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.

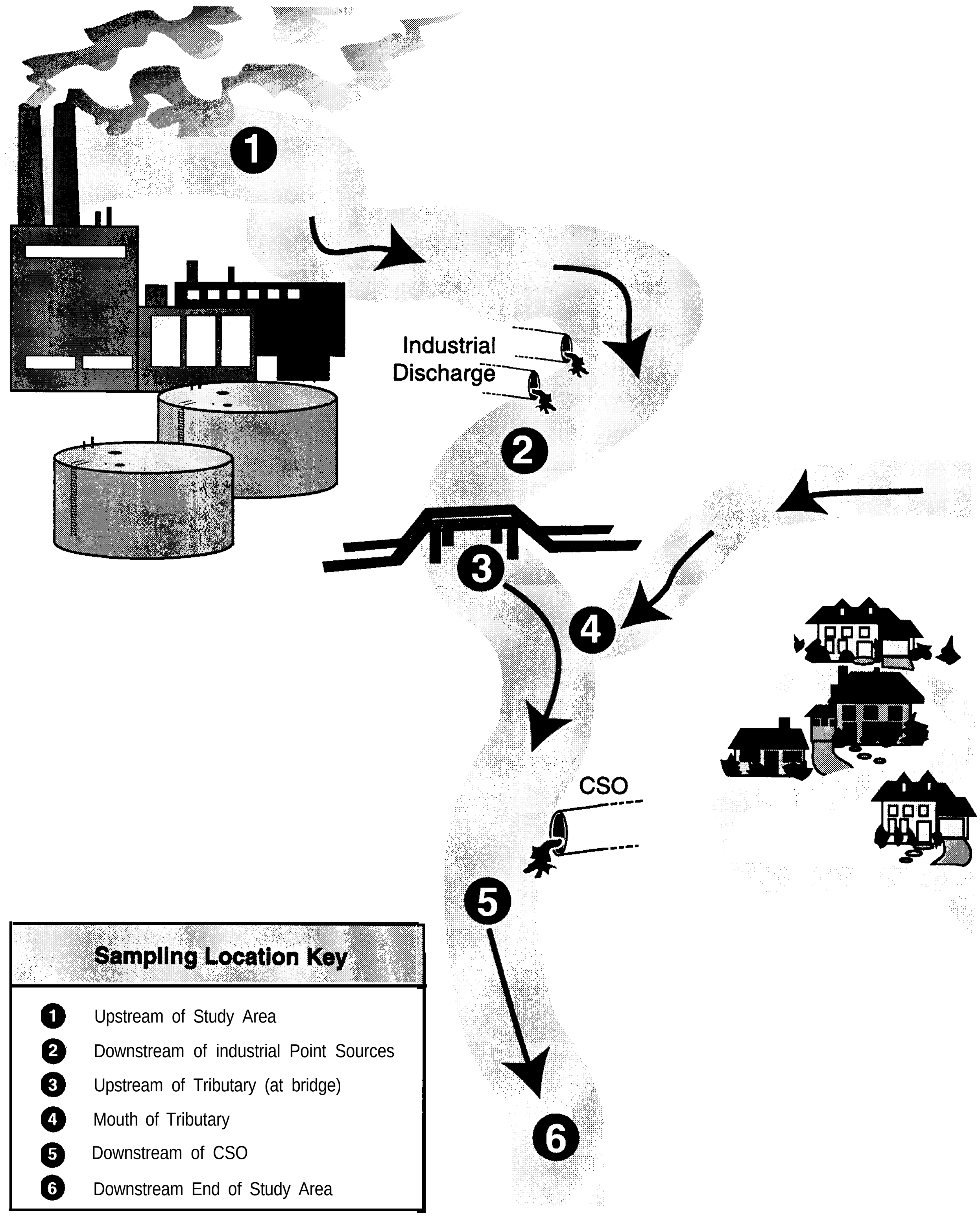
The permittee should also consider making cooperative sampling arrangements when pollutants from multiple sources enter a receiving water or when several agencies share the cost of the collection system and the POTW. The identification of new monitoring locations should account for sites that may already 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

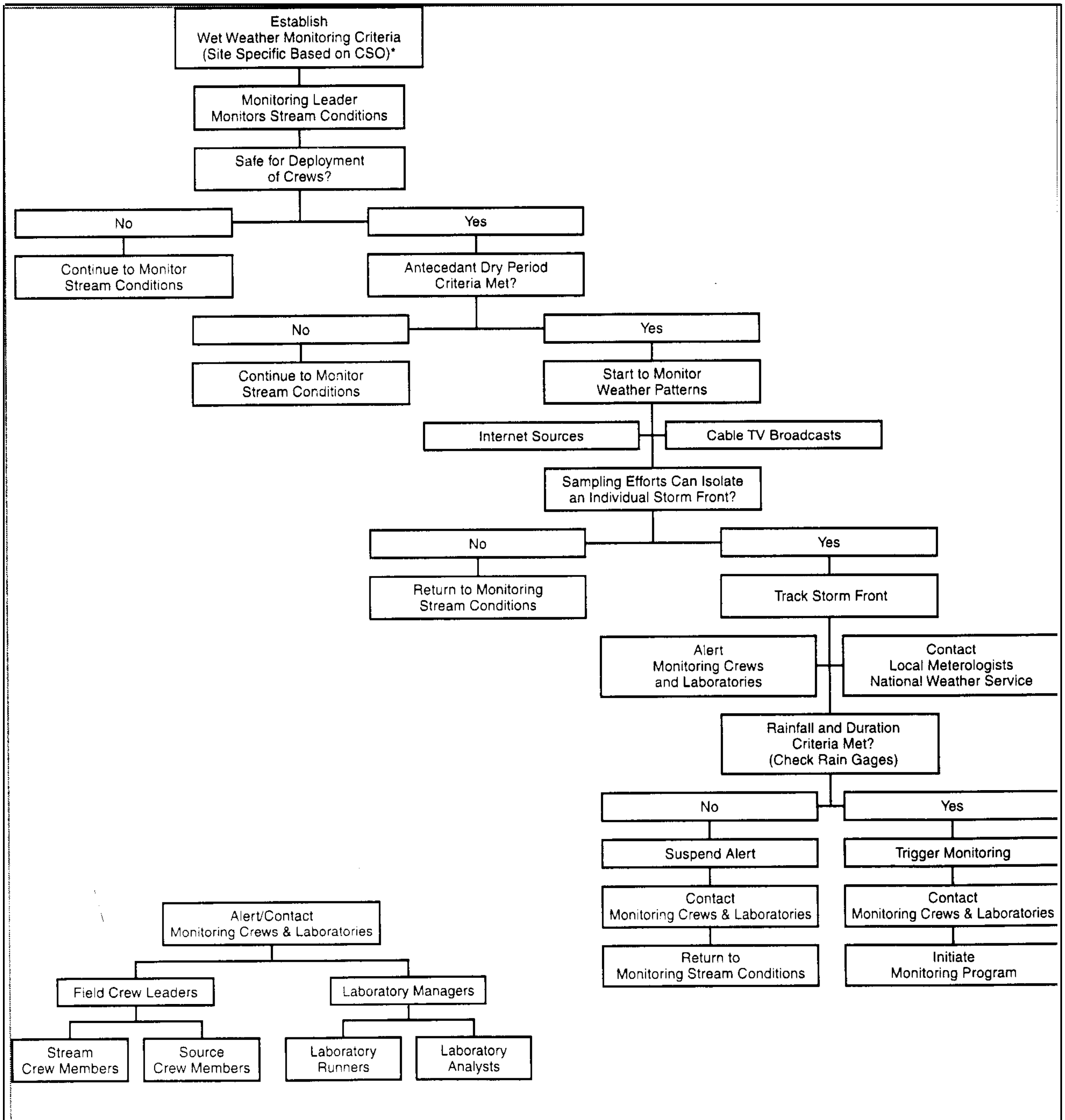
- Identify monitoring contact personnel
  - Laboratory managers
  - Consultant crew leaders
  - Municipality crew leaders

- 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.