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

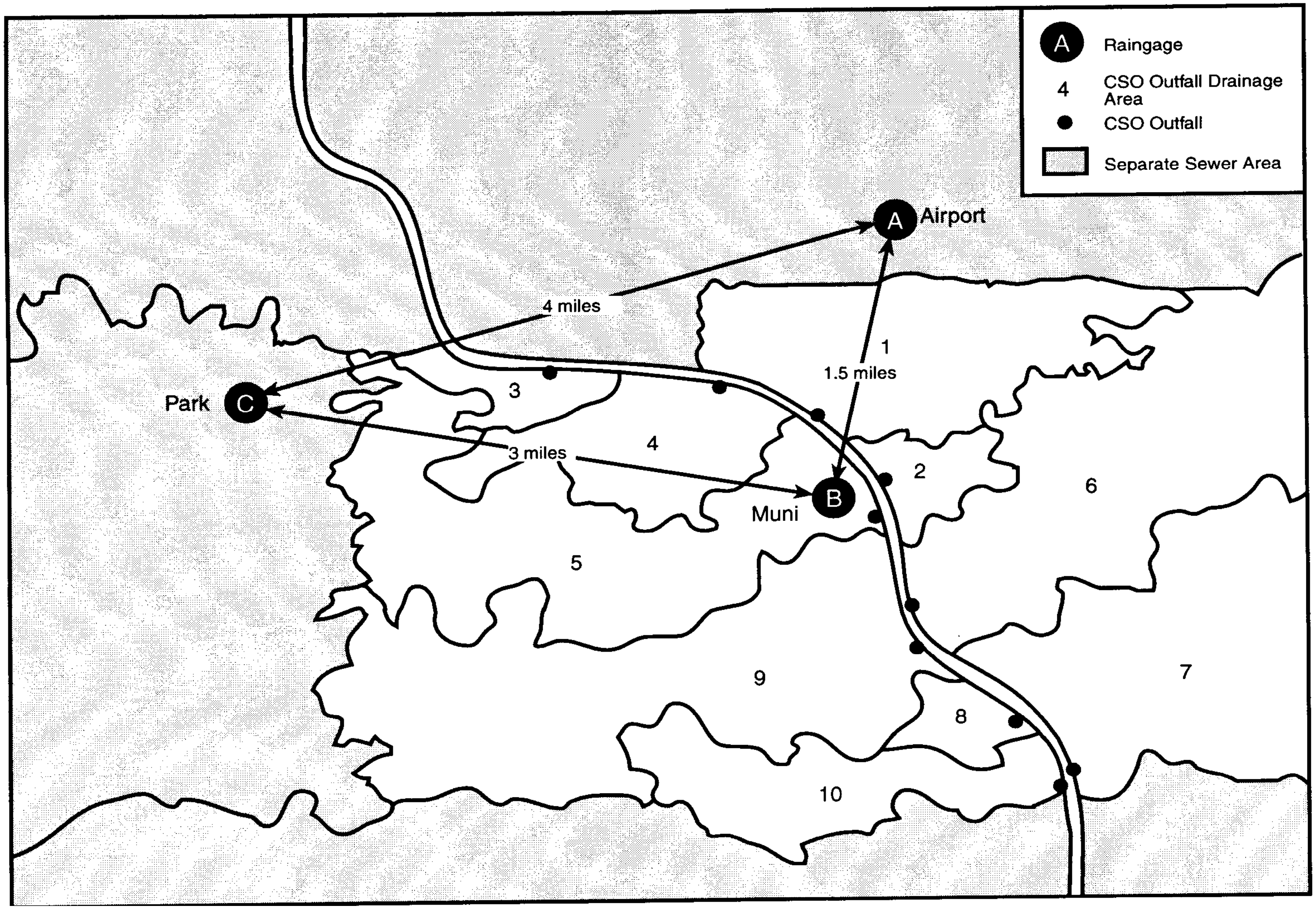
Using this method, the estimated precipitation at the sampling location is calculated as the weighted average of the precipitation at the surrounding rain gages. The weights are the reciprocals of the squares of the distances between the sampling location and the rain gages. The estimated rainfall at 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

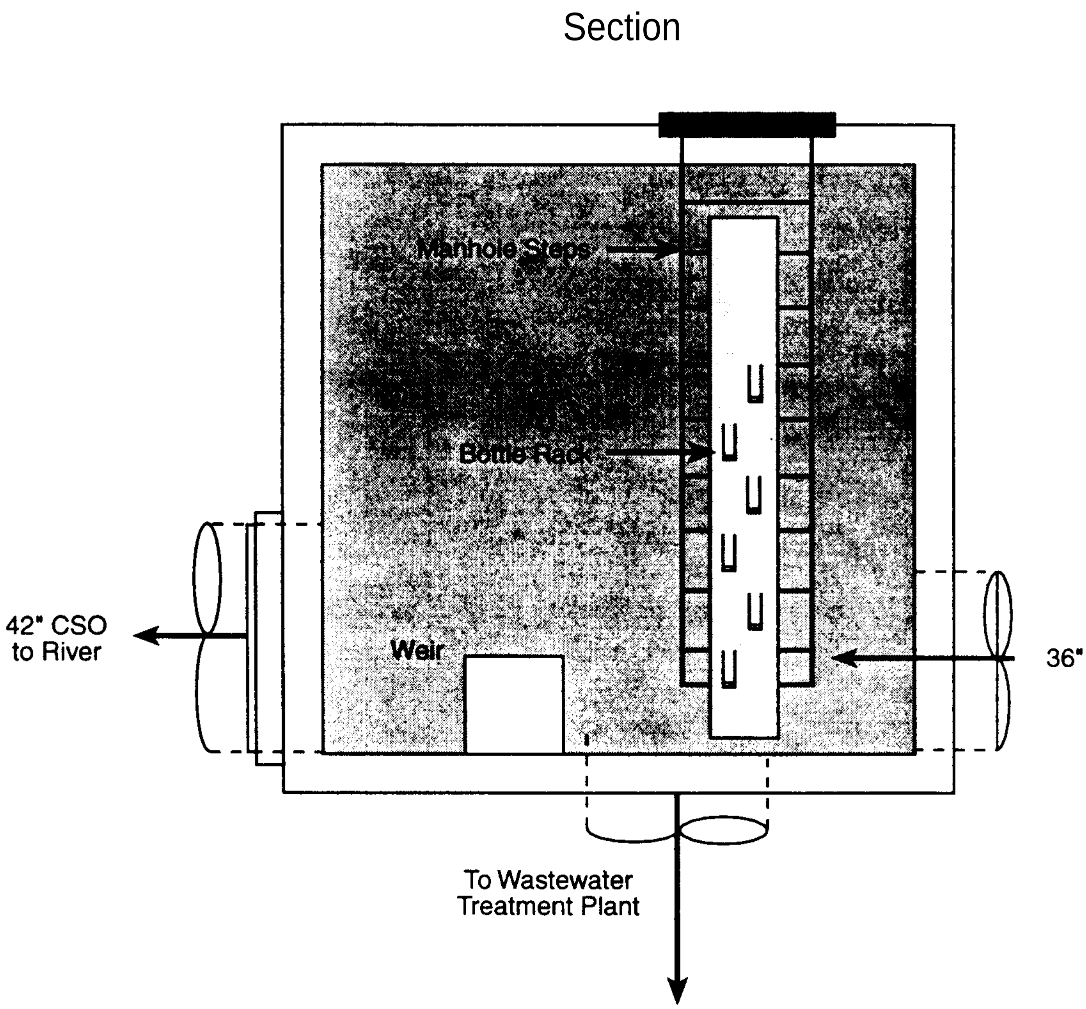


Exhibit 5-7. Example Outfall Bottle Rack Readings

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

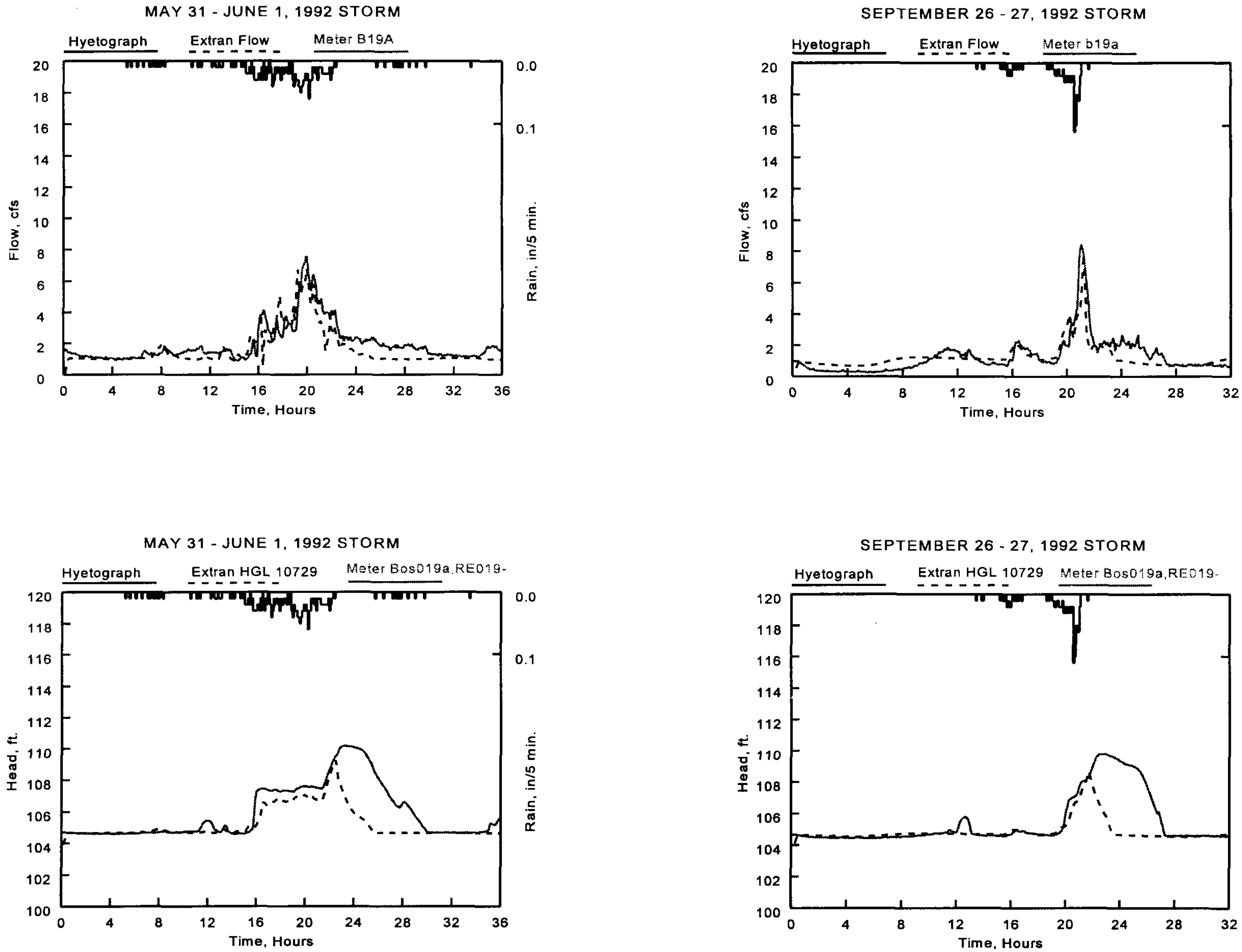
Comparing the overflow volumes of different outfalls indicates which outfalls contribute the bulk of the overflow volume and, depending on loading measurements, may contribute most heavily to water quality problems. To compare the hydraulic performance of different outfalls, flows should be normalized 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]

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[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).