}
5	4.20×10^5	18.7	4.00×10^{12}
6	1.00×10^5	10.2	5.20×10^{11}
		Total Load	**1.54×10^{14}**

Average Concentration	Total Flow	Estimated Total Load***
3.14×10^6	112.1	1.79×10^{14}

* For CSOs, fecal coliform concentrations typically range from 2.0×10^5 - 1.1×10^6 colonies/100 ml (Metcalf & Eddy, 1991).
** Load = [Concentration (No./100 ml) x Total Flow (ml)] / 100 (since concentration is for 100 ml)
Total Flow (in ml) = cfs x 1800 (# of seconds in one 30-minute interval) x 28,321 (# of ml in one cf)
*** Load estimated by multiplying the average bacteria concentration by the total flow

Single composite samples or average data may be sufficient for a preliminary estimate of pollutant loadings from CSOs. Establishing an upper-bound estimate for such 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 rarer events that 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.

5.5 SAMPLING AND DATA USE CASE STUDY

The case study in Example 5-2 presents an approach for sampling and data analysis used by Columbus, Georgia. The City found this approach useful in assessing CSO control options.[1]

Example 5-2. Sampling and Data Use Case Study

Columbus, Georgia

The City of Columbus, Georgia, in a CSO technology demonstration project, found significant correlation between the timing and volume of CSO pollutant loadings and the pre-storm dry weather conditions. These relationships can be used for:

1. quantifying annual and event loads to assess water quality impact,
2. developing alternatives and evaluating treatment controls, and
3. operating the disinfection process.

The Approach

The approach involves conducting discrete sampling (for flow and water quality) and using these sampling results and historical rainfall data to establish annual load and design rate relationships (% of annual quantity vs. design flow for volume and pollutants). The discrete sampling is timed to obtain more samples at the beginning of the storm event and fewer samples as the event progresses (pollutant weighted sampling}. Using this sampling plan in Columbus has resulted in data that show a significant correlation between the cumulative volume and pollutant mass for different pre-storm conditions.

Flow measurements can be correlated with rain rate measurements to establish a rainfall/runoff relationship for the total event and rainfall intensity. These pollutant and runoff correlations are used with the historical rainfall data to quantify annual pollutant loads and to define a relationship between design rate and annual quantity for control or treatment.

Using the Data

These relationships can be used to evaluate any specific control or various combinations of controls and define annual pollutant quantities for each control level. Types of controls include collection system maximization of flows and attenuation, storage, and direct treatment.

The entire procedure can be applied using simple spreadsheet methods or can be incorporated into more sophisticated modeling efforts.

The methodology can be used in either the presumption or demonstration approaches. In the presumption approach, where the objective is to treat the mass from 85% of the annual volume using primary clarification, the Columbus method can show that the objective can be reached with facilities at much smaller flow rates by applying better treatment to the more polluted, more frequent rainfall events. The net result can be less costly to facilities.

[1] The specific approach used by Columbus, GA, may not be appropriate for all CSO communities.

Example 5-2. Sampling and Data Use Case Study (Continued)

Cost-benefit levels of control can be determined from "knee-of-the curve" analyses using design rate relationships, and may represent different annual objectives for different pollutants to be reduced. For example:

- Treatment rate versus percent annual pollutant treated can be used to define the design storm criteria
- Treatment rate versus percent annual CSO volume treated can be used to define the level of high rate disinfection.

Alternatively, different levels of control can be evaluated to estimate the end-of-pipe loads and resulting in-stream concentrations for various flows. This provides a historical distribution of in-stream concentrations that can be compared to a waste load allocation to define statistical exceedances in a wet weather permit.

Finally, the evaluated treatment options can be compared using life-cycle costs and pollutant removal results, Fur chemical disinfection, the TSS loading relationship can be used in controlling the rate of disinfection. The disinfectant feed is varied according to the variation of incoming solids to accomplish the disinfection objective while minimizing the potential for overdosing.

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 4.8.1). For purposes of the post-construction compliance monitoring program, all sampling and analysis needs to be done in accordance with EPA regulations.

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 CS0 controlplan 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.* (Section II.C.1)

As discussed in Chapter 2, the CSO Policy intends for the permittee to use either the presumption approach or the demonstration approach in identifying controls that will provide for attainment of water quality standards (WQS). Under the demonstration approach, the permittee demonstrates the adequacy of its proposed CSO control program to attain WQS. Generally, permittees 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 attained when certain performance-based criteria identified in the CSO Policy are achieved, as shown by the permittee in its long-term control plan (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. Chapters 7 (CSS Modeling) and 8 (Receiving Water Modeling) discuss the different modeling considerations related to the demonstration and presumption approaches.

6.2 RECEIVING WATER HYDRAULIC MONITORING

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 on 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 the permittee determine 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 temporary or permanent installation of gages to determine depth and velocity variations during wet weather events. In all cases, the permittee will need to use existing mapping information or perform a new survey of the physical characteristics of the receiving water in order to interpret the hydraulic data and understand 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 USGS and the U.S. Army Corps of Engineers.

For a CSO outfall located near a USGS gage, the monitoring team can use the nearest USGS gage 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 stream flow measurements. Some of the CSO flow monitoring devices described in Exhibit 5-5 of Chapter 5 also may be used to measure open channel flow in rivers and streams. The USGS (1982) and USDI (1984) have published detailed manuals on stream gaging and measurement techniques.

Estuaries

Estuaries connect rivers and oceans and thus represent a complex system of tides, salinity, and upstream drainage. 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 are dispersed. Based on velocity and salinity patterns, estuaries can be classified as one of the following types:

- ***Stratified estuaries*** have a large fresh water inflow over a more dense 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.

[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. Using flow data from the one or two gages closest to a CSO outfall, flow at the outfall can be estimated based on the relative watershed areas between the gages and the outfall.

Classification depends on the river outflow. Rivers with large flows generally lead to more stratified estuaries (U.S. 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 continuously 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 (including CSOs) and outflows. 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 due to 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, however, when simplifying assumptions, such as complete mixing in the lake, are made.) Pollutant fate and transport analysis requires definition of parameters such as 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

Receiving water hydraulic data can be analyzed to characterize the relationship between depth, velocity, and flow in the receiving water. 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[2]
- 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 and 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.

[2] Stage-discharge curves, also referred to as rating curves, are plots of water level (stage) vs. discharge. Development of these curves is discussed in Bedient and Huber (1992). USGS (1982) and USDI (1984)) discuss methods for developing hydraulic curves for various types of flow monitoring stations.

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 compared with model calculations in order to validate the model.

6.3 RECEIVING WATER QUALITY MONITORING

Collection and analysis of receiving water quality data is necessary when available data are not sufficient to describe water quality impacts from CSOs. This section discusses some approaches for conducting receiving water sampling and for analyzing the collected samples. (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, safety concerns, and use of boats. Sampling during wet weather events is typically more complicated than sampling during dry weather, since it often requires 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 when 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. Many weather services also have Internet sites that provide real-time radar updates across the U.S. Radar coverage can also be arranged in some areas for real-time observation of rainfall conditions. These efforts represent an additional cost to the program, but they can be invaluable for planning wet weather surveys and can result in significant savings in costs associated with false starts and unnecessary laboratory charges. Section 4.6 discusses a strategy for determining whether to initiate monitoring for a particular wet weather event.

The rainfall, darkness, and cold temperatures that often accompany wet weather field investigations can make even small tasks difficult and sometimes unsafe. Contingency planning and extensive preparation can, however, minimize mishaps and help 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 appropriate safety procedures and equipment
- A health and safety plan identifies the necessary emergency procedures, safety equipment, and nearby rescue organizations and emergency medical services
- 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
- Boat crews are used when landside and bridge sampling are infeasible or unsafe.

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). NOAA's Status and Trends Program also provides information on standard protocols for sampling and analysis. Collection and analytical methods depend on the constituents in the receiving water (e.g., salinity, suspended sediments, ionic strength) as well as the required precision and accuracy. Samples should be labeled with unique identifying information and should have chain-of-custody forms documenting the changes of possession between time of collection and time of analysis (discussed in Section 5.4.1). The use of sample bar code labels and recorders can be particularly helpful during wet weather sampling when paper records are often infeasible.

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).[3]

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 assess whether water quality problems are attributable to CSOs and other wet weather events[4]

[3] Use of these statistical packages generally requires solid statistical capabilities, so they should be used cautiously by someone who is not experienced in statistical data evaluations and survey design. For information on SAS, contact: SAS Institute, Inc., SAS Campus Drive, Cary, NC 27513 or (919) 677-8000. For information on SPSS, contact: SPSS Incorporated, 444 N. Michigan Avenue, Chicago, IL 60611 or (800) 543-2185.

[4] An alternative approach is to stratify the analysis by those samples that time travel analyses (e.g., Lagrangian analysis) indicate are impacted by CSO discharges. Many instream samples collected during a wet weather event represent times either before or after the CSO "slug" has passed.

- Comparing data from downstream of CSOs to data collected upstream of CSOs (or to a reference point) to distinguish CSO impacts.

Since CSO controls must ultimately provide for attainment of WQS, receiving water analyses should be tailored to the applicable WQS. If the WQS for a pollutant contain numeric criteria specifying frequency, magnitude, and duration, receiving water analyses should use the same frequency, magnitude, and duration (see Sections 4.5, 9.1, and 9.2 for additional discussion.)

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 decay rates, 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. Sediment and biological monitoring may be cost-effective supplements or, in limited cases, alternatives to water quality sampling. Since sediment and biological monitoring do not address public health risks, they can only be used as alternatives when bacterial contamination is not a CSO concern. The following sections discuss sediment and biological sampling techniques and data analysis.

6.4.1 Sediment Sampling Techniques

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 sampling 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 brought back to the surface.

Ideally, dredging should disturb the bottom as little as possible and collect all fine particles.[5]

In cases where sediments are physically amendable to coring, core samples can be collected to determine how pollutant types, concentrations, and accumulation rates have varied over time.

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).

[5] 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 (toxics, metals, total solids), and benthic makeup (discussed in Section 6.4.3). Sediment sampling locations for CSO investigations should include the depositional zone below the outfall. The same sediment 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. In comparing the chemical composition and biological communities of multiple sites, it is important to select sites that have similar physical characteristics.

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.

Additional information on sediment monitoring is available in EPA's *Guidance for Sampling of and Analyzingfor Organic Contaminants in Sediments* (U.S. EPA, 1987).

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. Biological sampling should be accompanied by habitat assessment since it is necessary to separate out the effects of habitat condition when determining the presence and degree of biological impairment due to CSOs. It may be difficult to trace any impacts to CSOs unless there are no other significant pollutant sources present. Biological sampling results may be more useful for determining the overall impacts from all pollution sources on the biological health of the receiving water.

Collection and Handling of Biological Samples

This section describes collection techniques for fish, phytoplankton, zooplankton, and benthic macroinvertebrates. Additional information on sampling methods for these species, as well as for riparian and aquatic macrophytes, 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.

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

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

[6] 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.

Exhibit 6-1. Overview of Field Biological Sampling Methods

Sample Parameter	Information Gained	Method of Collection	References
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 et al., 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.		
Phytoplankton Algae)	• Chlorophyll a • Community structure • Primary productivity • Biomass • Density	• Plankton buckets attached to 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 et al., 1989; Wetzel and Likens, 1979
Limitations:	Small organisms can pass through the net, and periphytometers can only be used for algae that attach to a substrate.		
Zooplankton	• Community structure • Distributions • Biomass • Sensitivity • Density	• Plankton buckets attached to 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 et al., 1989; Wetzel and Likens, 1979
Limitations:	Small organisms can pass through the net; some zooplankton migrate vertically in the water column, so it is possible to miss some species.		
Benthic invertebrates	• Community structure • Biomass • Density • Distributions • Tissue analysis	• Ponar grab sampler • Eckman dredge sampler • Surber sampler • Hess sampler • Kick net or D-ring net • Artificial substrates	APHA, 1992; ASTM, 1991; Lind, 1985; Merritt and Cummins, 1984; Pennak, 1989; Weber et al., 1989; Klemm, 1990; Wetzel and Likens, 1979; Plafkin et al., 1989
Limitations:	Some methods are time-consuming and labor-intensive; some methods can only be used in shallow waters.		
Riparian and aquatic macrophytes	• Community structure • Distributions (depth & basin wide) • Biomass • Density • Tissue analysis	• Usually qualitative visual assessments • Quantitative assessments using quadrant or line point methods	APHA, 1992; ASTM, 1991; Dennis and Isom, 1984; Vollenweider, 1969; Weber et al., 1989; Wetzel and Likens, 1979; Plafkin et al., 1989
Limitations:	Limited to the growing season for many species.		

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 provide valuable information about the degree of organic enrichment, local dissolved oxygen conditions, and the presence and nature of toxics in the sediments of lakes and reservoirs.

Monitoring teams generally use dredges, artificial substrates, and kicknets to sample benthic macroinvertebrates, depending on the bottom substrate and water depth. 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, 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.[7]

[7] 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, 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.

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, the presence of suitable habitats, extinction rates, competition, predation, physical disturbance, pollution, and other factors (Crowder, 1990).

A qualitative data assessment can help determine which factors have caused measured variation in species diversity. In such an assessment, the collected species 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, it is important when using lists of indicator species 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. Before conducting a biological assessment, investigators should contact local authorities to determine whether biological reference data can be obtained to use in the CSO study. Data should be from biological reference sites that have similar physical characteristics (e.g., comparable habitat).

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 used successfully 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 control actions
- Support use attainability analyses
- 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 (Plafkin et al., 1989). Reference conditions are defined based on data from systematic monitoring of either a site-specific control station or several comparable sites in the same region. A site-specific control is generally considered to be representative of the "best attainable" conditions for a particular waterbody. When using data from several regional sites, the sites are 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* (U.S. EPA, 1996).

CHAPTER 7

CSS MODELING

This chapter discusses the use of modeling to characterize the combined sewer system (CSS) and evaluate CSO control alternatives. It discusses different approaches to identifying 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 information needs of 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 the impacts of CSOs on receiving waters. Although not every CSS needs to be analyzed using complex computer models, EPA anticipates that most permittees will need to perform some degree of modeling to support CSO control decisions.

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 controlplan. 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.* (Section 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. (Section 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. (Section 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 or have been analyzed using a more complex model. In the second case, the results from the more complex model can be used to enable proper characterization of system hydraulics in the simple model.

Running a model in both continuous mode and single event mode can be useful for some systems. When only long-term hourly rainfall data are available, it may be desirable to calibrate the model using more refined single event rainfall data before running the model in continuous mode. For instance, if a CSS is extremely responsive to brief periods of high-intensity rainfall, this may not be adequately depicted using hourly rainfall data.

The CSO Control Policy also states that after instituting the nine minimum controls (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 (WQS). 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 described in this Policy.* (Section 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.* (Section II.C.1)

The long-term control plan (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 proposed LTCP 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 "*thepermitting 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* . . . ." (Section 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. Generally, the permittee should use the simplest model that meets the objectives of the modeling effort. Although complex models usually provide greater precision than simpler models, they also require greater expense and effort. 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 hydrology, hydraulics, and water quality:

- **Hydrology** is the key factor in determining runoff in CSS drainage basins. Hydrologic modeling is generally done using runoff models to estimate flows influent to the sewer system. These models provide input data for hydraulic modeling of the CSS.
- **CSS hydraulic modeling** predicts the pipe flow characteristics in the CSS. These characteristics include the different flow rate components (sanitary, infiltration, inflow, and runoff), the flow velocity and depth in the interceptors, and the CSO flow rate and duration.
- **CSS 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. CSS water quality is measured in terms of bacterial counts and concentrations of important constituents such as BOD, suspended solids, nutrients, and toxic contaminants.

Since hydraulic models are usually used together with a runoff model or have a built-in runoff component, runoff models are discussed as part of hydraulic modeling in the following sections.

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 in the CSS is less common, and a community may decide to rely on CSS water quality monitoring data instead.

Several factors will dictate whether CSS 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 CSS water quality variations are difficult to relate to parameters such as land use, rainfall intensity, and pollutant accumulation rates. For these cases, using statistics (such as mean and standard deviation) of CSS water quality parameters measured in the sewer system can be a valid approach. One limitation of this approach, however, is that it cannot account for the implementation of best management practices (BMPs) 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 focuses 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. 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.

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

	CSS Hydraulic Modeling	CSS Water Quality 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 overflow events per year	Long-term continuous simulations (preferred) or design storm simulation	Limited - Not usually performed
Capture at least 85% of wet weather 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 and/or Long-term continuous simulations	Use measured concentrations or, in limited cases, contaminant transport simulations

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. In such cases, loading estimates can be developed using measured concentrations or simplified screening methods, coupled with hydraulic modeling.

Demonstration Approach. Under the demonstration approach, the permittee needs to show that the planned controls will provide for attainment of 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 (such as 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 (such as bacteria and acutely toxic contaminants), it may be necessary to consider the timing of the pollutant load during 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:

- **Runoff models** based on Soil Conservation Service (SCS) runoff curve numbers,[1] runoff coefficients, or other similar methods 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. Runoff models do not 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.[2])

- **Models based on the kinematic wave approximation** of the full hydrodynamic equations.[3] These models can predict flow depths, and therefore flow and discharge volumes, in systems that are not subject to surcharging or back-ups (backwater effects).

[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)

[2] The SWMM RUNOFF model also has limited capabilities for flow routing in the CSS.

[3] 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 fully hydrodynamic equations (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)

These models require the user to input hydrographs from runoff model results. (The TRANSPORT block of SWMM is an example.)

- **Complex, dynamic models** based on the full hydrodynamic equations. They can simulate surcharging, backwater effects, or looped systems, and represent all pertinent processes. These models require the user to input hydrographs from runoff model results. (The EXTRAN block of SWMM is an example.)

Exhibit 7-2 compares the flow routing capabilities of the three SWMM blocks. 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 complex models. These features, however, are becoming less significant because complex 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.

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 characteristics of the above three model categories in mind. For example, a complex, dynamic model may be appropriate when CSOs are caused by back-ups or surcharging. Since models differ in their ability to account for such factors as conduit cross-section shapes, special structures, pump station controls, tide simulation, and automatic regulators, these features in a CSS may guide the choice of one model over another.

2. **Ability to accurately represent runoff in the CSS drainage basin.** The runoff component of the hydraulic model (or the runoff model, if a separate hydrologic model is used) should adequately estimate runoff flows influent to the sewer system. It should adequately characterize rainfall characteristics as well as hydrologic factors such as watershed size, slope, soil types, and imperviousness.

3. **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 it can simulate all the hydraulic features controlling the overflow, but it often requires extensive resources for its application. In addition,

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[3]	No	Yes	Yes

[1] After Huber and Dickinson, 1988.

[2] Backwater may be simulated as a horizontal water surface behind a storage element.

[3] The RUNOFF block sub-model is primarily intended to calculate surface runoff, but includes the capability to simulate simple channel conveyance of flows. The TRANSPORT and EXTRAN blocks are sewer conveyance models with no runoff components and thus require user input of hydrographs.

most of these models use a complex finite-difference technique to solve for the governing equations. Sound simulation of hydraulic behavior requires that the modeler achieve numeric stability of the solution technique through the selection of appropriate time and space intervals. In some cases, however, estimates of overflow at unmonitored locations can be made based on monitoring in areas with similar geographic features (like slope, degree of imperviousness, or soil conditions), based on V/R ratios[4] and drainage basin characteristics (see Section 5.3.3).

4. **Need for long-term simulations.** Long-term simulations are desirable to predict CSO frequency, volume, and pollutant loadings over certain time periods, like one year. This information can help support the presumption approach. For large systems, long-term simulations using a complex dynamic model often require lengthy computer run times and may be impractical.

5. **Need to assess water quality in CSS.** If CSS water quality simulations are needed, the permittee should consider the model's capability to simulate water quality. To simulate CSS water quality, it is often better to use actual pollutant concentrations from monitoring results together with modeled CSS flows.

6. **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, bacteria analysis typically requires hourly rather than daily loading data, and the hydraulic model must be capable of providing this resolution.

7. **Ability to assess the effects of control alternatives.** If control alternatives involve assessing downstream back-ups or surcharging and the effects of relieving them, correct simulation may require use of a dynamic model, since other models do not simulate surcharging or back-ups.

8. **Use of the presumption or demonstration approach.** Some permittees using the first presumption approach option-no more than four untreated 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, which requires 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 a hydraulic simulation approach may be needed.

   If a permittee is using the demonstration approach, receiving water monitoring and/or modeling is necessary. The time intervals for pollutant transport in a receiving water model may influence the time intervals for CSS quality modeling.

[4] V/R is the ratio of the overflow volume to the rainfall depth.

This in turn will constrain the time resolution for CSS hydraulic modeling. The permittee should consider the level of time resolution derived when selecting a model.

9. **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, they are generally commercial models that cost more than public domain models and can be used incorrectly by inexperienced users. 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 and accuracy is robustness, which is a model's lack of propensity to become unstable. Instabilities are uncontrolled oscillations of the model's results 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 incomplete sewer information and short conduits. Resolving model instabilities can be time-consuming and requires extensive experience with the model.

7.2.2 Selecting CSS 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), a five-year study initiated in 1978 (U.S. EPA, 1983a). 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). The EMC is 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 BMPs. They require calibration and are not regularly used due to the expense and difficulty of defining site-specific rates.

Many models do not address the potentially important role of chemical reactions and transformations within the CSS. Calibration may be difficult because pollutant loading into the CSS is often uncertain.

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 pollutant concentration simulation in the CSS, and the degree of sophistication of the model, depends partly on the needs of the receiving water quality simulation (if used) and, ultimately, on the level of detail required to demonstrate attainment of WQS. If it is only necessary to estimate the 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, in many cases it is appropriate to combine sophisticated hydraulic modeling with approximate CSS water quality modeling.

2. **Ability to assess control and BMP alternatives.** When the control alternatives under assessment include specific BMPs or control technologies, the CSS water 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, this limitation can be circumvented by using a sediment potency factor, which relates the mass of a given pollutant to sediment transport. However, this alternate approach has limited usefulness for CSO concerns since it is generally not appropriate for bacteria and dissolved metals. As noted earlier, another alternate approach is to combine the results of hydrologic and hydraulic modeling of the CSS with bacteria and dissolved metals concentrations from sampling results to estimate pollutant loads.

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. Most models translate pollutant concentrations from sources and

CSO quantity to pollutant loading without taking separate account of the timing of pollutant delivery due to transport through the CSS. Some basins 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 may 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 generally are more difficult to use. If a simpler model is applicable to the situation and can be properly calibrated, it may be sufficient and can be more accurate.

7.3 AVAILABLE MODELS

Exhibit 7-3 summarizes several runoff and hydraulic models and Exhibit 7-4 summarizes several water quality models. These models have been developed by EPA and the Army Corps of Engineers and are available in the public domain. Some of the models in Exhibit 7-3 are runoff models (such as STORM); others have a runoff component but also simulate flow in the CSS (such as SWMM and Auto-Q-ILLUDAS).

An increasing number of high-quality commercial models and pre-/post-processors are also available. Commercial models can be either custom-developed software or enhanced, more user-friendly versions of popular public domain models. In exchange for the cost of a commercial model, users generally receive additional pre- and/or post-processing capabilities and technical support services. Several of the available commercial models are listed in Exhibit 7-5.[5] Commercial pre/post-processors exist for use with some of the public domain models. Pre-processors can help users prepare their input files for a model. Post-processors provide additional capabilities for analyzing and displaying the model output through graphing, mapping, and other techniques. For

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

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

Model Name	Characteristics				
	Hydraulic Time Scales	**Hydraulic Simulation Type**	**Assess Control Alternatives**	**Key to Reviews**	**Major References**
EPA Statistical'	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'	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 for that purpose.

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

Some of the public domain models listed above are available from EPA's Center for Exposure Assessment Modeling (CEAM). CEAM can be contacted at:

CEAM
National Exposure Research Laboratory-Ecosystems Research Division
Office of Research and Development
USEPA
960 College Station Road
Athens, GA 30605-2700
Voice: (706) 355-8400
Fax: (706) 355-8302
e-mail: ceam@epamail.epa.gov
CEAM also has an Internet site at http://www.epa.gov/CEAM/

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

Model Name	Characteristics				
	Quality Time Scales	**Pollutant Types**	**Pollutant Routing-Transport Capability**	**Pollutant Routing - Transformation Capability**	**BMP Evaluation Capability**
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
PB-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, O[2]	high	no	medium
HSPF	Continuous - Sub-hourly	S, N, O	high	high	high
SWMM	Continuous - Sub-hourly	S, N, O[2]	—[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 SWMM received a low rating from Shoemaker et al. for "weak" quality simulations. This rating may not be justified when SWMM's pollutant routing-transport capabilities are compared to those of other models.

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

Some of the public domain models listed above are available from EPA's Center for Exposure Assessment Modeling (CEAM). CEAM can be contacted at:

CEAM
National Exposure Research Laboratory-Ecosystems Research Division
U.S. EPA Office of Research and Development
960 College Station Road
Athens, GA 30605-2700
Voice: (706) 355-8400 Fax: (706) 355-8302
e-mail: ceam@epamail.epa.gov
CEAM also has an Internet site at http://www.epa.gov/CEAM/

Exhibit 7-5. Selected Commercial CSS Models

Package Name	Type of Hydraulic Simulation	Water Quality Capability	Contact
Hydra/Hydra Graphics	Dynamic	No	PIZER Incorporated 4422 Meridian Avenue N Seattle, Washington 98103 (800) 222-5332 www.pizer.com
Eagle Point Hydrology Series	Dynamic	No	Eagle Point Software 4131 Westmark Drive Dubuque, Iowa 52002-2627 (800) 678-6565 www.eaglepoint.com
Mouse	Dynamic	Yes	Danish Hydraulic Institute Agern Allé 5 DK-2970 Hørrsholm, Denmark 011-45 45 179 100 www.dhi.dk
HydroWorks	Dynamic	Yes	HR Wallingford, Wallingford Software Howbery Park Wallingford Oxfordshire OX10 8BA, UK 01 1-44(0)1491 835381 www.hrwallingford.co.uk
XP-SWMM32	Dynamic	Yes	BOSS International 6612 Mineral Point Rd. Madison, Wisconsin 53705-4200 (800) 488-4775 www.bossintl.com

example, SWMMDuet[6] allows the integration of SWMM and Arc/INFO for database management and GIS analysis.

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 cost and data requirements. The *Water Resources Handbook* (Mays, 1996) discusses both hydraulic and water quality models and compares their attributes.

[6] SWMMDuet is a SWMM/GIS Interface. Further information can be obtained from the Delaware Department of Natural Resources at (302) 739-3451.

7.4 USING A CSS MODEL

7.4.1 Developing the Model

In developing the model, the modeler establishes initial conditions for various model components (such as the level of discretization) and input data parameters (such as percent imperviousness of subcatchments). These elements are then adjusted through model calibration, which is discussed in the next section.

Until recently the modeler had to compromise between the level of detail in a model (temporal and spatial precision), 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. However, for increased model complexity to lead to greater accuracy, complex models should be used by knowledgeable, qualified modelers who have sufficient supporting data. In some cases, where detail is not required, a simplified model may save time spent filling the data requirements of the model, preparing tiles, and doing the model runs. Shoemaker et al. (1992, Tables 7 to 9) provides a tabular summary of the main input and output data 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 precisely the geometry of the CSS and the land characteristics of the drainage basin are described in the model. At a very coarse level of discretization, the CSS is a black box with lumped parameters and the model (e.g., STORM) primarily simulates CSOs. 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 when 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?

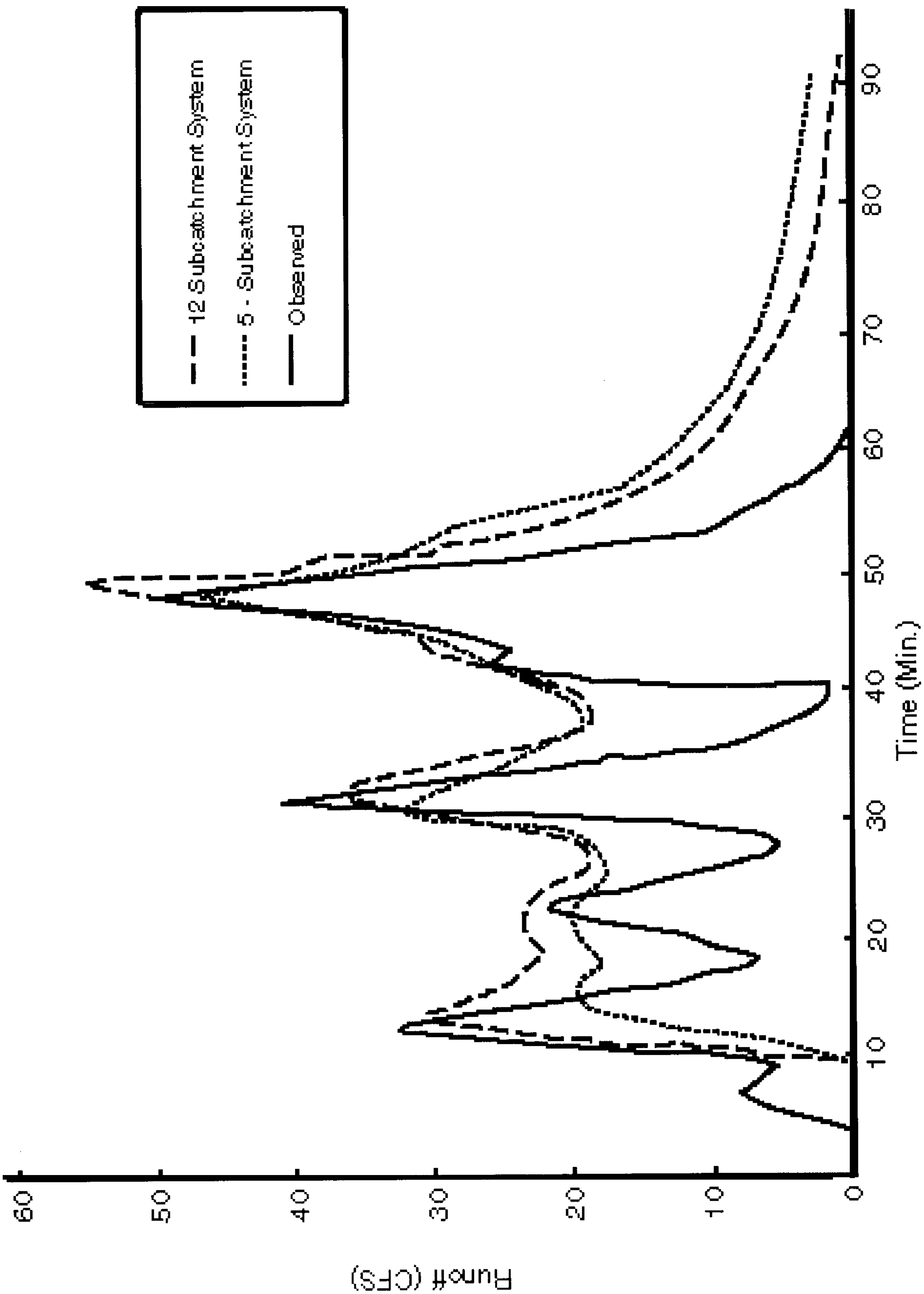
For systems that are controlled hydraulically at their downstream ends, it may only be necessary to model the larger downstream portion of the CSS. If flows are limited due to surcharging in upstream areas, however, a simulation neglecting the upstream portion of the CSS would over-estimate flows in 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 five subcatchments (coarse discretization) and a simulation based on twelve subcatchments (finer discretization) with observed values. Only marginal improvement is observable when subcatchments are increased from five to twelve. 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 tit 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 better match the observed conditions and demonstrate the credibility of the simulation results. 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 running a model using a set of input data and then comparing the results to actual measurements of the system. If the model results do not reasonably approximate actual measurements, the modeler reviews the components of the model to determine if adjustments

Exhibit 7-6. Levels of Discretization



should be made so that the model better reflects the system it represents.[7] For example, a CSS hydraulic model used to simulate overflows is calibrated by running the model using measured rainfall data to simulate the volume, timing, and depth of CSOs. 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 within scientifically credible ranges and runs the model a second time, again comparing the results to observations. Initial calibration runs often point to features of the system, such as a connection or bypass, which may not have been evident based on the available maps. The modeler repeats this procedure until satisfied that the model produces reasonable simulations of the overflows. Models are usually calibrated for more than one storm, to ensure appropriate performance for a range of conditions. Exhibit 5-9 shows some example model calibration plots of flow and depth during storm events. For calibration, the most important comparisons are total volumes, peak flows, and shapes of the hydrographs.

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 fit 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.

[7] Model calibration is not simply "curve fitting" to meet the data. Model adjustments should make the modeled elements of the system better reflect the actual system.

The availability of adequate calibration data places constraints on which models are appropriate. When identifying the time period for conducting CSS flow monitoring, the permittee should consider the effect of using larger data sets. The *Combined Sewer Overflow 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 calibrating a CSS model:

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 amenable 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 amenable to direct measurement (e.g., percent imperviousness) will be the primary adjustment factors for calibration.

3. **Calibrate the model first for the representation (prediction) 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 pollutant parameters** only after an acceptable flow 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 long-term simulations and/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. They are therefore useful for assessing the long-term performance of the system under the presumption approach. Long-term simulations also assess receiving water quality accurately under the demonstration approach. Water quality criteria need to be evaluated with the frequency and duration of exceedance in order to be relevant. This is best done using long-term continuous simulations or skillfully done probabilistic simulations. Although continuous simulation models should be calibrated using continuous data where possible, they may be calibrated with single events if antecedent conditions are taken into account. As the speed of desktop computers increases, modelers may 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 formulating 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 so much data that analysis and interpretation are difficult
- Limitations in the accuracy of hydrologic input data (due to the inability to continuously simulate spatially variable rainfall over a large catchment area) may lead to an inaccurate time series of hydraulic conditions within the interceptor
- The more storms that are simulated, the greater the chance that instabilities will occur in complex models. Correctly identifying and resolving these instabilities requires capable, experienced modelers.

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 indicate that problems, such as instabilities (see Section 7.2.1) occurred.

Most models also produce plot tiles, 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, a 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 the occurrence and frequency of water quality criteria 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, the permittee 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 may be more difficult in a continuous simulation because of the difficulty of specifying continually changing boundary conditions for the model parameters.

In interpreting model results, 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
- Model predictions are only estimates of the response of the system to rainfall events.

Model Accuracy and Reliability

Since significant CSO control decisions may be based on model predictions, the permittee must understand the uncertainty (caused by model parameters that cannot be explicitly estimated) and environmental variability (day-to-day variations in explicitly measurable model inputs) 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. 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.

Evaluating model accuracy and reliability is particularly important for the analysis of wet-weather episodic loading, such as CSOs. Such analysis invariably involves estimation of duration (averaging period) and frequency of excursion above a water quality criterion, regardless of whether the criterion is expressed as average monthly and maximum daily values, or as a maximum concentration for a given design stream flow (e.g., 7Q10). 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 for continuous simulations, and first-order error analysis and Monte Carlo simulations for non-continuous simulations:

- **Sensitivity analysis** is the simplest and most commonly used technique in water quality modeling (U.S. EPA, 1995g). Sensitivity analysis assesses 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 estimates 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 compared to the number of runs typically done for sensitivity or first-order error analysis. Monte Carlo analysis can be used to define uncertainty (due to uncertain model coefficients) and environmental variability (using historical records to characterize the variability of inputs such as stream flow).

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.[8] The output consists of an assessment of the water quality impact in terms of duration and frequency of exceedances of water quality criteria. CSO pollutant concentrations are the main "uncertain" (sensitive) input variables and can be varied over a range of reasonable values to assess their impact on the resulting water quality. Uncertainty analysis can improve management decisions and indicate the need for any additional data collection to refine the estimated loads. For instance, if a small change in CSO pollutant concentrations 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 concentrations used in the model.

7.5 EXAMPLE SWMM MODEL APPLICATION

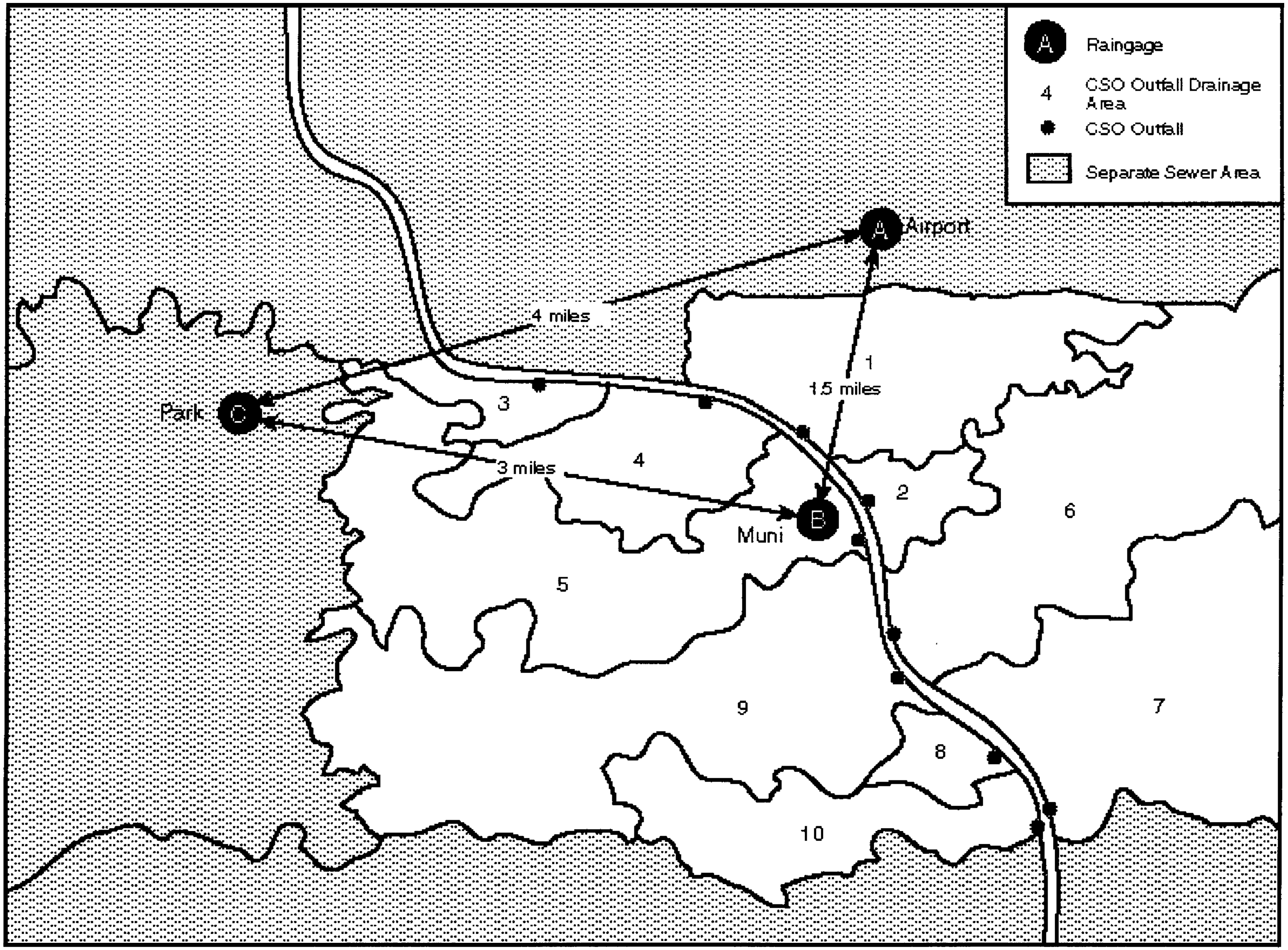
This section applies the Storm Water Management Model (SWMM) to a single drainage area from the example CSS drainage area presented in Chapters 4 and 5. While some of the details of the application are particular to the SWMM model, most of the explanation applies to a range of hydraulic models. The TRANSPORT block of the SWMM model was chosen for the flow routing because the system hydraulics 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 done 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 modeler then divides selected portions of the CSS and drainage area into segments and translates drainage area and sewer data into model parameters. This process, referred

[8] Continuous simulations do not require use of the "mean" rainfall event or "design" flow data.

Exhibit 7-7. Drainage Area Map



Not to Scale

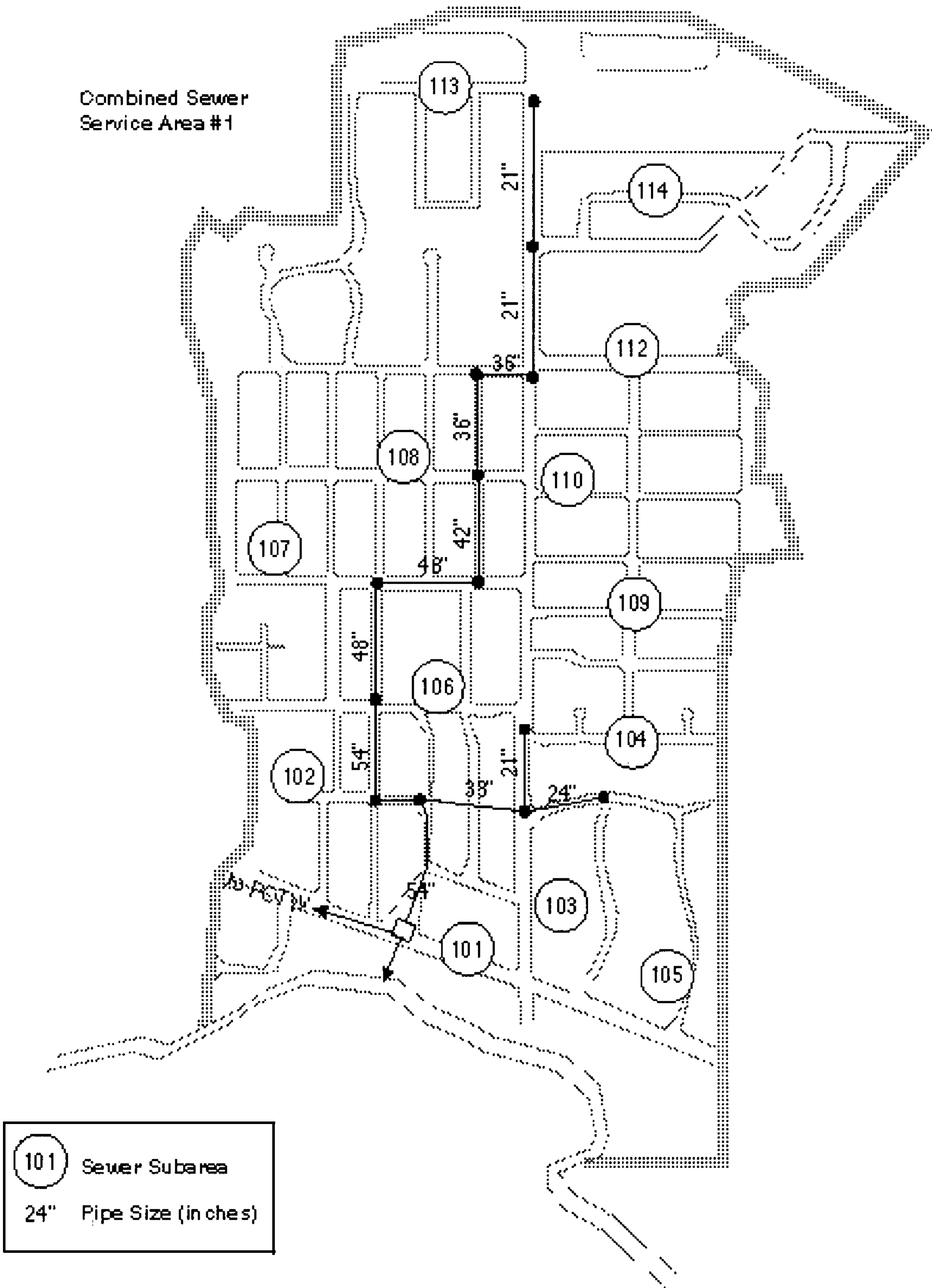
to as discretization, begins with the identification of drainage boundaries, the location of major sewer inlets using sewer maps, and the selection of channels and pipes to be represented in the model. The drainage area is then further divided into subareas, each of which contributes to the nodes of 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 modeler should use the flow routing features of the model 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 unless the upstream conduits and their subcatchments are 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. The system is not directly modeled upstream of these points. Instead, runoff from the upstream area is estimated and routed into the 21-inch pipes. Exhibit 7-8 shows the modeled sewer lines and the subareas tributary to those lines for Service Area 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.

Exhibit 7-9 shows the main RUNOFF block data inputs (by subcatchment area number) for the example. The subcatchment area is measured directly from maps. Subcatchment width is generally measured from the map, but 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. Exhibit 7-10 presents the main TRANSPORT block inputs by element number. It lists the number and type of each element (including upstream elements), the element length (for pipe elements), and inflow (for manholes).

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

Subarea No.	Inlet No. (manhole)	Width (ft)	Area (ac)	Imperv %	Slope (ft/ft)	Manning's Coeff.		Depression Storage		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

Exhibit 7-10. SWMM Transport Block Input Parameters (SWMM H1 Card)

Sewer Element Data				Element Type	Inflow (cfs) [for manhole] or Length (ft) [for pipe element]	Pipe Dimension (ft)	Pipe Slope (ft/10 ft)	Manning Pipe Roughness (n)
Element No.	Upstream Element No. 1	Upstream Element No. 2	Upstream Element No. 3					
125	175	**0**	**0**	manhole	0.087	NA	NA[1]	NA[1]
175	126	**0**	**0**	sewer pipe	1000	.45	0.5	0.014
126	176	177	**0**	manhole	0.188			
177	150	0	**0**	sewer pipe	840	2.75	0.28	0.014
150	178	179	**0**	manhole	0			
178	127	0	**0**	sewer pipe	390	1.75	0.39	0.014
127	0	0	**0**	manhole	0.097			
179	128	0	**0**	sewer pipe	651	2.0	0.34	0.014
128	0	0	**0**	manhole	0.163			
176	129	0	**0**	sewer pipe	733	4.5	0.07	0.014
129	180	0	**0**	manhole	0.076			
180	130	0	**0**	sewer pipe	841	4.0	0.16	0.014
130	181	0	**0**	manhole	0.176			
181	131	0	**0**	sewer pipe	620	4.0	0.09	0.014
131	182	0	**0**	manhole	0.136			
182	132	0	**0**	sewer pipe	727	3.5	0.12	0.014
132	183	0	**0**	manhole	0.103			
183	133	0	**0**	sewer pipe	771	3	0.16	0.014
133	184	0	**0**	manhole	0.221			
184	134	0	**0**	sewer pipe	1110	2.75	0.13	0.014
134	185	0	**0**	manhole	0.258			
185	135	0	**0**	sewer pipe	1007	1.75	0.4	0.014
135	0	0	**0**	manhole	0.131			

[1] Parameter is not applicable 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.

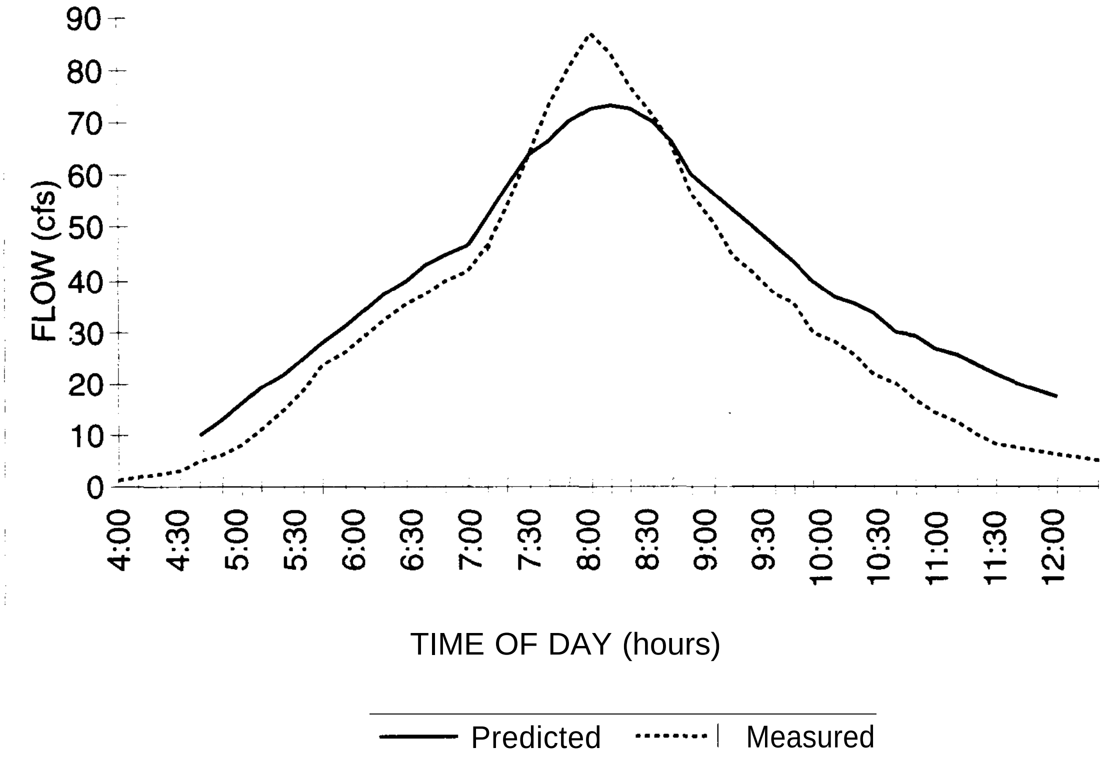
7.5.3 SWMM Hydraulic Modeling

Exhibit 7-11 shows the output hydrograph for element (manhole) 125 from the TRANSPORT block, with the measured flow for the event plotted for comparison. The peak flow, shape of the hydrograph, and the total volume of overflow for thiscalibration 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 single events (actual or design) and/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.

To predict the number of overflows per year, the calibrated model can be run in a continuous mode and/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 (e.g., 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, the model was run in continuous mode, using data from the

Exhibit 7-11. Flow Hydrograph



38-year rainfall record. The model predicted that between 12 and 32 overflow events would occur 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 Pollutant 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 generated 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 event 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.

Exhibit 7-13 presents predicted and observed values for BOD and total solids concentrations. 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.

The modeling in this example could 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.

Exhibit 7-12. Pollutographs

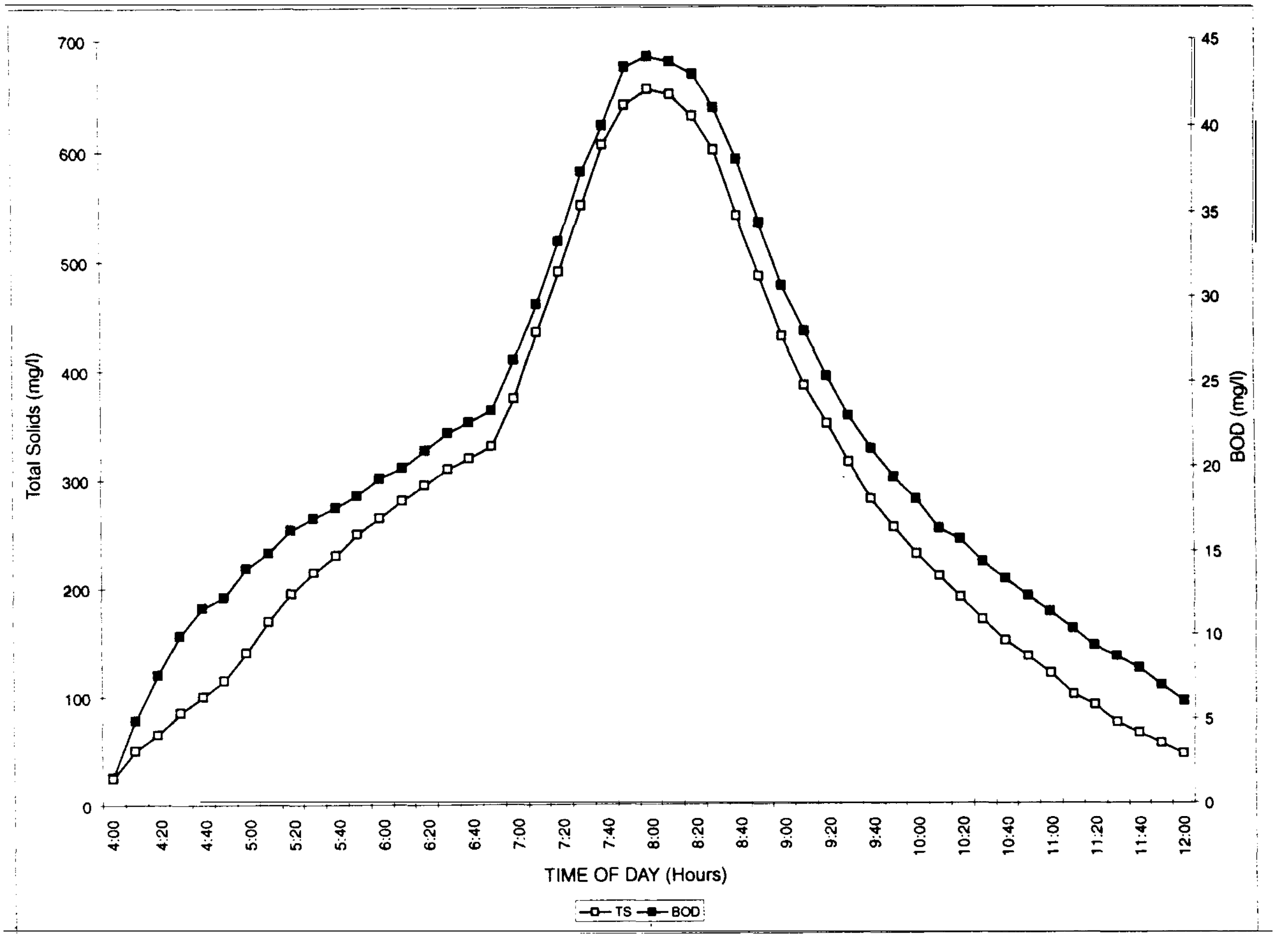


Exhibit 7-13. Predicted and Observed Pollutant Concentrations

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

7.6 CASE STUDY

Example 7-1 is a case study illustrating the CSS and CSO modeling strategy that was developed and implemented by the City of Indianapolis, Indiana. The City, after carefully evaluating available options and regulatory requirements, developed this modeling strategy to characterize system hydraulics and estimate average annual CSO characteristics (i.e., volume, frequency, percent capture, and pollutant loads). The City used the CSS and CSO models to determine CSO impacts on the receiving streams (the White River and its tributaries within the City's combined sewer area), and is now using the models to evaluate various CSO controls and develop an LTCP.

Recognizing that the interceptor sewers and regulators, not the combined sewers, control wet-weather system conveyance capacity to the wastewater treatment plants (and therefore control the occurrences of CSOs), the City used SWMM/EXTRAN to develop a detailed model of interceptor sewers and regulators that included approximately 82 miles of sewer, 173 regulators, and 134 outfalls. The City used SWMM/RUNOFF to generate runoff flows from drainage subcatchments and to calibrate wet-weather flow to the EXTRAN model. The City then used the linked RUNOFF/EXTRAN models to establish critical input data for the STORM model of the CSS, specifically the regulator/interceptor capacities (STORM "treatment rates") and the impervious area estimates (STORM "C" coefficients). The City performed long-term (44-year) continuous simulations using STORM to compute average annual CSO characteristics. The selected modeling strategy enabled the City of Indianapolis to accurately determine interceptor sewer conveyance and system storage capacities, identify system optimization projects, characterize overflows and pollutant loads to receiving streams, and evaluate various CSO control strategies.

Example 7-1. Modeling Case Study — Indianapolis, Indiana

The City of Indianapolis has a population of 741,952 (1990 census) and is the largest city in Indiana. As reported in the City's CSO Operational Plan (December, 1995), the service area includes a combined sewer area of approximately 41 square miles with approximately 82 miles of interceptor sewer, 173 regulators, and 134 outfalls. Pipe sizes in the interceptor sewer system range from 12 inches to 120 inches.

Model Development Strategy

The City used a two-phased modeling strategy to characterize its CSS. Phase 1 focused on the system of interceptor sewers and regulators that deliver flow to the City's advanced WWTPs for treatment, since this part of the system controls the occurrence of CSOs. Phase 1 modeling analysis using SWMM/EXTRAN supported the characterization of the system (required under the CSO Operational Plan), determined the hydraulic capacity of the interceptor sewer system to capture combined sewer flows for treatment, and identified low-cost capital improvement projects to maximize flows to the WWTPs.

For initial analysis and hydraulic characterization of CSOs, the City generated inflow hydrographs to the interceptor model using a ramped hydrography function, which is a synthetic approximation of the rising limb of the actual inflow hydrographs associated with most rain events. The site-specific inflow rates are defined as a function of the ramp slope and the impervious area within the watershed tributary to each model inflow node. Ramped inflow hydrographs are more effective than observed or design event hydrographs for analyzing and evaluating interceptor sewer system capacities and identifying constraints in the system. However, ramp hydrographs cannot be used to calibrate the EXTRAN and STORM models since the response to precipitation must be simulated for calibration. For these reasons, the City used ramped inflow hydrographs in Phase 1 to estimate interceptor system capacities and the SWMM/RUNOFF model for model calibration, and for more detailed analysis, in Phase 2. This let the City efficiently perform initial analysis and hydraulic characterization of CSOs and identify low-cost capital improvement projects to maximize the capture of combined sewer flows in Phase 1, even before model calibration was complete.

In Phase 2, modeling focused on characterization of sewersheds using a more detailed hydrologic (rainfall/runoff) model (RUNOFF) and linking this model directly to the EXTRAN interceptor model developed in Phase 1. The City used the linked models with flow monitoring data from a network of eight flow monitors in the interceptor system and rainfall data for calibration and verification of the interceptor model. Phase 2 modeling also focused on developing and calibrating the CSO model (STORM), using flow monitoring and sampling data at four representative outfalls and simulations to characterize the volume, frequency, and pollutant loads of CSOs. Using regulator/interceptor capacities ("T") from the EXTRAN model, and impervious area estimates ("C") from RUNOFF, the City performed continuous simulations using STORM and the available historical (44-year) hourly precipitation data to generate average annual CSO statistics. STORM can efficiently perform long-term simulations because it uses constant values for "T" and "C", which in the prototype system may vary during long-term simulation. For example, "C" values may vary due to changes in soil moisture conditions in the subcatchments. Therefore a range of values for the CSO characteristics were obtained to reflect these variations in system behavior.

CSS and CSO Characterization Results

As a result of Phase 1 modeling, the City developed its CSO Operational Plan to implement the NMC. The plan used the system conveyance capacity and in-system storage analyses to define a program of hydraulic modifications to the system at 28 individual locations. These modifications enhanced the capture of combined flows during wet weather and reduced overflows to the area's smaller and most sensitive CSO receiving streams. During Phase 2, the City determined average annual CSO characteristics for each CSO outfall, for each major drainage system, and on a system-wide basis using the STORM model of the CSS.

STORM simulations determined that an average annual CSO volume of 4,000 to 5,500 million gallons is discharged from the CSS; CSOs occur at an average frequency of 24 per year; and the interceptor system captures 59 to 66 percent of average annual wet weather combined sewage flow. STORM simulations were also used to estimate that the CSS discharges 1.8 to 2.5 million pounds of BOD and 6.3 to 8.5 million pounds of TSS to the receiving streams on an average annual basis. Based on Phase 2 modeling, the City identified five initial CSO facility projects to demonstrate the effectiveness of various CSO control alternatives. These facilities are now under construction and STORM simulations have been used to estimate that untreated CSO volumes will be reduced by over 80 percent at these five locations.

CHAPTER 8

RECEIVING WATER MODELING

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

8.1 THE CSO CONTROL POLICY AND RECEIVING WATER MODELING

Under the CSO Control Policy a permittee should develop a long-term control plan (LTCP) that provides for attainment of water quality standards (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 that would result from different CSO control measures. The presumption approach does not explicitly call for analysis of 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 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 (Section II.C.1). Under the demonstration approach, "[w]here 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." (Section II.C.4.b)

Established under Section 303(d) of the CWA, the total maximum daily load (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 to model-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 WQS by several hundredfold, as well as moderate dissolved oxygen (DO) depressions, solving the bacterial problem will likely solve the DO problem and so it may be sufficient to monitor bacteria only. Reducing the scope of modeling in this fashion may substantially reduce costs.

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, DO, 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 DO).
- The number and geographical distribution of CSO outfalls and the need to simulate sources other than CSOs.

This section discusses some important considerations for hydrodynamic and water quality modeling of receiving waters, and how these considerations affect the selection and use of a model.

The purpose of receiving water modeling is primarily to predict receiving water quality under different CSO pollutant loadings and flow conditions in the receiving water. 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; elsewhere a hydrodynamic model may be necessary.

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 conditions that vary over time. 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 receiving water quality must be predicted. The following factors should be considered for different water body types:

- ***Rivers-*** Rivers generally flow in one direction (except for localized eddies or other flow features) and the stream velocity and depth are a function of the flow rate. The flow rate in relatively large rivers 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, the flow observed during model calibration surveys, 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, assuming a constant river flow may suffice for bioaccumulative toxicants (e.g., pesticides) because long-term exposure is ofimportance. For DO, however, the time variations in river flow rate may be need to be considered.

- ***Estuaries-*** CSO impacts in estuaries are affected by tidal variations of velocity and depth (including 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 and thermal stratification. Wind-driven currents can be monitored directly or simulated using a hydrodynamic model (which may need to cover the entire lake to simulate wind-driven currents properly). Thermal stratification can generally be measured directly.

Because the same basic hydrodynamic equations apply,[1] some of the major models for receiving waters can be used to 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 its 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, models that assume steady-state conditions 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 moderating effects of longitudinal dispersion. However, QUAL2EU cannot give an accurate estimate of the duration of excursions above WQS.

8.2.2 Receiving 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

[1] The basic hydrodynamic equations are for momentum and continuity. 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).

typically delivered in 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 but characteristic 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, usually over a period of days (e.g., 21 days) depending on the nutrient, 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 to 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 combined sewer system (CSS) models, vary in complexity. EPA has produced 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. Ambrose et al. (1988a) summarizes EPA-supported models, including receiving water models.

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

Types of Simulation

Water quality parameters can be simulated using either single-event, steady-state modeling or continuous, dynamic modeling. Many systems may find it beneficial to use both types of modeling.

Many of the simpler approaches to receiving water evaluation assume 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 is 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.

Due to the random nature of CSOs, the use of dynamic simulation may be preferable to single-event, worst-case, steady-state modeling. Dynamic techniques allow the modeler to derive the fraction of time during which a concentration was exceeded and water quality was impaired. For instance, when using daily simulated results, specific concentrations are first ranked with the corresponding number of occurrences during the simulation period. Frequency distribution plots are then developed and used to determine how often the l-day-acute water quality criteria are likely to be exceeded. The same approach can be used to develop frequency distributions for longer periods such as 4-day or 30-day average concentrations. EPA (1991a) recommends three dynamic modeling techniques: continuous simulation, Monte Carlo simulation, and lognormal probability modeling.

Continuous simulation models solve time-dependent differential equations to simulate flow volume and water quality in receiving waters. These deterministic models incorporate the manner in which flow and toxic pollutant concentrations change over time in a continuous manner rather than relying on simplified terms for rates of change. They use daily effluent flow and concentration data with daily receiving water flow and concentration data to estimate downstream receiving water concentrations. If properly calibrated and verified, a continuous simulation model can predict variable flow and water quality accurately-although at a considerable time and resource expenditure, however.

Monte Carlo simulation is generally used for complex systems that have random components. Input variables are sampled at random from pre-determined probability distributions and used in a toxic fate and transport model. The distribution of output variables from repeated simulations is analyzed statistically to derive a frequency distribution. However, unlike continuous simulation models, the temporal frequency distribution of the output depends on the temporal frequency distribution of the input data. For instance, if the water quality criterion is based on a 4-day average, the input variables must use the probability distributions based on a 4-day average.

Lognormal probability modeling estimates the same output variable probability distributions as continuous and Monte Carlo simulations but with less effort. However, like Monte Carlo simulation, the input must be probability distributions based on input data for the specific temporal frequency distribution desired. The theoretical basis of the technique permits the stochastic nature of the CSO process to be explicitly considered. This method assumes that each of the four variables that affect downstream receiving water quality (rainfall, runoff, event mean concentration of contaminant in the runoff (EMC), and streamflow) can be adequately represented by a lognormal probability distribution. When the EMC is coupled with a lognormal distribution of runoff volume, the distribution of runoff loads can be derived. The storm water load frequency is then coupled with a lognormal distribution of streamflow to derive the probability distribution of in-stream concentrations. The main advantage of lognormal probability modeling is that the probability distributions can be derived using only the median and the coefficient of variation for each input variable.

8.3.1 Model Types

The following sections discuss techniques for simulating 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), vaporization (for toxics), and settling and resuspension (for bacteria and 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:[2]

C_x = max pollutant concentration at distance X from the outfall (M/L^3)
C_e = pollutant concentration in effluent (M/L^3)
C_u = pollutant concentration upstream from discharge (M/L^3)
Q_e = effluent flow (L^3/T)
Q_u = stream flow upstream of discharge (L^3/T)
Q_s = stream flow downstream of discharge, $Q_u + Q_e$ (L^3/T)
X = distance from outfall (L)
u = stream flow velocity (L/T)
K = net decay rate (die-off rate for bacteria, settling velocity divided by stream depth for settling, resuspension velocity divided by stream depth for resuspension, vaporization rate divided by stream depth for vaporization) (1/T)
e = 2.71828...

Since bacteria and toxics can settle out of the water column and attach to sediments, sediments can contain significant amounts of these pollutants. Resuspension of sediments and subsequent desorption of bacteria and toxics into the water column can be an important source of receiving water contaminants. Modeling of sediment resuspension requires estimation of

[2]M=unit of mass, L=unit of length, and T=unit of time.

resuspension velocities and knowledge of sediment transport processes. Thomann and Mueller (1987) discusses how to determine the solids balance in a river and estimate sediment resuspension velocities. Modeling of sediment transport is complex and is often done using computer models such as WASP5 and HSPF.

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):

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

where: D_y = lateral dispersion coefficient (L^2/T)
W = stream width (L)
π = 3.14159...

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 (L)
u^* = shear velocity (L/T).

In turn, the following equation estimates shear velocity:

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

where: g = acceleration due to gravity (L/T^2)
s = slope of channel (L/L)
d = water depth (L).

The model DYNTOX (LimnoTech, 1985) is specially designed for analysis of toxics in rivers and can handle all three dynamic modeling techniques. U.S. EPA (1991a) and the WLA series by Delos et al. (1984) address the transport of toxics and heavy metals in rivers.

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, 1995g) 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:

$$D = D_o e^{-K_a t} + \frac{W}{Q}\left(\frac{K_d}{K_a - K_r}\right)\left[e^{-K_r t} - e^{-K_a t}\right]$$

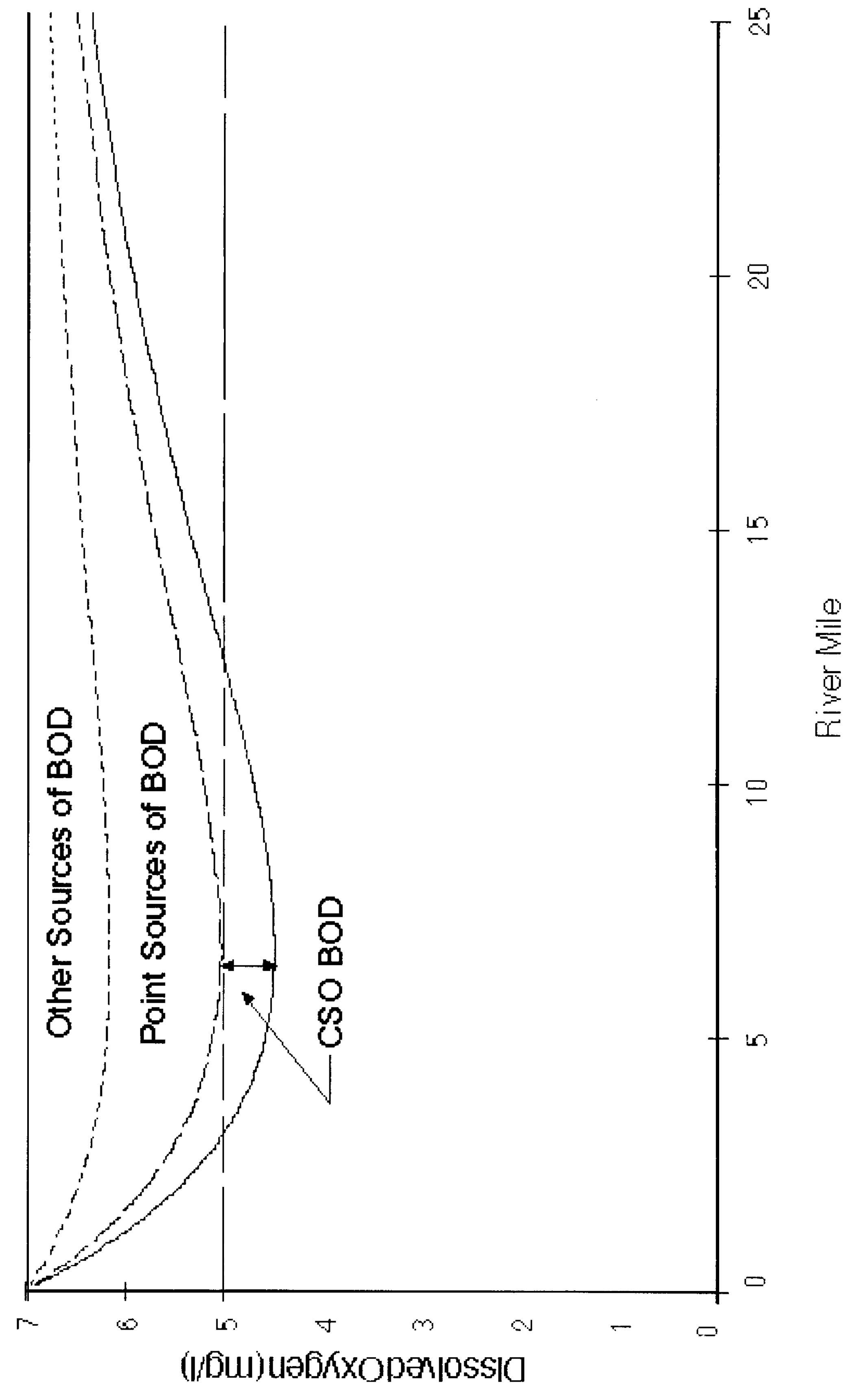
where: D = DO deficit downstream (M/V)
D_0 = initial DO deficit (M/V)
K_a = atmospheric re-aeration rate (1/T)
t = time of passage from source to downstream location (T)
W = total pollutant loading rate (M/T)
Q = total river flow (V/T)
K_d = biochemical oxygen demand (BOD) deoxygenation rate (1/T)
K_r = BOD loss rate (1/T).

This method can address the joint effects of multiple steady sources through the technique of superposition (Exhibit 8-1). Superposition is used when linear differential equations, such as the Streeter-Phelps equation, govern pollutant concentrations along a receiving stream. For such linear systems, the concentration of a pollutant in a river due to multiple steady-state sources is the linear summation of the responses due to the individual sources. Superposition techniques are also used to estimate pollutant concentrations due to multiple steady-state sources of toxic pollutants. 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.

More sophisticated modeling techniques are also necessary to assess the effects of sediment oxygen demand (SOD) and plant respiration (which remove oxygen from the receiving water), and photosynthesis by aquatic plants (which adds oxygen to the water). The Streeter-Phelps equation makes the simplifying assumption that there are only point sources of CBOD, so SOD, photosynthesis, and respiration are assumed to be zero. If photosynthesis, respiration, and SOD are significant, more complex analysis is needed to evaluate these factors. These distributed sources and sinks of DO and BOD are addressed by Thomann and Mueller (1987) and by several computer models, including QUAL2EU and WASPS.

Nutrients/Eutrophication. Nutrient discharges affect river eutrophication over time scales of several days to several weeks. Nutrient/eutrophication analysis considers the relationship between

Exhibit 8-1. Dissolved Oxygen Superposition Analysis



nutrients and algal growth. Analysis of nutrient impacts in rivers is complex because nutrients and planktonic algae,[3] 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 loadings and 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 the following equation (Freedman and Marr, 1990):

$$C = \frac{M}{V} e^{\left(-K - \frac{Q}{V}\right)t}$$

where: C = concentration (M/L^3)
M = mass loading (M)
Q = flow (L^3/T)
K = net decay rate (bacteria die-off, settling and resuspension, volatilization, photolysis, and other chemical reactions) (1/T)
V = lake volume (L^3)
t = time (T).

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 on chemical models for lakes and impoundments (Hydroqual, Inc., 1986). This guidance, which also applies to bacteria, describes simple and complex models and presents criteria for selecting models and model parameters.

[3] 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.

Oxygen Demand/Dissolved Oxygen. Simple analytical approximations can model oxygen demand and DO in cases where DO mixing occurs quickly relative to depletion by 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_0, 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. A modeler able to define all of the above parameters may choose to apply a more spatially resolved model.

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 experienced 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.[4]

Nutrient/Eutrophication Impacts. For lakes, simple analytic equations often can analyze end-of-pipe impacts and whole-lake impacts, but evaluating mixing phenomena 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 inflow and outflow rates. Where urban areas draining to the lake constitute a significant fraction of the total drainage area, flow

[4] Such techniques should not be used by inexperienced modelers as they can lead to inaccuracies if they are not used with caution.

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 area1 loading, W^1, from:

$$W' = a\bar{z}\left(\frac{Q}{V} + v_s\right)$$

where:
- W' is the allowable area1 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 area1 loading determined in Step 3 to the value of W^1 obtained in Step 5.

Additional approaches are discussed in Reckhow and Chapra (1983b).

ESTUARIES

Unlike most rivers, estuaries are tidal (i.e., water moves upstream during portions of the tidal cycle and downstream during other parts of the cycle). 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., 1990; Martin et al., 1990; 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.

8.3.2 Computer Models Supported by EPA or Other Government Agencies

This section describes some computer models relevant to receiving water modeling. Most of these models are supported by EPA's Center for Exposure Assessment Modeling (CEAM). CEAM maintains a distribution center for water quality models and related data bases.[5] CEAM-supported models relevant to modeling impacts on receiving water include QUAL2EU, WASPS, HSPF, EXAMSII, CORMIX, MINTEQ, and SMPTOX3. The applicability and key characteristics of the CEAM-supported models are summarized in Exhibit 8-2.

[5] See Section 7.3 for information on obtaining models from CEAM.

Exhibit 8-2. EPA CEAM-Supported Receiving Water Models

Applicability to Hydraulic Regimes and Pollutant Type

	Rivers & Streams			Lakes & Impoundments			Estuaries			Near Field Mixing
Model	**Nutrients**	**Oxygen**	**Other**	**Nutrients**	**Oxygen**	**Other**	**Nutrients**	**Oxygen**	**Other**	
QUAL2EU	✓	✓	✓							
WASP5	✓	✓	✓	✓	✓	✓	✓	✓	✓	
HSPF	✓	✓	✓	✓	✓	✓				
EXAMSII			✓			✓			✓	
CORMIX	Near-field mixing model for all water body types									✓
MINTEQ	Equilibrium metal speciation model									
SMPTOX3			✓							

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) [1]	Quasi-3-D (zonal)	2.10	Doneker & Jirka, 1990
MINTEQ	Steady	None	3.11	Brown & Allison, 1987
SMPTOX3	Steady	1-D	2.01	LimnoTech, 1992

[1] CORMIX was originally developed assuming steady ambient conditions; Version 3 allows for application to some unsteady environments (e.g., tidal reversal conditions) where transient recirculation and pollutant build-up can occur (CEAM, 1998).

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.[6] Because it assumes steady flow and pollutant loading, its applicability to CSOs is limited. QUAL2EU can, however, 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, QUAL2EU 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 for 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.

WASP5 is essentially a pollutant fate and transport model. Transport can be driven by another hydrodynamic model such as DYNHYD5. DYNHYD5 is a one-dimensional/quasi-two-dimensional model that simulates transient hydrodynamics (including tidal estuaries).

[6] A conservative substance is one that does not undergo any chemical or biological transformation or degradation in a given ecosystem. (U.S. EPA, 1995g)

HSPF is a one-dimensional, comprehensive hydrologic and water quality simulation package which can simulate both receiving waters and runoff to CSSs for conventional and toxic organic pollutants. HSPF simulates the transport and fate of pollutants in rivers and reservoirs. It simulates three sediment types: sand, silt, and clay.

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[7] 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 calculate. The CORMIX model cannot be calibrated in the classic sense since rates are fixed based on the built-in logic of the expert system.

MINTEQ determines geochemical equilibrium for priority pollutant metals. Not a transport model, MINTEQ provides a means for modeling metal partitioning in discharges. It provides only steady-state predictions. The model usually must be run in connection with another fate and transport model, such as those described above. A number of assumptions (e.g., equilibrium conditions at the point of mixing between a CSO and the receiving water) must be made to link MINTEQ predictions to another fate and transport model, so it should be used cautiously in evaluating wet weather impacts.

SMPTOX3 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. SMPTOX3 is an interactive computer program that uses an EPA technique for calculating concentrations of

[7] In some applications CORMIX has proven inaccurate for single port discharges.

toxic substances in the water column and stream bed as a result of point source discharges to streams and rivers. The model predicts pollutant concentrations in dissolved and particulate phases for the water column and bed sediments, as well as total suspended solids. SMPTOX3 can be run at three different levels of complexity: as described above (highest complexity), to calculate toxic water column concentrations but no interactions with bed sediments (medium complexity), or as a total pollutant toxics model (low complexity) (LimnoTech, 1992).

The following additional models are supported by EPA or other government agencies:[8]

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 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. DYNTOX Version 2.1 and the draft manual are available from the Office of Science and Technology in EPA's Office of Water (202-260-7012).

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. 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, coliform bacteria, inorganic suspended solids, algal/nutrient/DO dynamics (11 parameters), alkalinity, pH and carbonate species (4 parameters).

[8] McKeon and Segna (1987), Ambrose et al. (1988a) and Hinson and Basta (1982) have reviewed some of these models.

8.4 USING A RECEIVING WATER MODEL

As was the case for CSS models (see Section 7.4), receiving water modeling involves developing the model, calibrating and validating the model, performing the simulation, and interpreting the results.

8.4.1 Developing the Model

The input data needs for a specific receiving water model depend upon the hydraulic regime and model used. The permittee should refer to the model's documentation, 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.

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. Achieving a high degree of accuracy in calibration can be difficult because:

- Pollutant loading inputs typically are estimates rather than precisely known values.
- Three-dimensional receiving water models are still not commonly used for CSO projects, so 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, which require more input data and take significantly longer to run (although 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.

CSO loadings commonly are simulated separately from other loadings in order to assess the relative impacts of CSOs. This is appropriate because the equations that best approximate receiving water quality are usually linear and so effects are additive (one exception, however, is the non-linear algal growth response to nutrient loadings).

8.4.4 Using Modeling Results

By calculating 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 three 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 models 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 such as temperature, point sources, and flow. In either case, modelers can analyze the output for the frequency of water quality criteria 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 WQS. In the receiving waters, critical or design water quality conditions might be periods of low flows and high temperature that are established based on a review of available data. Flow, temperature, and other variables for these periods then form the basis for analysis of future conditions.

It is useful to assess the sensitivity of model results to variations in parameters, rate constants, and coefficients. A sensitivity analysis can determine which parameters, rate constants, and coefficients 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 water quality standards (WQS). As discussed in previous chapters, permittees can consider a variety of methods to analyze the performance of the combined sewer system (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 long-term control plans (LTCPs) that provide 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 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 the 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. This makes modeling the in-stream impact of CSOs more complicated than modeling the impacts of steady-state point source discharges such as POTWs. 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. Notwithstanding these limitations, however, properly-applied modeling techniques can be useful in analyzing the impact of CSOs on receiving waters.

CSO pollutant loads can be incorporated into receiving water models using either a steady-state or a dynamic approach, as discussed in Chapter 8. A steady-state model can provide an approximate solution using, for example, average loads for a design storm. A dynamic approach incorporates time-varying loads and simulates the time-varying response of the water body. The steady-state approximation uses some average conditions that do not account for the time-varying nature of flows and loads. Thus a steady-state model may provide less exact results, but typically requires less cost and effort. A dynamic model requires more resources but may result in a more cost-effective CSO control plan, since it does not use some of these simplifying assumptions.

Generally, the modeler should use the simplest approach that is appropriate for local conditions. 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

The demonstration approach requires the permittee to show that its selected CSO controls will provide for attainment of WQS. 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, a total maximum daily load, including a wasteload allocation and a load allocation, or other means should be used to apportion pollutant loads...* (Section II.C.4.b)

The first step in analyzing CSO impacts on receiving water is to identify the pollutants or stressors of concern and the corresponding WQS. 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 also may be of concern.

State WQS include designated uses and both numerical and narrative water quality 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 water quality criterion of concern is expressed as a daily average concentration, 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 a requirement to prevent solids and floatables build-up. In such cases, the permittee could consider developing a site-specific, interim numeric performance standard that would result in attainment of the narrative criterion.

As noted in Chapter 2, a key principle of the CSO Control Policy is the review and revision, as appropriate, of WQS and their implementation procedures. In identifying applicable WQS, the permittee and the permitting and WQS authorities should consider whether revisions to WQS are appropriate for wet weather conditions in the receiving water.

EPA's water quality criteria assist States in developing numerical standards and interpreting narrative standards (U.S. EPA, 1991a). EPA recommends that water quality criteria for 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 critical low flow, however, is not necessarily the best choice for wet-weather flows, which may not occur simultaneously with drought conditions. Consequently, a design flow-based control strategy may be overly conservative, and suitable mainly for situations where monitoring data are very limited or areas are highly sensitive.

Some water quality criteria are expressed in formats that vary from the magnitude-duration-frequency format. In some cases, such as State WQS for indicator bacteria, water quality criteria are expressed as an instantaneous maximum and a long-term average component. The long-term average component of water quality criteria for fecal coliforms typically specifies a 30-day geometric mean or median, and a certain small percentage of tests performed within a 30-day period that may exceed a particular upper value. For dissolved oxygen (DO) and pH, State criteria may be expressed as fixed minimum concentrations, rather than as magnitude-duration-frequency.

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.

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 CSO flow). 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 WQS excursions.

- ***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. 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 WQS attainment is in *Guidelines for the Preparation of the 1996 State Water Quality Assessments (305(b) Reports)* (U.S. EPA, 1995f).

9.3 EXAMPLES OF RECEIVING WATER ANALYSIS

This section presents three examples to illustrate key points for analyzing CSO impacts on receiving waters. 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.

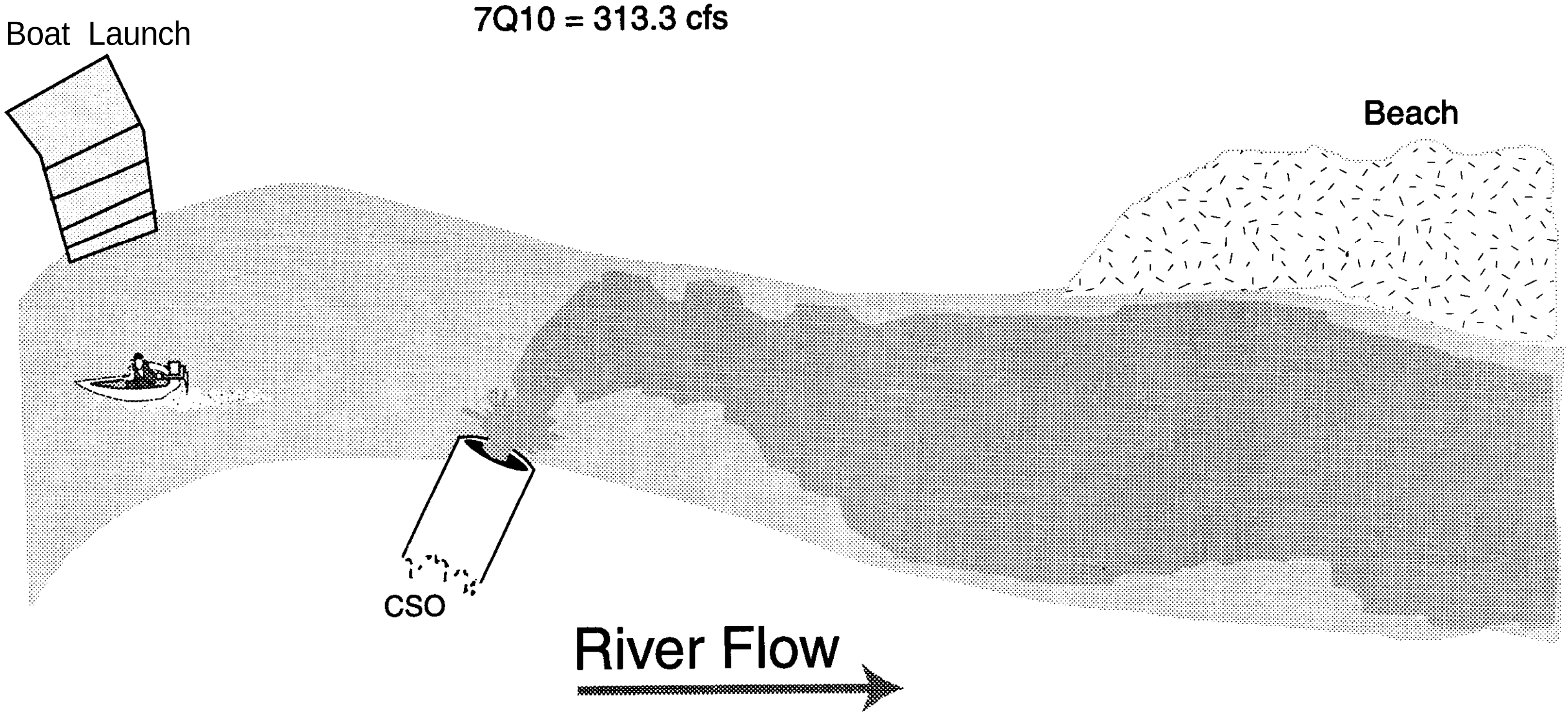
The first example shows how design flow analysis or more sophisticated methods can be used to analyze bacteria loads to a river from a single CSO event. The second example, which is more complex, involves bacterial loads to an estuary. The third example illustrates how biochemical oxygen demand (BOD) loads from a CSS contribute to DO 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 coliforn-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.

Exhibit 9-1. Map For Example 1



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) The State allows mixing zones, so the water quality criterion must be met at the edge of the mixing zone. If the criterion is met there, it will also be met at points farther away.

(2) Die-off will reduce the numbers of bacteria as distance from the discharge 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 can be predicted precisely and that the long-term average characteristics of the CSS will remain constant. In the absence of additional CSO controls, 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.[1]

(2) The largest discharge is approximately 1.1 million cubic feet, but most of the CSOs are less than 200,000 cubic feet.

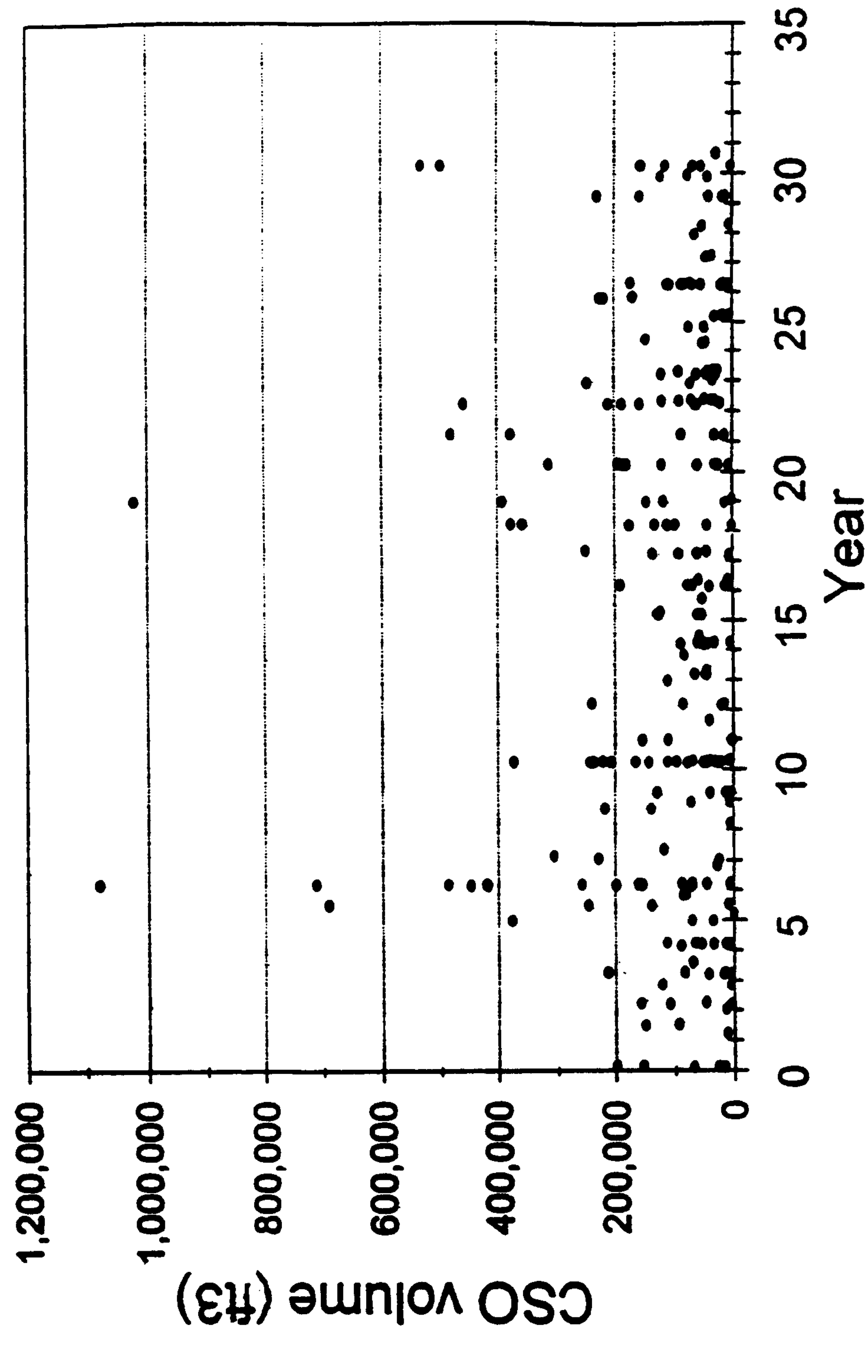
(3) The maximum number of overflow events in any one month is 18.

(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.

[1] An overflow event is the discharge from one or more CSO outfalls as the result of a single wet weather event. In this example, the number and volume of CSOs pertains to the discharges from the single outfall.

Exhibit 9-2. CSO Events for Example 1



Water Quality Standards

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.[2]

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.[3] In the worst-case month, which had 18 overflow events, the geometric mean is still only 400 MPN/100 ml based on 30 daily samples. It is therefore extremely unlikely that the geometric mean concentration WQS 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*, but probably only 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. It is possible that an actual overflow event might not result in an excursion above the 1000 MPN/100 ml criterion *if* the flow in the receiving water were sufficiently large. The permittee, however, must demonstrate that the likelihood of a 30-day period when CSOs result in non-attainment of the WQS more than 10 percent of the time is *extremely low*. This means that the analysis must consider both the likelihood of occurrence of overflow events and the dilution

[2] 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.

[3] 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.

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. It 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 WQS 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 lo-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. The background (upstream) fecal coliform concentration is 100 MPN/100ml, so C_U is set to 100. 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, the mass balance equation may be rearranged to express the CSO concentration that just meets the standard, in terms of the CSO flow volume:

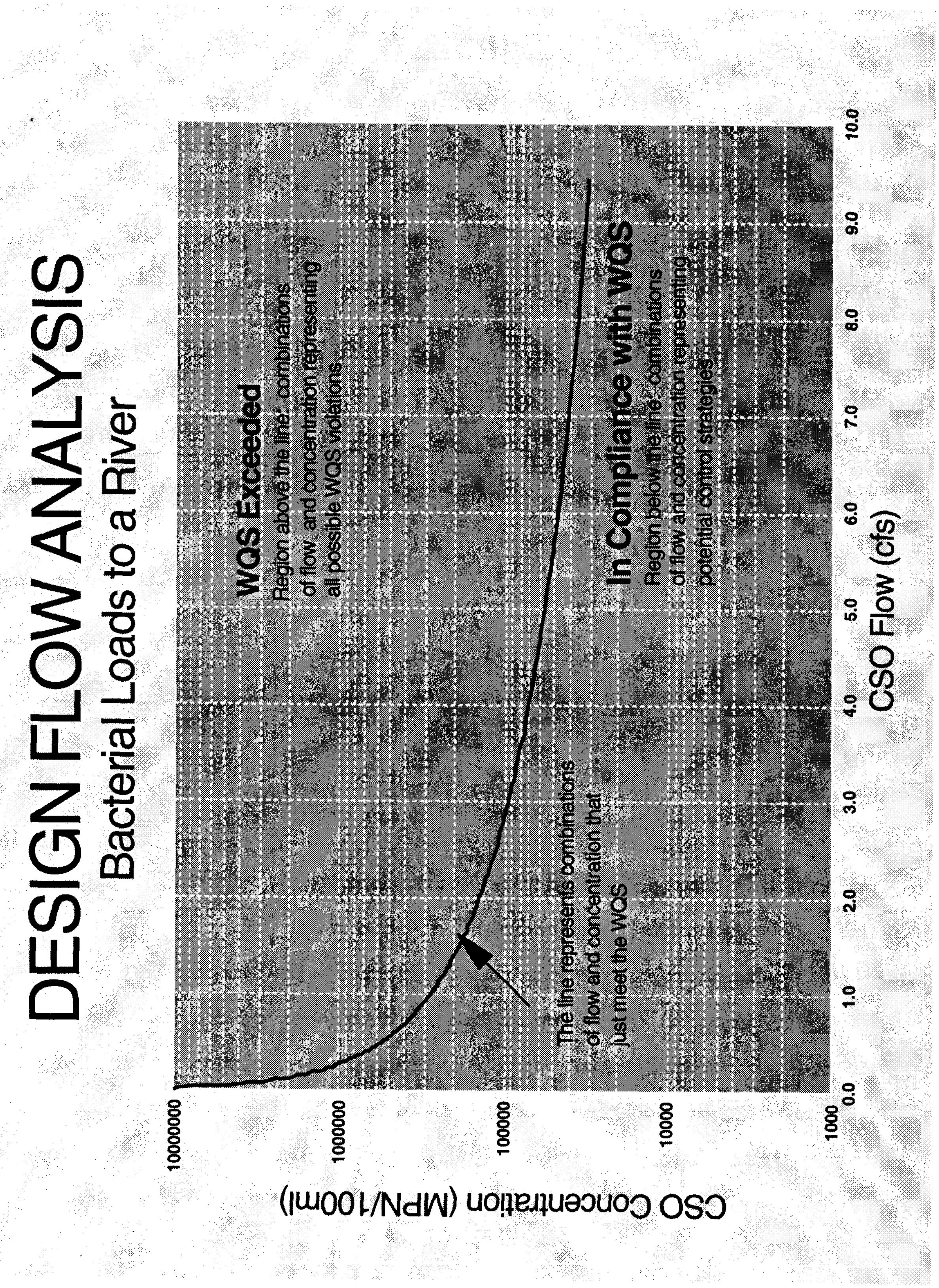
$$C_{CSO} = \frac{C_{RW}(Q_{CSO} + Q_U) - C_U Q_U}{Q_{CSO}} = \frac{1000(Q_{CSO} + 313.3) - 100 \times 313.3}{Q_{CSO}}$$

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. 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 shows 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 1 cfs, the WQS would be met at the design low flow of 313.3 cfs in the receiving water when the concentration in the CSO remained below 0.28×10^6 MPN/100 ml. At a CSO flow of 6 cfs, however, the concentration must be below 0.048×10^6 MPN/100 ml for WQS to be attained.

Since the typical concentration of fecal coliforms in CSOs is approximately 2×10^6 MPN/100 ml, demonstrating attainment of the water quality criterion via a design low flow analysis would be difficult.

Exhibit 9-3. Design Flow Analysis



A design low flow analysis is often 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, this 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. Dilution effects can be considerable in areas of multiple sources of storm water discharge. Design flow analysis is usually not sufficient in circumstances involving multiple storm water discharges, highly sensitive habitats, and river areas particularly prone to sediment deposition.

Design Flow Frequency Analysis

A design flow frequency analysis differs from design flow analysis in that it also considers the probability of exceeding WQS at a given flow. Although still simple, the design flow frequency 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.

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

Over the 31 years, 238 CSO events occur, giving an average of 0.64 events per month. However, 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.

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.

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. The resulting table of predicted receiving water concentrations can be analyzed to determine the percentage reduction in CSO volume needed to meet the WQS.

The design flow frequency analysis can give results that are overly 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 data on CSOs in April, since this is the month with the highest average number of CSOs and is the only month in which overflows occur more than 10 percent of the time, on average.[4]

Exhibit 9-4 summarizes the April receiving water flows in a flow-duration curve, which indicates the percent of time a given flow is exceeded. The distribution of flows is asymmetrical, with a few large outliers. An analysis of flow data indicates that daily flows typically are lognormally distributed. April's flows are lognormal with mean natural log of 7.09, which is ln (1,200 cfs)[5], and standard deviation of 0.46.

The 31 years of CSS data include 96 overflow events in April. 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.

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

[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. Monte Carlo analysis can often be performed using a spreadsheet. The resulting distribution can then be used for analyzing control strategies. Also see discussion in Section 8.3.

[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 = $e^{7.09}$ = 1,200 cfs.

Exhibit 9-4. Flow Duration Curve

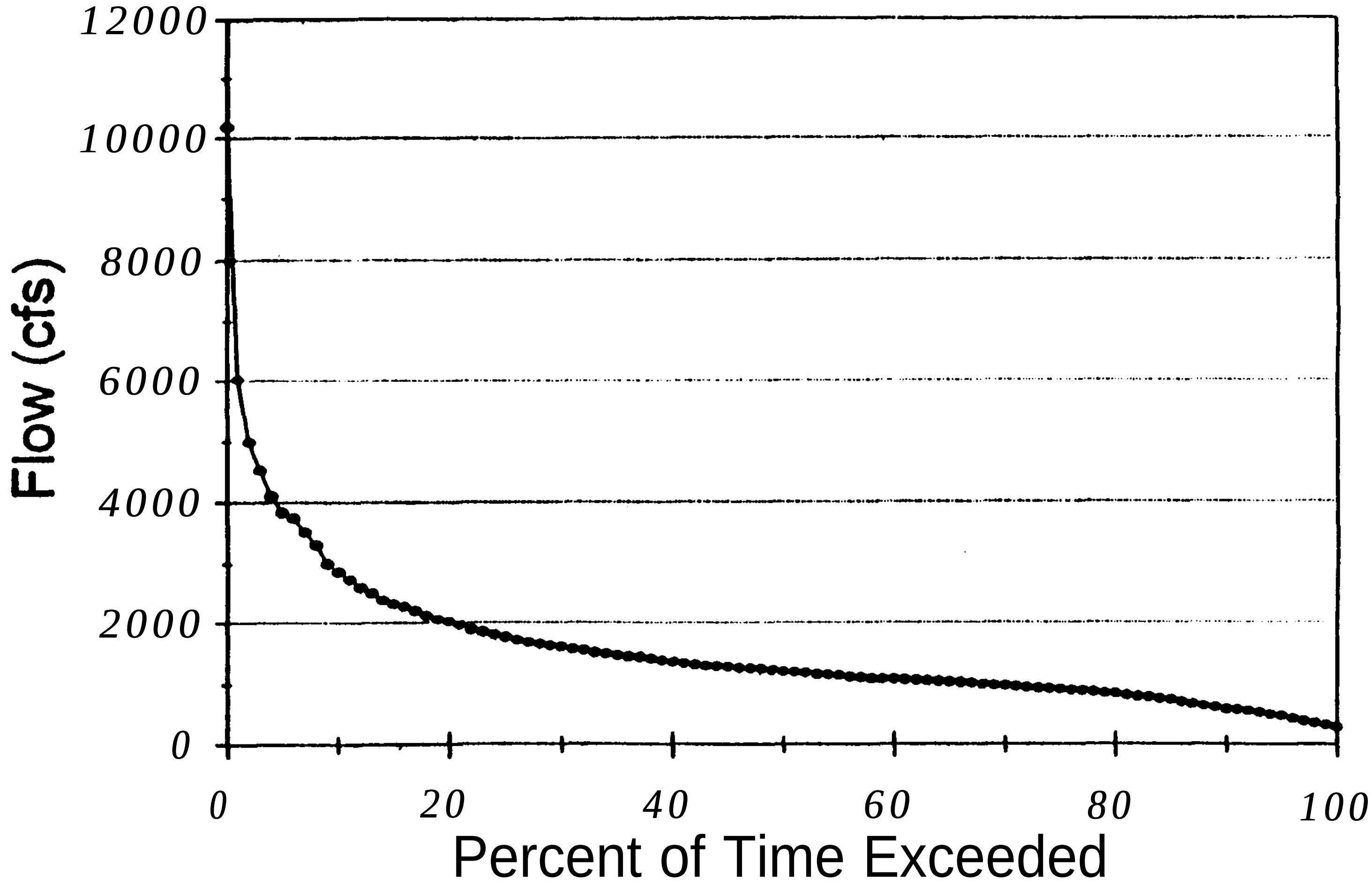
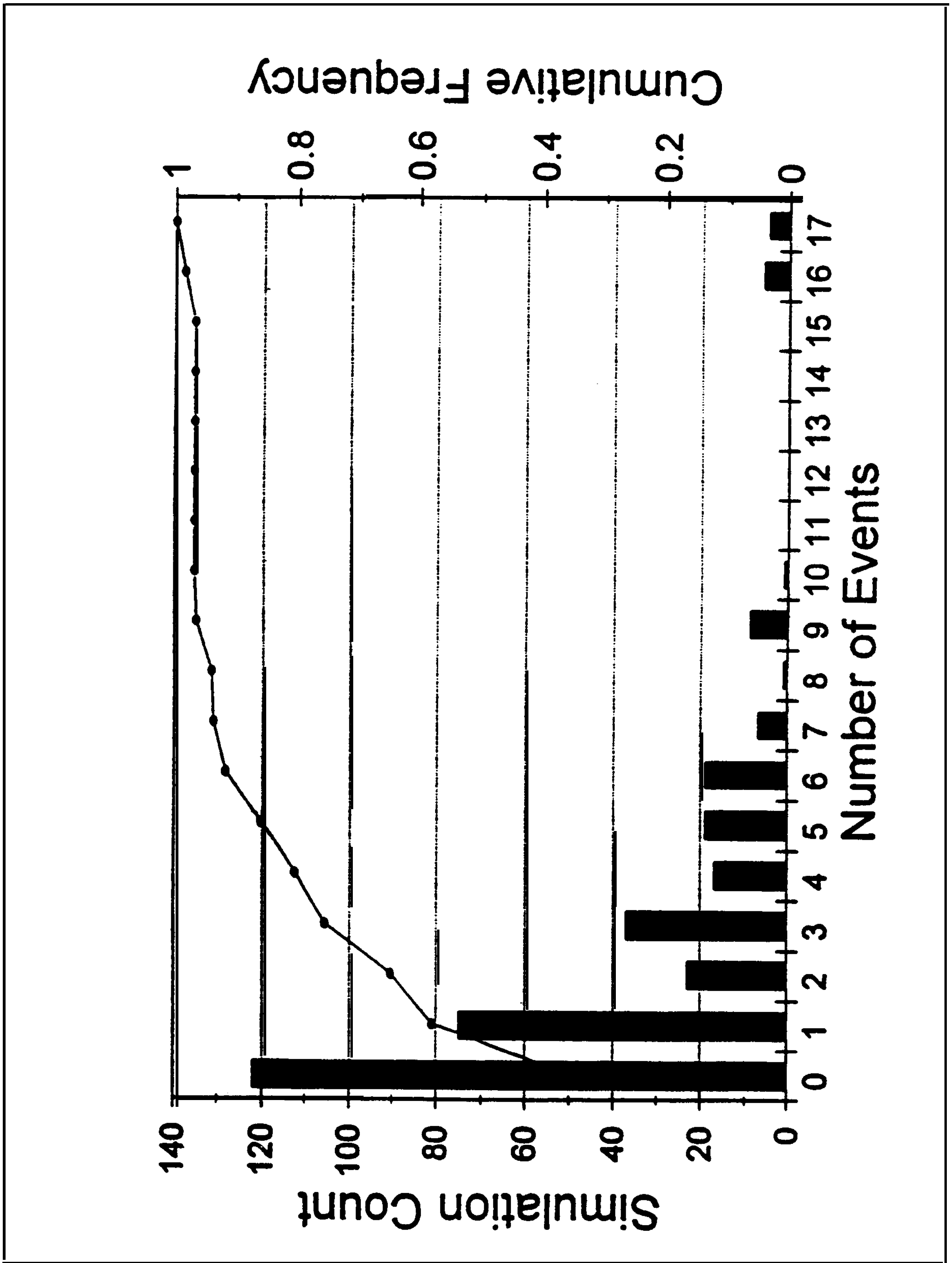


Exhibit 9-5. Expected Exceedances of Water Quality Criterion



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.

Once set up, the Monte Carlo simulation readily evaluates potential control strategies. For instance, to evaluate a control strategy with the goal of a 20-percent reduction in CSO flow and a 30-percent reduction in coliform levels, the Monte Carlo simulation is rerun for these reduced CSO flows and coliform levels. The results show that of the 342 simulated Aprils, 82 percent were 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.[6] A more exact analysis needs accurate information about the relationship between CSO flows and loads and receiving water dilution capacity.

Continuous 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

[6] An analysis of flow distribution must be made so that the appropriate Monte Carlo distribution and range are calculated.

analysis of the data, introduces 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 days (i.e., greater than 10 percent of the days in a month) 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 10.3 years (3 occurrences over 31 years). Although the CSS produces relatively frequent overflows, the rate of actual WQS exceedances is quite low. Exhibit 9-7, which plots CSO volumes versus receiving water flow volume, illustrates why WQS exceedances 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 model is based on precipitation series or rainfall-runoff relations that are likely to change with time. Therefore, an analysis of the uncertainty present in predictions should accompany any predictions based on continuous simulation modeling. An LTCP justified by the demonstration approach should include a margin of safety that reflects the degree of uncertainty in the modeling effort.

Exhibit 9-6. Excursions of Water Quality Criterion by Month

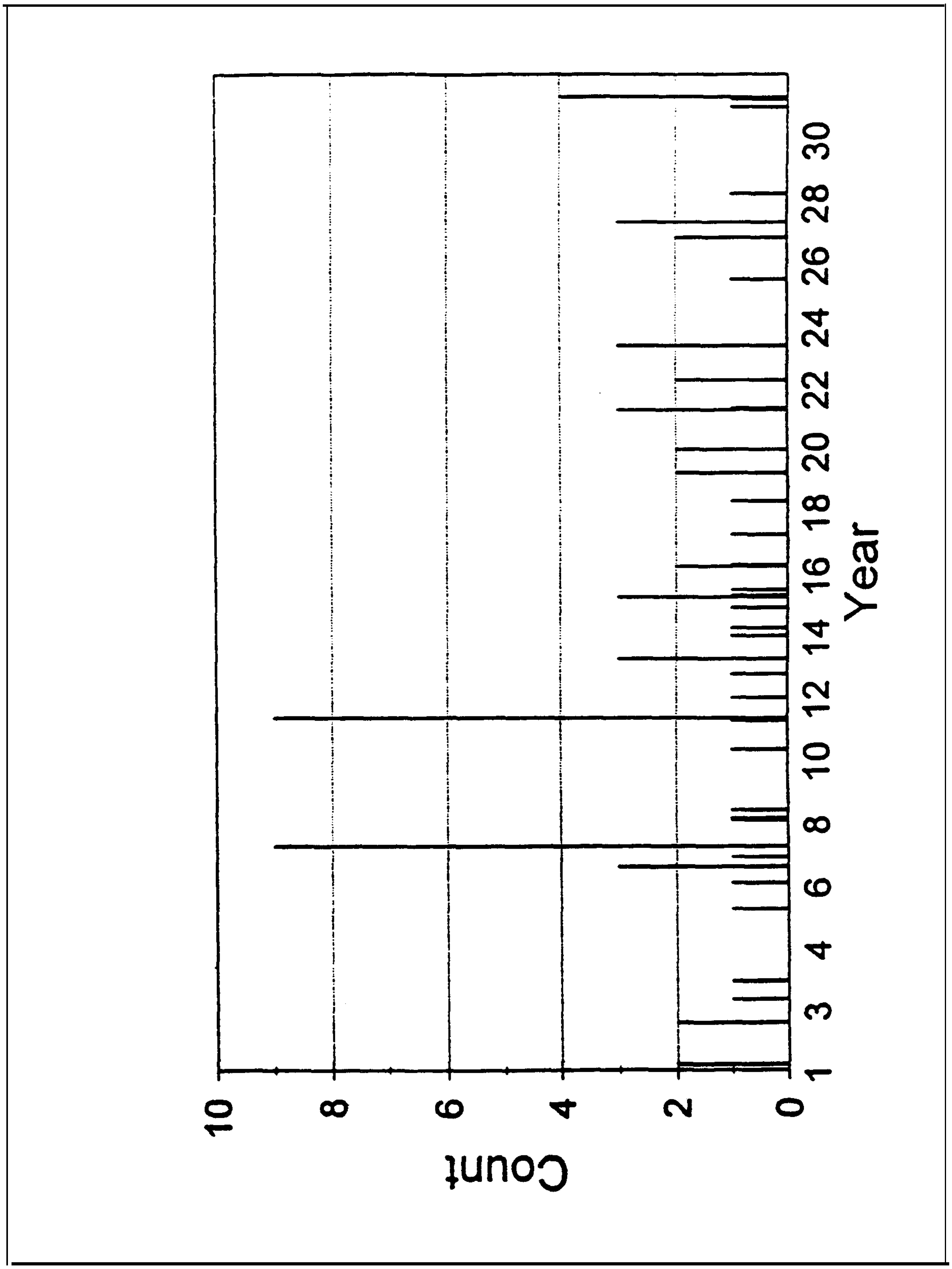
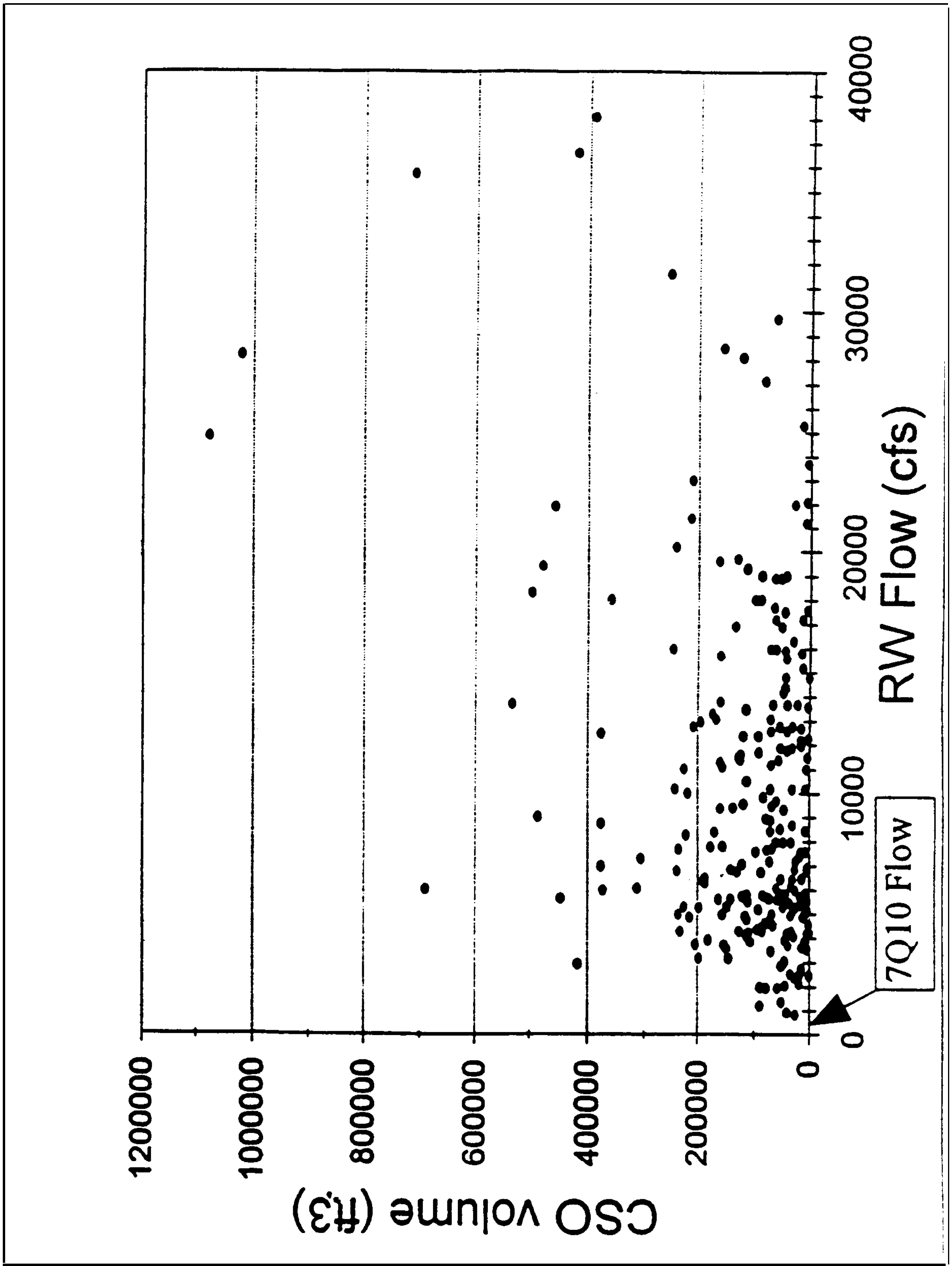


Exhibit 9-7. Receiving Water Flow During CSOs



9.3.2 Example 2: Bacterial Loads to an Estuary

The second example involves bacterial WQS in a tidal estuary. Like the previous example, it attempts to estimate the frequency of excursions of the WQS. However, the fate and transport of bacteria in an estuarine system is more complex than the transport in freshwater systems. Estuaries are both dispersive and advective in nature which creates considerable variations in the water quality. Dispersion is caused by the effects of tidal motion, which is the result of upstream and downstream currents. Advection is the result of the freshwater flow-through in the estuary. Exhibit 9-8 is a map of the estuary with the locations of the CSO outfall, mixing zone, and two sensitive areas (beach and shellfish bed) with more-restrictive bacterial standards.

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 shell fishing 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 no more than 20 percent of samples exceed 400 MPN/100 ml.

Design Condition Analysis

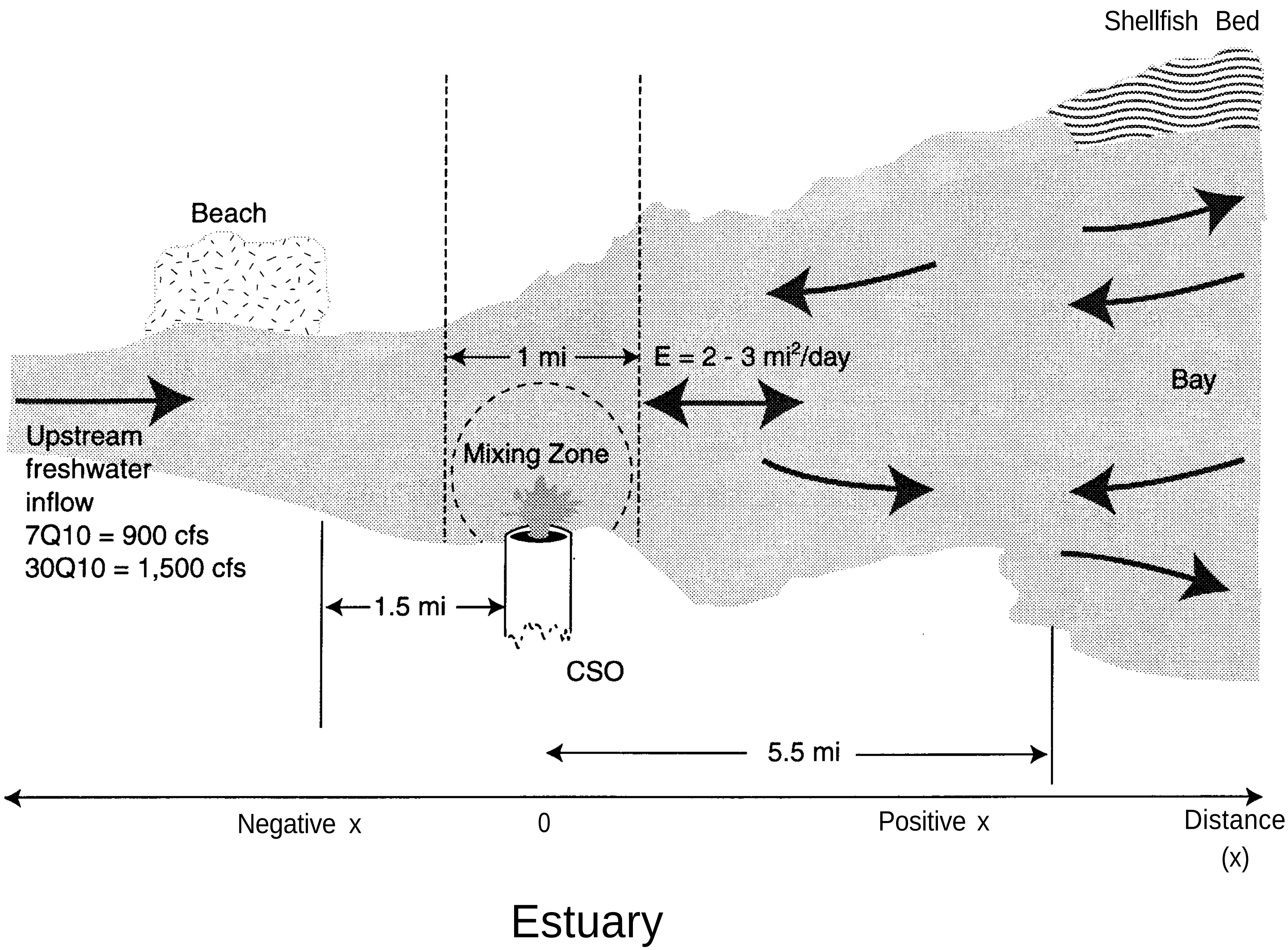
The use of a “design-condition” approach in an estuary requires the use of a model which includes several simplifications to the overall transport. The simplifications can be summarized through the following assumptions:

1. The estuary is one-dimensional. It is not strongly stratified near the source and the longitudinal gradient of bacterial concentration is dominant.

2. The bacterial concentration is described as a type of average condition over a number of tidal cycles. In other words, the model does not describe the variations in bacterial counts within the tidal cycle, but from one tidal cycle to the next.

3. The estuary is in a steady-state condition and area, flow, and reaction rate are constant with distance.

Exhibit 9-8. Map for Example 2



Under these assumptions, the following mass balance equation can be derived for an infinitely long estuary with a waste input at x = 0. This differential equation is often referred to as the one-dimensional advection-dispersion equation.

$$E\frac{d^2n}{dx^2} - U\frac{dn}{dx} - Kn = 0 \qquad (1)$$

for $n = n_0$ at $x = 0$ (2)

$n = 0$ at $x = +/- \infty$ (3)

where E is the tidal dispersion (mi^2/day), U = Q/A the net non-tidal velocity, K is the bacteria die-off rate (/day), and n is the bacterial concentration (MPN/100 ml).

The solutions to equation (1) with conditions (2) and (3) are:

$n = n_0 \exp(j_1x)$ for $x \leq 0$

$n = n_0 \exp(j_2x)$ for $x \geq 0$

where $j_1 = \frac{U}{2E}(1+\alpha)$ the coefficient j_1 is associated with negative values of x

$j_2 = \frac{U}{2E}(1-\alpha)$ the coefficient j_2 is associated with positive values of x

and $n_0 = \frac{W}{Q\alpha}$ n_0 is the concentration at x = 0, the point of the CSO input and W is the CSO input load to the estuary

where $\alpha = \sqrt{1+4KE/U^2}$ a is a coefficient that accounts for the dispersive nature of the estuary.

The ratio KE/U^2, referred to as the Estuary Number, strongly controls the character of the solution. As KE/U^2 approaches zero, advection predominates and the concentrations in the estuary become increasingly similar to the transport in a stream and, as KE/U^2 becomes large, the concentrations approach those in a purely dispersive system. Note that in a well-mixed river with no tides, a is equal to 1, and n_0 is given by the input CSO load divided by the flow. In an estuary, the concentration is reduced by the coefficient a due to the transport of the substance upstream and downstream because of tidal mixing.

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	=	2×10^6 coliforms/100 ml
Q_e	=	0.1 MGD as maximum average per month, 2 MGD as daily maximum

Selected data for the example are presented in Box 9-2. A mixing zone of 0.5 mile up- and down-estuary is allowed. The beach location (1.5 miles up-estuary of the outfall) and the shellfish bed (5.5 miles down-estuary of the outfall) are of particular interest. 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 sufficiently long to allow the variability in the load, as well tidal cycles, to be averaged out. The model was applied to a variety of conditions, including freshwater flow at 7Q10 and 30Q10 levels and bacteria loads at the estimated event maximum daily average load and expected maximum 30-day average load. Because the result depends on the value assigned to the dispersion coefficient, sensitivity of the answer to dispersion coefficients of 2 mi^2/day and 3 mi^2 /day, representing the expected range for the part of the estuary near the outfall, was examined.

Exhibit 9-9 displays the results of this analysis. It predicts fecal coliform counts at different locations in the estuary under different assumptions for tidal dispersion and non-tidal velocity.

Exhibit 9-9. Steady-State Predictions of Fecal Coliform Count (MPN/100 ml)

Upstream Flow	**7Q10: 900 cfs**		**30Q10: 1,500 cfs**			
Load	**Event Maximum Load**				**Average Load**	
Dispersion (mi²/day)	**E = 2**	**E = 3**	**E = 2**	**E = 3**	**E = 2**	**E = 3**
Upstream Mixing Zone (x = −0.5 mile)	1672	1640	1192	1302	60	66
Downstream Mixing Zone (x = 0.5 mile)	2,420	2,096	2,200	1,960	110	98
Beach (x = −1.5 mile)	504	666	246	414	12	20
Shellfish Bed (x = +5.5 mile)	238	268	378	386	18	18
Applicable WQS (MPN/100 ml) – shellfish/bathing areas – other	400 1,000	400 1,000	400 1,000	400 1,000	200 400	200 400

It is most appropriate to compare the geometric mean criteria to the 30Q10 upstream flow and average load (since 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 may 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. Potential WQS excursions at the beach are a concern only at low upstream flows, since 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. In this example, sensitivity analysis was performed on the dispersion coefficient, which varied within an expected range. Similar analysis can be made using other sensitive design variables such as temperature, which influences the coliform die-off rate and ultimately the predicted coliform count. 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, which 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.

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 (Ambrose et al, 1990; Martin et al., 1990).

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 river on a coastal plain. 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. A POTW with advanced secondary treatment discharges three miles upstream of the CSO (Box 9-3).

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 l-day minimum of 5.0 mg/l. The State also requires that WLAs for BOD be calculated on the basis of the l-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

POTW
- Distance Upstream = 3 mi
- BOD_5 = 11.5 mg/l
- Q_e = 10 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 = l 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 l-day CSO volume of 4 MGD, with an average BOD_5 concentration of 200 mg/l.

As described in Chapter 8, initial scoping was carried out using a simple, steady-state DO model (see Section 8.3.1, Rivers-Oxygen Demand/Dissolved Oxygen subsection)[7]. The initial scoping assumes the presence of the upstream industrial point source and the POTW, 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

[7] Similar DO analysis is discussed in Thomann and Mueller (1987).

was assumed for other reaches upstream of the CSO. This is a simplifying assumption that is sufficient for the scoping analysis described here. SOD in the river reach below the CSO has been included in the analysis since this is the reach of concern. Since there are many sources of SOD other than CSOs, contributions of SOD from other sources should be considered at the next level of analysis.

Results of the scoping model application are shown in Exhibit 9-10, which shows the interaction of the point source, POTW, and CSO. The exhibit combines two worst-case conditions: high flow from the episodic source and low (7410) 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.

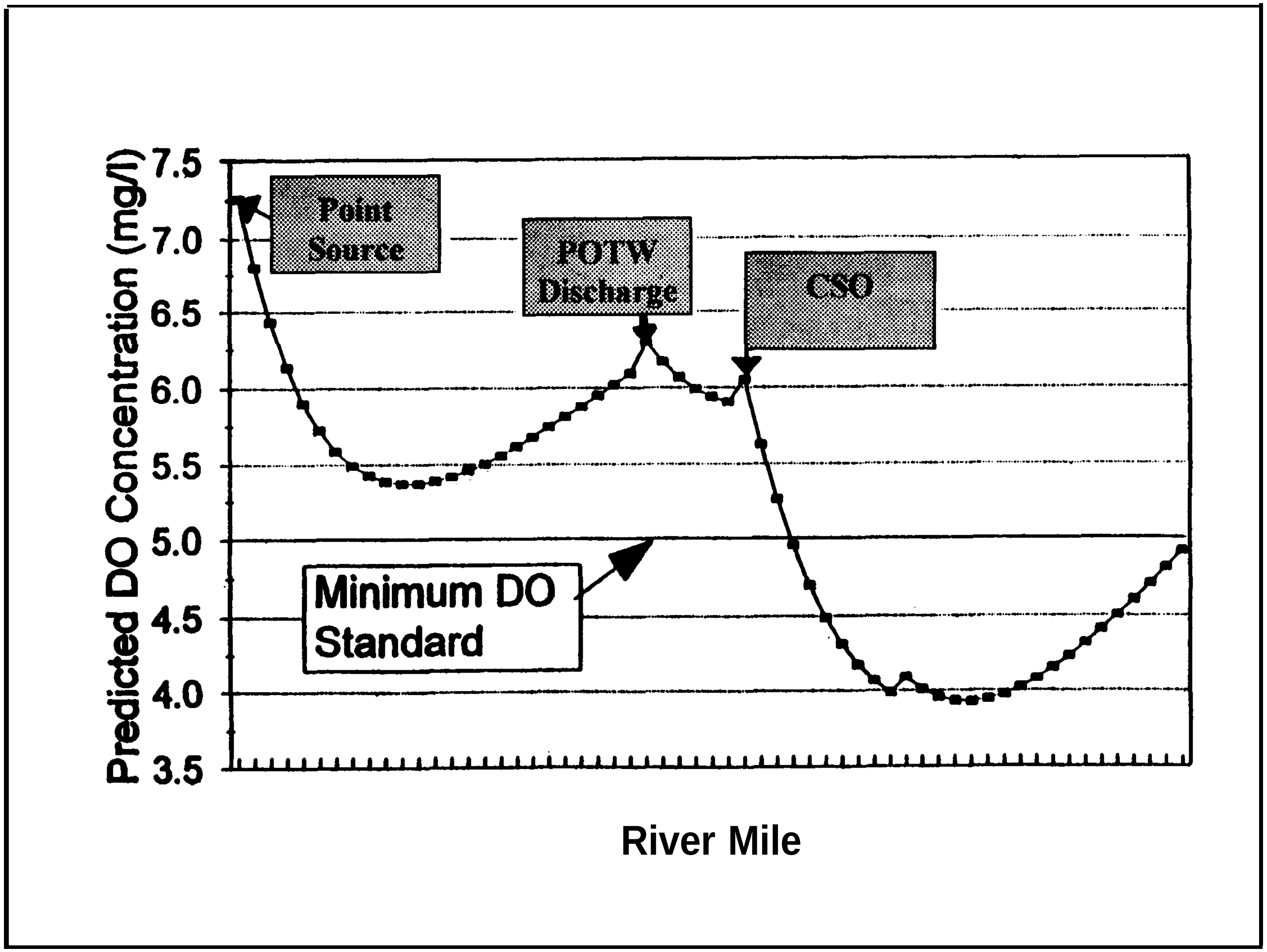
Design Flow Frequency Analysis

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-year 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 CSO. Design flow was simulated using the worst-case CSO flow over a variety of concurrent upstream

[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 interval was determined to be appropriate. The three-year return interval 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



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.

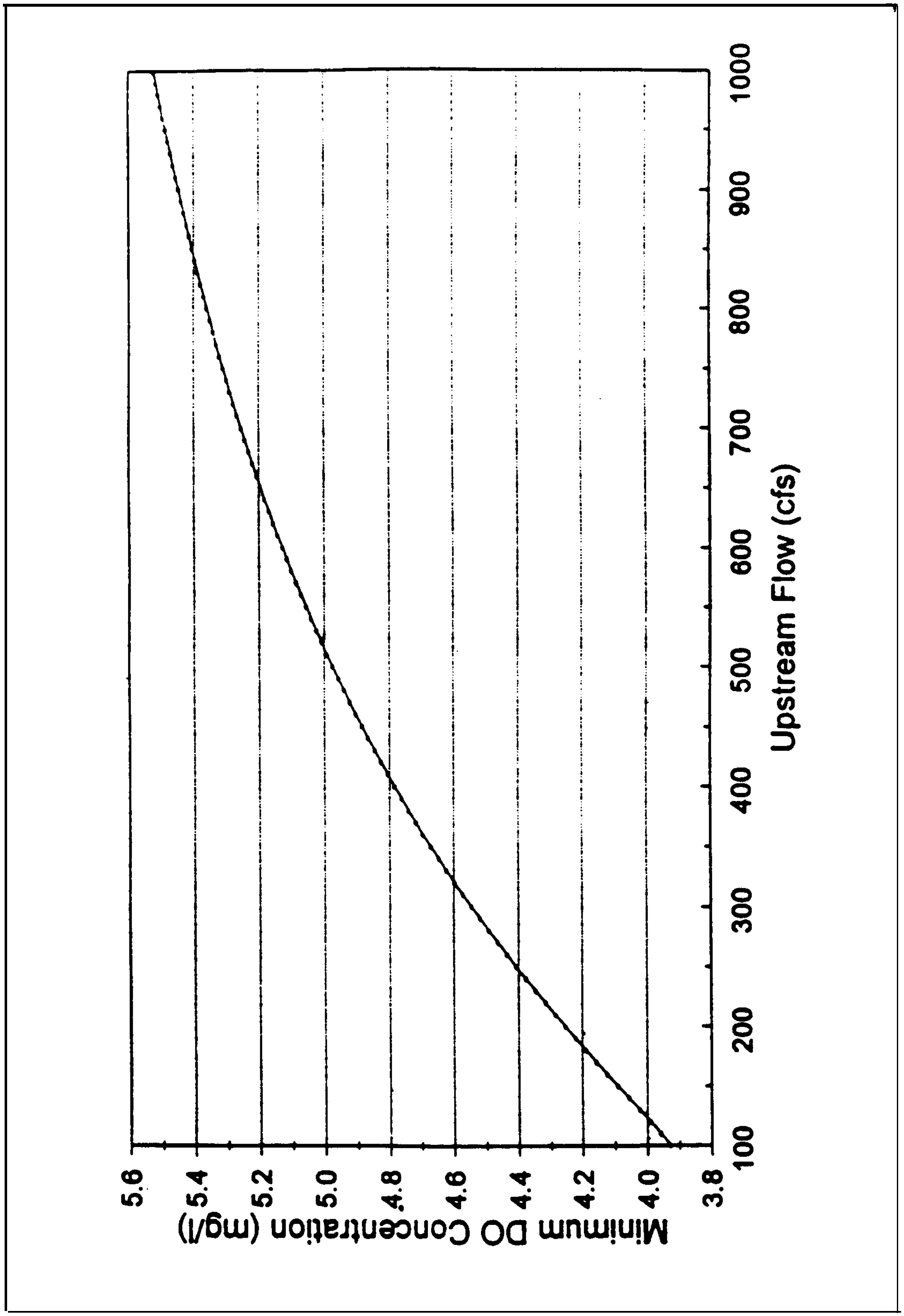
The target rate of WQS excursions is one in three years. An upper bound for the actual long-term average rate of excursions can be established as the probability that flow is less than 510 cfs in the river multiplied by the probability that a CSO occurs:

$$P_{exc} = p(Q<510cfs)f_{CSO}$$

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 x 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 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.

Exhibit 9-11. Relationship Between DO Concentration and Upstream Flow



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. For example, the use of a constant CSO load is a conservative, simplifying assumption that is appropriate for the scoping level analysis presented here. 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, and a complex dynamic simulation is not always necessary. The method should be appropriate for the receiving water problem. 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 references listed above, many documents contain information useful in designing a monitoring program for CSO controls. This section briefly highlights information from these documents, as well as from some of the documents listed above.

- 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)." In *Water Quality Standards Handbook* (EPA, 1994). 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-l
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 and confined space entry; verifying first aid and wet-weather training, CPR, 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-Sampling Follow Up

— Filing sample logs and diaries
— Cleaning and maintaining equipment
— Disposing of chemical wastes properly
— Reviewing documentation and audit reports

Table A-l (continued)
Checklist of Considerations for Documenting Monitoring Program Designs and Implementation (expanded from Ward et al., 1990)

Laboratory Analysis

Preparations Prior to Sample Analysis

__ 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
__ 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-l (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 Monitoring Plans

CSO Drainage and Sewer System Map

- ___ Up-to-date
- ___ Shows "as-built" sewer system
- ___ Shows drainage areas with land use information
- ___ Shows location of major industrial sewer users
- ___ Shows location of all direct discharge points, including all related CSO, POTW, storm water, and industrial discharges
- ___ Distinguishes bypass points from CSOs points and shows locations
- ___ Shows locations of CSO quantity and quality monitoring sites
- ___ Identifies receiving waters
- ___ Identifies designated and existing uses of receiving waters
- ___ Shows areas of historical use impairment

CSO Volume

- ___ Identifies number of storms to be monitored
- ___ Identifies number of CSO outfalls to be monitored
- ___ Ensures that sampling points include major CSOs
- ___ Provides for monitoring of POTW influent flow
- ___ Ensures adequacy of method of flow measurement
- ___ Identifies frequency of flow measurement during each storm event
- ___ Identifies storm statistics to be reported-mean, maximum, duration
- ___ Identifies storm statistics to be reported for all storms during the study period

CSO Quality

- ___ Identifies number of storms to be monitored
- ___ Identifies number of CSO outfalls to be monitored
- ___ Ensures that sampling points include major CSOs
- ___ Provides for monitoring of POTW influent quality
- ___ Provides for monitoring of drainage areas representative of land use and sewer users
- ___ Identifies method and frequency of sampling
- ___ Identities parameters to be analyzed
- ___ Ensures adequacy of detection limits
- ___ Identifies toxicity test(s) to be conducted
- ___ Identifies receiving water(s) to be sampled
- ___ Provides for monitoring of aesthetics

APPENDIX B

Table B-l

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-[d]	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-[e]						
DO	x					
CBOD, NBOD	x					
NH3		x				
Temperature	x	x	x	x	x	x
Inorganic P			x	x	x	x
Inorganic NPDES			x	x	x	x
Chlorophyll a [f]			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
Oxygen per unit chlorophyll a						
Algal oxygen production rate	x					
Algal oxygen respiration rate	×					

Table B-l (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				x	x	x
Phosphorous to chlorophyll ratio			x	x	x	x
ratio			x	x	x	x

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]
Light Parameters						
Daily solar radiation			x	x	x	x
			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 of 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		
O_2 consumption per unit of NH_3 oxidation				
O_2 consumption per unit of NO_2 oxidation		*Meteorological Data*		
O_2 production per unit photosynthesis		Solar radiation		Yes
O_2 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			

Table B-2 (continued)
Model Input Parameters for Qual-2E

Input Parameter	Variable by Reach	Input Parameter	Variable by Reach	Variable with Time
Phytoplankton Parameters		*Flow Data*		
Maximum growth rate		Upstream boundaries	Yes	
Respiration rate		Tributary inflows	Yes	
Settling rate	Yes	Point sources	Yes	
Nitrogen half-saturation constant		Nonpoint sources	Yes	
Phosphorous half-saturation constant		Diversions	Yes	
Light half-saturation constant				
Light extinction coefficient	Yes	*Constituent Concentrations*		
Ratio of chlorophyll a to algal biomass	Yes	Initial conditions	Yes	
Nitrogen fraction of algal biomass		Upstream boundaries		Yes
Phosphorous fraction of algal biomass		Tributary inflows	Yes	
		Point sources	Yes	
Coliform Parameters		Nonpoint sources	Yes	
Die-off rate	Yes			

Table B-3
Comparison of Qual-II With Other Conventional Pollutant Models Used in Waste Load Allocations

Model	Temporal Variability: Water Quality	Temporal Variability: Hydraulics	Variable Loading Rated	Types of Loads	Spatial Dimensions	Water Body	Water Quality Parameters Modeled	Process Simulated: Chemical/Biological	Process Simulated: Physical
DOSAG-I	Steady-state	Steady-state	No	multiple point source	I-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	I-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	I-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, CBOD, 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_{Ss}	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.

Table B-5
Summary of Data Requirements for Screening Approach for Metals in Rivers

Data	Calculation Methodology	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	Average water depth is cross-sectional area divided by surface width.
• Reach lengths, x	R, S	
• Stream velocity, U	R, S	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	

Table B-5 (continued)
Summary of Data Requirements for Screening Approach for Metals in Rivers

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	
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_{t2}		
Derived Parameters		
• Partition coefficient, K_p	All	Partition coefficient is a very important parameter. Site-specific determination is preferable.
• Settling velocity, w_s	S,L	Parameter derived based on suspended solids vs. distance profile.
• Resuspension velocity, W_{rs}	R	Parameter 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.