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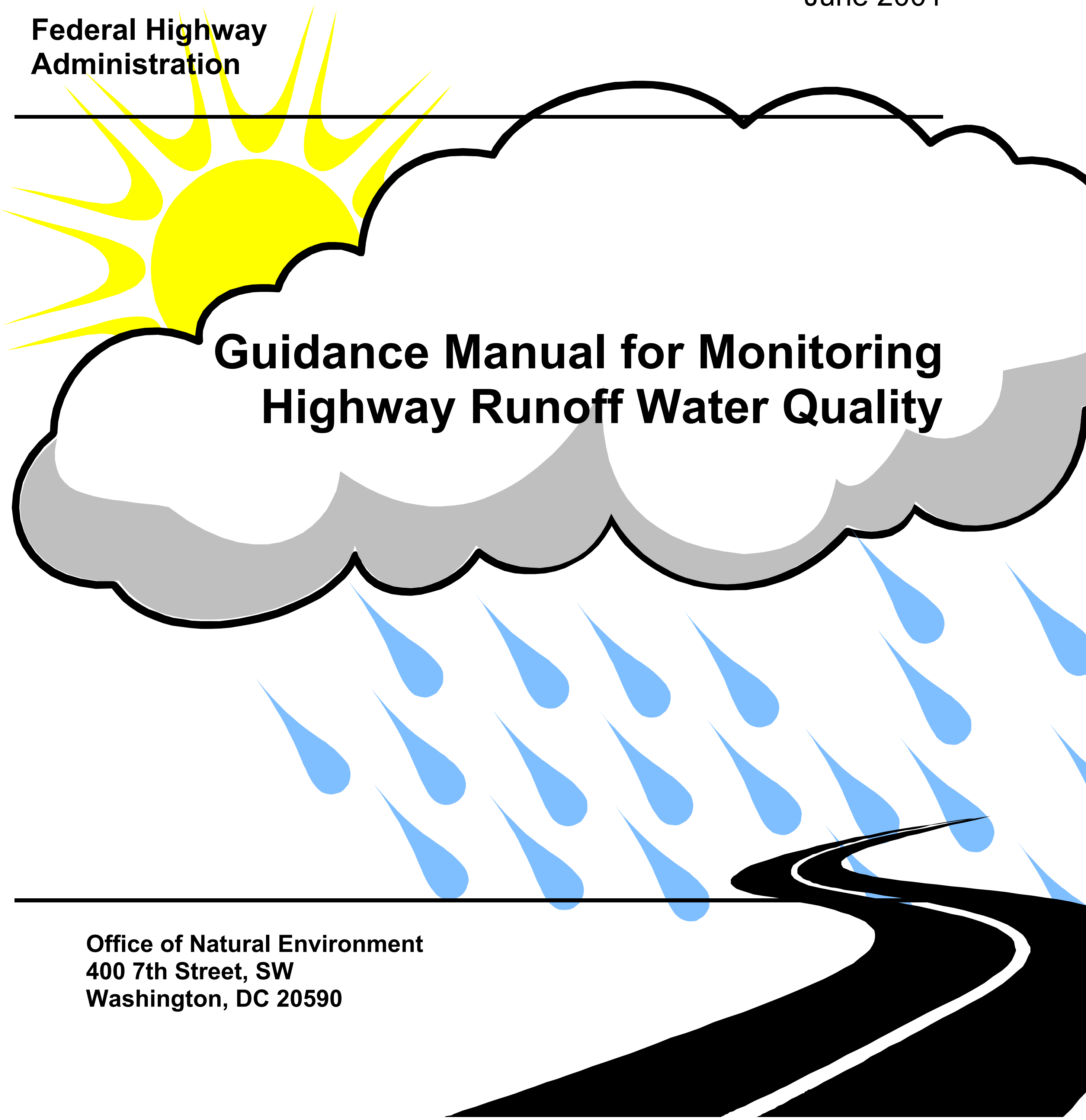
Guidance Manual for Monitoring Highway Runoff Water Quality



Office of Natural Environment
400 7th Street, SW
Washington, DC 20590

FORWARD

This report provides guidance for selecting and using stormwater runoff monitoring equipment for monitoring of highway runoff. This report will be of interest to engineers and scientists who are responsible for stormwater monitoring.

Office of Natural Environment
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NOTICE

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16. Abstract

This document provides guidance for selecting and using stormwater runoff monitoring equipment for monitoring of highway runoff. The guidance provided is intended to help achieve stormwater monitoring program goals through the collection of more useful and representative rainfall, flow, and water quality information. Ultimately it is intended to improve monitoring information that will lead to better highway runoff management decision making.

Guidance is provided to assist the user in not only selecting equipment, but also approaching highway stormwater runoff monitoring design in a comprehensive manner. Included are recommendations for specific equipment and monitoring methods and their use in conjunction with meeting monitoring program goals.

Results of field evaluations of equipment are included, as appropriate, from work conducted under *Evaluation of Water Quality Monitoring Equipment for Measurements of the Constituents of Highway Stormwater Runoff.* Example health and safety plans and a standard operating procedures document for conducting runoff monitoring are included for reference by users of the manual.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
fl	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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Sections of this document are based upon work originally authored by Mike Milne (URS Group, Inc.), Eric Strecker (GeoSyntec Consultants), Terry Cook (URS Group, Inc.), Gail Boyd (URS Group, Inc.), Krista Reininga (URS Group, Inc.), and Lynn Krasnow (URS Group, Inc.) for the Washington State Department of Ecology's (DOE) November 1995, "Stormwater Monitoring Guidance Manual". The thoroughness and specific insight provided in the DOE Manual were instrumental in assembling this updated guidance.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

1. INTRODUCTION

1.1. Scope

This document provides guidance for selecting and using stormwater runoff monitoring equipment for the monitoring of highway runoff. The guidance provided is intended to help achieve stormwater monitoring program goals through the collection of more useful and representative rainfall, flow, and water quality information. Ultimately it is intended to improve monitoring information that will lead to better decision-making with respect to highway runoff management.

The guidance contained should not be regarded as a rule, requirement, or regulation. It should be used to provide insight into strategies, approaches, and techniques that are appropriate and useful for monitoring the water column within highway stormwater conveyance systems. Experience and knowledge of local conditions should always be considered when applying this guidance.

This document addresses equipment and methods that were readily available at the time it was written. As the state of the art is continuously progressing, more sensitive devices and equipment based on new technologies will likely become available. Although the technology may change somewhat from the equipment described, most of the basic flow and water quality monitoring methods discussed in this document have a long history of use and will most likely remain viable even as new and different technologies emerge.

This manual focuses on water quantity and quality measurement and therefore does not address in detail sediment sampling methods and techniques, biological assessment, monitoring of receiving waters, monitoring of groundwater, streambank erosion, channel instability, channel morphology, and a variety of other useful activities that in many circumstances may be as, or even more, useful than measuring and monitoring water quality for assessing impacts of highway runoff.

1.2. Format of This Document

This document is broken down into six main sections following this introduction:

- Section 2 provides a detailed look at stormwater monitoring programs as they apply to the highway environment.
- Section 3 discusses some of the considerations that go into selecting monitoring equipment within a monitoring program.
- Section 4 presents detailed information about each type of monitoring equipment.
- Section 5 provides general guidance on installation of monitoring equipment.
- Section 6 provides information on parameters and analytical methods and their relationship to equipment selection.
- Section 7 describes health and safety issues related to conducting stormwater monitoring and its implications for equipment selection.

In addition, three appendices have been included in this guidance document. The first provides detailed information on methods for data analysis, which is important to consider prior to selecting monitoring equipment. The second appendix is a sample Health and Safety Plan for conducting monitoring activities. The final appendix is a sample standard operating procedures document that was used for conducting work used to provide data to support the information included in this manual.

1.3. Context within a Stormwater Quality Monitoring Plan

This guidance addresses the selection of monitoring equipment within the larger context of an existing or concurrently developed Stormwater Quality Monitoring Plan and/or Implementation Program. In order to provide a basis for the equipment selection decision-making process, Section 2 of this guidance expounds upon the relationship between setting and achieving monitoring program goals and monitoring methodology and equipment.

2. STORMWATER QUALITY MONITORING OVERVIEW

This chapter introduces stormwater monitoring, provides insight into complexities specific to highway monitoring, and discusses approaches to developing stormwater monitoring programs to meet specific management goals.

2.1. Physical and Chemical Characteristics of Stormwater Runoff

In this guidance manual, the term "stormwater" refers to more than just storm-driven surface runoff. Here the term is expanded to cover water and other substances that are transported through stormwater conveyance systems during, after, and between storm events. In addition to the runoff from rainfall or snowmelt, a typical stormwater sample may contain materials that were dumped, leaked, spilled, or otherwise discharged into the conveyance system. The sample may also contain materials that settled out in the system toward the end of previous storms and were flushed out by high flows during the current event being sampled. Stormwater also can include dry weather flows such as pavement washing, pavement cutting wash water, irrigation, or base flows.

Stormwater quality tends to be extremely variable (USEPA, 1983; Driscoll et al., 1990). The intensity (that is, volume or mass of precipitation per unit time) of rainfall often varies irregularly and dramatically. These variations in rainfall intensity affect runoff rate, pollutant washoff rate, in-channel flow rate, pollutant transport, sediment deposition and re-suspension, channel scour, and numerous other phenomena that collectively determine the pollutant concentrations, pollutant forms, and stormwater flow rate observed at a given monitoring location at any moment. In addition, the transitory and unpredictable nature of many pollutant sources and release mechanisms (e.g., spills, leaks, dumping, construction activity, landscape irrigation runoff, vehicle washing runoff), and differences in the time interval between storm events also contribute to inter-storm variability. As a result, pollutant concentrations and other stormwater characteristics at a given location should be expected to fluctuate greatly during a single storm runoff event and from event to event.

Numerous studies conducted during the late 1970s and early 1980s showed that a potentially significant source of pollution is stormwater runoff from urban and industrial areas (USEPA, 1983; Driscoll et al., 1990). As a result, federal, state and local regulations have been promulgated to address stormwater quality.

Increasingly, the impacts of hydrologic and hydraulic changes in watersheds are being recognized as significant contributors to receiving waters not meeting beneficial criteria. These impacts include stream channel changes (erosion, sedimentation) as well as water level fluctuations in wetlands.

2.2. Stormwater Quality Monitoring Challenges

The primary purpose of a monitoring program should be to obtain information necessary to make sound resource management decisions. For example, a typical stormwater monitoring program may be intended to identify pollution problem areas and determine which problem(s) are the most significant. Monitoring results would then be used to develop control strategies and prepare plans and budget estimates for addressing those problems.

The principal challenge facing developers of stormwater monitoring programs in selecting appropriate flow and water quality sampling equipment is the great variability in stormwater pollutant concentrations, both temporal and spatial. Stormwater quality at a given location varies greatly both between storms and during a single storm event; therefore, a small number of samples are not likely to provide a reliable indication of stormwater quality at a given site. As a result, collection of numerous samples is generally needed for accurate characterization of stormwater quality at a site. Stormwater quality also tends to be quite variable from place to place, and may need to be monitored at a number of strategically located stations to characterize stormwater quality over a larger area. Consequently, selecting monitoring equipment and procedures involves the need to make decisions that balance the cost of obtaining more extensive and accurate information (and the increased reliability it provides) against the cost of implementing less intensive and possibly misdirected and/or ineffective control programs based on sparse data.

Experience has shown that it is generally expensive and time-consuming to collect enough stormwater samples to answer many of the common stormwater quality questions (e.g., What are the water quality trends at a given location? Is a given BMP effective?) with a high level of statistical confidence. An entire program budget could be devoted to a monitoring effort to achieve a high confidence level, but doing so would leave insufficient resources for pollution control. Conversely, a poorly designed monitoring program could lead to erroneous conclusions and poor management decisions, resulting in misdirected or wasted resources (e.g., staff time, funds, credibility, and political support). Therefore, before a monitoring program is begun, it is critical to clearly identify and prioritize decisions that must be made, determine the type and quality of information needed to support those decisions, and then compare this list of needs to the resources available for monitoring. If the available resources cannot support the scale of monitoring needed to provide the quality of information deemed necessary, then the following options should be considered:

- Evaluate alternative means for acquiring the information needed to support management decisions. For example, sediment sampling and analysis may be a cost-effective alternative to water column monitoring in some situations, especially those in which the focus is on long-term impacts of erosion and sedimentation or tracing specific pollutants to their respective sources.

- Consider a phased approach that addresses only a subset of the overall geographic area, or only the most important stormwater questions, to obtain useful results within resource limitations (e.g., funds, personnel, time).

- Utilize available data from other locations to support decision-making.

The key question should be "Will the information provided from the monitoring program under consideration (and capable of implementation) significantly improve my ability to make sound management decisions?" If the answer is no, the monitoring program should be reexamined.

2.3. Complexities Specific to the Near-highway Environment

Numerous difficulties are encountered in monitoring stormwater runoff in the near-highway environment. Complications in designing and selecting methods for monitoring highway runoff fall into two primary categories: operational constraints and physical constraints.

2.3.1. Operational Constraints

Although health and safety are always of primary concern in establishing a stormwater monitoring program in any environment, the near-highway environment presents significant safety hazards not encountered in many other locations. The repercussions of improper selection of equipment and procedures may present a serious risk to monitoring personnel as well as the general public. Health and safety risks related to site selection and the implications for equipment selection are discussed in Sections 3.1.2.

2.3.2. Physical Constraints

Although many of the conditions found in monitoring highway runoff are also found in many urban settings, a few physical conditions are particularly relevant to near-highway monitoring sites. Factors found at near-highway sites that directly affect site and equipment selection include:

1. Predominance of small- to medium-sized watersheds for monitoring

Depending on the drainage system selected, watersheds for highway sections typically range in size from less than 0.5 acre to around 50 acres. Larger systems often cannot be verified (i.e., mapped and checked for illicit or municipal connections) in a cost-effective manner, particularly in urban areas, and may include runoff from adjacent land uses.

2. Short time of concentration and "peaky" flow

Small, highly impervious watersheds that have minimal times of concentration can be quite difficult to monitor due to "peaky" flows (i.e., flows rise and fall directly in response to a rainfall). The range of flows that needs to be measured accurately is large. Monitoring sites where large changes in flow rate occur in a relatively short period of time require particular attention during equipment selection, installation and use. Rapidly changing flow conditions can cause:

- equipment with poor data density recording capabilities to miss brief periods of significant flow;
- automatic samplers to collect samples from flows that have changed since the sampler trigger was initiated;
- automatic samplers to collect no sample due to low flow conditions after the trigger has occurred; and
- errors in flow measurement due to unsteady conditions or flows below the minimum that can be measured.

The frequency of flow measurements must be of the same magnitude as the time of concentration for the watershed if flows are to be estimated accurately. Time of concentration is a function of the rainfall intensity and watershed size, and it decreases as intensity increases. Data density must be adequate to ensure that high intensity, short duration events are recorded. For small watersheds, this means that flow rate data may need to be collected at less than five-minute intervals.

3. Possible large percent error in watershed parameters

Flow calculations and loading estimates can be greatly affected by the accuracy of the measurement or estimate of watershed parameters. Particularly in low gradient highways, it may be difficult to estimate or measure (to less than 10% error) watershed parameters such as tributary drainage area and percent imperviousness. For this reason, equipment that is capable of measuring a wide range of flow rates (often in excess of three orders of magnitude) without large errors (<20%) is optimal.

Watersheds that are smaller than 1 acre, have minimal longitudinal slopes, and are in high traffic areas are common in the near-highway environment. These factors may complicate watershed delineation. Shallow longitudinal slope often means that very small rises in the pavement surface due to uneven slabs, cracks, settling, minor modifications to the pavement surface, rutting, broken curbs, and dikes can have a major impact on drainage patterns, and thus on watershed area estimations. The inability to accurately assess watershed area may also be compounded by safety concerns related to surveying highways that are in use.

In addition, it has been suggested that runoff coefficients for the Rational Method for some highways may be on the order of 0.6 to 0.8, which is lower than expected for highly impervious systems. This may be related to losses due to infiltration through cracks and joints and conversion of a portion of runoff into aerosols and spray from high-speed traffic (Caltrans, 2000).

4. Downstream access issues

It may be difficult to obtain access to flows exclusively from a highway section due to direct connection to municipal systems. Connections between highway and municipal systems are quite common in urban areas. It is important to determine whether there are any possible connections that would affect the tributary area and water quality.

5. Steep pipe slopes and high velocities

Another factor frequently encountered in the near-highway environment is steep pipe slopes resulting in high flow velocities in both open conveyance systems and pipes. Steep gradient conveyance conditions may, for example, be present in fill sections and in areas where the grade of the road is steep. These conditions require special attention during equipment selection and possible modifications to the conveyance to facilitate accurate flow records and sampling.

6. Numerous outfalls

Many highway systems do not drain large watersheds to a single tributary drainage point as is typically observed in municipal systems. Connections to receiving waters or conveyance systems may occur at numerous locations, (e.g., there may be one outfall per inlet). This may limit the total area that can be effectively monitored with a small number of monitoring stations, complicate the site selection process, and decrease the applicability of results to similar watersheds.

7. Lack of a well-defined drainage system

Many highway sections may not have a well-defined drainage system or may include sections that do not specifically drain to a separate storm sewer system. This is the case where curbs and dikes are not in place or ditches or unlined channels serve as the primary conveyance system.

8. Right-of-way issues

Inter-governmental agreements may need to be established to enable monitoring efforts on federal, municipal, or county property because in many cases access to conveyances in the established right-of-way may not be possible.

9. Representativeness of highway sections

Depending on the goals of the monitoring program, selection of highway sections may require information beyond standard watershed parameters (e.g., average daily traffic volumes, number of lane miles, existence of specific features such as sound walls, or cut or fill construction). It may be difficult to extrapolate results from watershed monitoring studies completed on a small number of sites to a larger highway system without site-specific information to enhance the representativeness of the sites monitored.

2.4. Regulations as Drivers for Monitoring Programs

A number of regulatory drivers exist for implementation of stormwater monitoring programs including:

- the Clean Water Act: total maximum daily load (TMDL) and National pollutant discharge elimination system (NPDES) Phase I and II;
- the Endangered Species Act; and
- state, county, and local regulations.

Details about each of these regulations can be obtained from the U.S. Environmental Protection Agency (USEPA), state, county, and local resources.

Descriptions of current federal laws, regulations, and proposed rules can be found on the USEPA laws and regulations home page:

http://www.epa.gov/epahome/lawreg.htm

2.5. Highway Stormwater Monitoring Goals

The stormwater monitoring goals should have a specific effect on the scope of any monitoring effort. The following sections examine the most common objectives for stormwater monitoring in the near-highway environment including specific guidance on monitoring approaches and equipment to assist in meeting the goals. The following potential objectives are discussed:

- monitoring to estimate pollution concentrations and loads;
- monitoring to identify stormwater pollutant sources;
- monitoring to characterize stormwater quality trends;
- monitoring to evaluate BMP performance; and
- monitoring to assess compliance with surface water quality criteria.

Each section can help to develop the combination of monitoring locations, frequency, parameters, and methods that are best suited to specific data needs and resources.

2.5.1. Monitoring to Estimate Pollutant Concentrations and Loads

This section provides guidance on stormwater monitoring to estimate pollutant concentrations and loads. The sections below discuss the key considerations associated with program development and implementation.

2.5.1.1. Determine Objectives And Scope

Information on stormwater pollutant concentrations and pollutant loads may be used for a variety of purposes including:

- participation in a watershed-based monitoring program or permitting effort;
- watershed management planning;
- source pollution assessment;
- other stormwater management needs;
- assessment of parameters of concern; and
- calculation of pollutant loading for TMDL development or compliance.

Developing specific, realistic approaches to achieve monitoring objectives is essential.

2.5.1.2. Develop Monitoring Plan

The following sections provide guidance on developing a specific approach to achieving monitoring objectives.

Select Monitoring Locations

The number of locations to be monitored depends on specific program objectives, regulatory requirements (if applicable), the size and complexity of the drainage watersheds and conveyance system, and the budget allocated to monitoring. In addition, the frequency of sampling at each location should be considered.

While some programs sample at a minimum number of sites mandated by a regulatory program, others monitor additional locations because the results help support critical decisions in the stormwater management planning process. If the highways in the study area are large and complex and differ in design and other factors expected to affect water quality, there may not be sufficient resources to conduct a monitoring program that will allow development of reliable estimates of pollutant concentrations and loads for every outfall. For this reason, most programs collect data at a few selected stations and extrapolate these data to develop estimates of water quality and pollutant loads for a larger area.

The first step in applying this approach is to review watershed characteristics and drainage system information. Based on this review, locations that are representative of highway types and watersheds in the monitoring area should be selected.

Some programs use stations that monitor relatively small catchments that have fairly homogeneous characteristics (grade, material type, etc). Data may then be extrapolated to represent catchments within the project area that are believed to have similar sources and pollutant-generating mechanisms. Other programs use stations that sample relatively large highway catchments representing a composite area of highway sections and types. These stations are typically located in streams or other stormwater conveyances toward the lower end of a highway watershed to collect samples that are indicative of runoff quality from the larger area.

When using the extrapolation approach, it should be noted that although many previous studies [e.g., USEPA, 1983: Driscoll et al., 1990] have identified correlations between stormwater quality and watershed characteristics (e.g., land use), the correlations were not very strong. In addition, there are several factors that can result in different runoff water quality from the same land use. These factors include differences in watershed size, seepage, slope, and time of concentration. Adjacent land use and activities (e.g., being near metal smelters) can impact dustfall and consequently runoff water quality. Thus, extrapolation of data to represent other watershed locations may not provide the most realistic basis for estimating cumulative pollutant loads from the drainage system. However, despite its limitations, extrapolation of results from a small watershed to a larger area is often the chosen alternative and may represent the only viable approach.

Select Sampling Frequency

Because of the variation in the concentration of pollutants observed between storms, even at a single sampling station there will generally be a need to monitor at least five storm events to obtain reasonably representative results. A statistical analysis may be conducted to estimate how many events need to be monitored to achieve various confidence levels.

To perform a power analysis, one will need to determine the magnitude of the change desired to be detected; the confidence level; and the statistical power, or probability of detecting a difference. As a starting point, the confidence level and power should be set at 95% and 80% respectively; under these conditions, there is a 5% chance that a significant change will be reported where none exists, and a 20% chance that a significant change will be missed. The power analysis is discussed in detail in Appendix A.

The power analysis often shows that many samples would be needed to discern a small (e.g., 25%) change. In such cases, a determination should be made as to whether overall objectives can be met without detecting small changes. If available resources prohibit the frequent monitoring of all locations, then reducing the number of locations or parameters may be necessary. It is recommended that statistical confidence in the results of the monitoring program be considered of higher importance than collecting information at a larger number of locations or obtaining detailed analytical results for a large number of water quality parameters.

Select Parameters and Analytical Methods

Monitoring studies requiring estimates of pollutant loads and concentrations typically include the following parameters.

Conventional Parameters

Total Suspended Solids (TSS)
Total Dissolved Solids (TDS)
Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Total Hardness
Fecal Coliform Bacteria
Oil and Grease
Total Petroleum Hydrocarbons (TPH)
pH

Temperature

Nutrients

Total Kjeldahl Nitrogen (TKN-N)
Ammonia Nitrogen (NH_3-N)
Nitrate+Nitrite (NO_3-N + NO_2-N)
Total Phosphate
Ortho-Phosphate

Heavy Metals (Total and Dissolved)

Cadmium (Cd)
Copper (Cu)
Lead (Pb)
Zinc (Zn)

The above list may serve as a starting point for establishing a monitoring program.

If significant monitoring has already been done in the area, consideration should be given to deleting some or all parameters that were shown to be consistently below levels of concern. It may be necessary to monitor additional parameters, depending on the regulatory framework of the monitoring program. Once the parameters for monitoring have been selected, the analytical detection limits needed to meet data quality objectives must be determined. For example, when comparing runoff water quality to acute aquatic criteria, low metals detection levels often are required.

<u>Select Monitoring Methods</u>

Flow-weighted composite sampling is often preferred for all parameters, except those that are likely to transform rapidly (fecal coliform or other human pathogens) or adsorb to sample containers (oil and grease). Grab sampling is required for these parameters. The flow-weighted composite samples are typically collected during the entire period of discharge if this is possible. If a large number of monitoring locations (>5) are needed and flow-weighted composites are desired, use of automated monitoring methods is recommended. Because stormwater quality can vary dramatically during a storm event, a single grab sample will not provide a good basis for estimating pollutant concentrations or loads. Most monitoring programs will probably need to either analyze a series of grab samples collected at intervals throughout the storm, or analyze a single flow-weighted composite sample collected throughout the storm. The latter alternative is generally far less expensive than the former.

It is possible to collect flow-weighted composite samples using manual methods, but this is generally impractical if there are more than a few stations to monitor. Moreover, manual monitoring can be more costly than automated monitoring if the program encompasses more than a few storm events. For these reasons, many monitoring programs have found that using automated monitoring equipment and methods is more appropriate than manual monitoring. Details about selecting specific monitoring equipment are provided in Section 3.

<u>Select Storm Criteria</u>

The application requirements for NPDES permits that require monitoring specify that “representative” storms must be monitored. As defined in the regulations, a “representative” storm must yield at least 0.1 inch of precipitation; must be preceded by at least 72 hours with less than 0.1 inch of precipitation; and, if possible, the total precipitation and duration should be within 50% of the average or median storm event for the area. Programs that are not part of the NPDES permit application process or in fulfillment of an NPDES permit may have other requirements.

In general, it is desirable to monitor a broad range of storm conditions rather than just "representative" storms. For example, in the Pacific Northwest it is often difficult (and rare) to identify storms where there has been a 72-hour dry period prior to the storm.

2.5.2. Monitoring to Identify Stormwater Pollutant Sources

This section provides guidance on stormwater monitoring to identify sources of stormwater pollutants. The following sections discuss the key considerations associated with each phase of plan development and implementation.

2.5.2.1. Determine Objectives and Scope

One objective of some stormwater monitoring programs is to obtain information on stormwater pollutant sources. Monitoring for source identification is usually performed after monitoring at a downstream area of a watershed or catchment has shown strong evidence of a water quality problem. Thus, source identification monitoring is often the second phase in a two-phase monitoring program; the first phase may have involved one or more of the following:

- monitoring to estimate pollutant concentrations and loads (discussed in Section 2.5.1);
- sediment monitoring;
- dry-weather inspections; and
- biological monitoring.

The scope of the source identification monitoring is usually based on the results of initial monitoring to estimate concentrations and/or loads. If the initial monitoring finds significant pollutant concentrations and/or loads, follow-up monitoring may be required to identify and prioritize the sources. On the other hand, if the initial monitoring did not reveal any significant stormwater pollution, there may be little reason to conduct source identification monitoring.

The results of the previous studies that triggered the source identification study should be carefully reviewed. Reviewing the literature for information on typical sources of the observed pollutants is also recommended. Land use data should be examined for the catchment area(s) where the pollution was observed to identify potential sources. A visual survey of the area should be conducted to identify any obvious sources of the observed pollution. The findings of source identification studies in other areas should be reviewed, and local conditions and initial observations should be discussed among peers and stormwater professionals. In some cases, the likely source(s) of a particular problem may be easily identified. Follow-up monitoring can be used to confirm initial findings.

Source identification monitoring programs may be used for a variety of purposes including:

- compliance with permits;
- watershed management planning;
- non-point source assessment;
- source control; and
- illicit connection identification.

2.5.2.2. Develop Monitoring Plan

The following sections provide guidance on developing a specific approach to identify stormwater pollutant sources.

<u>*Select Monitoring Locations*</u>

The number of locations to be monitored depends on the size and complexity of the drainage basin(s), the number of pollutant sources present, and funds allocated to monitoring. In addition, the frequency of sampling at each location should be considered.

The typical approach for selecting monitoring locations is summarized below.

- Review the results of previous monitoring to identify the locations that had pollutant concentrations near or above their respective water quality criteria. List the specific pollutants of concern associated with each of these monitoring locations. Review the published literature to identify the typical source(s) for each pollutant of concern. Review available information for each catchment area and identify any likely source areas for the observed pollutants.

- Conduct wet- and dry-weather inspections of the stormwater conveyance system in each catchment area with an identified water quality problem.

- Conduct stormwater monitoring. Select monitoring locations upstream and downstream of the likely potential source areas identified in Step 1. If limited resources and/or logistical constraints make it impractical to monitor every location, monitor upstream and downstream locations that "bracket" a number of sources. Alternatively, rank the potential source areas with regard to pollutant concentrations/loads observed in prior sampling, proximity to sensitive receiving waters, and other factors that may indicate their relative importance. Then select monitoring locations according to their priority.

- Monitor at each location. Generally, at least three or four storms will need to be monitored. However, if major differences in upstream and downstream water quality are found during the first storm or two, additional monitoring may not be necessary.

- Review the analytical results. Compare each station to its adjacent upstream station. If the downstream station exhibits higher concentrations and/or loads, this may indicate that pollutants are entering the channel between the two stations.

- Visually inspect the channel segment between the two stations. If there is an outfall in the segment, determine what activities occur within the catchment that drain to that outfall or the contributing watershed and determine whether they may account for the observed pollutants. If a tributary drainage channel enters the main channel within the segment, visually inspect the tributary channel for potential sources and monitoring locations. Continue this process until the probable source(s) of the observed pollutant(s) have been identified.

In general, choose monitoring sites that are as close as possible to the suspected sources. This approach will reduce the chance that pollutants released from the source will be masked or diluted during monitoring. Additionally, select locations where sampling and flow measurement can be conveniently and safely obtained. If it is not possible to monitor all sites, select those locations that align with the highest priority information needs.

Select Sampling Frequency

Source identification monitoring does not typically require long-term monitoring of numerous storms. In general, monitoring should be halted once the key source(s) of the pollutant(s) of concern are identified. Once a key source has been identified, the focus should be on implementing control measures rather than continued monitoring.

Some stormwater pollutant sources may be major contributors in one storm and minor contributors in the next. Therefore, a potential source should not be ruled out based on the results from a single storm event. To reduce the chance of overlooking significant sources, monitor at least three or four storms that encompass a range of conditions and seasons. Try to monitor during the early portions of the first storm that occurs after a prolonged dry period, as this often represents the "worst-case" scenario. If there is a major source within a given drainage area, it will most likely be identified while the flow rate is increasing during the storm's early stages or during high intensity periods of the storm.

Select Parameters and Analytical Methods

As noted above, source identification monitoring is typically conducted only after stormwater pollution has been identified through prior monitoring. Source identification monitoring usually focuses on those pollutants measured near or above their respective levels of concern (e.g., water quality criteria) in previous samples. It is not generally necessary to monitor parameters that appear consistently below their levels of concern, unless there is reason to believe that some easily monitored constituent is strongly correlated with a pollutant of concern that is difficult or costly to monitor.

Once the parameters for monitoring have been selected, the analytical detection limits needed to meet data quality objectives must be determined.

Select Monitoring Methods

Although use of either grab or composite sampling, and manual or automatic collection (or a combination of these methods) are appropriate techniques, this document specifically addresses selecting and using automated equipment aimed at collecting flow weighted composite samples. This section is intended to aid in the decision-making process during the program development stage.

Typically, the two basic choices for source identification monitoring are collecting a single grab sample and collecting a flow-weighted composite sample. Another possible approach is to collect a series of grab samples at intervals during a storm and analyze them individually; however, this approach is seldom used because it is much more expensive than the typical approaches. Finally, a series of grab samples could be allocated and composited, but not flow- or time-averaged. The advantages and disadvantages of the single grab and flow-weighted composite approaches are summarized below.

Single Grab Sample

A single grab sample collected during "first flush" or high intensity conditions, when pollutant concentrations are expected to be at their highest, can be used to identify stormwater pollution sources. This approach has several advantages when compared to flow-weighted composite sampling.

- It can be done using either manual or automated methods.
- It is suitable for any parameter.
- It is not necessary to sample the entire duration of the storm.
- Continuous flow measurement is not required.
- Generally, neither equipment installation or channel modifications are required, so it is easy to move to new locations as necessary to track down a source.

The single grab sample approach also has several disadvantages.

- Peak pollutant concentrations do not always coincide with the "first flush," especially in areas subject to frequent, low-intensity storms.
- In large basins, peak pollutant concentrations may occur during peak flow, which could occur any time during the storm. This makes it difficult to collect a single grab sample from the expected "worst-case" portion of the storm event.
- Depending on the location of the pollutant sources relative to the monitoring site, the runoff from a contaminated source area may not be present in the "first flush."

Flow-Proportional Composite Sample

A flow-proportional composite sample collected during the entire duration of a storm can be used to identify stormwater pollution sources. This approach has advantages when compared to the single grab sample approach.

- It is less likely to omit a source due to stormwater quality changes during the storm.
- The results provide a better indication of the relative importance of a source than does a single grab "snapshot."

Flow-proportional composite sampling also has disadvantages.

- Manual flow-proportional composite sampling is generally impractical if there are more than a few stations to monitor.
- Automated equipment is costly to buy and install and it requires frequent inspection and maintenance. Since source identification monitoring at any given location is usually a short-term program, automated equipment may need to be moved from place to place to track a pollutant to its source. Some of the automated methods and equipment allow for a mobile "package station" to be set up for easier movement of equipment.

Some monitoring programs are set up to collect composite samples only during the initial portion (e.g., the first three hours) of a storm runoff event. This alternative is generally less labor-intensive than monitoring the full storm because it reduces equipment calibration time and the risk of unacceptable samples (due to overfilling or underfilling of bottles, capturing less than 60% of the storm, failing to collect enough material to conduct analytical tests, etc). However, this approach would not discern any elevated contaminant concentrations that could occur during the later stages of a storm as a result of increased rainfall intensity, and possibly from contributions from pervious areas and/or contributions from distant portions of the catchment area.

Select the best approach for the specific situation based on the advantages and disadvantages described. Most source identification programs rely on grab sampling because it is generally more cost-effective and more flexible than flow-proportional composite sampling. In order to increase the potential for grab sampling to detect sources, consider collecting multiple grab samples throughout the storm event and then compositing them on an equal basis.

Details about selecting specific monitoring equipment are provided in Section 3.

2.5.3. Monitoring to Characterize Stormwater Quality Trends

This section describes how to develop and implement a monitoring program to detect water quality trends or changes in pollutant levels over time. Trend analysis can be an important and powerful tool in demonstrating benefits of stormwater pollution control and/or the effects of increasing urbanization. This type of monitoring program may be appropriate for assessing the overall effectiveness of a stormwater pollution control program. The following sections discuss the key considerations associated with each phase of the monitoring plan development and implementation.

2.5.3.1. Determine Objectives and Scope

Readers of this section likely will have concluded (at least tentatively) that general monitoring objectives should include an evaluation of the effectiveness of stormwater pollution control programs through an analysis of long-term trends in stormwater quality. Trend analysis may be an objective of a monitoring program to fulfill permit requirements, or it may be performed voluntarily to provide information to demonstrate program effectiveness and support planning decisions or permit negotiations. This type of monitoring is sometimes the only practical approach for assessing source control best management practices (BMPs) and many smaller structural BMPs in a watershed (e.g., input/output monitoring is impossible or difficult at best).

Even in cases where the minimum monitoring requirements do not include trend analysis, the potential merits of trend analysis should be reviewed to determine whether it might provide useful information. Specific monitoring requirements should also be reviewed to determine whether the information provided is sufficient to support management decisions. These requirements may or may not have been based on information relevant to site-specific conditions. If a minimum monitoring program does not collect adequate data to allow statistically verifiable confidence in the results, there is little basis for any conclusions regarding the effectiveness, or lack thereof, of a stormwater quality management program.

Trend analysis generally requires monitoring a large number of storms in order to distinguish real changes in stormwater quality from natural variability or "noise." A power analysis should be performed using existing data in the watershed or from sites evaluated to be similar to help determine the monitoring frequency for your program. (Power analysis is described in detail in Appendix A.)

At this point specific, realistic monitoring objectives need to be developed. Section 2.5.3.2 should be reviewed to develop the combination of monitoring locations, frequency, parameters, and methods best suited to data needs and resources. While reviewing these sections, the following general process should be followed:

1. If enough data are available for a power analysis, perform the analysis (step 2); if not, plan to collect sufficient data to permit a power analysis.

2. Perform power analysis.

2a. Establish desired statistical confidence interval (typically 90 or 95% confidence in the mean value).

2b. Establish desired sensitivity.

3. Evaluate results of power analysis.

3a. Is a monitoring plan for trend analysis feasible based on recommendations of power analysis? If the answer is yes, go to Step 4.

3b. Are lower confidence limits or cruder sensitivity acceptable? If the answer is yes, adjust confidence limits and/or sensitivity of the power analysis and return to Step 2.

4. Does the existing program satisfy the sampling frequency and number suggested by the power analysis?

4a. If the answer is yes, develop a monitoring plan.

4b. If the answer is no, adjust the monitoring plan to fulfill sampling requirements suggested by the power analysis or change monitoring plan objectives.

Steps 1 through 3 involve power analysis, which is a statistical tool that can be used to ensure that the number of samples is sufficient to enable detection of a trend, with a specified level of statistical confidence. (Power analysis is described in detail in Appendix A.) It is used to determine the number of samples required achieving a desired level of statistical confidence. The desired level of confidence may be achieved by increasing the number of sample locations and/or the number of samples collected at each location depending on the sampling approach.

To reduce the cost of an extensive monitoring program, the sampling program could be limited to analysis of a few indicator parameters. Parameters such as turbidity and conductivity can be monitored continuously with automatic field probes at reasonable costs. These parameters are sometimes good indicators of pollutant levels (especially of metals). Whether these parameters are good indicators of the target parameters (chemicals of concern) can be confirmed by collecting samples for laboratory analysis during a number of storms and performing regression analyses. This approach has limited value, as it would likely be necessary to collect a large number of storms to establish the relationships, and then after BMP implementation the process may have to be repeated, as these relationships will change. A more straightforward approach would be to sample for a few constituents throughout the study (e.g., TSS, copper, zinc, and total phosphorous).

2.5.3.2. Develop Monitoring Plan

The following sections provide guidance on developing a specific approach to achieving monitoring objectives.

<u>Select Monitoring Locations</u>

Ideally, a trend analysis program should encompass all stormwater outfalls that leave the study area. However, staff and budget constraints may preclude monitoring every outfall at the optimum frequency; if the study area is large and complex, available staff and funding may be insufficient to monitor every catchment. If locations for a trend analysis are not specified in a permit, a sufficient number of locations should be chosen to adequately assess overall water quality.

Consider locations where:

- the effectiveness of basin-wide programs can be assessed; or
- the effectiveness of programs targeted to a specific basin or type of basin can be assessed.

Trend analysis generally requires monitoring a large number of storm events. Thus, if available resources are limited, only a few locations may be able to be monitored (the extrapolation approach described in Section 2.5.1.2 applies to trend analysis monitoring). The representativeness of one location may be established using the results of monitoring at several locations. For the purposes of statistical hypothesis testing, a control location must also be sampled unless pre-implementation monitoring of the catchment is conducted.

The number of required locations and samples may be balanced by reducing the number of parameters to be analyzed, or by identifying an indicator parameter that is amenable to continuous field monitoring. For trend analysis, the monitoring locations should be generally at stations located in the lower portion of a watershed that are fairly representative of the larger drainage basin. If previous data are available, select a monitoring location with relatively high pollutant loads. This will make any reductions due to management practices easier to detect by the statistical sampling design.

<u>Select Sampling Frequency</u>

A power analysis is particularly appropriate for determining the number of samples (i.e., storms) that will need to be monitored to detect a water quality trend. The power analysis may indicate that a large number of storms would need to be monitored to satisfy program objectives. If this is the case, the number of monitoring locations should be reduced. Alternately, using continuous monitoring for indicator parameters (such as turbidity or dissolved oxygen) might be considered; this approach may allow monitoring of a much larger number of storms than would be possible using traditional sampling and laboratory analysis.

The number of events to be sampled for trend analysis may be set by the power analysis, or may be determined by what is feasible, balancing the needs of compliance monitoring with those of trend monitoring. However, if collecting a sufficient number of samples is not possible, it may prove difficult to discern trends. Sampling for trend analysis need not be annual. A frequency convenient for the permittee (e.g., once every permit cycle or every five years) may be used to acquire the needed data. Thus, it may be more cost-effective to conduct an intensive sampling effort every five years rather than a less intense annual program.

The number of samples set by the power analysis accounts for the variability in the concentration of pollutants observed between storms, even at a single sampling station. It is recommended that this number of samples be collected over as long a period as necessary. An attempt should be made to collect samples during different times of the year to account for seasonal variations in pollutant concentrations.

Select Parameters and Analytical Methods

In most cases, a sampling program for the analysis of long-term trends in water quality will be relatively narrow in scope, focusing on parameters that have been shown, through stormwater quality characterization studies, to occur in concentrations that impact water quality. Once the parameters for monitoring have been selected, the analytical detection limits needed to meet data quality objectives must be specified.

Select Monitoring Methods and Equipment

General considerations for the choice of monitoring methods and equipment are discussed in detail in Section 2.5.2.2. After considering the arguments for grab versus composite, and manual versus automated approaches to sample collection, choose a method or combination of methods consistent with program goals. In general, composite sampling is much superior to grab sampling for long-term trend analysis, except for those parameters for which composite sampling is not appropriate (e.g., oil and grease, TPH, bacteria). Details about selecting specific monitoring equipment are provided in Section 3.

Select Storm Criteria

As discussed in Section 2.5.2.2, it is generally desirable to monitor a broad range of storm conditions, rather than just the USEPA defined "representative" storms. This is particularly applicable to trend analysis, since monitoring only the so-called representative storms may introduce bias. If use of continuous monitoring of indicator parameters is feasible, data from all storms should be included in trend analyses.

2.5.4. Monitoring to Evaluate Individual Best Management Practice (BMP) Performance

Many studies have been conducted to assess the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in stormwater. However, these individual BMP evaluations have utilized a broad spectrum of methods and reporting procedures. These inconsistencies complicate, if not prohibit, comparisons of the findings of different studies. The studies have included the analysis of different constituents and different methods for data collection and analysis. These differences alone contribute significantly to the range of BMP effectiveness reported, which complicates assessment of other factors that may have contributed to the variation in performance. In addition, removal efficiencies are increasingly being questioned as an appropriate measure of performance since the removal. The efficiency appears to be mainly controlled by the influent concentration.

Typically, structural BMPs have well-defined boundaries and are generally relatively easy to monitor. Other types of BMPs, especially non-structural BMPs (e.g., street sweeping, catch basin cleaning, sewer cleaning, illicit discharge elimination), are more difficult to monitor; partly because they tend to be geographically interspersed with many pollutant sources and can be influenced by many factors that cannot be "controlled" in an experimental sense. Some non-structural BMPs, such as public education programs, oil recycling programs, and litter control programs are virtually impossible to monitor or at best can be evaluated using trend monitoring as described in Section 2.5.3.

This section provides guidance on monitoring well-defined structural BMPs. It is assumed that many stormwater quality management programs will want to consider the possibility of implementing some structural BMPs, but would be inclined to experiment with them on a pilot-scale by testing and demonstrating their performance, costs, and practical implications before committing to larger-scale implementation. Programs that already have structural BMPs in place may also want to test their performance for a variety of reasons.

2.5.4.1. Determine Objectives and Scope

Studies of BMP performance are usually conducted to obtain information regarding one or more of the following questions:

- What degree of pollution control or effluent quality does the BMP provide under normal conditions?
- How does this performance vary from pollutant to pollutant?
- How does this normal performance vary with large or small storm events?
- How does this normal performance vary with rainfall intensity?
- How do design variables affect performance?
- How does performance vary with different operational and/or maintenance approaches?
- Does performance improve, decay, or remain stable over time?
- How does this BMP's performance compare with the performance of other BMPs?

BMP performance monitoring has been prescribed by some permits, but often the wording of such requirements is vague. Local program-specific objectives are likely to be the soundest basis for planning a BMP monitoring study.

Nationally many stormwater programs need BMP performance data, and many are planning or conducting performance monitoring. The concept of sharing monitoring results is very appealing but could be seriously constrained if pre-planning to maximize the chances of yielding comparable/compatible monitoring approaches, analytical protocols, and data management is not implemented. Some of the guidance provided in this manual and referred to in literature citations is intended to stimulate the users of this manual to expand their thinking and look for ways to broaden their program's objectives to facilitate exchanges of more transferable data among programs.

As an example, in a review of the use of wetlands for stormwater pollution control (Strecker et al., 1992), a summary of the literature was prepared regarding the performance of wetland systems and the factors that are believed to affect pollutant removals. The studies reported in the reviewed literature were inconsistent with respect to the constituents analyzed and the methods used to gather and analyze data. Several pieces of information were improperly collected and recorded, which decreased the ability to evaluate the effectiveness of stormwater wetlands as BMPs. Furthermore, the lack of such basic information limits the transferability of the studies' findings into better design practices.

The technical literature has many reports of monitoring programs to evaluate BMP performance. Those that address some of the conceptual and strategic aspects of monitoring (e.g., Strecker, 1994; Urbonas, 1994) could be of particular value during this planning stage. In addition, USEPA and the American Society of Civil Engineer's Urban Water Resources Research Council have compiled a National Stormwater Best Management Practices Database (on the world wide web at www.bmpdatabase.org). The purpose of this effort is to develop a more useful set of data on the effectiveness of individual BMPs used to reduce pollutant discharges from urban development. A review of the protocols established for the database is useful in determining what and how information should be collected and can be used for improving information collected for local use.

It is also valuable to review the monitoring methods and findings of other reported programs, because they may contain concepts (or even data) that are transferable to your situation. In considering the use of data collected elsewhere, critical attention should be paid to differences that might lead to erroneous conclusions (e.g., weather, soil types, role of specific sources of pollutants). Particular care should be taken to avoid the types of errors that are often introduced by assuming (rather than determining) that certain pollutants are associated with certain sediment fractions. The association of pollutants with particular particle sizes is very important (in fact, this association is the reason that most BMPs are effective), but this association varies dramatically from place to place and must be determined based on careful local studies of relevant factors—not simply assumed from other studies. When using data from relatively early studies, it is important to consider the fact that the state of the art of analysis has advanced considerably in the past decade or so; for example, many data entries recorded as "non-detect" may no longer be relevant.

2.5.4.2. Develop Monitoring Plan

The following sections provide guidance on developing a specific approach to achieving monitoring objectives.

<u>*Select Monitoring Location*</u>

Care must be taken to locate flow measurement and sampling sites in places that are likely to yield good data over diverse operational conditions. For performance monitoring approaches that are intended to compare changes in pollutant loads (i.e., "loads in" versus "loads out" of the BMP), it is especially important to use accurate flow measurement methods and to site the points of measurement at locations that maximize the attainment of credible data. The added cost of a weir or flume may be justifiable because without it measurement errors could propagate through various aspects of the analysis.

<u>*Select Monitoring Frequency*</u>

The frequency with which monitoring should be performed will depend upon a program's specific objectives and the degree of accuracy needed. To address the latter, compare the cost of learning more (i.e., conducting more intensive monitoring) versus the cost implications of moving forward too far and implementing extensive controls before having learned enough to guide planning, stormwater management commitments, and/or negotiations with regulatory agencies. The cost of controlling unimportant pollutants and/or unimportant sources, or implementing ineffective BMPs, could easily exceed the cost of monitoring to learn more about actual BMPs, performance under the conditions that prevail in a system. Clearly, there is a need for balance. Endless studies should not be substituted for control actions.

In general however, many measurements (i.e., many samples collected during many events) are necessary to obtain enough data to be confident that actual BMP performance is observed and not just "noisy" data (e.g., variability artifacts caused by external factors, equipment and operator errors). Consequently, BMP effectiveness studies can be expensive and time-consuming.

Select Parameters and Analytical Methods

Under ideal circumstances, a given BMP will be targeted toward controlling a well-defined, locally important problem caused by a particular pollutant or combination of pollutants. When selecting parameters for performance monitoring, it follows that one would probably look for changes in concentrations (and/or loads) of the target pollutant(s), or would look within the BMP to examine accumulations of the target pollutant(s). In cases where it is known that there is a high degree of correlation between the concentration of the target pollutant(s) and some other parameter (e.g., fine particles, TSS, TOC), then it may be possible to use a less costly monitoring approach to track the substitute, or "proxy" parameter(s). Although this approach can introduce some uncertainty because it does not track the target pollutants, it is still worth considering. If the correlations are known to be strong and the cost differences pronounced, this strategy may provide a way to obtain much more data (i.e., more frequent observations during more storm events and/or at more locations). Such improvements in data quantity could more than offset the uncertainties introduced by imperfect correlations.

There are many precedents for using proxy parameters and indicators. For example, fecal coliform are bacteria often used as proxies for pathogens and as an indicator of fecal contamination. TOC and COD are sometimes used as proxies for BOD. Turbidity is commonly used as a proxy for suspended solids, which in turn, is sometimes used as a proxy for other pollutants of concern (e.g., metals, PAHs). It is important to remember that other factors could also account for observed changes in the proxy parameter relationship to other pollutants.

In many BMP monitoring programs, there are opportunities to obtain additional information at little or no incremental cost. Such information may turn out to be valuable to the overall stormwater program at some time in the future and/or to other programs.

Recommend Parameters

This section presents a recommended list of constituents for BMP monitoring. Strecker (1994), Urbonas (1994), and the ASCE Database website (www.bmpdatabase.org) provide more information on BMP monitoring parameters. The choice of which constituents to include as standard parameters is subjective. The following factors were considered in developing the recommended list of monitoring parameters:

- The pollutant is one that has been identified as prevalent in typical urban stormwater at concentration levels that could cause water quality impairment (as identified by USEPA 1983 and recent Municipal NPDES data).
- The analytical test is one that can be related back to potential water quality impairment.
- Sampling methods for the pollutant are straightforward and reliable for a moderately careful investigator.
- Analysis of the pollutant is economical on a widespread basis.
- The pollutant is one that might be controlled through practical BMPs rather than elimination of the source. (e.g., treating to remove pesticides downstream instead of eliminating pesticide use in the right-of-way)

Although not all of the pollutants recommended here fully meet all of the factors listed above, the factors were considered in making the recommendations. When developing a list of parameters to monitor for a given BMP evaluation, it is important to consider the upstream land uses and activities. Table 2.1 presents a list of suggested standard parameters for assessing the effectiveness of BMPs. It assumes that flow-weighted composite samples will be collected using automated procedures; thus, the table does not include parameters not amenable to this type of sampling, such as fecal coliform. The parameters recommended in Table 2.1 are generally present and are of concern in typical near-highway runoff. The table includes a typical cost for each of the tests.

The parameters listed in Table 2.1 represent the most basic arrangement of parameters. There may be appropriate applications where other parameters should be included. For a discussion of why some parameters were not included, see Strecker (1994).

Select Monitoring Methods and Equipment

BMP monitoring can be an especially useful application for some automated systems (e.g., continuous flow recorders, auto samplers, continuous monitoring probes) for the following reasons.

- Automated systems can provide data covering virtually the entire volume of runoff that passes through the BMP (i.e., they are not likely to miss or leave out small events and the beginnings and ends of other events).
- Automated systems are well suited to providing data sets that are useful (recognizing that performance evaluations are generally based on the differences between inlet and outlet concentration data sets, both of which are inherently noisy).
- The information obtained from good performance monitoring programs can be so valuable (by protecting against inappropriate BMP applications) that the cost of using automated systems is often justifiable.

BMP monitoring can also be performed using manual methods. Such methods are usually preferred under the following circumstances.

- Available resources for equipment purchase/installation (e.g., funds, personnel, time) are very constrained and/or there is not the political will to invest in a program, despite the inherent value of the resultant information.

TABLE 2.1
RECOMMENDED STANDARD ANALYTICAL TESTS FOR URBAN STORMWATER BMP ASSESSMENTS

Lab Analyses	Detection Limit
Conventional	
TSS	1 mg/l
BOD5	3 mg/l
COD	1 mg/l
Total Hardness	25 mg/l
Nutrients	
TKN – N	0.3 mg/l
NH3 – N	0.3 mg/l
Total phosphorus –P	0.05 mg/l
Ortho-phosphate – P	0.05 mg/l
Nitrate + nitrite (NO3 + NO2) - N	0.1 mg/l
Total Metals	
Cd (cadmium)	0.2 µg/l
Pb (lead)	1 µg/l
Cu (copper)	1 µg/l
Zn (zinc)	1 µg/l
Dissolved Metals	
Cd (cadmium)	0.2 µg/l
Pb (lead)	1 µg/l
Cu (copper)	1 µg/l
Zn (zinc)	1 µg/l

Source: Strecker, 1994

- The target pollutants are ones that do not lend themselves to automated sampling or analysis (e.g., oil and grease, volatile organic compounds, bacteria).

- The physical setting of the BMP does not allow the use of automated systems.

Details about selecting specific monitoring equipment are provided in Section 3.

Select Storm Criteria

The establishment and application of appropriate storm selection criteria can be a challenging aspect of planning BMP monitoring programs. Ideally, data should be obtained from all phases of all storms for as long a study period as possible, for the following reasons:

- It is desirable to know what the BMP does during periods of very low flow, normal flow, and very high flows. The performance of some BMPs varies dramatically with throughput rate. Some may even release pollutants that had been previously trapped.

- Performance must be estimated on the basis of differences between relatively noisy data sets (i.e., inlet versus outlet data) and intensifies the value of large volumes of credible data (not just a few samples from portions of a few storms).

- For some BMPs with significant wet storage and/or base flows it is important to characterize the water quality of dry weather flows as well. This is particularly important when the wet volume of the BMP is large relative to the storm event. The comparison of inflow to outflow during a storm event is not valid because the outflow may have had little or no relationship to the incoming storm. This mistake has been made often in past studies.

Despite the desire for extensive and high quality data, there is still a need to tailor program methods to be consistent with available resources.

2.5.5. Monitoring to Assess Compliance with Surface Water Quality Criteria

This section provides guidance on stormwater monitoring to assess compliance with surface water quality criteria for protection of human health and aquatic life. The section begins with an overview of surface water quality criteria. The section then shows how the general approach to stormwater quality monitoring can be applied to compliance monitoring. Sections 2.5.5.1 and 2.5.5.2 discuss the key considerations associated with each phase of program development and implementation.

In addition to surface water quality standards, stormwater discharges may affect compliance with standards for groundwater quality and/or marine sediment quality. However, stormwater monitoring is typically of limited value with regard to assessing compliance with groundwater and/or sediment quality standards. Compliance with the groundwater standards is generally assessed through groundwater monitoring (rather than stormwater monitoring) because stormwater quality is likely to change substantially while percolating through soils, and the extent of the change is very difficult to predict without a great deal of site-specific information. Similarly, compliance with sediment quality standards is generally assessed through sediment monitoring within receiving water bodies. This is because numerous storms would need to be monitored to develop useful estimates of total annual sediment loads, and the particulate portion of each sample would need to be divided into particle size fractions prior to chemical analysis to allow even a qualitative evaluation of potential sediment transport/deposition. For these reasons, this manual does not address stormwater monitoring to assess compliance with groundwater or sediment quality standards.

Overview of Water Quality Criteria

USEPA describes water quality criteria and their relationship to water quality standards in the following paragraphs:

“Water quality standards are laws or regulations that the States adopt to enhance and maintain water quality and to protect public health. Water quality standards provide the foundation for accomplishing the goals and objectives of the Clean Water Act. More specifically, water quality standards help to:

Restore and maintain the chemical, physical and biological integrity of the Nation's waters; and,

Where attainable, achieve water quality that promotes protection and propagation of fish, shellfish and wildlife and provide for recreation in and on the water. This goal is commonly known by the expression "fishable and swimmable"; and,

Prohibit the discharge of toxic pollutants in toxic amounts; and,

Eliminate the discharge of pollutants to navigable waters.

Water quality standards apply to surface waters of the United States, including rivers, streams, lakes, oceans, estuaries and wetlands. Water quality standards consist, at a minimum, of three elements: 1) the "designated beneficial use" or "uses" of a waterbody or segment of a waterbody; 2) the water quality "criteria" necessary to protect the uses of that particular waterbody; and 3) an antidegradation policy. Typical designated beneficial uses of waterbodies include public water supply, propagation of fish and wildlife, recreation, agricultural water use, industrial water use and navigation. Water quality criteria describe the quality of water that will support a given designated use. Under authority of section 304 of the Clean Water Act, USEPA publishes, on an advisory basis, water quality "criteria" that reflect available scientific information on the maximum acceptable concentration levels of specific chemicals in water that will protect aquatic life or human health.

These criteria are intended to provide protection for all surface waters on a national basis and may be used by the States for developing enforceable water quality criteria that protect the designated use as a part of their water quality standards. When properly selected criteria are met, they are expected to protect the designated use with a margin of safety. The antidegradation policy ensures that existing water quality is maintained and protected. States use criteria developed by USEPA under section 304 to adopt enforceable maximum acceptable concentration levels of a pollutant in ambient waters. The water quality criteria adopted into a State water quality standard may or may not be the same number published by USEPA under section 304. States have the discretion to adjust the section 304 criteria to reflect local environmental conditions and human exposure patterns or to derive a criterion from an independent methodology as long as it is scientifically defensible. Water quality criteria can also be expressed in either numeric form or narrative form by the States in their water quality standards. USEPA reviews and approves State water quality standards every three years. To date, virtually all States have narrative and numeric water quality standards that protect human health and aquatic life from exposure to some chemicals and conditions in the water, including toxic and bioaccumulative pollutants. However, few States have adopted numeric criteria for biological integrity, excessive nutrient enrichment, excessive sedimentation, wildlife protection or flow control" (USEPA, 1998).

Water quality standards may include bacteria, dissolved oxygen, temperature, pH, turbidity, and toxic organic and inorganic compounds in marine and freshwater bodies.

State Water Quality Standards (WQS) often are based on Federal Water Quality Criteria (WQC) for the protection of human health and aquatic life (40 CFR 131.36). However, Federal WQC may include additional compounds not listed in WQS.

Note that WQC are considered guidelines, whereas WQS constitute enforceable regulations. In this section, WQC is used to encompass both state standards and the Federal guidelines.

There are two general categories of water quality criteria: aquatic (or marine) criteria, and human health criteria. These are summarized below.

Criteria for the Protection of Aquatic/Marine Life

Criteria for the protection of aquatic and marine life were developed based on laboratory toxicity tests with representative organisms using test solutions spiked with pollutants to simulate exposure. In order to apply the results of these tests, USEPA has classified aquatic life standards as either "acute" or "chronic" based on the length of time the organisms are exposed to listed concentrations.

Criterion maximum concentrations (CMC - acute) are intended to protect against short-term exposure. Criterion continuous concentrations (CCC - chronic) are designed to protect against long-term exposure. In deriving the acute criteria, the laboratory organisms were exposed to pollutant concentrations for 24 to 48 hours. USEPA suggests one hour as the shortest exposure period that may cause acute effects and recommends the criteria be applied to one-hour average concentrations. That is, to protect against acute effects, the one-hour average exposure should not exceed the acute criteria. USEPA derives chronic criteria from long-term tests that measure survival, growth, reproduction, or in some cases, bioconcentration. For chronic criteria, USEPA recommends the criteria be applied to an averaging period of four days. That is, the four-day average exposure should not exceed the chronic criteria.

WQC for aquatic life were developed based on an allowable exceedance frequency of once every three years, based on the theory that an ecosystem is likely to recover from a brief water quality exceedance, provided it does not occur very often.

Human Health

Water quality standards for the protection of human health contain only a single concentration value and are intended to protect against long-term (chronic) exposure. For carcinogenic compounds, a lifetime exposure over 70 years is generally used to calculate the criteria. For noncarcinogens, exposure periods are more chemical-specific and depend on the particular endpoint and toxic effect.

USEPA has defined two levels of protection for human health criteria. The first criteria were derived based on cumulative risks associated with drinking water and eating organisms that live in the water. The criteria for carcinogenic compounds is the calculated water-column concentration that would produce a one in a million (10^{-6}) lifetime cancer risk if water were consumed and a given amount of organisms from that water was eaten every day. The second criteria are based on consumption of organisms alone (the water is not consumed). These standards apply to saltwater or other water that is not a drinking water source but does support a fishery that is used as food. The organism's only standard for carcinogenic compounds is the calculated water concentration that would produce a one in a million (10^{-6}) lifetime cancer risk if a person were to consume a given amount of fish or shellfish from that water body (without drinking the water).

Application of Water Quality Criteria to Stormwater

The WQC are intended to protect the beneficial uses of streams, lakes, and other receiving water bodies. Most of the man-made conveyances within a near-highway stormwater drainage system do not support these beneficial uses. Thus, monitoring to assess compliance with WQC is usually conducted in a receiving water body (rather than in the stormwater conveyance system that discharges into it) to provide a direct measure of whether the beneficial uses of the water body are impaired or in danger of becoming impaired.

Direct comparisons between stormwater quality and the WQC should be interpreted with caution because such comparisons do not account for mixing and dilution in the receiving waters or the effects of receiving water hardness levels on heavy metals. This is especially true when the stormwater discharge is very small relative to the receiving water body.

The variable nature of stormwater quality further complicates comparison to WQC. Stormwater quality varies both between storm events and during a storm event, so it is very difficult to extrapolate data from one storm to another or to generate statistically representative data for all types and combinations of storms.

In spite of the limitations mentioned above, comparisons between stormwater quality and WQC can provide valuable information for stormwater management. WQC can be used as screening criteria, or "benchmarks" for assessing stormwater quality problems and establishing management priorities. Direct comparisons with the WQC can over-estimate the potential impact of the stormwater discharges on the receiving water bodies, because mixing and dilution are not taken into account. However, the relative frequency and magnitude of concentration exceedances within storm sewer systems higher than the WQC can help determine priorities for additional investigations and/or implementation of control measures. Frequently occurring, large exceedances are a clear indication that further investigation and control measures are warranted. Marginal or occasional exceedances are more typical and more difficult to interpret.

2.5.5.1. Determine Objectives and Scope

Readers of this section likely have concluded (at least tentatively) that it is necessary to compare stormwater quality to water quality criteria for protection of aquatic or marine life and human health. The results of a stormwater quality monitoring program to assess compliance with water quality standards or criteria may be used for a variety of purposes:

- Compliance with watershed-based permits
- Compliance with an individual industrial permit

- Determination of need for additional BMPs
- Watershed management planning
- Non-point source assessment

Section 2.5.5 described the key issues associated with comparing stormwater quality data to WQC. In general, comparisons between stormwater quality and WQC should be used to assess stormwater quality problems and establish management priorities rather than to identify apparent water quality violations. The latter objective should be assessed through monitoring the receiving water body. This can provide a direct measure of the degree to which aquatic/marine life or human uses of the water body have been impaired.

As previously indicated, the WQC are based on specified periods of exposure (i.e., one-hour or four-day exposure for aquatic/marine life; lifetime consumption of water/fish by humans). Also, the standards allow for occasional exceedances (generally, once in three years). Therefore, a strict comparison with the WQS or WQC would require measuring stormwater quality at one-hour increments, and determining whether any standards are likely to be exceeded more than once in three years.

Because most human health-based criteria are based on lifetime exposures, direct comparisons with transient stormwater concentrations often may be inappropriate. Pollutant concentrations in water often decrease due to sedimentation, volatilization, biodegradation, and other attenuation processes during transport and storage prior to human consumption. Some fraction of the pollutants is likely to be removed if runoff is stored in a surface reservoir prior to consumption. Also, most surface drinking water supplies are treated prior to distribution. This treatment will likely remove a portion of pollutants that exceed criteria (typically PAHs and arsenic).

If comparisons are performed with criteria intended to protect humans who consume fish and shellfish, consider how stormwater quality compares to ambient concentrations during dry weather periods. In either case, the results of such comparisons should be used only as guide and not in a rigorous regulatory manner. Often, a more direct measure of the potential threat to human health is gained by measurement of pollutant concentrations in edible portion of the food organisms (tissue analysis) rather than through comparison with water quality standards.

Most dischargers do not have the resources (i.e., funds, personnel, time) to conduct the comprehensive monitoring that would be required to support a rigorous assessment of compliance with WQC. For these reasons, most stormwater quality studies focus on pollutants commonly encountered in stormwater and conduct limited sampling to determine whether unusually high concentrations are present at representative locations. Comparisons with WQC are then used to help identify problems and establish priorities for addressing them.

It is necessary to develop a specific, realistic approach to achieving monitoring objectives. Section 2.5.5.2 below should be reviewed to develop the combination of monitoring locations, frequency, parameters, and methods that are best suited to data needs and resources.

Compile and review the relevant existing information that is available for the area. A thorough review of the existing relevant information can help in selecting the most appropriate monitoring locations, parameters, and methods for a given situation. In particular, it is important to review any water quality monitoring data available for a stormwater system and the receiving water bodies to identify locations and pollutants of potential concern.

2.5.5.2. Develop Monitoring Plan

The following sections provide guidance on developing a specific approach to achieving monitoring objectives.

<u>Select Monitoring Locations</u>

The number of locations to be monitored depends on program objectives, permit requirements (if applicable), the size and complexity of drainage basin(s), and the resources allocated to monitoring. In addition, the frequency of sampling at each location should be considered.

In general, monitoring locations for WQC comparisons should be located in the main drainage channel just before it discharges into the receiving water body. Monitoring after mixing with the receiving water should not be conducted unless the data are to be used to support application for a mixing zone or a mixing zone has been granted, or the objective is to assess impacts on receiving waters. If possible, a few representative locations should be chosen rather than attempting to monitor all possible locations. Locations that drain directly to receiving waters that are known to be impaired should be selected first. Locations that drain directly to other receiving waters should be chosen second, and locations that drain to closed storm drain conduits should be chosen last.

<u>Select Monitoring Frequency</u>

The variable nature of stormwater makes determination of a representative exposure period difficult. Watershed or catchment specific characteristics often influence the duration of runoff, with runoff from large catchments typically lasting longer than runoff from smaller catchments for the same storm size. The site-specific nature of runoff event duration makes it difficult to determine which exposure period is appropriate for a given location.

It is not feasible or desirable to monitor every storm event to determine whether criteria are exceeded more than once every three years. Resources necessary for such monitoring may be better spent on implementing BMPs. Instead, it is recommended that monitoring programs attempt to sample a representative subset of storms that occur throughout the storm season. Storms that occur after a long dry period often contain higher concentrations of pollutants than similar storms that occur after a short dry period. If a limited number of storms is to be sampled, it is recommended that storms occurring after a long dry period be sampled in order to consider the "worst-case." If possible, it is recommended three to five storms per season be sampled. If "worst-case" data produce reproducible results showing compliance with water quality objectives, it may be possible to decrease the frequency of monitoring. Additionally, if data show consistent exceedances, it may be desirable to focus efforts on controlling the problem rather than additional monitoring.

<u>Select Parameters and Analytical Methods</u>

Entities conducting monitoring will need to select the parameters and analytical methods most appropriate to their specific situation. Table 2.2 lists the common urban runoff constituents that may be found at highway sites. This list may serve as a starting point for a monitoring program. If significant monitoring has already been completed in the area, consider deleting any parameters that were consistently below levels of concern, particularly if these previous monitoring efforts included highway sites.

TABLE 2.2
LABORATORY PERFORMANCE STANDARDS FOR COMPARISON OF TYPICAL URBAN STORMWATER RUNOFF CONSTITUENTS WITH FRESHWATER WATER QUALITY STANDARDS

Parameter	Units	Target Detection Limit
Conventional		
PH	pH	N/A
Turbidity	mg/L	4
Total Suspended Solids	mg/L	4
Total Hardness	mg/L	5
Chloride	mg/L	1
Bacteria		
Fecal Coliform	MPN/100ml	2
Total Coliform	MPN/100ml	2
Enterococci	MPN/100ml	2
Metals-Total Recoverable		
Total Recoverable Digestion	µg /L	0.2
Cadmium	µg /L	1
Copper	µg /L	1
Lead	µg /L	5
Zinc		
Metals-Dissolved		
Filtration/Digestion	µg /L	0.2
Cadmium	µg /L	1
Copper	µg /L	1
Lead	µg /L	5
Zinc		
Organics		
Organophosphate Pesticides (scan)	µg /L	0.05 - .2
Note:		

This list includes constituents found in typical urban stormwater runoff. Additional parameters may be needed to address site specific concerns.

Once the parameters for monitoring have been selected, it is necessary to specify the analytical detection limits needed to meet data quality objectives. Table 2.2 lists the recommended method detection limits for comparing stormwater samples to WQC.

It has long been recognized that different metal forms (species) show different levels of toxic effects. In general, the most toxic metal forms are ionic where the metal is present, dissolved in the free ionic form. Recognizing this fact, USEPA recently revised WQC for those metals for which criteria are based on toxicity tests to allow comparison with dissolved metal concentrations (40 CFR 131, May 4, 1995). Specifically, USEPA developed revised criteria for the following dissolved metals: arsenic, cadmium, chromium, copper, lead, mercury (acute only), nickel, silver, and zinc. Chronic criteria for dissolved mercury were not proposed because the criteria were developed based on mercury residuals in aquatic organisms (food chain effects) rather than based on toxicity. For comparisons with WQC, the dissolved metals fraction should be determined. If selenium or mercury is of concern, total concentrations should also be measured to enable comparison with criteria based on bioaccumulation by organisms.

The distribution of pollutants between the dissolved and particulate phases will depend on where in the system the sample is collected. Runoff collected in pipes where sediment is generally present at low to moderate concentrations will generally have a higher percentage of pollutants present in the dissolved form. Runoff collected in receiving waters will generally have a higher percentage of pollutants present in particulate form due to higher concentrations of suspended solids and therefore "receptor" sites to which pollutants can attach. It is difficult to determine how much of the dissolved pollutants found in storm system pipes will remain in the dissolved form when they are mixed with suspended sediments in receiving waters. As a result, it is difficult to determine the ecological significance of moderate levels of dissolved pollutants present within the conveyance system. In addition, hardness values for receiving waters are often different from stormwater. Hardness affects the bio-availability of heavy metals and this further complicates the ecological impact of dissolved heavy metals.

If loads to the receiving waters are of concern (for example, discharge to a lake known to be a water quality limited water body) it may be desirable to determine total recoverable metals in addition to dissolved metals to allow assessment of the relative load from different sources. Finally, total recoverable metals data together with dissolved metals can be used to assess the potential metals in sediment.

Select Monitoring Methods

The arguments for grab versus composite sampling, and manual versus automated approaches to the collection of samples, must be considered, then the combination of sampling that best fits program objectives and budget should be chosen.

Storm events affect stream flows for variable lengths of time depending on the storm duration, antecedent conditions and catchment characteristics. Runoff persists for a few hours or up to typically two days. This suggests runoff rarely persists long enough to be considered comparable to chronic exposure duration. Discrete sampling over the course of the storm event will provide concentration information that can be used to determine how long WQC were exceeded during the storm. Alternatively, discrete samples can be composited on a time-weighted basis over time scales comparable to the acute and chronic WQC exposure periods (one-hour and four days), respectively. However, the latter would likely include dry-weather flows since few storms last four days. For catchments that are relatively small (a few acres), one or more one-hour composite samples should be collected during the first few hours of flow. This can be done by collecting and combining three or more grab samples.

Flow-weighted composite sampling can be used for comparison with water quality objectives (for example if flow-weighted composites are collected to measure loads). However, it should be recognized that a flow-weighted sample would contain more water from peak flows than from the initial part of the storm. Results from Santa Clara Valley Nonpoint Source Monitoring Program indicated that for a large watershed with significant suspended sediment concentrations (200 - 400 mg/L), the peak total metals concentration is generally 1.5 times the flow-weighted composite concentrations (WCC, 1993). Results from monitoring a smaller highly impervious industrial catchment with lower suspended sediment concentrations were more variable and no conclusions could be drawn as to the relationship between flow-composite concentrations and grab samples due to difficulties in grab sampling runoff that only occurred during precipitation.

Composite samples should not be collected for certain water quality measurements (e.g., PAHs, bacteria) due to sorption losses during compositing. Grab samples should be collected if analyses are to be conducted for these parameters.

Select Storm Criteria

Because the initial objective of the monitoring is to consider a to a search and make them consistent "worst-case" picture, it is desirable to select storms with the highest pollutant concentrations rather than a representative mix of storms. "Worst-case" conditions are likely to occur after long antecedent dry periods (72 hours to 14 days). Therefore, if feasible, storms should be selected with antecedent periods greater than 72 hours. Few relationships between storm volume and water quality have been observed. Lacking any basis for storm volume selection for "worst-case" conditions, and acknowledging that storm characteristics are highly dependent on climatic region, the following may be used as a starting point:

Rainfall Volume:	0.10 inch minimum No fixed maximum
Rainfall Duration:	No fixed maximum or minimum
Typical Range:	6 to 24 hours
Antecedent Dry Period:	24 hours minimum
Inter-event Dry Period:	6 hours

If these criteria prove inappropriate, site-specific storm event criteria can be developed by analyzing long-term rainfall records using USEPA's SYNOP or another appropriate analytical program. This could include USEPA's SWMM model, which incorporates the features of SYNOP.

It should be noted that biasing the storm selection to the "worst-case" would not provide a representative sample of the population of all types of storm events. The resulting data should be used in screening mode and not to estimate statistically derived exceedance frequencies. The level of effort required to sample all representative types and combinations of storm conditions to generate reliable population statistics is beyond the resources of most agencies. For this reason a "worst-case" approach should be taken. Often permits require monitoring of "representative" storms that have been predefined. Operationally and practically, storm event criteria may need to be further defined beyond the regulatory definition. The use of a probability of rainfall above a certain magnitude, during a specific period, based on a quantitative precipitation forecast (QPF) serves as a good indication of when and how to mobilize for monitoring efforts. QPFs for a geographic area can be obtained from the National Weather Service and site specific information can be obtained from private weather consultants.

3. MONITORING EQUIPMENT SELECTION

This section of the guidance provides a list of issues that are important to consider before and during equipment selection and monitoring plan development.

3.1. Monitoring Location

As discussed in Section 2.5, stormwater monitoring in the near-highway environment can be aimed at attaining one or more goals. This section discusses in detail the relationship between monitoring location and equipment selection, independent of the specific goal of the program. More specifically, this section addresses how three main factors affect equipment selection.

- Watershed type
- Specific site characteristics
- Site location within the watershed

3.1.1. Watershed Type Considerations

As mentioned in Section 2.3, the near-highway environment often presents a variety of challenges when it comes to selection of monitoring equipment. One of the most important factors to assess during site selection is whether or not a particular watershed presents complexities that unduly constrain the type of equipment that can be placed in the field.

Typically, watersheds in the near-highway environment are relatively small in size (<50 acres and often <10 acres or even smaller than 1 acre). For example, a one-mile long section of four-lane highway including median and shoulder may cover approximately 11 acres. Single inlets often drain less than 0.5 acres. In addition, these small watersheds are highly impervious and moderately sloped. These characteristics have significant implications for monitoring of quantity and quality. With small areas, moderate to steep slopes, and highly impervious surfaces, flow rates from highways vary dramatically and quickly. Typical times of concentration from highway sections can be less than five minutes. Flow monitoring in these conditions can be difficult. Some commonly used primary devices are not well suited to monitoring rapidly changing highly varied flow conditions.

Monitoring difficulties inherent to the near-highway environment can be exacerbated through poor site selection. Choosing a watershed type that is compatible with monitoring program goals is the first step in site selection.

Often, selecting a watershed type will significantly limit potential sites, expediting site selection. For example, depending on monitoring goals, it may be easier to monitor fill sections because they may have outfalls close to the inlet, which means that verification of the drainage system is not difficult and there is little chance that backup of the system potentially caused by the monitoring equipment will cause upstream flooding and public safety problems. In this case, equipment that may impede flow such as nozzles, weirs, and flumes may be appropriate, whereas in cut sections, pipe slopes may be shallow and backwater conditions may result. Consequently, some types of equipment should not be used in these situations.

3.1.2. Specific Site Characteristics Considerations

The specific location also dictates what type of equipment to use. A variety of considerations must be taken into account when selecting equipment for monitoring runoff and rainfall at a specific site including:

- proximity to mobilization location (How often will visits to the site be required based on the equipment used?);
- proximity to telemetry connections (Is there access to nearby cell towers or land-lines?);
- proximity to utilities (Are there nearby accessible electrical utilities?);
- accessibility for installation of equipment (Large or cumbersome devices such as large flumes can be difficult to transport to some locations.);
- personnel safety during installation and monitoring. (Does installation or use require personnel to take significant risks during installation?);
- potential for vandalism (High crime areas may require more covert and/or vandal-proof equipment and enclosures.);
- potential public safety risk (Is there a potential for increased flooding, upstream or downstream if flood flows occur?); and
- specific watershed hydrology (The monitoring equipment should be tailored to the watershed size, slope, and other characteristics.).

3.1.3. Considerations Related to Location Within a Watershed

In addition to selecting a monitoring site, the location within the site for conducting monitoring must be selected. There are four primary locations in the near-highway environment that are used to monitor runoff:

- on the surface (gutter flow, typically grab sample);
- at inlets (typically grab sample);
- mid-conveyance (manhole, in-pipe or open channel); and
- outfall.

Each of these locations has both operational and programmatic advantages and disadvantages that are program and site specific. As monitoring is conducted further downstream from the highway, flow monitoring results tend to be less variable; however, effects due to specific sources and practices may be more difficult to observe. The monitoring location is often directly related to the goals of the monitoring program. BMP effectiveness studies may benefit from upstream isolation of the source area affected by the BMP, where loading estimates may be most appropriate at outfalls to receiving waters.

Operationally, the specific location in the monitored watershed can affect accessibility of the monitoring equipment for maintenance and installation of equipment. Risk to monitoring personnel should be a high priority criterion when selecting a monitoring location.

3.2. Monitoring Frequency

Monitoring frequency directly impacts the selection of monitoring equipment. Typically, the larger the number of storms and the shorter the period between events that need to be monitored, the greater the benefit of using automated equipment. Prior to setting up the monitoring plan and selecting equipment, a detailed analysis of the number of events required to meet program goals should be conducted. This analysis may be limited to regulatory requirements or may involve a detailed statistical analysis to determine the number of samples required to achieve a selected level of confidence in water quality sampling results. This provides a basis for cost effective selection of a level of automation. Similar results from manual sampling will require a crew of two to remain at each station during an event. The cost of manpower should be compared to equipment/installation costs.

3.3. Range of Flows to be Monitored

The range of flows encountered in the near-highway environment can be quite large. Measuring low flow rates accurately is important where a significant portion of flow volume is the result of either base flow or low intensity events due to climate. Climatic regions that have significant annual rainfall depths but do not have very intense events on a regular basis and/or small drainage areas are good examples of locations where low flow measurement is important.

The smaller the watershed the larger the relative difference between significant low flows and peak flow (area normalized flows). This is due to the time of concentration of the watershed being on the same order as the duration of very brief and intense rainfall periods (<five minutes). Many primary devices lose considerable accuracy or their capacity is exceeded when flows range more than three orders of magnitude. Low flow measurements may not be accurate where the monitoring installation is designed to measure infrequent larger magnitude storm events. For example, the use of pressure transducers or area velocity sensors in small watersheds could result in a significant amount of flow not being measured as the depth of flow is on the order of the sensor size.

4. COMMERCIALLY AVAILABLE EQUIPMENT

4.1. Data Loggers

4.1.1. Description

Data loggers are used to monitor signals from various pieces of equipment and store the impulses that they generate. When data loggers are combined with software to measure and route signals between instruments and analyze data, they are referred to as "data acquisition systems" and are often used as the execution center of a monitoring station. Most data loggers have several input ports and can accommodate a variety of sensory devices, such as a probe or transducer (e.g., flow meters, rain gauges, etc.). While specific design characteristics vary between instruments, overall data logger design is relatively standard. Some water quality samples have data loggers built into them; however, they are usually more limited in terms of capability (e.g., programmability, communication options, etc.) than independent data loggers.

Data loggers suitable for stormwater monitoring applications are typically constructed of weather-resistant materials capable of protecting the internal circuitry from water and dust hazards. They are designed to operate at extreme temperatures, from as low as -55^{o} C to as high as 85^{o} C (-67^{o} F to 185^{o} F). In addition, most models can be securely mounted in remote locations, providing protection from wind and rain, wildlife, and vandalism.

Typical data loggers for field use consist of the following components: a weatherproof external housing (a "case"), a central processing unit (CPU), or microprocessor, a

Data Logger with Weatherproof Housing
(Vaisala Inc., Handar Business Unit)

quantity of random-access memory (RAM) for recording data, one or several data input ports, a data output port, at least one power source, and an internal telephone modem. In addition, most data loggers have an input panel or keyboard and a display screen for field programming. The CPU processes the input data for storage in RAM, which usually has a backup power source (such as a lithium battery) to ensure that data are not lost in the event of a failure of the primary power. Data stored in RAM may be retrieved by downloading to a portable personal computer (PC) or to a host PC via modem.

Data loggers vary in size from 0.2 to 9 kilograms (0.5 to 20 pounds) or more. Both portable and fixed data-logging systems are available. For long-term, unattended monitoring projects, a fixed instrument capable of serving as a remote transmitting unit (RTU) may be preferable to a portable one. Manufacturers of data loggers suitable for stormwater monitoring include:

Data Logger without Housing (Campbell Scientific)

Campbell Scientific, Logan, Utah; Global Water Instrumentation, Fair Oaks, California; Handar, Inc., Sunnyvale, California; In-Situ, Inc., Laramie, Wyoming; ISCO, Inc., Lincoln, Nebraska; Logic Beach, Inc., La Mesa, California; and Sutron Corporation, Sterling, Virginia.

4.1.2. Programmability

Most data loggers can be programmed to record data at user-selected intervals. The user may select a sampling interval from a range of time intervals available for each device. For example, a particular model may be designed to permit a user to select a data recording frequency from once every two seconds to once every 48 hours, with the choice of frequencies varying by two-second intervals. The minimum and maximum intervals vary from vendor to vendor, and often vary among models offered by the same vendor. In addition, some data loggers have the ability to record event-related data, such as minimum and maximum discharge rates and event timing and duration.

Most data loggers are field programmable, meaning that the software is equipped with an interface that permits on-site manipulation. However, some less expensive models may only be programmed at the factory. These models provide the advantage of cost savings but provide limited versatility, especially if project requirements change over time.

In addition to being field programmable, most data loggers possess the capability of remote programming via telephone modem. These models offer a significant advantage over factory programmed and field programmable data loggers because they allow the user to manipulate the program or monitor its effectiveness remotely. A network of data loggers used in a multi-site monitoring effort can be reprogrammed more efficiently than by traveling from site to site. An example where this would be very useful is if a predicted storm rainfall depth changes after sites are set up, the sampling interval could be adjusted remotely.

Although many vendors offer data loggers with the capability of remote manipulation via modem and PC, the user-friendliness of the various models may vary greatly between vendors. Most vendors have developed software packages that are provided free of charge with the purchase of their data logging systems. These software packages allow for remote data logger programming, and provide for data manipulation, analysis, and presentation at the host PC location. The interface environments used by these packages vary from DOS-like command lines to menu-driven point-and-click environments.

Most data loggers that are provided with vendor-developed software packages require an IBM-compatible PC with Windows™ to run the packages. Therefore, this additional cost should be considered when evaluating a particular model. Another point of consideration is the format in which a particular model logs the data it receives. Some models log data in a format that can be converted from ASCII files to any of several readily available spreadsheet or word processing files, while others require the use of their particular vendor-developed software for data analysis and manipulation.

4.1.3. Data Capacity

Memory type and capacity vary greatly between instruments. Standard capacity varies between models and vendors from less than 8K to more than 200K. In general, one data point uses 2 bytes of information; therefore, a data logger with 64K of memory could be expected to have a maximum data point capacity of 32,000 data points before data downloading or additional memory would be required. However, some types of data require as much as 4 bytes of memory per point. It should be noted that when recording sets of data related to storm events, memory might be exhausted more quickly than expected.

The type of memory used by a particular model is also an important consideration. Most data loggers use non-volatile RAM (memory that is not lost in case of a power failure). Although this provides insurance that essential data will not be lost, the use of non-volatile memory may not be necessary if the data logger is equipped with a backup power source. A backup power source is automatically activated when the primary power source is lost. Typically, a lithium battery supplies backup power, with protection varying from 1 to 10 years.

Most models are programmed to stop recording data upon exhaustion of available memory ("stop when full"). However, some models are equipped with wraparound or rotary memory, which rewrites over the oldest data when available memory becomes exhausted. When using rotary memory, it is therefore important to realize that data may be lost if they are not downloaded regularly.

Data loggers separate from water quality samplers increase the flexibility of the system because of their increased programmability over those loggers on samplers. Memory capacity is often an issue (even with the current inexpensive memory) and requires that careful attention be paid to downloading data before it is overwritten.

4.1.4. Communications

Models vary in their ability to accept input from more than one source. Some data loggers are designed with a single analog input channel, while others are designed with up to 16 channels. In addition, some of the newer models accept digital input data. The choice of a particular model should be based upon the number of sensors or probes from which the instrument will be required to accept data.

Data loggers can accept information from many different types of sensors and transducers. This allows for versatile use of most data logging systems. Some vendors offer probes and transducers with built-in data loggers; however, these systems typically cannot accept input data from other sensory devices and their ability to communicate output data is often limited.

With regard to output communications, all data loggers interface with the standard RS-232 interface type, and some possess the capability to communicate with other interface types. In most cases, data can be downloaded on-site to a laptop PC or a unit may be transported to a lab or office so that the data can be downloaded to a desktop PC. Data loggers also can be equipped with an internal modem for telecommunications, allowing a user to download data from a remote host PC without having to mobilize to the field site.

In most cases, use of a telephone modem requires an IBM-compatible PC as the host and the vendor's software. Typically, the user can select baud rates. However, some models are capable of only a few baud rates, a limitation that should be considered when choosing a specific model. Some machines also possess the capability to transmit data via line-of-sight, UHF/VHF, or satellite radio. These options also allow for remote manipulation of programming and downloading of data.

4.1.5. Power Requirements

In general, data loggers are energy efficient devices. An internal battery, with the option of using external electrical power, powers most data loggers. Some also can be equipped to use solar power.

Data loggers powered by internal batteries typically offer a choice of cell type. That is, whereas some models offer the option of using either rechargeable cells or standard 12-volt alkaline cells, others offer the option of either alkaline or lithium. The choice of power source, and potentially model selection, depends on several factors, including site accessibility, distance, amount of data to be recorded, total cost, and operating temperature. Especially in remote locations, solar power with battery backups should be considered. The sunlight can be used to recharge batteries and the batteries can be used during periods of no or weak sunlight.

Alkaline cells are less expensive than lithium or rechargeable batteries, but they have a shorter life and must be replaced more often. While alkaline cells offer a potential power life of several months, lithium cells offer a potential power life of several years. However, since lithium batteries are considered a hazardous material, data loggers using lithium batteries are subject to more stringent shipping requirements than models using standard alkaline cells. Since alkaline batteries must be replaced and discarded frequently, the use of alkaline batteries may actually be more expensive than rechargeable batteries. However, whereas rechargeable batteries offer less battery waste and a potential cost savings, the time and cost required to recharge the batteries should be considered when evaluating power options.

Operating temperature range is another important factor to consider when choosing a power supply. Lithium expands both the minimum and maximum temperatures at which a data logger can be used. Under extreme conditions, it may not be feasible to use a data logger powered by alkaline batteries.

4.1.6. Data Logger Summary

The selection of a particular data logger depends on several factors. The first factor to consider is the expected number and type(s) of input data. For example, if a stormwater monitoring task requires recording three different parameters (e.g., surface water temperature, flow, and pH), then a data logger with at least three data input channels is required. Similarly, if a user intends to use a transducer that conveys information as digital data, then the user must select a data logger with the capacity to accept and store data in this form.

The next factors to consider are programmability and memory capacity. In considering these factors, it is important to identify the frequency at which data will be recorded and evaluate the possibility that conditions may arise that would require a change in this frequency. In addition, a user should consider how frequently data will be downloaded (e.g., once per month, once per quarter), and identify the preferred method of interrogation (i.e., downloading at the site or downloading via modem). Programmability and memory capacity requirements should be easy to identify once these considerations have been evaluated.

The selection of a power source partially depends on the frequency at which data will be collected, since power life varies greatly between power source types. Each available power source (AC power, solar power, or alkaline, lithium, or rechargeable batteries) offers advantages and disadvantages. The choice of one source over the others depends on specific project requirements, including cost. AC power generally provides the most flexibility. Solar power has the advantage of potentially not needing to replace the battery for long periods as part of the available operating power is diverted to recharging onsite batteries; however, in practice they are often much more problematic than AC power. Solar power may be the only viable option for stations that are located in remote locations. The characteristics of certain battery types should be understood when selecting a DC power source as each battery type has properties that will affect its performance (e.g., heat/cold, storage capacity, etc).

The final consideration influencing data logger selection is cost. However, once individual project needs have been identified, it is likely that several data acquisition systems will accommodate the needs within a close range of costs. In this case, the final selection of a particular data logger may depend on a user's preferred communication software, availability of a power source, or the range of programming options for flexibility in future project applications. In general, independent devices (separate from water quality sampling equipment) offer the most flexibility and features; however, they place greater demands on the abilities of the sampling team.

4.2. Flow Measurement Methods and Equipment

4.2.1. Methods for Measuring Discharge Rate

Natural channels, engineered open channels, and pipes are used as stormwater conveyances. In each case, hydraulic considerations dictate the mathematical relationships that can be used to describe the discharge rate at a given point in time. One of the primary hydraulic considerations is whether the flow configuration represents an "open" or "closed" channel. Open channel flow has a free water surface, and because the flow is driven by gravity, it varies with depth. Closed channel flow, in which the flow fills a conduit, is caused by and increases with the hydraulic pressure gradient. Some stormwater conveyance system pipes may function as open channels during periods of low storm runoff and as closed channels when the runoff volume becomes sufficiently large or when water is backed up due to downstream flow conditions (e.g., tide, river flooding, etc).

In general, the discharge rate in an open channel depends on the depth of flow and several other factors (Chow, 1959) including:

- Geometric shape and changes in shape and slope along the length of the channel (affects potential for development of turbulence and/or varied flow and therefore the choice of methods and instruments used for measurement of discharge).

- Hydraulic roughness of the conveyance surface, whether natural or manmade (affects the energy losses of the flow).

- Rate at which the depth of flow changes over time (steady vs. unsteady flow).

- Spatial scale over which the discharge rate changes (uniform vs. varied flow).

The measurement of the discharge rate in an open channel is more difficult to attain than that of a full pipe, because the free surface will change with respect to time.

Typically, stormwater collection systems for transportation sites will fit the open channel flow configuration. However, many highways are drained by piped systems that may be flowing full at times. Therefore, methods used for measuring discharge in full pipes will also be discussed.

Table 4.1 summarizes available discharge measurement methods, the requirements for their use, typical highway use, and required equipment. Each of these methods is discussed in more detail in the following sections.

Volume-Based Methods

The concept behind volume-based flow measurement is simple—all the discharge is collected over a short period of time, the volume is measured, and the collected volume is divided by the length of the time period.

$$Q = V/T$$

where, Q = discharge, m^3/s (ft^3/s)
V = volume, m^3 (ft^3)
T = time, s

A stopwatch can be used to measure the period required to fill a receptacle of known quantity to a predetermined level. The receptacle must be large enough that it requires some accurately measurable period of time to fill. The receptacle could be a bucket, a drum, or a larger container such as a catch basin, holding tank, or some other device that will hold water without leakage until the measurement is made.

This method is easy to understand, requires relatively simple equipment, and can be very accurate at low rates of discharge. At higher rates of discharge, collecting all the runoff from typical highway conveyances (an essential component of the method) may become infeasible. This method is most useful for conducting limited research and for calibrating equipment.

Stage-Based Empirical Equations

Discharge rate can be estimated from the depth of flow (i.e., water level or stage) using well-understood, empirically-derived mathematical relationships. That is, for a set hydraulic configuration, the relationship between stage and discharge is known. The most commonly used empirical relationship, the Manning equation, is appropriate for open channels in which flow is steady-state (i.e., the discharge rate does not vary rapidly over time) and uniform (the depth of flow does not vary over the length of the channel) (Gupta, 1989). In automated stormwater sampling, the Manning equation is commonly used to estimate the discharge rate of the flow stream.

TABLE 4.1
DISCHARGE MEASUREMENT METHODS

Method	Major Requirements For Use	Typical Highway Use	Required Equipment
Volume-Based	▪ Low discharge rates	▪ Calibrating equipment ▪ Manual sampling	Container and stopwatch
Stage-Based Empirical Equations	▪ Open flow ▪ Known channel/pipe slope ▪ Channel slope, geometry, roughness consistent upstream	▪ Manual or automatic sampling	Depth Measurer
Stage-Based Weir/Flume	▪ Open flow ▪ Constraint will not cause flooding	▪ Manual or automatic sampling	Weir/flume and depth measurer
Stage-Based Variable Gate Meter	▪ 4-, 6-, or 8-inch pipes only	▪ Not typically used for highways	ISCO Variable Gate Meter
Velocity-Based	▪ None	▪ Automatic sampling	Depth measurer and velocity meter
Tracer Dilution	▪ Adequate turbulence and mixing length	▪ Calibrating equipment	Tracer and concentration meter
Pump-Discharge	▪ All runoff into one pond	▪ Not typically used for highways	Pump

$$Q = \frac{1}{n} AR^{2/3}S^{1/2}$$

where,
- Q = discharge, m^3/s
- n = Manning roughness coefficient (dimensionless)
- A = cross sectional area, m^2
- R = hydraulic radius, m =A/(wetted perimeter)
- S = slope of the channel, m/m

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2}$$

where,
- Q = discharge, ft^3/s
- n = Manning roughness coefficient (dimensionless)
- A = cross sectional area, ft^2
- R = hydraulic radius, ft =A/(wetted perimeter)
- S = slope of the channel, ft/ft

Manning Equation

The variables required for the Manning equation are the slope of the energy grade line (usually assumed to be the slope of the channel bottom), the cross-sectional area of the flow, the wetted perimeter, and an empirical roughness coefficient that takes into account channel material, age, and physical condition.

The Manning equation truly applies only to steady and uniform flow but can provide a fairly accurate estimate of discharge rates if certain conditions are met. The channel slope and cross-sectional geometry must be constant for some distance upstream of the site, the exact distance varying with overall system hydraulics (a rule of thumb is a length of 20 channel diameters upstream). Flow conditions at the site should not be affected by downstream features (i.e., no backflow effects). The cross-sectional area and wetted perimeter are both geometric functions of the channel shape and the depth of flow. The "roughness" of the conveyance walls can be described by a roughness coefficient. Additional information on applicability and values for Manning's roughness coefficients for common channel types are provided in most hydraulics texts (Chow, 1959 and Gupta, 1989).

Use of the Manning equation assumes that the slope of the channel bottom is accurately known. Monitoring studies using this technique to estimate discharge rate often rely on as-built drawings to determine channel slope. Because these drawings vary in accuracy, direct measurement of the slope of the channel bottom and verification of hydraulic conditions is recommended.

The discharge rate from stormwater runoff tends to be unsteady. This is due to changes in the intensity of precipitation and the dynamic nature of overland flow, which causes the discharge rate to vary with time, either gradually or rapidly. Depending on the frequency with which the depth of flow is measured, rapid fluctuations in discharge rate will be missed and the total runoff volume from a storm event will be miscalculated.

Other Empirical Stage-Discharge Relationships

Another empirical relationship used to estimate discharge is the Chézy equation (Gupta, 1989):

$$Q / A = C\sqrt{RS}$$

where,
- Q = discharge, m^3/s (ft^3/s)
- A = cross sectional area, m^2 (ft^2)
- R = hydraulic radius, m (ft)
- S = slope of the energy grade line, m/m (ft/ft)
- C = discharge coefficient, $m^{1/2}/s$ ($ft^{1/2}/s$)

Under open channel flow, the coefficient "C" can be defined as:

$$C = \frac{R^{1/6}}{n}$$

where n = Manning roughness coefficient (dimensionless).

When "C" is substituted into Chézy's equation, the resulting equation is identical to the Manning equation.

A failure of both the Manning and Chézy equations is that they imply that the Manning "n" value is constant for a given channel. However, it is known that for natural channels "n" may vary greatly with respect to discharge (Ponce 1989). Therefore, when consideration is given to applying these equations to a natural channel, the alluvial material in the channel and expected flow magnitude should be evaluated first. It may be desirable to select another discharge measurement approach for natural channels with highly varied surfaces and discharge rates.

Stage-Based Weirs and Flumes

The accuracy with which discharge is estimated can be improved by using a weir or flume to create an area of the channel where hydraulics are controlled (control section). Each type of weir or flume is calibrated (i.e., in the laboratory or by the manufacturer) such that the stage at a predetermined point in the control section is related to the discharge rate using a known empirical equation. (For examples, see Stevens, 1991.)

Weirs

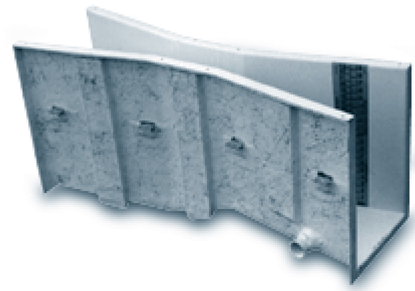
A weir is an obstruction (usually a vertical plane) built or placed across an open channel (or within a pipe under open channel flow) so that water flows over the weir's top edge (or through a well defined opening in the plane). Many types of weirs can be used to measure discharge; the three most commonly used are the rectangular, trapezoidal (also called a Cipolletti weir), and triangular. The weir opening (i.e., the rectangular, trapezoidal, or triangular opening) is called the "notch." Specific discharge equations are used for each type of weir.

Weirs are simple, inexpensive, and relatively easy to install. A weir can be used to regulate flow in a natural channel with irregular geometry, a situation where the Manning equation, for example, would not provide reliable estimates for the discharge rate. However, a weir will back water up in channels by creating a partial dam. During large storm events, backed-up water could cause or worsen flooding upstream, particularly in a closed conduit. Some jurisdictions prohibit the use of weirs for this reason. When evaluating the suitability of a monitoring site for a weir, it is important to determine whether the system was "over designed." That is, will the conveyance be able to move the design capacity after weir installation? In the case where the downstream depth of flow is greater than the crest of the weir, a different stage-discharge relationship for the weir will apply.

Another potential problem that weirs introduce to a channel is that sediments and/or debris may accumulate behind the weir, which can alter the hydraulic environment. By altering the hydraulic environment, these materials also change the empirical relationship between depth of flow and discharge rate. Therefore, weirs must be inspected regularly and all the accumulated sediment and debris removed.

Flumes

A flume is a specially built reach of channel (sometimes a prefabricated insert) with a converging entrance section, a throat section, and diverging exit section.



Parshall Flume (Plasti-Fab, Inc.)

The area or slope (or both) of the flume is different from that of the channel, causing an increase in water velocity and a change in the level of the water flowing through the flume (Grant, 1989). Stage-discharge relationships have been established for a variety of flume configurations (USGS, 1980; Gupta, 1989; Stevens, 1991). The USGS has developed and tested a modified Palmer-Bowlus flume (USGS, 1985) for use in circular pipes carrying highway stormwater runoff, where the flow can be under both open and pressurized channel flow. This flume has been designed to measure the discharge under pressurized flow by using two bubbler sensors (discussed later in this section) to detect the hydraulic pressure change between an upstream and downstream location on the flume. This system has been found to be one of the most accurate available after calibration is performed.

Because the velocity of water accelerates as it passes through a flume, the problem of sedimentation associated with weirs is avoided; however, problems with debris accumulation may still occur. Another benefit is that flumes introduce a lower headloss than weirs, resulting in a reduced backwater effect. A flume may be more expensive and difficult to install than a weir due to its more complex design.

H-Flume (Tracom, Inc.)

Staged-Based Variable Gate Metering Inserts

A relatively new development in flow metering technology is ISCO Inc.'s (Lincoln, Nebraska) Variable Gate Metering Insert. Discharge flows through the insert and under a pivoting gate, creating an elevated upstream level that is measured with a bubbler system (discussed later in this section). The meter uses an empirical relationship to calculate the discharge rate based on the angle of the gate and the depth of flow upstream of the gate. This approach can be used only under conditions of open channel flow in circular pipes. Currently the system is only available for pipe diameters of 10.16, 15.24, and 20.32 cm (4, 6, and 8 inches). The Variable Gate Metering Insert was designed to measure the discharge rate under fluctuating flows and should be effective at both very high and very low flow rates. Its main limitation is the size of the conveyance for which it is designed. Most stormwater conveyances used for monitoring are at least 24 inches in diameter. The insert may be useful for sampling very small catchment areas. Again, problems with debris accumulation can occur.

Velocity-Based Method

The continuity method is a velocity-based technique for estimating discharge rate. Each determination requires the simultaneous measurement of velocity and depth of flow. These parameters may be measured using any of the methods discussed in Section 4.2.4 (Equipment for Measuring Velocity).

Discharge rate is calculated as the sum of the products of the velocity and the cross-sectional area of the discharge at various points across the width of the channel:

$$Q = A_i V_i$$

where,

Q = discharge, m^3/s (ft^3/s)

A_i = cross-sectional area of the flow at section i, m^2 (ft^2)

V_i = mean velocity of the flow at section i, m/s (ft/s)

The sections i = 1-n are planar segments of a cross-section of the flow where n is the number of points across the width of the channel. In stormwater runoff applications, the conveyance is small enough that a single cross-sectional area and estimate of average velocity is typically used to estimate discharge rate. Typically, it is not necessary to segment the cross-sectional area of the flow. The accuracy of this method is dependent on the ability of a sensor to measure velocity over a range of discharges.

Although this method is useful for calibrating equipment, it is more sophisticated and expensive than the stage-discharge relationships previously discussed. In addition, this method is suitable only for conditions of steady flow. That is, water level must remain essentially constant over the period required for obtaining velocity measurements. This is not generally a problem in small conveyance systems when instruments that make measurements rapidly are employed.

Additional relationships, developed for pipes that are flowing full, are the Darcy-Weisbach equation and the Hazen-Williams equation. These equations are used in systems where pressurized flow (i.e., pipes flowing full, no free water surface) is present (Gupta, 1989).

Tracer Dilution Methods

Tracer dilution methods can be used where the flow stream turbulence and the mixing length are sufficient to ensure that an injected tracer is completely mixed throughout the flow stream (USGS, 1980; Gupta, 1989). Tracers are chosen so that they can be distinguished from other substances in the discharge. For example, chloride ion can be injected into fresh water; dyes or fluorescent material can be used if turbidity is not too high.

Dilution studies are well-suited for short-term measurements of turbulent flow in natural channels and in many manmade structures such as pipes and canals. However, these methods are better suited to equipment calibration than to continuous monitoring during a storm event. Two dilution methods can be used to determine discharge rate as described below.

Constant Injection Rate Tracer Dilution Studies

A known concentration of tracer is injected at a constant rate into a channel. The concentration of the tracer in the discharge is measured at a downstream point over time. After some time period has passed, the tracer becomes completely mixed in the discharge so that the downstream concentration reaches steady-state. Discharge is calculated from the initial tracer concentration, the tracer injection rate, and the steady-state downstream concentration.

Total Recovery Tracer Dilution Studies

A discrete "slug" of tracer is injected into the channel. Near-continuous measurements of tracer concentration in the discharge are taken at a downstream point until the plume has entirely passed. Discharge is calculated from the volume and concentration of injected tracer and the total area under the concentration-time curve.

Pump Discharge Method

In some cases, the overall discharge rate for a catchment may be measured as the volume of water that is pumped out of a basin per unit time while holding the water level in the basin constant. This method can be applied at sites where discharge runs into a natural or manmade basin from several directions or as overland flow. If the pump is pre-calibrated, the number of revolutions per minute, or the electrical energy needed to pump a given volume, may be used as a surrogate for measuring the pumped volume during a stormwater runoff event. Application of this method requires considerable knowledge of the installed pump's performance. Because this setup (i.e., all of the runoff from a catchment flows into one pond or basin which can be pumped out) is rarely encountered in the field as the only available monitoring method, pumps are not discussed further in this manual.

4.2.2. Factors Influencing Equipment Selection for Measuring Discharge Rate

Various factors influence the selection of equipment for measuring discharge rate. This section provides an overview of key factors.

Site location

- The likelihood that field personnel will be exposed to hazardous conditions while making visual observations or while installing, maintaining, or operating automated equipment.

- The likelihood that equipment will be vulnerable to vandalism or theft if left unsecured.

Site condition

- The presence of turbulence, foam, or mist associated with the discharge (these may affect depth of flow measurements).

- The presence of large air or water temperature gradients (these may affect depth of flow measurements).

- The presence of surface-active materials or organisms that can affect the accuracy of a probe (this may interfere with the functioning of the probes).

- The expected concentrations of suspended solids, settleable solids, or debris in the discharge. (High concentrations of solids that can settle will inhibit the functioning of probes installed at the channel invert and debris may gather on or around the probes.)

Expected discharge rates

- The minimum and maximum discharge rates expected during a storm event.
- The likelihood of full-pipe (surcharged) flow in closed conduits (limits the use of stage-discharge relationships).

Allowable loss of capacity

- The likelihood that the installation of a weir or flume in a channel will cause flooding upstream.

Accuracy

- Regarding quantitative data, the accuracy achievable with a given instrument compared to that needed to meet monitoring program objectives.

Expense

- Equipment costs plus the costs to install, operate, and maintain a piece of equipment, including training time for field personnel.

Installation requirements

- The time required to install, and, if necessary, calibrate a given piece of equipment.
- The potential need to retrofit a conveyance.
- The potential need to purchase or build mounting brackets or secure housing.

Operations and maintenance requirements

- The time required to inspect and maintain the equipment between storm events.
- The potential for a piece of equipment to break or malfunction.
- The possibility that repairs will be conducted in the field.
- The degree to which electronic components are protected against water damage.
- The type of power supply required.

Special considerations for near-highway sites

- Catchments draining highway sites are often smaller than those draining residential, commercial, or industrial areas. Therefore, the conveyances used to transport runoff are likely to be relatively small. Methods and instruments must be evaluated with respect to their usefulness in relatively restricted spaces.

4.2.3. Equipment for Measuring Depth of Flow

A variety of instruments may be used to measure water depth. Because some techniques are relatively cumbersome, they are more useful for calibrating equipment than for routine or continuous data collection during storm events. The equipment required for each technique, and the associated advantages and disadvantages for sampling runoff at transportation sites, are described below. Table 4.2 summarizes available equipment for measuring depth of

TABLE 4.2
EQUIPMENT FOR MEASURING DEPTH OF FLOW

Method	Major Requirements for Use	Typical Highway Use
Visual Observations	• Small number of sites and events to be sampled • No significant health and safety concerns	Manual sampling
Float Gauge	• Stilling well typically required	Manual or automatic sampling
Bubbler Tube	• Open channel flow • No velocities greater than 5 ft/sec	Automatic sampling
Pressure Transducer	• Better if remains submerged	Automatic sampling
Ultrasonic Depth Sensor	• Open channel flow • No significant wind, loud noises, turbulence, foam, steam, or floating oil & grease	Automatic sampling
Pressure Probe	• Open channel flow • No organic solvents or inorganic acids & bases	Automatic sampling
Ultrasonic Uplooking	• No sediments or obstructions likely to cause errors in measurement	Automatic sampling
Radar/Microwave	• Similar to Ultrasonic Depth Sensor but can see through mist and foam	Automatic sampling
3-D Point Measurement	• Since requires highly controlled systems, typically not useful in the field	Automatic sampling

flow, major requirements for use, and typical highway use.

Visual Observation

The visual method of measuring depth of flow requires that personnel be present at a site and in a position to take readings throughout a sampling event. Depth of flow can be measured using a fixed or hand-held staff gauge, meter stick, or some other physical gauge. Although visual observations can be simple and inexpensive to obtain, this method is not generally recommended for programs involving large numbers of sites or sampling events. Under these circumstances, labor costs can outstrip those associated with automated equipment. Visual measurements are generally not as accurate due to difficulty in positioning to read gauges and fluctuating depths. Health and safety issues such as the potential for exposure to inadequate oxygen, toxic or explosive gases, storm waves in manhole vaults, or to hazardous traffic conditions at street level, must also be considered when evaluating manual versus automated observation techniques.

Float Gauge

A float gauge consists of a float that is free to move up and down in response to the rising and falling water surface in a channel. Prior to an actual stormwater sampling event, the site is calibrated to establish an initial reference depth. During the storm, the float rises and falls with changes in water surface elevation, and a device attached to the float records the magnitude of these changes. The changes in water surface elevation are converted to depth of flow by the float gauge. A data logger can record the depth of flow, and if capable of performing mathematical equations, can also determine the discharge rate. The data also can be used as input with compatible software to compute the discharge rate.

In some applications, use of a float gauge requires a stilling well. A stilling well is a reservoir of water connected to the side of the conveyance that isolates the float and counterweight from turbulence in the main body of the discharge. The need to retrofit an existing channel or conduit with a stilling well, a potentially expensive and time-consuming process, is the principal drawback of this technique. However, this method may be useful if sampling is conducted at a site where a float gauge and stilling well have previously been installed.

Bubbler Tube

Bubbler tubes are used by some types of automated flow meters to measure the depth of flow. Compressed air (or gas) is forced through a submerged tube attached to the channel invert (i.e., bottom of the channel). A pressure transducer measures the pressure needed to force a bubble out of the tube. This pressure, in turn, is linearly related to the depth of the overlying water:

$$P = \rho h$$

where:
P = hydrostatic pressure, N/m^2 (lb/ft^2)
ρ = specific weight of water, N/m^3 (lb/ft^3)
h = depth of water, m (ft)

Bubbler tubes are commonly integrated with a flow meter, or a data logger that is capable of performing mathematical calculations. This approach allows the measurement of depth to be immediately converted to a discharge. These real-time inputs along with a program that tracks accumulated flow volumes can be used to trigger the collection of samples for flow-weighted compositing by an automated sampler.

Bubbler Flow Meter (ISCO)

Bubbler tubes are simple to use and are not usually affected by wind, turbulence, foam, steam, or air-temperature gradients. Accuracy is not lost under dry conditions in a conveyance between runoff events. (Some other types of probes must remain submerged.) Although they are generally reliable, bubblers are susceptible to error under high velocity flow. That is, as discharge velocity increases to over 1.5-1.8 m/s (5-6 ft/s), a low-pressure zone is induced around the mouth of the bubbler tube, which is interpreted by the flow meter as a drop in discharge rate. These instruments therefore should not be used in channels where the slope of the bottom exceeds 5-7%. Also, sediments and organic material can plug bubbler tubes. Some units are periodically purged with compressed air or gas to prevent this problem, but visual inspection and periodic maintenance are recommended for any unit installed in the field. Bubblers are commonly available in integrated systems, such as those manufactured by ISCO and American Sigma, but they also are sold as independent devices.

Ultrasonic Depth Sensor

An ultrasonic depth sensor consists of a sonar-like device mounted above the surface of the water at a known distance above the bottom of the channel. A transducer emits a sound wave and measures the period of time taken for the wave to travel to the surface of the water and back to a receiver. This time period is converted to a distance and then converted to a depth of flow, based on measurements of the site configuration. As with bubbler tubes, an ultrasonic sensor can be integrated into a flow meter or interfaced with a data logger. An ultrasonic depth sensor and data logger can provide the real-time flow data necessary to trigger an automated sampler to collect a stormwater sample for flow-weighted compositing.

Ultrasonic-depth Sensor Module (ISCO)

Some manufacturers have built redundancy into their ultrasonic depth-measuring instruments. Redundancy helps to ensure that useful data will be collected even if some of the sensors in the array become fouled with grease, surface-active materials, or organisms. Experience has shown that this type of fouling can occur during storm events. Because an ultrasonic sensor is mounted above the predicted surface of the water, it is not exposed to contaminants in the runoff (unless the depth is greater than anticipated or installed in a pipe that reaches fully pressurized flow). However, ultrasonic signals can be adversely affected by wind conditions, loud noises, turbulence, foam, and steam, and they will require periodic inspection and maintenance. Ultrasonic signals also can be affected by changes in density associated with air temperature gradients. However, some manufacturers build a compensation routine into their instruments.

Background noise can interfere with a sensor's ability to accurately measure water depth. For example, an ultrasonic sensor was used to measure the depth of flow at an urban stormwater sampling site in Portland, Oregon located in a manhole, in which runoff from an arterial pipe splashed down into the main conveyance. To dampen the effect of the interfering signal, the ultrasonic sensor was retrofitted with a flexible noise guard.

Pressure Probe

A pressure probe consists of a transducer that measures the hydrostatic pressure of the overlying water, mounted at the bottom of the channel. This hydrostatic pressure is converted to a depth of flow. Some pressure probes have a built-in thermometer to measure the temperature of the water, allowing for temperature compensation in the depth of flow calculation. As with bubblers and ultrasonic probes, the pressure probe can be integrated into a flow meter or interfaced with a data logger to provide real-time inputs to an automated sampler. If the instrument is fitted with a thermometer, the temperature data used for compensation can possibly also be input to memory and retrieved as additional useful data.

Submerged probes are not adversely affected by wind, turbulence, foam, steam, or air temperature gradients. However, because contaminants in the water may interfere with

Pressure Transducers (In-Situ Inc.)

or damage the probe, periodic inspection and maintenance is recommended. Dry conditions between storms can affect the accuracy of the probe, as can sudden changes in temperature.

Ultrasonic "Uplooking"

This depth of flow sensor is mounted at or near the bottom of the channel or pipe. It uses ultrasonic signals to determine the depth of the flow. This sensor is very accurate unless interference occurs. However, according to one vendor, this equipment is not recommended for stormwater applications because the sensor is likely to become covered by sediment and debris. This then interferes with the signal and does not allow the sensor to work properly.

Radar/Microwave

A variation of the ultrasonic method is a non-water contacting instrument that emits and reprocesses electromagnetic waves in the radar/microwave spectrum. By altering the wavelength of the electromagnetic signal, problems associated with foam, mist, and rapid changes in air temperature and pressure are eliminated or significantly reduced.

A radar/microwave sensor is used in the same manner as an ultrasonic "downlooking" sensor for measuring fluid levels in tanks. Based on experience, this device does not present a significant advantage over other methods of level measurement, since foam and mist are not typically a serious concern during stormwater monitoring.

Radar/microwave sensors have not been extensively tested by manufactures for this type of application, and there is no existing literature that shows them presently being used for stormwater monitoring.

3-D Point Measurements

This instrument measures the three velocity components at a point by applying ultrasonics and the Doppler principle. This instrument can be useful for studying boundary layers in fluid systems. However, this approach is very sophisticated and requires a high degree of accuracy in a controlled system to produce reasonable results. A large amount of time is also required to make each measurement. Consequently, its use is not practical for continuously measuring the mean velocity of water in a conveyance at a highway site.

4.2.4. Equipment for Measuring Velocity

Use of the continuity equation for measuring discharge requires estimating average velocity as well as depth. The velocity of a discharge may be measured using visual methods (i.e., the float-and-stopwatch and the deflection, or drag-body methods); tracer studies; or instruments such as rotating-element current meters or pressure, acoustic, ultrasonic (Doppler) and electromagnetic sensors. Electromagnetic sensors have been found to be the most accurate. Among these methods, many are more useful for the calibration of automated equipment than for continuous data collection. Only the ultrasonic and electromagnetic methods are recommended for measuring velocity during a storm. In the following text, velocity measurement methods potentially suitable for calibration are briefly described. (More details are available in USGS, 1980). More extensive discussions, including advantages and disadvantages associated with stormwater sampling, are provided for the ultrasonic and electromagnetic sensors.

Methods Suitable for Calibration

Float-and-Stopwatch Method

In this method, the time it takes for a float to move a known distance downstream is determined. Velocity is calculated as the distance traversed divided by the travel time. The characteristics of a good float are: an object that floats such that it is partially submerged, allowing some averaging of velocity above and below the surface of the water; an object that is easily observed and tracked; an object that is not easily affected by wind; and an object that does not cause problems if not recovered. Citrus fruits such as oranges, limes, or lemons are commonly used as floats. Ping-pong balls and Styrofoam float well but are too light and are easily blown by the wind. They may also pose environmental problems if not recovered.

In a variation of this method, a vertical float with a weighted end is used. The vertical float provides a better measure of mean velocity over the depth of the water column than a float moving primarily at the surface.

In addition, it can be designed to minimize bias due to wind.

In most cases this method is not accurate enough to be of significant utility in stormwater monitoring studies and is particularly inaccurate for very deep systems and where there is a significant difference in velocity across the water surface (e.g., in natural channels).

Deflection (or Drag-Body) Method

In this method, the deflection or drag induced by the current on a vane or sphere is used as a measure of discharge velocity. This method is only practical for short-term, real-time measurements, such as equipment calibration, because an object of this size inserted into the flow will accumulate debris, causing it to change the hydraulic form, provide inconsistent data, and (possibly) break away.

Tracer Studies

Tracer methods have been developed to measure discharge velocity under uniform flow (USGS, 1980). As described in the flow measurement methods section, for Total Recovery Tracer Dilution studies, a discrete slug of tracer is injected into the discharge. Concentration-time curves are constructed at two downstream locations. The time for the peak concentration of the dye plume to pass the known distance between the two locations is used as an estimate of the mean velocity of the flow. This method is not practical for continuous discharge measurement, but it is useful for site calibration.

Rotating-Element Current Meters

A current meter or current meter array can be used to measure the velocity at various points throughout a flow stream. The measured point velocities can be combined to estimate a mean velocity for the flow. As with the deflection or drag-body method, if employed for longer periods, a current meter inserted into the flow will accumulate debris causing it to malfunction and possibly break away. This method should therefore only be used for short-term measurements such as during equipment calibration or to develop a rating curve. Two types of readily available instruments that meet USGS standards are the type AA Price and Pigmy current meters.

Pressure Sensors

A pressure sensor or transducer measures the dynamic pressure head at a given point in the flow. The dynamic pressure is a measure of the point velocity and can be used to estimate the mean velocity of the flow. A common example of a pressure sensor is the pitot tube used on an airplane or on some boat speedometers.

The same caution described for bubbler tubes must be applied to pressure sensors. That is, as the velocity of the discharge increases above 1.5-1.8 meter/second (5-6 feet/second), a low- pressure zone is induced across the sensor, interpreted by the flow meter as a drop in discharge rate. These instruments should not be used in channels where the slope of the bottom exceeds 5 to 7 %.

Acoustical Sensors

An acoustical sensor emits a sound wave under water across a channel and measures the time required for the signal's return. Transit time is correlated with channel width. The relative positions of the emitting and receiving sensors are used to estimate velocity. A minimum depth of flow is required. This type of sensor can only be used at sites with sufficient baseflow to provide the medium in which the sound wave travels. If there is no baseflow, the lower portions of the rising and falling limbs of the hydrograph will be lost.

<u>Methods Most Suitable for Continuous Velocity Monitoring</u>

Ultrasonic (Doppler) Sensors

An ultrasonic sensor applies the Doppler principle to estimate mean velocity. A sound wave, emitted into the water, reflects off particles and air bubbles in the flow. The shift in frequency of waves returning to the sensor is a measure of the velocity of the particles and bubbles in the flow stream. The instrument computes an average from the reflected frequencies, which is then converted to an estimate of the average velocity of the flow stream.

Area Velocity Sensors Module (ISCO)

The sensor is mounted at the bottom of the channel. However, because the ultrasonic signal bounces off suspended particles, the signal may be dampened (i.e., not able to reach portions of the flow stream) when suspended solid concentrations are high. The sensor may also be mounted on the side of the channel, slightly above the invert. Combined with the appropriate hardware and software, the sensor can filter out background signals associated with turbulence in the discharge.

Ultrasonic Doppler sensors can be used under conditions of either open channel or pressurized flow. When combined with the hardware and software required for real-time discharge measurement, data logging, and automated sampling, and when properly calibrated, this system is capable of greater accuracy than one relying on a stage-discharge (i.e., Manning equation) relationship. The ultrasonic sensor-based system may be more expensive, but the additional expense may be justified by program objectives. Without routine maintenance, the accuracy of ultrasonic sensors may decrease due to fouling by surface-active materials and organisms.

Electromagnetic Sensors

Electromagnetic sensors work under the principle stated in Faraday’s Law of electromagnetic induction; that is, a conductor (water) moving through an electromagnetic field generates a voltage proportional to its velocity. This instrument, mounted at or near the channel bottom, generates the electromagnetic field and measures the voltage inducted by the flow. Although velocity is measured at only a single point, that measurement is used to estimate the average velocity of the flow stream.

Electromagnetic sensors can be pre-calibrated for many types of site configurations. The sensor is usually mounted at the channel invert but can be mounted on the side of a channel, slightly above the invert, if high solid loadings are expected. A built-in conductivity probe senses when there is no discharge in the conveyance.

These types of instruments are not sensitive to air bubbles in the water or changing particle concentrations, as is the ultrasonic sensor, but can be affected by extraneous electrical "noise." As with the ultrasonic system, when an electromagnetic sensor is combined with the hardware and software required for real-time discharge measurement, data logging, and automated sampling, and when properly calibrated, it may be capable of greater accuracy in specific circumstances than a system relying on a stage-discharge relationship. On the other hand, the electromagnetic sensor-based system may also be more expensive, but the additional expense may be justified by program objectives.

Acoustic Path

These sensors are used to determine the mean velocity of streams and rivers, and where they are applicable they have been found to be one of the most accurate flow measurement systems. The method consists of an array of sensor elements that are installed at an even elevation across the channel. The number of sensor elements used is dictated by the channel width. Larger channels require more sensors. Due to the sensor array's height above the channel bottom, its use is generally limited to larger channels that have a baseflow present. It is not practical for smaller diameter conveyances with no baseflow, as is typically found at highway sites. Additionally, stormwater conduits for highway runoff are generally small enough that a single point measurement for velocity provides a reasonable estimate for the average velocity. For these reasons, acoustic path sensors are rarely applicable to highway runoff monitoring situations.

4.3. Sampler Equipment

4.3.1. Introduction

Federal and state water quality regulations often either require or encourage the analysis of highway runoff to determine the magnitude (e.g., pollutant loads) or concentrations of pollutants present for assessing potential impacts to receiving waters. For almost all constituents, samples of stormwater runoff should be collected and taken to a laboratory for analysis. As with measurements of discharge, stormwater samples can be collected manually or automatically. Both approaches, their applicability to monitoring for various pollutants, and their advantages and disadvantages, are discussed in this section.

The American Society for Testing and Materials (ASTM) defines sampling as "obtaining a representative portion of the medium being sampled" (ASTM, 1989). A sample is representative if it possesses the same qualities or properties as the subject medium at the point and time of collection (Stenstrom and Strecker, 1993). However, one of the fundamental characteristics of water quality, whether in a stormwater conveyance or in a receiving water body, is the large inherent variability in the concentrations of constituents over time and space (USEPA, 1983; FHWA, 1989). This variability is caused in part by changes in storm intensity, the mechanism by which pollutants are mobilized from surfaces, as well as the timing of discharges from different sub-areas of a catchment. As a result, the concentration of a pollutant, even when measured at a fixed point at a single site, typically fluctuates greatly over the duration of a storm event (Woodward-Clyde Consultants, 1991a). For some pollutants, concentration can vary with depth depending on the degree of mixing. In lower velocity situations materials present in the particulate phase, those denser than water (e.g., natural sediment particles, pollutants adsorbed to sediment particles, and relatively dense pieces of debris) tend to be found in higher concentrations near the bottom of a channel. Those less dense (e.g., oil and grease, woody debris, and plastic particles) tend to float. Only completely dissolved materials, or suspended particles under turbulent flow, are likely to be well mixed over the depth of the water column.

Pollutant concentrations vary on other scales, such as along the length of a conveyance, between conveyances in a catchment, and between catchments and watersheds. However, it is primarily the spatial and temporal variability discussed above that influence the choice of method for water quality sampling. "Method" means not only the choice of manual versus automated sampling, but also the number of grab samples necessary to meet program objectives. If a single grab is not adequate, a series of grab samples collected over the course of a storm may be analyzed individually to provide discrete measures of pollutant concentrations over time.

Individual grab samples can be composited in one of several ways (USEPA, 1992):

1. Constant time - constant volume: Samples of equal volume are taken at equal increments of time and composited to make an average sample. (Note: This method is not acceptable for samples collected for compliance with USEPA's NPDES Municipal Stormwater Permit Application.)

2. Constant time - volume proportional to flow increment: Samples are taken at equal increments of time and are composited proportional to the volume of flow since the last sample was taken. This method does result in a flow-weighted sample; however, it is seldom employed, as it requires extensive measurements to determine volumes applicable for each sample.

3. Constant time - volume proportional to flow rate: Samples are taken at equal increments of time and are composited proportional to the flow rate at the time each sample was taken.

4. Constant volume - time proportional to flow volume increment: Samples of equal volume are taken at equal increments of flow volume and composited.

Each of these methods results in a sample that is more representative of average conditions during a storm than a single grab sample. However, use of the second and fourth methods described above would require continuous monitoring of the discharge. Automated samplers can be programmed to act in this manner; however, this is not a practical approach for personnel sampling by hand. The third method described above also requires some system for the measurement of the discharge rate, but this must only be monitored periodically, when each grab sample is retrieved.

As mentioned above, the series of samples can also be flow-weight composited to provide an average picture of water quality and a better estimate of the impact of the discharge on receiving water quality. The time composite methods are also sometimes used, but are only typically recommended where flow rate does not vary significantly with time. The type of chemical constituent being measured may also dictate the type of sampling method. The extent of grab sampling or selected compositing will significantly influence equipment selection.

Grab Versus Composite Samples

A grab sample can be considered representative of runoff at a single site at the precise time of collection. Depending on the degree to which pollutant concentrations vary during a storm, data derived from a grab sample may or may not present an accurate representation of pollutant concentrations and loadings over the course of a storm. Despite this potential shortcoming, grab sampling for some constituents is incorporated into most sampling programs for the following reasons:

- A grab sample collected during the first 30 minutes or less of a storm has been used to characterize pollutants associated with the first flush (those pollutants that build up in the collection system, on paved surfaces, and in storm sewer system during the antecedent dry period).

- Some pollutants such as temperature, pH, total residual chlorine, bacteria, and volatile organic compounds transform rapidly. The compositing techniques when used with these parameters will introduce a source of bias.

- Some pollutants (i.e., oil and grease) adhere to surfaces so that transfer between sampling containers must be minimized. If program objectives require characterization of the average oil and grease concentration over the duration of a storm, this information should be derived from a number of grab samples that are analyzed individually.

Two approaches may be taken to obtain more representative data for those parameters that do not transform rapidly:

- Grab samples may be taken at predetermined intervals throughout a storm and analyzed individually.

- Grab samples taken at predetermined intervals may be mixed together in equal volumes or in volumes weighted by the discharge rate at the time of collection.

The first method provides the most detailed information about the variability of pollutant concentrations during a storm. However, the analysis of each grab sample separately increases laboratory costs and is typically only used to answer specific questions about stormwater quality.

More typically, the practice (compositing) of mixing together a series of grab samples is used. Whether the compositing procedure entails sampling at equal time intervals between grab samples or by the rate of discharge at the time each grab sample is collected, the resulting sample is considered to represent an average picture of stormwater quality over the compositing period. Time-weighting gives a representation of the average concentration while flow weighting presents an average that can be used to estimate pollutant loads. The use of composite samples provides a clear opportunity for reducing monitoring program expenses and provides a good method for obtaining pollutant loads.

Manual Versus Automated Sampling Methods

For a monitoring program that is small in scope, with relatively few sampling sites and storm events, manual methods for obtaining grab and composite samples may be preferable to those employing automated equipment. The principal advantage to manual sampling is the relatively low cost of equipment and station setup. In addition to the capital outlay required for the purchase of automated samplers, other potentially substantial costs include installation, training personnel to use the samplers correctly, field maintenance and operations (i.e., replacing batteries, interrogating data loggers, retrieving and cleaning sampling receptacles).

However, manual sampling is not recommended for monitoring programs involving large numbers of sites or sampling events where flow-weighted composites will be collected over multiple events. Under these circumstances, labor costs can far exceed those associated with automated equipment. Health and safety issues such as the potential for exposure to inadequate oxygen, toxic or explosive gases, storm waves in manhole vaults, and hazardous traffic conditions at street level, must also be considered when evaluating manual versus automated sampling techniques.

The following sections describe methods and equipment used to collect grab and composite samples.

4.3.2. Water Quality Sampling Equipment

Water quality monitoring equipment can be broken into two general categories: manual equipment and automated equipment. Each are discussed in this section. In addition, overland flow samplers and *in situ* water quality devices are discussed.

Manual Water Quality Sampling Equipment

Manual equipment can be used in collecting grab samples, composite samples, or both.

Manual Grab Sampling Equipment

Stenstrom and Strecker (1993) provide a more detailed review of manual sampling techniques and equipment. If site conditions allow, a grab sample can be collected by holding the laboratory sample bottle directly under the lip of an outfall or by submerging the bottle in the flow. A pole or rope may be used as an extension device if field personnel cannot safely or conveniently approach the sampling point. Alternatively, a clean, high-density polyethylene bucket may be used as a bailer and sample bottles may be filled from the bucket. Care should be taken not to stir sediments at the bottom of the channel.

As described earlier, the concentrations of suspended constituents tend to stratify within the flow stream depending on their specific gravity and the degree to which flow is mixed by turbulence. Use of a discrete-depth sampler for multiple samples should be considered when constituents lighter or heavier than water are targeted, or if the discharge is too deep and/or not mixed well enough to be sampled in its entirety (Martin et al., 1992). However, highway runoff sampling sites usually drain relatively small catchments and contain fairly shallow flows. Collection of depth-integrated samples at these sites is not typical.

Given the extremely low detection limits that laboratory analytical instruments can achieve, leaching of water quality constituents from the surface of a bailing device or sample bottle can affect water quality results. Sample bottles of the appropriate composition for each parameter are usually available from the analytical laboratory. Depending upon the pollutant to be analyzed, bailers and discrete-depth samplers should be made of stainless steel, Teflon™-coated plastic, or high-density polyethylene. When in doubt, a laboratory analyst should recommend an appropriate material type for the collection device.

Manual Composite Sampling Equipment

If grab samples will be composited based on discharge rate (i.e., grab samples collected during high flow contribute more to the composited sample than those collected during low flow), some receptacle for storing the individual grab samples prior to compositing will be required. The use of polyethylene jugs, or the polyethylene cubes with screw-on caps manufactured for shipping chemicals, is recommended. These can be shaken to remix the sample prior to pouring out the required volume. The volume required from each receptacle can be measured in a graduated cylinder and poured into a bucket for compositing. Both the cylinder and the bucket should be made from a Teflon™-coated plastic or high-density polyethylene and should be cleaned prior to use.

Automated Water Quality Sampling Equipment

An automated sampler is a programmable mechanical and electrical instrument capable of drawing a single grab sample, a series of grab samples, or a composited sample, *in situ*. The basic components of an automated sampler are a programming unit capable of controlling sampling functions, a sample intake port and intake line, a peristaltic or vacuum/compression pump, a rotating controllable arm capable of delivering samples into sample containers, containers, and a housing capable of withstanding moisture and some degree of shock. Commonly used brands include: ISCO, Lincoln, Nebraska; American Sigma, Medina, New York; Manning, Round Rock, Texas; and Epic/Stevens, Beaverton, Oregon.

An automated sampler can be programmed to collect a sample at a specific time, at a specific time interval, or on receipt of a signal from a flow meter or other signal, (e.g. depth of flow, moisture, temperature). The sampler distributes individual samples into either a single bottle or into separate bottles that can be analyzed individually or composited. Some automated samplers offer multiple bottle configurations that can be tailored to program objectives.

Automatic Sampler (American Sigma Inc.)

Important features of automated samplers include:

- portability;
- refrigeration;
- volatile organic compound (VOC) sample collection; and
- alternative power supplies.

Portable samplers are smaller than those designed for fixed-site use, facilitating installation in manholes and other confined spaces. If a suitable confined space is not available or undesirable (e.g., because of safety issues), the sampler can be housed in a secure shelter at the sampling site. Portable samplers can use a 12V DC battery power supply, solar battery, or AC power.

Although none of the portable samplers currently available are refrigerated, ice may be added to the housing of some units to preserve collected samples at a temperature as close to 4°C as possible. The objective of this cooling is to inhibit pollutant transformation before the sample can be analyzed. Refrigerated samplers hold samples at a constant temperature of 4°C. However, their large size and requirement for a 120V AC power prohibit most field installations.

An automated sampler designed for VOCs is currently available from ISCO.

VOC Sampler (Isco)

The bladder pump used by this instrument minimizes physical disturbance of the samples (as opposed to the physical disturbances imparted by peristaltic vacuum pumps), reducing the loss of volatile compounds. The VOC sampler distributes the sample into sealed 40-ml sample bottles, as required by USEPA protocol. However, at present, the caps for the sample bottles are not compatible with automated laboratory equipment, requiring more handling in the laboratory.

In typical installations for highway sampling, an intake line is bracketed to the channel bottom. The intake tubing should be mounted as unobtrusively as possible, to minimize disturbance of the site hydraulics. Generally, the optimum position for the intake is at the channel bottom. However, if high solid loadings are expected and potential deposition could occur, the intake can be mounted slightly higher on one side of the channel wall. Typically, a strainer is attached to the intake to prevent large particles and debris from entering the tubing. The strainer is usually installed so that it faces upstream, into the flow. This configuration minimizes the development of local turbulence that could affect representative sampling of constituents in the particulate phase.

Two types of pumps are incorporated into automated samplers for typical water quality sampling (i.e., not VOC sampling): peristaltic and vacuum/ compressor. A peristaltic pump creates a vacuum by compressing a flexible tube with a rotating roller, drawing a sample to the pump that is then pushed out of the pump. Field experience has shown that the reliability of peristaltic pumps in drawing a consistent sample volume is greatly reduced as the static suction head (i.e., distance between the flowstream surface and the sampler) increases. It may be possible to increase the efficiency of these samplers by placing the pump closer to the sample source, reducing the suction head. In general, the sampler itself should be installed no more than 6 meters (20 feet), and preferably less, above the channel bottom. If the sampler is to be installed at greater than 20 feet above the channel invert, it may be necessary to use a remote pump that is placed closer to the flowstream to ensure reliable sample collection.

The degree to which sampler lift affects the concentration of total suspended solids (and other pollutant parameters) is not well known, especially the effect on coarser material. That is, the mean transport velocity achieved by the peristaltic pump is sufficient to draw suspended solids; however, the pulsed nature of the flow may allow suspended solids to settle back down through the pump tubing during transport. In work performed with the USGS for this study, it was found that suspended solid concentrations did not vary with pumping height (0 to 24 feet). However, sample volumes delivered to sample bottles did vary from sample to sample at high lift heights for some of the older sampler models.

Another concern with peristaltic pumps is their incompatibility with Teflon™-lined tubing in the pump assembly. Compression of the intake tubing by the rollers tends to create stress cracks and small recesses in the lining where particles can accumulate. Under these circumstances, some pollutant concentrations could be underestimated and the cross-contamination of samples can occur. Although Teflon™-lined tubing is preferable because it reduces the potential loss of pollutants through surface interactions, this advantage cannot be accommodated with a peristaltic pump.

A vacuum/compressor pump draws a sample by creating a vacuum. This type of pump can create a higher transport velocity in the intake tube and provide a more steady and uniform discharge than a peristaltic pump. However, the higher intake velocity can scour sediments in the channel near the sampler intake, resulting in disproportionately high concentrations of suspended solids.

After a sampler is installed, it must be programmed to collect the desired sample size. Calibration of peristaltic pumps is achieved by one of two methods: automatic or timed. In automatic calibration, the actual volume of the sample drawn is measured using a fluid sensor located at the pump and the known pump speed. In timed calibration, the volume is determined from the number of revolutions of the peristaltic pump and the time taken for the sample to travel from its source to the sample container. Calibration by this latter method is site specific, incorporating the pump speed, the head (vertical distance above the sample source), and the length and diameter of the intake tubing. The Manning and Epic samplers, which employ vacuum pumps, permit adjustment for specific sample volumes via a fluid level device in a chamber. Because it cannot be flushed as the tubing can, this chamber can cause sample cross-contamination.

<u>Remote Communications with Automatic Equipment</u>

The ability to remotely access the memory and programming functions of an automated sampler is a highly desirable feature for large stormwater sampling networks. Although this feature increases the capital cost for a system, it can greatly reduce the expertise and training necessary for field crews, since many of the technical aspects of equipment set-up and shutdown can be conducted by a system supervisor remotely.

Currently, modem communication is an available option to most commercially produced automated samplers. However, there are several common drawbacks that may be encountered with the communication systems currently offered by manufacturers:

- Full access to all sampler programming features is currently not available. This means that trained field crews may still be necessary to ensure sampler programming is correct.
- For multiple instrument systems (i.e., separate flow meter and automated sampler) communication and complete operation of both components through one modem system is generally not available.

Remote communication for both samplers and flow meters is a rapidly advancing technology, and companies like American Sigma and ISCO currently are developing systems that address the problems described above.

Overland Flow Sampler

An overland flow sampler is a non-automated sampler that can be used to take discrete grab samples or a continuous sample over some duration. This type of sampler may be useful for collecting stormwater samples at the highway shoulder. One manufacturer's (Vortox, Claremont, California) unit within this class of samplers consists of an upper ball valve, a lower ball valve (through which runoff enters), and a sample container. The upper valve can be adjusted to control the rate of intake, allowing continuous sampling of storm events of different durations provided depth of flow is not highly variable. The lower ball valve seats and closes the intake when the water level reaches the top of the container.

Overland flow samplers (manufactured by Vortex) are available in two sizes: 3 liters (0.8 gallon) and 21 liters (5.5 gallons). They can be set into existing sumps or in the ground, but they must be installed with the top of the sampler flush with the ground surface.

This instrument is inexpensive and simple to operate. Since the overland flow is not concentrated there are few other methods for collecting this flow. However, this sampler is not capable of taking flow or time-weighted composites or of sampling the entire discharge during a large storm event. In fact, there is no way of knowing what part of the storm was actually sampled, especially where flow depths are variable.

Other manufacturers of samplers that can be used for overland flow include GKY's "FirstFlush" sampler and D-Tec Corporation's "Environmental Liquid Sampler" (ELS).

Recently, the USGS developed and began testing an automated overland flow sampler that may be capable of time-weighted composite sampling.

In Situ Water Quality Devices, Existing Technology

As described in the sampler section, the concentration of most pollutants in stormwater runoff is likely to vary significantly over the course of a given storm event. Some of this variability can be captured through the collection of multiple samples. The ideal data set would contain not just multiple samples, but a continuous record of constituent concentrations throughout a storm, capturing both the timing and magnitude of the variations in concentration. Given the availability of other continuous data, this approach might allow better correlation with potential causative factors. Unfortunately, the laboratory costs for even a near-continuous data set would be prohibitive. This study for FHWA determined that between 12 and 16 individual samples resulted in a mean that was within 10 to 20% of the actual event mean concentration. *In situ* monitoring devices offer a possible solution to obtaining a continuous record of water quality; however, currently, they are only practical for a limited set of parameters.

In situ water quality probes have been adapted from equipment developed for the manufacturing and water supply/wastewater industries. *In situ* water quality monitors attempt to provide the desirable near-continuous data set described above at a relatively low cost, eliminating (or reducing) the need for analysis of samples in the laboratory.

In general, water quality monitors are electronic devices that measure the magnitude or concentration of certain specific target constituents through various types of sensors. Discrete measurements can be made at intervals of one minute or less. Most monitors use probes that provide a controlled environment in which a physical and/or electrochemical reaction can take place. The rate of this reaction is typically driven by the concentration of the target constituent in the discharge. The rate of reaction, in turn, controls the magnitude of the electrical signal sent to the display or a data-logging device.

Probes to detect and measure the following physical and chemical parameters are currently available for practical use in the field:

<u>Physical parameters</u>

- Temperature
- Turbidity

<u>Chemical parameters</u>

- pH
- Oxidation-reduction potential (redox)
- Conductivity
- Dissolved oxygen
- Salinity
- Nitrate
- Ammonia
- Resistivity
- Specific conductance
- Ammonium

There are some potential probes for heavy metals, but given the complexities associated with highly variable solid concentrations and other factors, this study found that they are not practical for field application. Instruments can be configured to measure the concentrations of several of these parameters simultaneously (i.e., multi-parameter probes) and provide data logging and PC compatibility. Manufacturers of this type of instrument include YSI, Inc., Yellow

Springs, Ohio; ELE International, England; Hydrolab, Austin, Texas; Solomat, Norwalk, Connecticut; and Stevens, Beaverton, Oregon.

In many cases, the electrochemical reaction that drives a probe's response is sensitive to changes in temperature, pH, or atmospheric pressure. Where appropriate, monitors are designed to simultaneously measure these associated properties. Data on the target constituent are then corrected through a mathematical routine built into the probe's microprocessor (e.g., dissolved oxygen probes are compensated for temperature and atmospheric pressure, pH probes for temperature, and ammonia probes for pH), or are adjusted in a spreadsheet after being downloaded to a personal computer.

Despite the advantage of these instruments for measuring near-continuous data, they require frequent inspection and maintenance in the field to prevent loss of accuracy due to fouling by oil and grease, adhesive organics, and bacterial and algal films. Therefore, these instruments should always be cleaned and calibrated before use. Because water quality probes are designed to operate while submerged in water, exposure of the electrochemically active probe surface to air should be minimized.

In Situ Water Quality Devices, Future Technologies

There are several *in situ* water quality devices that are used by industry, but they are not currently applicable to stormwater monitoring. However, as the technology advances they may become applicable and therefore are discussed in this section.

Ion-Selective Electrodes

An ion-selective electrode places a selectively permeable membrane between the discharge and an internal solution of known ionic strength. The voltage differential across the membrane is proportional to the difference in ionic strength between the two solutions. Ion-selective probes are currently available for the ionic forms of a number of parameters, including ammonia, ammonium, copper, lead, nitrate, and nitrite.

An ion-selective electrode is specific to the targeted ion and will not measure other ions or other complex forms. For example, depending on the target parameter, a nitrate-selective electrode will not measure the concentration of nitrite in the discharge. However, these instruments are sensitive to interference from other ions, volatile amines, acetates, surfactants, and various weak acids. At present, the degree of interference can be judged only by comparing the performance of the probe to that of one in a reference solution, a procedure likely to prove unwieldy in the field. Consequently, this type of probe is not typically used for stormwater monitoring.

On-Line Water Quality Analyzers

On-line water quality analyzers are spectrometers, similar to those used in analytical laboratories. A light source that generates a known intensity of light over a range of wavelengths (i.e., ultraviolet or infrared) is transmitted through a sample introduced into a flow cell. The instrument collects light absorbency information at multiple wavelengths and produces a light absorbency signature (manufacturer's specifications, Biotronics Technologies, Inc., Waukesha, Wisconsin, and Tytronics, Inc., Waltham, Massachusetts). The instrument is calibrated using 30 or more randomly varied mixtures of standards; the ultraviolet (UV) light-absorbency characteristics of a sample are then compared to a baseline calibration file of known "UV signatures."

On-line analyses are used in the water treatment and wastewater industries. Until recently, on-line spectrometric analyzers were impractical for stormwater field use. The state of technology of these systems was comparable to that of computers 20 years ago—highly trained specialists operated large machines in a controlled laboratory environment. However, an increased demand for portability, the increased power and decreased cost of microprocessor technology, the development of new statistical and mathematical analysis software, and the availability of standardized control systems (i.e., communication interfaces, actuators, and programmable controllers) have fostered the emergence of a new generation of instruments.

Three types of spectrometers are currently available or under development for environmental applications:

- Ultraviolet-Array Spectroscopy (UVAS) employs a broad-spectrum light generated by a Xenon lamp and delivered to the sample through fiber optic cables. Light is transmitted through the sample in specially designed optical probes. The light transmitted through the sample is collected and returned to the analyzer where it is dispersed into wavelengths and projected onto a photodiode detector array. Current applications are the detection of multiple contaminants (metals, nitrates, organics, and aromatic hydrocarbons) in groundwater, the detection of metals (chromium, zinc, and mercury) in industrial wastewater, and water treatment quality parameters (copper, iron, molybdate, triazole, phosphorate) in industrial process and cooling waters.

- Liquid Atomic Emission Spectrometry (LAES) employs a photodiode detector array, similar to that used in UVAS. A high-energy arc is discharged directly into the liquid as the source of excitation and the resulting atomic light emission is analyzed by special pattern recognition techniques. Qualitative analysis is derived from the detection of emission lines whereas quantitative analysis is a function of intensity. Use of LAES has been demonstrated for the analysis of metals, hydrogen, and sulfur.

- Like UVAS, Near Infrared (NIR) analysis employs the transmission of light through a liquid. This technology has been used extensively in the food processing industry and is under evaluation for application elsewhere.

To date, portable on-line analyzers have not been tested extensively for use in stormwater monitoring. The "ChemScan" analyzer, manufactured by Biotronics Technologies, Inc., reportedly adjusts automatically for changes in the turbidity of the discharge and fouling of the optical windows, features that suggest applicability to stormwater situations. According to the manufacturer, routine maintenance is limited to a periodic baseline correction and occasional chemical cleaning of the flow cell.

Particle Size Analyzers

There is a particle size analyzer available that can be installed *in situ*. It employs laser diffraction to determine the particle size distribution. However, the unit costs approximately $30,000, is 3 feet long and 5 inches in diameter, and must be submerged. Currently it is not applicable for stormwater monitoring.

Research has been ongoing for many years on applying ultrasonics for particle size analysis. However, it is presently not available for field stormwater application.

In Situ Filtration and Extraction System

Axys Environmental Systems, Ltd., British Columbia, Canada manufactures an *in situ* filtration and extraction system for monitoring trace organics, metals, and radionuclides in stormwater. These systems retain the target pollutant on a resin filter as a portion of the discharge passes through it. After the storm event, the filter is taken to the laboratory and the pollutant is removed through solid phase extraction. The filtration system is comprised of a microprocessor, a pump, a flow meter, and a DC power supply. A pre-filter for suspended solids can be attached if levels high enough to clog the resin filter are anticipated. Pollutants trapped in the pre-filter can also be extracted and analyzed.

These systems can be programmed so that samples of the discharge pass through the filter at equal time intervals, or so that signals from an external flow meter trigger flow- or time-weighted composite sampling. As with other types of automated samplers, the sampling history is stored in internal memory.

Filtration and extraction systems reduce the potential for contamination of a sample during handling in the field and eliminate the need to transport large volumes of water to an analytical laboratory. The detection limit of the samples depends on the amount of water flowing through. Because large volumes of water can be passed through the system, even very small concentrations of pollutants can be detected. On the other hand, where suspended sediment concentrations are high, the pre-filter may become clogged as a large volume of water passes through it. Metals can be lost from the filter if the pH drops below 6.0 and resin filters are available for only a limited number of pollutants. Due to the potential for clogging, this methodology may not be useful for highway sites.

4.3.3. Sampling Equipment Summary

In general, manual sampling is not practical for accurate flow-weighted composite sampling of a large number of sites or sampling events over multiple years. Automated flow-measured systems are ideally suited for this role. An automated sampler combined with a reliable and accurate flow meter will provide a user with a useful system for monitoring highway stormwater runoff. There is currently a trend by some sampler manufacturers to integrate flow meters and samplers as one unit. This greatly facilitates the site installation and the role of field personnel during a storm event. It may also allow for better remote communications with both units.

The ability to interact with samplers via remote communications is a desirable advance in sampler technology. Additional improvements could include:

- The ability to make changes in programming by entering the sampler program at a specific step, rather than having to step through the entire program. This would be useful in general as well as in regard to the particular task of calibrating the sample volume.

- The ability to program the sampler to distribute a grab sample into one bottle and to composite a sample into the others (e.g., in a 4- or 8-bottle configuration).

- The ability to draw a sample at a velocity equal to or greater than the mean velocity of the discharge. This would ensure the collection of a representative sample of the discharge, including suspended particles. Because the discharge rate is likely to vary over the duration of a storm, this feature would require a variable-speed pump as well as additional programming capabilities.

The development of robust *in situ* instruments has changed the notion of appropriate technology for water quality monitoring. It is clear from the discussion above that these instruments are still evolving and that entirely new products are likely to become available in the next few years.

Typically, *in situ* filtration and extraction systems and overland flow samplers currently are not well suited to monitoring highway stormwater runoff.

4.3.3.1. Flow Measurement Equipment

A variety of methods and instruments are available for measuring flows within stormwater conveyances. The most useful technologies for the continuous measurement of discharge during a storm event have the following capabilities and characteristics:

- tolerant of site hydraulics and environmental conditions;

- accurate and capable of maintaining calibration over the range of hydraulic and environmental conditions expected during a sampling event;

- employ probes that are streamlined and non-intrusive or otherwise do not accumulate debris;

- retrievable internal memory or capable of integration with an external data logging device;

- capable of integration with a rain gauge, automated sampler, and other stormwater monitoring devices;

- capable of receiving programming instructions from a remote workstation by telemetry;

- capable of transmitting monitoring data to a remote work station by telemetry; and

- minimize the changes to hydraulics such that flooding is not increased.

Nearly all of these characteristics are currently available in flow metering equipment. However, not all of these characteristics are built into each instrument, nor are they available for all site conditions. Each site must be evaluated, including a site inspection, before a discharge measurement method and instrumentation are chosen.

In general, discharge measurement devices that are likely to collect a great deal of debris (i.e., drag-bodies and rotating-element current meters) are not useful for continuous monitoring. Some instruments (i.e., pressure transducers and ultrasonic and electromagnetic probes) are designed with a more streamlined profile but, in practice, pieces of flexible debris can become wrapped around these instruments as well. Adaptations that aid in the shedding of debris would be extremely useful and would widen the application of these instruments. It is also important that the hydraulic capacity of weirs or flumes not be reduced.

4.4. Precipitation Gauging Equipment

Precipitation gauges are devices used to detect and measure rainfall and snowfall. The use of such data includes investigating the relationship between rainfall and runoff. In addition, rainfall can be used to initiate sampling or flow measurement. The most common gauges measure precipitation by either volume or weight. New technology uses an infrared beam to measure precipitation via the frequency and via the frequency and blockage of a light beam.

The purpose of a precipitation gauge is to make a point estimate of rainfall and snowfall that is used as an index to approximate the volume of water falling over an area (the amount of liquid produced when snow is melted is known as the liquid equivalent). Precipitation amounts that fall at a particular gauge are equal to the amount of rainfall plus the amount of snowfall liquid equivalent.

Precipitation gauges provide adequate measures of precipitation amounts at a point but are less proficient at estimating precipitation amounts over large areas. How accurately the precipitation amounts are measured at such points is less important than how consistently the point measurements estimate the total precipitation amounts over an area represented by an individual gauge.

A typical precipitation gauge is 6 to 12 inches in diameter, and the area covered by this size gauge is approximately 55 to 110 square inches, or 14 to 28 billionths of a square mile. Most precipitation gauge networks have gauge densities on the order of one gauge (point) per 10, 20, or 50 square miles. Networks routinely sample the precipitation at an area-ratio of parts per trillion.

The number of precipitation gauges installed in a precipitation gauge system directly affects the quality of precipitation data. Generally, the higher the number of precipitation gauges, the better the estimate of incoming precipitation amounts. Locating a gauge at each monitoring site for small catchments is imperative because local variations in total rainfall and rainfall intensity can have significant effects on runoff when the watershed is minimal in size. Nearby locations may not be useful in estimating rainfall at the actual site.

Tipping Bucket Precipitation Gauges

The most widely used type of precipitation gauge is the tipping bucket rain gauge. This type of gauge measures precipitation amounts in various increments, usually 0.01 inch or 0.1 millimeter, depending on the model.

Tipping bucket gauges operate by funneling precipitation into a bucket mechanism that tips when filled to a calibrated level. A magnet attached to the tipping mechanism triggers a switch as the bucket tips. The momentary switch closure is counted by pulse counting circuitry of data loggers. The tipping of a bucket also brings a second bucket into position under the funnel. The second bucket is then ready for filling. After measurement, water is directed into drain tubes that allow it to exit out holes in the base of a gauge. Screens cover the exit holes to prevent insect entry. Heaters can be installed on these gauges so that snow and other freezing precipitation will melt on contact with the collection orifices, and the liquid equivalent of the frozen precipitation can be measured.

Tipping Bucket Rain Gauges
(American Sigma Inc.)

These gauges have been found to be quite reliable and require little manpower to operate. Most data loggers can be used with a tipping bucket precipitation gauge. However, since it takes 0.01 inches of precipitation to tip the bucket, it is possible that smaller precipitation amounts will not register due to evaporation between precipitation events. This can cause some error in precipitation amount data. The cost of these gauges ranges from $500 to $900, (including the price of heaters and mounting equipment). Overall, most tipping bucket gauges have a resolution of 0.01 inches and an average percentage error of ± 2.25% over an average range of 0 to 6 inches of precipitation per hour. The percent error rises significantly for higher precipitation intensity (greater than 6 inches per hour) and under windy conditions.

Optical Precipitation

Optical Precipitation Gauges are one of the more recent precipitation gauge technologies. This type of gauge has two sensors that face each other at either end of a "U" shaped bracket. The precipitation is measured by detecting the optical irregularities induced by drops falling through an infrared optical beam. These irregularities, known as scintillation, have characteristic patterns that are detected by the sensor and converted to precipitation rates. The higher cost models are equipped with a heating device for the sensors making it possible for the gauge to measure frozen precipitation.

Optical gauges are exclusively designed for remote data collection and require little to no manpower to operate, have no moving parts, are not affected by wind, and are able to measure very low intensity rainfall that may get held upon the side wall of a tipping bucket rain gauge. However, these gauges can only interface with a data logger that has RS232 input capability. Optical range gauges have an average percent error of ±5% over almost all precipitation intensities. The major drawback to this type of gauge is the cost ranging from $2,000 to $3,000.

Siphoning Precipitation Gauges

The siphoning precipitation gauge was the cutting edge of technologies for precipitation gauges until optical precipitation gauges emerged.

This type of gauge measures water levels in a tube called the measuring chamber. Each 0.04 inch of captured precipitation produces a 0.197 inch rise of the sample column in the measuring chamber giving added resolution to the measuring circuitry. A full sample column of 9.842 inches represents 1.969 inches of collected precipitation. Additional precipitation starts a self-siphoning process that empties the measuring tube in approximately 30 seconds. During this time, the gauge is unable to measure precipitation, and this could lead to inaccurate measurements during heavy precipitation events. There are heaters on this gauge that melt frozen precipitation so that the siphoning precipitation gauge can measure liquid equivalents for snowfall and other frozen precipitation.

Siphoning precipitation gauges are some of the most complex precipitation gauges used today, and have the advantage of no moving parts to wear or break. This type of rain gauge may have difficulty interfacing with some data loggers. Siphoning precipitation gauges cost about $1,100. Resolution of this type of rain gauge is 0.004 inches with a margin of error of ± 0.04 inches.

Manual Precipitation Gauges

The manual precipitation gauge consists of a funnel, an inner measuring tube, an outer over flow cylinder, and a dipstick. The inner tube has a capacity of two inches, and the over flow cylinder can hold up to 18 inches. Precipitation is measured by inserting the dipstick into the inner tube and reading the measurement shown on the stick at the water line. In cases where there is water in the overflow cylinder, the water from the cylinder is emptied into the inner tube and measured in the same manner. In the case of frozen precipitation, the funnel is removed allowing frozen precipitation to accumulate in both the inner tube and overflow cylinder. The frozen precipitation can be melted down and measured in the same manner as liquid precipitation.

Manual precipitation gauges do not have electronic data gathering capabilities. It is therefore necessary to measure the precipitation by hand for every precipitation event. This type of gauge has a resolution of 0.01 inches and can handle up to 20 inches for each precipitation event. The manual precipitation gauge is the least expensive of all the gauges discussed, ranging in price from about $250 to $400. This price includes the cost of a mounting stand. However, since data loggers cannot interface with this type of gauge the labor cost of taking readings for every precipitation event must be taken into consideration.

4.4.1. Precipitation Equipment Summary

Because of the additional labor costs associated with manual gauges, and the difficulty of siphoning gauges to interface with some data loggers, the choice of a precipitation gauge to be used as part of a water quality monitoring system of highway runoff is typically reduced to a decision between a tipping bucket type and an optical type precipitation gauge. The determining factor is the required accuracy. Some accuracy is lost when using tipping bucket gauges (several hundredths of an inch). However, the cost of the increased accuracy associated with optical precipitation gauges is high. If both types of gauges are equipped with a heater to permit measurement of snowfall, the costs of a tipping bucket gauge and the optical gauge are approximately $1,000 and $3,500, respectively. In addition, the data feed for tipping bucket gauges is not continuous, while the data feed for optical gauges is continuous. Finally, optical gauges are less susceptible to errors associated with windy conditions.

For the purpose of a water quality monitoring program, a tipping bucket type gauge is considered adequate. It provides a measurement accuracy to the few hundredths of an inch and is less expensive than an optical type gauge. However, if wind is an issue, the optical gauge should be considered. This may be especially important for highway sites, which often have windy conditions.

5. INSTALLATION OF EQUIPMENT

This section discusses typical installation and is not specific to a particular manufacturer. It addresses requirements and installation practices for each equipment type.

5.1. Installation

5.1.1. General Installation Considerations

Installation procedures, materials and field equipment requirements will vary depending on the type of monitoring equipment used and the conditions of the site that was selected for monitoring. Table 5.1 provides a list of the most common tools and equipment used for stormwater monitoring and equipment installation.

Before any installation activity begins in the field, a health and safety plan should be developed, read, and understood by all field personnel. Appendix B provides an example of a health and safety plan.

Once at the site, all safety concerns should be addressed before beginning installation of equipment. This usually involves:

- Setting up traffic control devices around the work area.
- Finding a safe place with a level, smooth surface to stage and assemble equipment.
- Checking for hazardous atmosphere (for manhole or confined space entry).
- Choosing appropriate personal protective equipment (PPE). Only personnel properly trained in confined space entry using proper equipment should enter conveyance systems for installation.
- Setting up winch and lifeline (for manhole or confined space entry) and additional health and safety equipment.

Equipment enclosures, where they are needed, should be selected to contain all monitoring equipment and provide adequate clearance for removal of samples and maintenance of equipment. Prefabricated shelters and large electrical equipment enclosures function well for this purpose. Manufacturers of monitoring equipment often provide prefabricated shelters; however, local sources are often a good low-cost alternative. Garden sheds have been used in some locations where space permits and vandalism is expected to be minimal. Locks should be installed on all equipment shelters. Alternately, portable platforms, such as trailers, have been employed to facilitate setup and transport of equipment. It should be noted that making equipment easily transportable also increases the risk of theft. Trailers should have wheels removed or otherwise immobilized. Stormwater monitoring equipment is susceptible to vandalism and theft due to its installation in isolated areas and the apparent lure of electronic equipment, however unuseful to the thief.

5.1.2. Data Loggers

5.1.2.1. Typical Installation

Data loggers should be installed as near to the sampling site as possible while still maintaining adequate accessibility. The location of the data logger can be dependent on the type of sensors installed. For example, pressure transducers often have vented cables that must not be allowed to

TABLE 5.1 COMMON TOOLS AND EQUIPMENT USED IN STORMWATER MONITORING

Sampler	Safety
• Sampler	• Portable gas monitor
• Sample collection jar(s)	• Safety line
• Graduated cylinder for sampler calibration	• Tripod, winch, and safety harness
• Suction line (0.24-in to 0.375-in diameter)	• Flashing lights for vehicle
• Strainer	• Traffic cones
• Battery	• Flashlights
• Masonry anchors & screws	• Protective Gloves
• Masonry drill bits	• Hard hat
• Tubing anchors or galvanized steel strapping	• Goggles
Flowmeter	**Miscellaneous**
• Flowmeter	• Battery powered drill
• Connection cable	• Hand tools (hammer, screwdriver, pliers, knife, hacksaw, wire strippers, measuring tape)
• Depth-measuring rod	• Manhole hook
• Data interrogator or laptop computer	• Buckets
• Batteries	• Ropes
• Bubbler tubing or pressure transducer w/cable	• Duct tape
• Cable ties	• Distilled water
• Calibration equipment (see flowmeter manual)	• Watch or stopwatch

sag or dip between the sensor and data logger.

Most commercially available data loggers can be equipped with a weatherproof housing that is useful to shelter field personnel to allow for more comfortable programming, data retrieval, and maintenance of equipment. Commonly, an enclosure is provided that is large enough to house all of the sampling equipment and allow for at least partial entry by field personnel. Enclosures also can provide added security for equipment if they are sturdy and can be locked.

It is recommended that the data logger be mounted off the ground to prevent damage and to make programming and data retrieval easier. A grounding rod should be installed to protect the equipment from lightning damage, especially if the equipment is hooked directly to a telephone or power line. Each manufacturer will provide detailed instructions, schematics, and diagrams that should cover most aspects of installation.

5.1.2.2. Special Cases

Manhole installation can create some challenges for installation of data loggers. In addition to weatherproofing the equipment, it may be necessary to protect it from corrosive atmospheres or submersion. An appropriate housing is required for this type of installation.

Some data loggers can be equipped with an external communications cable that can be attached to a personal computer or keypad for programming and data retrieval. This allows the data logger to be accessed without entering the manhole and can eliminate the problems associated with confined entry.

5.1.3. Flow Measurement Equipment

5.1.3.1. Typical Installation

Although installation of flow measurement equipment varies significantly depending on the type of equipment used, some general principals can help facilitate equipment selection and ease installation.

The most common equipment used in flow monitoring (weirs, flumes, etc.) can be broken down into two components typically referred to as primary and secondary devices. Primary devices are methods for altering flow in a predictable manner so that a known relationship between flow and measured depth can be used. Secondary devices measure the depth of flow in, upstream, or downstream of primary devices and include methods, for example bubblers, pressure transducers, or ultrasonic sensors described in previous sections.

Primary devices are sensitive to proper installation and setup in the field. Installers should have detailed specifications for the following:

- Slope and leveling tolerances for device;
- Minimum tolerances on dimensions for device;
- Proper upstream and downstream conditions;
- Calibration methods (if applicable);
- Proper structural support or anchoring (both hydrostatic and kinetic forces during large events are significant and should be examined and accounted for during design and installation); and

- Proper placement and setup of primary device to work in conjunction with secondary device.

Often these specifications will be provided by the manufacturer of the devices; however, primary devices are often custom-built, particularly in the case of simple devices such as weirs, and may require the designing engineer to compile installation instructions and specifications.

Secondary devices range significantly in their installation requirements. Most of these devices have similar housing and installation needs as data loggers as described above. ,

However, some require significantly more complex setup. Manufacturers of these devices such as ISCO, and American Sigma, provide detailed installation instructions and technical support for their products.

5.1.3.2. Special Cases

Due to the wide range of circumstances surrounding the installation of flow equipment, most installations require custom modification and best engineering judgment in order to obtain accurate, reliable, and repeatable flow measurement.

5.1.4. Sampling

5.1.4.1. Typical Installation

The installation of sampling equipment is similar in many ways to installation of data loggers. However, location for equipment is more difficult in many instances in that sampling equipment can be quite large compared to the space requirements for data loggers. Most samplers are designed for installation in manholes or in small enclosures. A sampler will typically be collocated with the data logger or flow measurement device.

A maximum height above the water surface is a key factor for sampler location. Typically samplers should be located as close to the sampling point as possible both in elevation and in distance. Maximum heights between water surface elevation should not exceed 20 feet in most cases.

Sample lines should be set up so that there are no sags or dips in the line that would prevent the line from draining when not in use.

Power requirements are similar to data loggers and often samplers have their own battery source that needs to be changed before events.

Access to equipment should be limited to prevent vandalism, yet provide personnel ample room to remove heavy sample bottles and replenish ice, if used.

5.1.5. Rain Gauges

5.1.5.1. Typical Installation

Installation of rain gauges is often a straightforward matter. Manufacturers provide guidelines on the appropriate mounting of the devices. The main concerns during installation are:

- Leveling the device
- Making sure that vegetation (trees) or structures are not obstructing rainfall
- Providing enough height above the ground to prevent vandalism

- Locating rain gauge in close proximity to other monitoring equipment to provide required connections for recording of rainfall depths and/or representative records

5.2. Putting It All Together

5.2.1. Introduction

The commonly used components of a stormwater monitoring system are described separately in the preceding sections. This section provides an overview of the integration of these components into functional systems for field use. The examples provided are the most common arrangements and should be used only as a general guide.

The configuration of a monitoring system is guided by program objectives including requirements for:

- Grab, composite, or continuous sampling of the discharge
- Sample volumes for laboratory analysis of discharge constituents
- Data logging/PC interface
- Remote communications
- Accuracy
- Reliability
- Ease of installation

Three types of common system configurations are described below. The systems differ in degree of automation in that the first system uses entirely manual methods to measure discharge and to collect flow-weighted composite samples for laboratory analysis. The second and third systems use automated equipment but differ in the degree of electronic linkage between the components.

5.2.1.1. Manual Sampling

Inexpensive manual sampling programs have been used by a number of stormwater monitoring programs. When conducting manual sampling, discharge can be collected using high-density polyethylene buckets. Compositing procedures are used to weight the volumetric contribution from each grab by the discharge rate at the time of collection. Discharge is estimated from measurements of the depth of flow and using the Manning equation (incorporating details of the hydraulic configuration at each site).

In some cases the use of manual sampling can reduce capital costs for equipment while improving reliability. Field personnel can ensure that each sample is collected in a manner consistent with program objectives. However, these cost savings are lost as the number of storms increases. The somewhat unpredictable timing of storms can also make it difficult to maintain a dedicated work force of trained field personnel who are often exposed to harsh environmental conditions and safety hazards. Finally, manual sampling when a crew is covering more than one site can be limited in accuracy due to the small number of samples that can be collected as well as the timing of collection.

5.2.1.2. Automated Flow Meter And Sampler - Without Remote Communication

This relatively simple system is used to monitor and collect stormwater runoff from highway sites. The system uses a bubbler flow measurement system to measure discharge via a standard hydraulic method such as the Manning equation. The bubbler is often chosen for its simplicity and low cost and because, unlike a flume or weir, it does not create a potential blockage problem in the conveyance. The bubbler could be linked to an automated sampler that is capable of collecting flow-weighted composite samples. Using this configuration with no telemetry requires field personnel to collect digital field data. This mandates frequent visits to the site before and after storms even for those events that did not require sampling to collect flow data and check equipment if flow measurements were desired.

5.2.1.3. Flume, Automated Flow Meter, And Automated Sampler - With Remote Communication

This more sophisticated system is often used where more control and real time information is required for managing and conducting monitoring. The flow meter receives and logs both rainfall data from a tipping bucket gauge and discharge data from a bubbler inserted into the flow, ideally using primary device (flume) to improve accuracy. A second bubbler could be used as a backup so that discharge can be measured even under pressurized flow. Another option would be to utilize a velocity sensor in combination with a depth measurement device. An automated sampler, capable of collecting flow-weighted composite samples, could be integrated into the system such that flow measurement can be utilized to trigger the sampler. The entire system could be linked to the storm event coordinator through a modem. The coordinator could thus interrogate the flow meter, download data, and even change the programming on this device without mobilizing to the site.

The ability to interrogate the flow meter allows the storm event coordinator to send field personnel to any of several sites in a local area based on the need for inspection, repair, or bottle replacement, thereby increasing the efficiency with which human resources are used. Linkage to a rain gauge at the site also would provide additional local data on storm intensity and volume. Telemetry could be installed using either a cell phone modem or landlines depending on proximity to utilities.

5.2.1.4. Summary and Conclusions

A variety of technologies can be applied to stormwater monitoring. The ability of the user to interface instruments and accessories is one of the most desirable features of equipment used in integrated systems. The best technology is user friendly for installation, operations, and maintenance and is one that provides accurate data at a reasonable cost. The extra costs associated with remote communications can be very valuable to the user in many situations, but they may not be necessary for successful stormwater monitoring.

There is no one best technology that will fit all stormwater monitoring goals and field conditions. Keys to successful stormwater monitoring include:

- establishing clear monitoring goals and objectives;
- selecting a site that meets the requirements of the monitoring goals and the criteria mentioned previously in this document; and

- selecting equipment that fits the site characteristics and monitoring requirements.

Site security is very important to successful operation of a water quality monitoring station. The more mobile the station set-up is, the more this is a challenge. The ability to move the station can be greatly enhanced by making equipment portable; however, portability makes equipment much less secure than installing equipment in either a shed or a manhole.

Steep sloped pipes that created high velocities and turbulent flows make monitoring of both flow and water quality difficult. Some modifications to the pipe bottom may be needed (smooth shallow weir) to allow for the collection of the sample downstream of the flow measurement.

Baseflow in pipes must be accurately accounted for; otherwise, the triggering of sample collection may occur prematurely. For general characterization studies, sites with baseflow should be avoided.

Field programming of equipment that requires a laptop computer is difficult in wet and cold conditions. Laptops that are highly weatherproof should be utilized.

When using different equipment brands, there likely will be some problems with incompatibility of the equipment. Frequent contacts with manufacturers will likely be required to resolve problems and create a workable monitoring station. In addition, as one sets up monitoring equipment for specific sites and applications, there will be software problems that will require manufacturer assistance to resolve.

Complete stations that include a flow meter, sampler, rain gauge, and data logger by one manufacturer eliminate most incompatibility problems and make data collection and analysis easier. However, special site requirements may necessitate specific equipment capabilities that one manufacturer might be unable to supply.

In situ water quality monitors are currently limited in the number of and detection limits of pollutants. It is likely that a subset of this equipment will undergo further development for general application. As yet, *in situ* monitors for other than some basic parameters (temperature, conductivity, DO, etc.) are not commonly used, but as technology develops and costs decline, these devices are likely to be considered for field applications.

The use of *in situ* monitoring equipment (probes) is difficult at best in the intermittent flow conditions of stormwater systems. This is due to its need for frequent calibration and the requirement that the probe be submerged at all times, including in-between storm events. Remote operation of this type of equipment does not appear to be practical.

6. ANALYTICAL METHODS AND QUALITY ASSURANCE/QUALITY CONTROL

The equipment selection process should take into account what water quality parameters are of primary interest. Parameters such as oil and grease, VOCs, TPH, and bacteria cannot be collected using automatic samplers, and a grab sampling program must be used in these cases.

The use of automatic samplers for monitoring suspended sediment or total suspended solids may not be representative of water column concentrations particularly in areas where the flow is not well mixed. Using an automatic sampler requires the selection of a location in the water column for the intake port. If the port is placed too low in the conveyance, bed load may be taken up in a sample. However, for low flow situations, placement of the sample port as low in the pipe as possible is helpful for ensuring that the intake port is below the water line. Suspended solids and sediment measurements therefore may be problematic using automatic sampling equipment. If detailed water quality information is desired for suspended solids and sediment, a grab sampling program may be required to compliment an automated sampling program by providing verification of the representativeness of automatic samples.

6.1. Quality Assurance/Quality Control (QA/QC) Process Overview

The QA/QC process is used to assure that data collected are of acceptable quality to enable reliable plans and/or decision-making. QA/QC involves planning, field procedures, laboratory procedures, and reporting. Typically, a QA/QC plan is developed prior to sample collection. During plan development, specific aspects of the sample collection and laboratory procedures are worked out with the program manager, the field crew, and the analytical laboratory. Specifics include labeling and communication protocols, the number and type of bottles to be filled, laboratory performance objectives, collection of QA/QC samples, preparation of blanks, reporting requirements, and validation procedures. Plan development also serves to initiate communication with the personnel involved in collection and analysis. After sample collection and analysis, data should be checked against the laboratory performance objectives and project data quality objectives to ensure the quality is acceptable prior to reporting. Corrections to reports, qualification of the data, or corrective actions with the laboratory (reanalysis) or field (re-sampling) should be used to resolve any problems prior to reporting the data.

6.2. Data Quality Objectives and Process

Data collection for environmental studies generally involves four phases of activities including planning, implementation, data assessment, and drawing conclusions (usually to support planning and/or decision-making). For many data collection efforts, lack of sufficient planning results in data of limited use in the assessment phase. As a result, such data do not provide the necessary information to draw sound conclusions. The use of Data Quality Objectives process (DQO) (USEPA; 1993, 1994a) in the planning stage is an important aid to develop data adequate to support planning and decision-making.

The first step in the DQO process is to identify the problem or concern to be addressed. The next steps are to identify the decisions to be made and the necessary inputs to planning and decision-making. The physical or geographic study boundaries are then defined and a decision rule is developed. Next, the acceptable limits of the decision errors are agreed upon. All of this information is then used to optimize the study design for obtaining the necessary data.

The results of the DQO process are specific recommendations on the frequency, location, and quality of data, which are needed to make a specific decision. The DQO process also ensures that data not necessary to make the decision are omitted. For example, if the question is whether additional BMPs are necessary, determining whether water quality objectives are attained in the receiving waters becomes important. An additional question may be: Is the exceedance of water quality objectives due to the site in question or other factors? The monitoring program will need to use sampling and analysis methods that produce data that are appropriate for comparison with water quality objectives. Additionally, the sample locations should be selected to enable evaluation of other possible sources. Specifically, field and laboratory methods will need to have sufficient control over contamination and sensitivity to allow comparison with the lowest expected water quality standard that may apply to the site.

Specific data quality objectives for monitoring programs were described in Chapter 2. Data quality efforts should be reviewed based on the ability to meet program goals.

6.3. Precision, Accuracy, Representativeness, Completeness, and Comparability

Precision, accuracy, representativeness, completeness, and comparability are several different measures of data quality. These measures can be affected by factors in the field or in the laboratory. Each term is explained below.

Precision

Precision is the measure of the repeatability of a given measurement. Imprecise data are generally a problem because individual samples are not a reliable measure of the mean site conditions making it necessary to gather more data to characterize a given site. Often, poor precision is due to field variability, problems with the sampling and sub-sampling procedures, contamination, or poor sensitivity of the laboratory methods. Variability in the field can often be minimized through the use of compositing procedures.

Precision is assessed through analysis of laboratory duplicate samples or matrix spike duplicate samples. Laboratory duplicates are prepared by splitting one sample into two and performing a separate analysis on each split. Matrix spikes and matrix spike duplicates are prepared by adding a known concentration of analyte to a sample or to a laboratory duplicate and determining the concentration of the sample plus the spike. The two values (sample and duplicate, or spike and spike duplicate) are compared to provide an estimate of the precision of the laboratory method.

Accuracy

Accuracy is the degree to which the measurement reflects the true value of the sample. Accuracy may be monitored using matrix spikes, standard reference materials, or performance evaluation samples. Factors that influence the accuracy include laboratory calibration procedures, sample preparation procedures, and laboratory equipment or de-ionized water contamination. Accuracy is usually expressed as a percent recovery, where the measured value is divided by the true value.

Representativeness

Representativeness is the degree to which the samples represent site conditions. Typically, representativeness is assessed through the analysis of field duplicate samples. Compositing is sometimes used to minimize field variability. Composite samples generate an average of site conditions.

Completeness

Completeness measures the success of the field and laboratory efforts by comparing the final validated data with the planned data collection activities. Completeness is used to assess how field situations and laboratory problems affected the overall success of the data collection efforts. If specific data are critical for a given decision, a goal of 100% completeness should be established.

Comparability

Comparability expresses the confidence with which one sample set can be compared to another sample set measuring the sample property. Comparability is generally evaluated by evaluating "check samples," which are well-characterized samples that have been evaluated by a number of analysis methods and laboratories.

6.4. Detection Limits/ Quantitation Limits

Method detection limits (MDL) and practical quantitation limits (PQL) are measures of the sensitivity of the laboratory analysis methods. The method detection limit is defined as the "minimum concentration of analyte that can be measured and reported with 99% confidence that the analyte concentration is greater than zero" (Federal Register, 40 CFR 136.2). The PQL is the minimum concentration of analyte that can be accurately and precisely quantified. Guidance for deriving PQLs from MDLs indicates the PQL is generally 5 to 10 times the MDL, depending on the analyte and the degree of confidence that is required. If sample values are reported between the range of the MDL and PQL, the reported value has more uncertainty than values reported above the PQL.

If the goal of the data collection activity is to determine specific concentrations for comparison with a numerical objective, then every effort should be made to ensure the PQL is below the expected water quality objective. It should be noted that the freshwater objectives for some metals (e.g., cadmium, copper, chromium (+3), lead, nickel, silver, zinc) are a function of the hardness of the receiving water. It is recommended the PQL of the analysis method be set at or below the expected water quality objective for the receiving water. Note that the hardness value selection will affect water quality objectives for freshwaters. One can choose to utilize the hardness measured in the stormwater or that of the receiving water. There is no specific guidance on how to take into account hardness. In most cases, the receiving water hardness should be used.

Both MDLs and PQLs are often specific to a given type of sample. Often the MDL for a sample is elevated due to the presence of interfering compounds. For example, MDLs for metals in salt water are generally 5 to 10 times higher than MDLs for fresh water due to salt interference with the atomic absorption instrumentation utilized for metals analyses.

6.5. Contamination/Blanks

Control over sample contamination is critical when attempting to measure concentrations of compounds at the parts-per-billion level. If contamination occurs, USEPA recommends that the detection limit for the affected compounds be raised to five times the level of contamination. Often this will invalidate the sample collection effort, making the data not very useful for comparison with the required objective or standard.

Contamination can be introduced either during the bottle/equipment preparation steps or during the sample collection, transport, or analysis steps. Control over all of these steps can be achieved through the use of standardized equipment cleaning procedures, clean sampling procedures, and clean laboratory reagents. The level of contamination introduced during each of these steps is determined by analysis of different types of blank samples. Each of these different types of blanks is described below:

- *Method Blanks* are prepared by the laboratory by analysis of clean Type II reagent water. They are used to determine the level of contamination introduced by the reagents and laboratory processing.

- *Source Solution Blanks* are determined by analysis of the deionized or Type II reagent water used to prepare the other blanks. The source solution blank is used to account for contamination introduced by the deionized water when evaluating the other blanks.

- *Bottle Blanks* are prepared by filling a clean bottle with source solution water and measuring the solution concentration. Bottle blanks include contamination introduced by the source solution water and sample containers. By subtracting the source solution blank result, the amount of contamination introduced by the sample containers can be determined.

- *Travel Blanks* are prepared by filling a sample container in the laboratory with Type II reagent water and shipping the filled water along with the empty sample containers to the site. The travel blank is shipped back with the samples and analyzed like a sample. The bottle blank result can be subtracted from the travel blank to account for contamination introduced during transport from the laboratory to the field and back to the laboratory.

- *Equipment Blanks* are usually prepared in the laboratory after cleaning the sampling equipment. These blanks can be used to account for sample contamination introduced by the sampling equipment, if the bottle blank results are first subtracted.

- *Field Blanks* account for all of the above sources of contamination. Field blanks are prepared in the field after cleaning the equipment by sampling Type II reagent water with the equipment. They include sources of contamination introduced by reagent water, sampling equipment, containers, handling, preservation, and analysis. In general, field blanks should be performed prior to or during the sample collection. Because the field blank is an overall measure of all sources of contamination, it is used to determine whether there are any blank problems. If problems are encountered with the field blank, then the other components of the sampling process should be evaluated by preparation of other blanks to identify and eliminate the specific problem.

EPA's recent guidance on the use of clean and ultra-clean sampling procedures for the collection of low-level metals samples (USEPA 1993) should be considered to ensure bottles and equipment are cleaned properly and samples are collected with as little contamination as possible. While ultra-clean techniques throughout are not necessary for stormwater runoff samples, some of the laboratory procedures should be employed. Metals levels in highway runoff are typically much greater than introduced errors associated with in-field clean sampling techniques. These techniques are typically employed in receiving waters where their applicability is more relevant.

6.6. Reconnaissance and Preparations

Reconnaissance and preparation are important components of any field sampling program. Proper reconnaissance will help field operations go smoothly and ensure field personnel are familiar with the sampling locations.

Site Visits

During the planning stage, a site visit should be performed by the field personnel, prior to conducting sampling. The purpose of the site visit is to locate access points where a sample can be taken and confirm that the sampling strategy is appropriate. Because of the transient nature of meteorological events, it is possible sites may need to be sampled in the dark. For this reason, the actual persons involved in the field sampling should visit the site during reconnaissance as a complement to a training program for the monitoring effort.

The training program should include:

- A discussion of what the programs goals are and why their efforts are important;
- Familiarization with the site;
- Training on the use and operation of the equipment;
- Familiarization with field mobilization, sampling, and demobilization procedures;
- Health and safety requirements; and
- QA/QC procedures.

Laboratory Coordination

Coordination with the laboratory is a critical step in the planning and sampling process. The laboratory should be made aware of specific project requirements such as number of samples, required laboratory performance objectives, approximate date and time of sampling (if known), required QA/QC samples, reporting requirements, and if and when containers or ice chests will be required. Laboratory personnel should be involved early in the process so they can provide feedback on methods and performance standards during the planning phase. Notifying the laboratory that stormwater sampling is planned is also important to allow the laboratory to plan for off hours sample delivery and to set up any analysis with short holding times.

6.7. Sample Containers/ Preservation/Holding Times

USEPA recommends that samples be collected and stored in specific types of sample container materials (e.g., plastic, glass, Teflon). For analysis of certain parameters, the addition of specific chemical preservatives is recommended to prolong the stability of the constituents during storage. Federal Register

40 CFR 136.3 lists recommended sample containers, preservatives, and maximum recommended holding times for constituents.

If composite sampling procedures are to be used to collect one large sample that will be sub-sampled into smaller containers, the composite sample bottle should be compatible with all of the constituents to be sub-sampled. In general, the use of glass containers will allow sub-sampling for most parameters (with the exception of fluoride).

Sample volumes necessary for the requested analysis should be confirmed with the laboratory prior to sample collection. Extra sample volume must be collected for field and laboratory QA/QC samples. As a general guide, if one station is to be used for field and laboratory QA/QC measurements, four times the normal volume of water should be collected.

6.8. Recommended Field QA/QC Procedures

Listed below are the recommended quality control samples and field procedures to be used during a sampling program.

Field Blanks.

Field blanks should be prepared at least once by each field sampling team to prevent or reduce contamination introduced by the sampling process. It is recommended that field blanks routinely be prepared and analyzed with each sampling event. In addition, it is desirable to prepare field blanks prior to the actual sampling event as a check on procedures. This will ensure field contaminated samples are not analyzed. Additional field blanks should be prepared if sampling personnel, equipment, or procedures change.

Field Duplicate Samples

Field duplicate samples should be collected at a frequency of 5% or a minimum of one per event, whichever is greater. Field duplicate samples are used to provide a measure of the representativeness of the sampling and analysis procedures. These types of duplicates are recommended, but they often are not done due to the expense.

Field Sample Volumes

Sufficient sample volumes need to be collected to enable the required laboratory QA/QC analysis to be conducted. In general, one station should be targeted for extra sample volume collection and identified on the chain-of-custody as the laboratory QA/QC station. If possible, this station should be the one where the data quality is most critical.

Chain of Custody

All sample custody and transfer procedures should be based on USEPA-recommended procedures. These procedures emphasize careful documentation of sample collection, labeling, and transfer procedures. Pre-formatted chain-of-custody forms should be used to document the transfer of samples to the laboratory and the analysis to be conducted on each bottle.

6.9. Recommended Laboratory QA/QC Procedures

Method Blanks

For each batch of samples, method blanks should be run by the laboratory to determine the level of contamination associated with laboratory reagents and glassware. Results of the method blank analysis should be reported with the sample results.

Laboratory Duplicates

For each batch of samples, one site should be used as a laboratory duplicate. For the laboratory duplicate analysis, one sample will be split into two portions and analyzed twice. The purpose of the laboratory duplicate analysis is to assess the reproducibility of the analysis methods. Results of the laboratory duplicate analysis should be reported with the sample results.

Matrix Spike and Spike Duplicates

Matrix spike and spike duplicates should be used to determine the accuracy and precision of the analysis methods in the sample matrix. Matrix spike and spike duplicate samples are prepared by adding a known amount of target compound to the sample. The spiked sample is analyzed to determine the percent recovery of the target compound in the sample matrix. Results of the spike and spike duplicate percent recovery are compared to determine the precision of the analysis. Results of the matrix spike and spike duplicate samples should be reported with the sample results.

External Reference Standards

External reference standards are artificial standards prepared by an external agency. The concentration of analytes in the standards are certified within a given range of concentrations. These are used as an external check on laboratory accuracy. One external reference standard appropriate to the sample matrix should be analyzed and reported at least quarterly by the laboratory. If possible, one reference standard should be analyzed with each batch of samples.

6.10. Data Validation

Completeness

Data reports should be reviewed for completeness. Reports should be checked to ensure all requested analyses were performed and all required QA data are reported for each sample batch.

Compliance with QA Objectives

Sample holding times should be compared to recommended maximum holding times listed in the Federal Register. Laboratory quality control sample data should be compared to target detection limits, and precision and accuracy goals and qualified according to USEPA functional guidelines for data validation (USEPA, 1988).

Corrective Actions

Data should be reviewed as soon as it is received from the laboratory. If problems with reporting or laboratory performance are encountered corrective actions (re-submittal of data sheets or sample re-analysis) should be performed prior to final data reporting or data analysis.

7. HEALTH AND SAFETY

Stormwater monitoring involves activities that have the potential to adversely affect the health and safety of field personnel. Stormwater monitoring field crews often work in wet, cold, and poor visibility conditions. Sampling sites may be located in highways, stream channels, or remote, poorly lit areas that need to be accessed on a 24-hour basis. Monitoring personnel and workers installing or maintaining equipment may be exposed to traffic hazards, confined spaces, biological hazards (e.g., medical waste and fecal matter), vectors (e.g., snakes and rats), fall hazards, hazardous materials, fast moving stormwater, and slippery conditions. **The information contained herein is for guidance only, and does not supersede or otherwise change any applicable state, local, or agency health and safety requirements or programs. A health and safety plan should be developed for each site.**

The following sections describe health and safety requirements for stormwater monitoring programs and are useful for evaluating the implications of these requirements during equipment selection and monitoring plan development. An example health and safety plan is provided in Appendix B.

7.1. Health and Safety During Field Activities

Health and safety of field crews during installation, maintenance, and monitoring activities should be of primary importance when selecting a monitoring site and associated monitoring equipment. This section describes some of the potentially hazardous activities typically conducted as part of monitoring program implementation.

Equipment installation and routine maintenance

Flow meters, water samplers, and ancillary equipment may need to be installed, depending on the objectives and scope of the monitoring program. Installation usually requires entry into confined spaces and the use of power tools. As required by OSHA, all personnel entering confined spaces must be properly trained and certified for confined space entry. The flow meter and automatic water sampler are often suspended within the manhole chamber or are located in an equipment shelter. Sampler intakes and flow meter sensors are secured to the stormwater conduit using mounting straps. Sample tubing and sensor cables are secured and routed to the water sampler and flow meter. Routine maintenance consists of visual inspections of sampler intakes, flow meter sensors, mounting hardware, and equipment desiccants (moisture adsorbent). Equipment calibrations may also be performed during maintenance visits.

Establish work zone and traffic controls

Field crews may need to establish safe work zones and, in some cases, provide traffic control. All work zones and traffic control systems must provide for the safety of both field crews and the general public (and must comply with applicable regulations regarding traffic control).

Opening and closing manholes

Field crews may need to remove and replace manhole covers. Manhole lids should be removed and replaced using a specially designed manhole hook.

Flow meter and automatic water sampler setup

Both the flow meter and automatic water sampler will need to be programmed and started before each storm. The sampler is made operational by a keypad located on the sampler. The flow meter is made operational by using a keypad, laptop computer, or telemetry. If the keypad is used, confined space entry may be required since the meter is often located in the manhole chamber.

Remove and replace automatic water sampler

Automatic water samplers sited in manhole chambers will need to be removed and replaced to service the sample bottles (i.e., install, check, remove). A cable harness can be rigged as the lifting handle. Full samplers can weigh between 60 and 70 pounds, so lifting is an issue. Often hoists must be employed.

Collect grab samples

Collecting grab samples requires using a manual sampling device such as a stainless steel or plastic beaker attached to a lanyard, pole, or other dipping apparatus. The sampler is lowered into the flow stream to collect the sample, which is then transferred into sample bottles.

7.2. Potential Hazards During Sampling

This section further describes potential hazards to field personnel that may be encountered during monitoring activities. These hazards are presented to provide a context for the equipment selection process. Many monitoring approaches help to minimize exposure of personnel and the public to potential hazards. **The summary provided here is not intended to include every type of hazard that could be encountered; rather, it is intended to serve as a starting point for a site-specific analysis for a given project.**

Confined Spaces

Storm sewers are classified as "confined spaces" under OSHA regulations. Regulations for entry into confined spaces are contained in Federal Register 29 CFR 1910.146 and in possibly more stringent state regulations. The regulations require that **no person shall enter a confined space without proper training and equipment**. The risks associated with confined spaces include dangerous atmospheres, engulfment, falls, falling objects, and bodily harm due to explosion and biological hazards.

Vehicle Traffic

Traffic hazards will be encountered when working on the side of or on a highway. These hazards are greatest during times of reduced visibility, such as during storm events and at night. The primary threats associated with working in or alongside roadways are workers being struck by passing vehicles or being involved in a vehicular collision. The risk associated with these threats is severe bodily injury or death.

Open Manholes and Manhole Lids

Storm sewer sampling sites are often located below grade, such that manholes must be opened during water sample collection and equipment maintenance activities. Opening manholes requires the removal of heavy steel lids. Improper manhole lid removal techniques can result in back injuries and/or crushed toes or feet. Specially designed manhole hooks along with proper lifting techniques provide the easiest and safest way for removing manhole lids.

Open manholes pose a threat to workers and the general public. Limited visibility, inattention, poor site control, slips, and/or trips could result in someone falling into an open manhole. The risks of such a fall include minor to fatal bodily injury.

Open Water Hazards

High flows commonly associated with storm events present a threat to workers. Slippery conditions, stream-side vegetation, and unstable stream banks could cause a worker to fall into a stream. The risks of such a fall include hypothermia, bodily injury, and drowning.

Biological Hazards

Rodents, pathogenic microorganisms, snakes, and viruses are potential biological hazards of concern. The primary threats associated with these hazards are bites and/or the contraction of diseases or infections.

Chemical Hazards

Although most stormwater sewers are not intended to contain hazardous materials, there is a potential for hazardous gaseous and/or liquid contaminants to be present as the result of industrial runoff, illicit storm sewer connections, and/or illegal dumping of waste. The presence of chemicals and/or chemical vapors may result in (but are not limited to) one or more of the following threats: toxic conditions, oxygen displacement, explosion, and/or fire. The risks associated with these threats include poisoning (acute and/or chronic), asphyxiation, and bodily injury.

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APPENDIX A
DATA EVALUATION AND STATISTICAL HYPOTHESIS TESTING

A-1 INTRODUCTION

A variety of data (including rainfall intensities and depths; discharge rates and flow volumes; the concentrations of chemical parameters; and the measurement of physical parameters) are generated during a stormwater monitoring program. We can examine these data for patterns and trends, comparing stormwater quality between different areas over time; input/output comparisons of structural best management practices (BMPs); and pre/post monitoring in a basin to compare source control BMP(s) implementation. However, the timing and magnitude of stormwater quality phenomena are influenced by many highly variable factors, such as: storm intensity and duration, the length of the antecedent dry period, and the magnitude and frequency of pollution-causing activities within the catchment area. We can only describe in a general way the potential influence of each factor. It is nearly impossible to assess in a statistical sense (i.e., with some level of error) interactions among all factors. We therefore use the tools of statistical analysis to infer, with a predictable level of error, generalities about average conditions (or trends over time) and the variability from the limited information obtained from our monitoring programs.

The first step in the process of evaluating a stormwater data set is to validate the chemical data, "qualifying" those that do not meet the criteria established in the QA/QC plan. After completing the data validation process, we conduct an initial evaluation using summary (univariate) statistics (Section A-3). The initial evaluation shows whether the data can be used in statistical hypothesis testing. The type of hypothesis tested is determined by the program objectives. These usually include one or more of the following:

- Characterization of stormwater discharges (e.g., average conditions, variability, ranges, etc.)
- Comparing stormwater discharge quality to state and federal water quality criteria
- Monitoring to detect trends in discharge quality over time and between different locations
- Monitoring to assess the effectiveness of BMPs for stormwater control

The statistical testing techniques appropriate to each of these objectives are discussed in Sections A-5 through A-8.

A-2 DATA EDITING, VALIDATION, AND TREATMENT

Prior to conducting a statistical test, data should be screened to eliminate potentially biased or non-representative values. Biased and non-representative values may arise due to equipment malfunctions, field or laboratory protocol errors, weather problems, human error, and similar events. In addition, there are procedures for addressing data below laboratory detection values, and estimation of particulate fractions of metals. Finally, data should be transferred to a normal distribution if statistical tests will be used, because they rely on normality of the data as one of their assumptions.

Percent Capture. If samples were taken using automated flow-weighted compositing equipment, estimate the percent of the total discharge that was captured (i.e., the amount of the total flow that was sampled by the equipment during the time the equipment was activated) for each sample. As a general rule, samples with less than 60% capture should be rejected as not representative of the event. In some circumstances, samples with less than 60% capture may be used, depending on the objective of the analysis. For example, the 60% capture criterion may not be applicable to a sample collected to characterize the "first flush" of a storm event. In compiling data, it is suggested that data with less than 80% capture (but greater than 60%) be noted.

QA/QC Qualifiers. Based on the results of the QA/QC evaluation, laboratory data considered suspect due to the contamination of blanks, exceedance of holding times, or low surrogate recoveries should be qualified or rejected. Ideally, statistical tests will be performed only on data that have passed this screening process. Although it is possible to use data that have been qualified as estimated values, a higher level of uncertainty is associated with the test results. It is up to the data user to make an educated decision whether to include estimated values.

Event Mean Concentrations (EMCs)

If EMCs will be used for data comparisons, then all data should either be collected as an EMC or, if individual samples are analyzed, an EMC should be computed. This can be accomplished by integrating the hydrograph (plot of flow rate versus time) and pollutograph (plot of concentration versus time). Pollutant mass is estimated by applying the trapezoidal rule to a number of corresponding time segments of the hydrograph and the pollutograph. The product of the partial flow volume and associated concentration estimates the mass in that segment of the discharge. The sum of all such segment masses estimates the total mass discharged by the event. The estimation of the total area under the hydrograph provides the total volume of runoff. Total mass divided by the total runoff volume provides the desired value for the EMC.

PQL and MDL. The method detection limit (MDL) is defined as the "minimum concentration of an analyte that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero" (40 CFR 136.2). The practical quantification limit (PQL) is the minimum concentration of an analyte that can be accurately and precisely quantified. In general, the PQL is 5 to 10 times the MDL, depending on the analyte. In general, statistical tests will be more accurate if the data values are above the PQL. However, statistical tests can be performed even if large amounts of the data are between the MDL and PQL, but the confidence (power) of the test may be lower due to increased uncertainty. Prior to conducting statistical tests, the data set should be examined to determine the percentage of points that are below the MDL and PQL. If a large proportion of the data is below the MDL, statistical testing may not be appropriate.

Averaging of Duplicates. Data from duplicate samples (laboratory or field) should be averaged prior to statistical analysis. That is, the average value should be used in place of either of the two duplicate values.

Calculating Metal Fractions. Where total and dissolved fractions of metals are measured, it is possible to estimate several other fractions from these numbers and the concentration of TSS. Perform the following calculations and add these data to the data set:

- Percent dissolved = (dissolved conc./total conc.)
- Suspended (µg/L) = (total conc. - dissolved conc.)
- Particulate (µg/g) = [suspended conc. (µg/L) / TSS conc. (mg/L)] * 1,000 mg/g

Distributional Tests. Many commonly used statistical tests (e.g., parametric Analysis of Variance) are based on the assumption that the data were sampled at random from a population with a normal distribution. Therefore, another attribute of the data that should be investigated is its apparent probability distribution. It is important to determine whether the probability distribution is normal or log-normal. Researchers have found that generally the log-normal distribution provides the best fit to stormwater quality data (USEPA 1983; Driscoll et al., 1990). If the data are not normally distributed, or if the data set contains a very high proportion of non-detects, a nonparametric statistical procedure should be utilized for testing trends. Non-parametric techniques examine the data based on rank rather than distribution.

Several methods can be used to determine the normality of a data set or of the transformed values, including the W-test, Probability Plot Correlation Coefficient (PPCC), and a graphical check of the data. These methods are useful for the analysis of stormwater quality data.

The procedure employed for the graphical test is to develop a log-probability plot for visual assessment of the log-normal distribution. First, compute the mean and standard deviation of the natural (base e) logarithm transforms of the EMCs. The theoretical distribution is constructed from these values (the log mean [U] and the log standard deviation [W]). When combined with the plotting position based on the normal distribution, this derived distribution indicates the expected value (assuming that the data follow a log-normal distribution) of a pollutant's concentration at any probability of occurrence. This expected probability distribution then can be compared with the data by plotting the two on the same log probability plot.

The plotting position of the individual data points can be determined by assigning an expected probability for each EMC in the ranked series of observed values. This position varies with the number of observations (N) in the sample, and is provided by the following general equation (Driscoll et al. 1990):

$$\mathrm{Pr} = \frac{m - \frac{1}{2}}{N}$$

Where m is the rank order of the observation and Pr is the plotting position (probability). A visual check of the data using a log probability plot can be a very effective test, and is recommended. For further quantitative information the PPCC could be used.

The PPCC test provides both quantitative and graphical representations of the goodness of fit of the distribution with respect to normality. Although the PPCC test is less commonly available in statistical programs than the W-test, it is straightforward in its application. It consists of creating a plot of the data on probability paper (i.e., paper with a probability scale along the long edge and a linear scale along the short edge). Plots of data that are normally distributed form a straight line. The correlation coefficient for the best-fit straight line can be calculated and compared with the critical value for that number of data points, as provided in the literature (Vogel, 1986). If data are better predicted by a log-normal distribution than a normal distribution, the log-normal distribution should be utilized for estimation of population statistics and analysis of variance tests.

The W-test (Shapiro and Wilk, 1965) is available in most statistical software programs. The W-test result is significant if the Prob < W (i.e., the probability that the test statistic "W" is less than the critical W-value). Typically W is assumed to be 0.05.

<u>Treatment of Non-detects.</u> When stormwater data sets include some non-detects within the data, separate data analysis techniques are required to accurately estimate sample statistics. When below-detection-limit data exist in a data set, they will affect statistical parameters computed from that set. For example, when below-detection-limit data are set to the detection limit (often cited as a conservative approach), it causes an overestimation of central tendency measures and an underestimation of dispersion measures, as opposed to what would have been obtained had the true values of the below-detection-limit data been known. Figure A-1 shows an example of the phenomena using a hypothetical log-normal distribution with a detection limit artificially set at 1.0.

The magnitude of the error made by failing to properly treat detection limit data is a function of the size of the data set (i.e., the total number of events for which a concentration was reported [N]; the percentage of the total set represented by detection limit data; and the value of the detection limit relative to the median of the data above the detection limit).

The treatment of detection limit data varies among workers in the field and the objectives for which the data are being analyzed. The traditional practice has been simply to take all detection limit data at their face value, the argument being that since the actual values are really lower, the average so calculated will be conservative for prediction of concentrations near the median. However, prediction of values that are exceeded rarely (i.e., pollutant concentrations that are observed less than 5% of the time) may very likely be under-predicted (see Figure A-1a). Others have set the values equal to one-half (or some other fraction) of the detection limit. When a significant percentage of a data set is at or below the detection limit, the treatment method can seriously affect analytical results and their interpretation. In statistical parlance, data sets with "less-than" observations are termed "censored data."

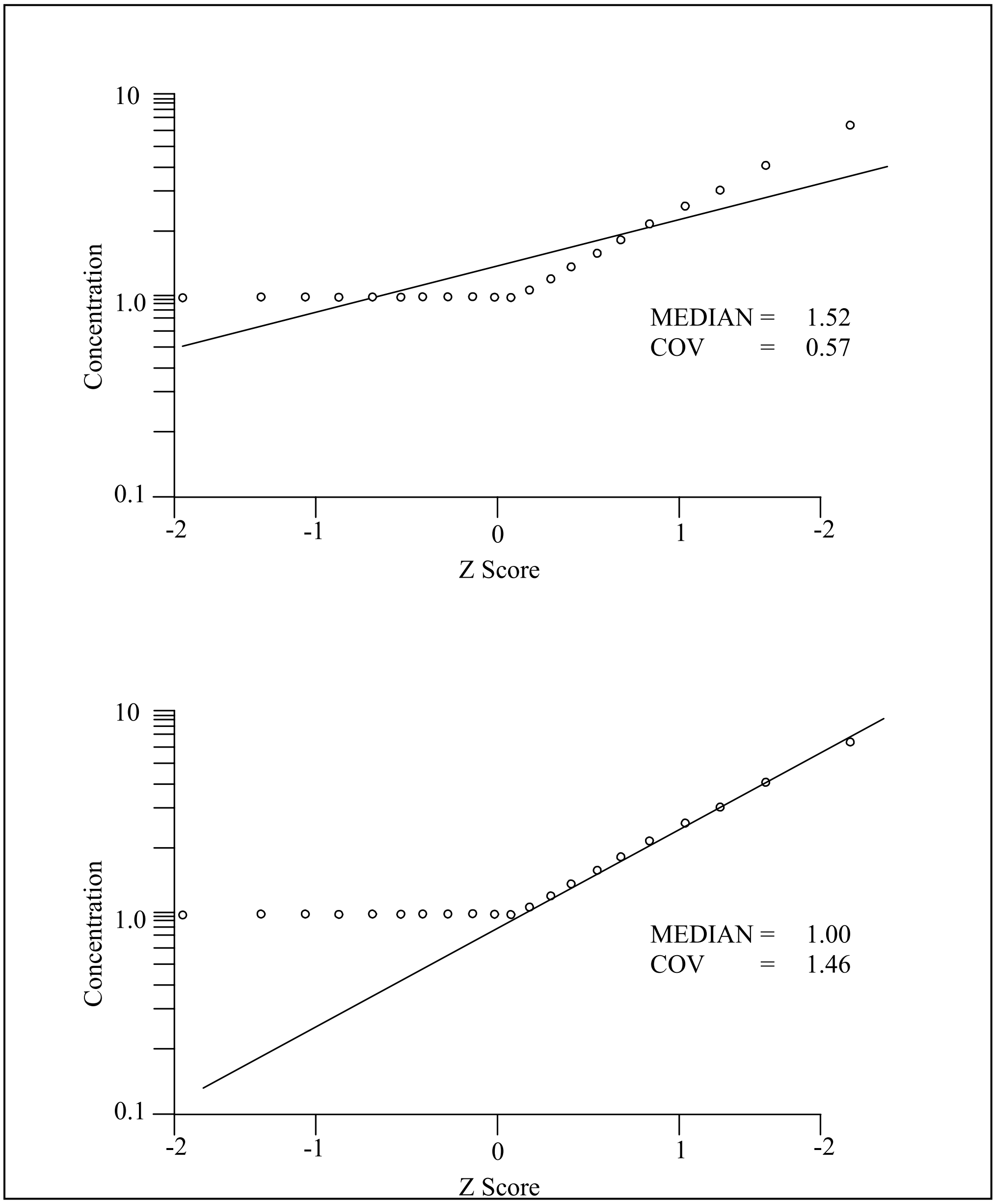

Figure A-1 (a and b) Comparison of Approaches to Analysis of Detection Limit Data

(a – using the detection limit)

(b – using maximum likelihood estimator)

Simply stated, the approach to treating detection limit data has been to ignore their magnitude, but use their probability (or plotting position) in determining the log-normal distribution that best fit the data set in question. That is, using regression, all of the data above the detection limit is fit to a log-normal curve and it is assumed that the detection limit data follows the same log-normal frequency distribution. This is accomplished as follows:

1. Transform the data to a normal distribution (in this case using a log transformation).

2. Rank order the data set in question (m = 1, 2,…, N).

3. Compute the probability (i.e., plotting position) associated with the rank order (m) as discussed earlier.

4. Compute the corresponding Z score (area under the standard normal curve; i.e., the number of standard deviations away from the mean) for each probability value.

5. Determine the regression line that best fits the data subset above the detection limit (i.e., regression fit of transferred data with Z score values).

6. Determine the log mean and log standard deviation from the regression line (i.e., the mean is the intercept of a Z score value of zero, while the standard deviation is the slope of the line).

7. Compute the arithmetic statistical parameters from these values as discussed in Section A-3.

The actual execution of the correction is much simpler than its description. A graphic illustration of the results of the procedure is presented by Figure A-1b, which also indicates how the pertinent statistics are affected. Newman and Dixon (1990) have developed a public domain software program called UNCENSOR to perform these calculations.

A-3 DESCRIPTIVE STATISTICS

The purpose of calculating general descriptive statistics is to gain an overview of the data and to prepare for more formal statistical hypothesis testing. The data are displayed in a variety of ways and summary statistics are generated. These exploratory techniques can provide clues as to the presence of major treatment effects (e.g., station, year, land use type) that can be tested for statistical significance. Descriptive statistics also indicate how groups of data can be combined or "pooled" prior to statistical testing. "Pooling" effectively increases the sample size and the power of the analysis to detect significant differences.

For example, if data collected at two physically similar or nearby highway monitoring stations have been demonstrated to not differ statistically from each other, the data could be pooled for further testing to compare to other locations or configurations. The reverse may be demonstrated by the descriptive statistics as well.

Summary Statistics. First, calculate simple descriptive statistics, characterizing the central tendency, variability, and distribution of the data set. Central tendency is measured by the sample mean (if normal, the arithmetic average of the data), the median (the 50th percentile of the distribution), and the mode (the most probable value). The variability of the data set is represented by the sample standard deviation and by its squared value, the variance. For non-parametric tests, data variability is measured by the interquartile difference, the difference between the values of the 1st (25th percentile) and 3rd quartile (75th percentile) values. Any statistical software program and most hand calculators can be used to calculate these parameters.

Descriptive Statistics Utilizing the Log-normal Distribution

This guidance applies when computing descriptive statistics utilizing the log-normal assumption. If a sample (a data set of N observations) is drawn from an underlying population that has a log-normal distribution, the following apply:

- An estimate of the mean and variance of the population is obtained by computing the mean and standard deviation of the log transforms of the data.
- The arithmetic statistical parameters of the population (mean, median, standard deviation, coefficient of variation) should be determined from the theoretical relationships (see Table A-1) between these values and the mean and standard deviation of the transformed data.
- The arithmetic mean so computed will not match that produced by a straight average of the data. Both provide an estimate of the population mean, but the approach just described provides a better estimator. As the sample size increases, the two values converge. For the entire population, both approaches would produce the same value.

A few mathematical formulas based on probability theory summarize the pertinent statistical relationships for log-normal probability distributions. These provide the basis for back and forth conversions between arithmetic properties of the untransformed data (in which concentrations, flows, and loads are reported) and properties of the transformed data (in which probability and frequency characteristics are defined and computed).

Using a two-parameter log-normal distribution, the definition of one single central tendency (e.g., median, mean) and one dispersion (e.g., standard deviation, coefficient of variation) parameter automatically defines the values for all of the other measures of central tendency and dispersion as well as the entire distribution. Table A-1 presents the formulas that define these relationships from which other values can be computed.

Box and Whisker Plots. The Box and Whisker Plot is a graphical method of displaying the variability, spread, and distribution of the data set. The "box" shows the 25th, 50th, and 75th percentile. One method of assessing variability is the interquartile range, defined above. The "whiskers" which illustrate the spread of the data, are obtained by multiplying the interquartile range by 1.5. These plots can also be used to display the degree of overlap between two data sets, used as an indication (but not proof) of whether the data sets are likely to be derived from the same populations. If data are log-normal, the plots can be produced using the log-transformed data.

TABLE A-1
RELATIONSHIPS OF LOG-NORMAL DISTRIBUTIONS

T = EXP (U)	S = M * CV
M = EXP (U + 0.5 * W^2)	W = SQRT (LN (1 + CV^2)
M = T * SQRT (1 + CV^2)	U = LN (M/EXP (O.5 * W^2))
CV = SQRT (EXP (W^2) - 1)	U = LN (M/SQRT (1 + CV^2)

Parameter designations are defined as:

	Arithmetic	**Logarithmic**
MEAN	M	U
STD DEVIATION	S	W
COEF OF VARIATION	CV	
MEDIAN	T	

LN(x) designates the base e logarithm of the value x
SQRT(x) designates the square root of the value x
EXP(x) designates e to the power x

A-4 HYPOTHESIS TESTING

Hypothesis testing is performed using statistical procedures to measure the significance of a particular effect (e.g., TSS concentration or station location). Statistical analysis is used to determine whether a particular mathematical model describes the pattern of variability in the data set better than a "random" model. Two types of models are commonly used. Respectively, they state that:

- There is a significant, mathematical relationship between a change in the magnitude of one variable to that of another variable (e.g., total suspended solids and total zinc concentrations in stormwater runoff).
- There is a significant effect of a treatment on the magnitude of a variable (e.g., an effect of station location or monitoring year or input/output of a BMP on total zinc concentration in stormwater runoff).

These hypotheses are tested using the tools of Correlation Analysis and Analysis of Variance (ANOVA), respectively. The following steps are common to both procedures:

- Formulate the hypothesis to be tested, called the null hypothesis (Ho)
- Determine the test statistic
- Define the rejection criterion for the test statistic
- Determine whether the calculated value of the test statistic falls above or below the rejection criterion

Test statistics, significance levels, and rejection criteria are described below.

Test Statistics. The sum of squares (of the deviations of the measurements from the mean) is used as a measure of the amount of variability in the data set that is explained by the statistical model. The total sum of squares can be decomposed into a portion due to variation among treatment groups ("sum of squares for treatments") and a portion due to variation within groups ("sum of squares for error"). The "mean square for error" is calculated by dividing the sum of squares for an effect source (treatment, error, or total) by the number of degrees of freedom for that effect. This "normalizes" the variability from one source for comparison with the variability from another. The "F-ratio" is then calculated as the ratio of the mean square for treatments to the unexplained variability mean square for error. If treatments have only a small effect on the variable of interest, then the portion of the total mean square due to variation within groups will be small relative to the portion between groups.

The probability that a given F-ratio could be generated by chance alone using a random model (i.e., by chance alone) is measured by the parameter "P > F." "F" is called the statistic of interest. A P-value of "0.10 > F," for example, would mean that the observed F-ratio could have been generated 10% of the time by chance alone. The effect of treatments is said to be "significant" if this probability is less than the chosen significance level (alpha), which is commonly set at 0.05.

Significance Levels. It is important to realize that statistical tests are not absolutely conclusive. There is always some degree of risk that one of two types of error will be committed:

- Rejection of a true hypothesis (Type I error); or

- Failure to reject a false hypothesis (Type II error).

If a calculated test statistic meets the rejection criterion, then reject the null hypothesis; otherwise, continue to assume that the null hypothesis is correct. The probability of committing a Type I error is denoted by the Greek symbol alpha (α), that of committing a Type II error by beta (β). Alpha is also called the "significance level of the test" (i.e., the probability of rejecting a true hypothesis). Common values for alpha are 0.10, 0.05, and 0.01. As the value of alpha decreases, the confidence in the test increases. However, at the same time, the probability of committing a Type II error (beta) also increases. Therefore, setting alpha too low will result in too strict a test, which will reduce the chance of rejecting a true hypothesis, but fail to reject many false ones. Statistical tests of runoff data generally use a target alpha of 0.05 or a 95% level of confidence.

Correlation Analysis. Correlation analysis considers the linear relationship between two variables. Correlation analysis can be used to identify parameters, which may explain or reduce some of the variability inherent in the process of statistical hypothesis testing, but doesn't necessarily imply a cause and effect relationship. Correlation is expressed on a scale from -1 to 1, with 1 representing perfect correlation; -1 representing perfect inverse correlation; and 0 representing no correlation.

Two-way Analysis of Variance. ANOVA is a statistical technique used to assess the effects of different treatments on a particular water quality parameter and to determine whether the effects of different levels of each treatment are significantly different from each other. For example, a two-way ANOVA can be used to determine the relationship between effects of the treatments station location and monitoring year on the total concentration of a parameter of interest. The ANOVA model tests whether:

- Stations differ from each other across all monitoring years; and

- Monitoring years differ from each other across all stations.

In addition, by testing for interactions in the station and year combinations, the model tests whether monitoring year influences the total zinc concentration at each station equally. In this approach, the null hypothesis states that there are no significant effects of station location or monitoring year on total zinc concentrations in stream samples. The two-way ANOVA is used to determine whether the null hypothesis can be rejected, indicating that significant differences between treatment effects were observed. If the null hypothesis is rejected, additional analyses are conducted to identify which of the stations or monitoring years were significantly different from each other.

Checking Assumptions. Two tests must be performed before the results of the ANOVA can be considered valid. These tests, performed on the "residuals" (i.e., that portion of the variability in the data set that is not explained by the statistical model), are used to check the validity of two important assumptions:

- Data were normally distributed; and
- Variability was homogenous across treatment effects (e.g., stations and years).

The degree to which the residuals are normally distributed is checked by performing the W-test. The homogeneity of the variances is checked using Levine's test for absolute values of residuals. To perform this test, the absolute values of the residuals from the ANOVA are used in a new Two-Way ANOVA as the response (y) values. The assumption of homogeneity is satisfied if no significant station or year effects are detected (i.e., Prob > F is less than alpha for all effects).

Nonparametric Analysis of Variance

If the assumptions of a parametric ANOVA cannot be met or if the proportion of non-detects in the data set exceeds approximately 15%, a Kruskal-Wallis nonparametric ANOVA can be used to examine hypotheses regarding significant differences in constituent concentrations between outfalls and between years. The nonparametric ANOVA evaluates the ranks of the observed concentrations within each treatment. "Non-detects" are treated as tied values and are assigned an average rank. If a significant difference between treatments is detected, a nonparametric multiple comparison procedure can be used to determine which treatments are heterogeneous. It should be noted that in general, nonparametric methods are less powerful than their parametric counterparts, reducing the likelihood that a (true) significant difference between treatments will be detected.

A-5 CHARACTERIZATION OF STORMWATER DISCHARGES

The characterization of runoff provides both qualitative and quantitative overviews of a storm event. The qualitative analysis for each monitored event should include a narrative describing the timing and nature of the field activities. The narrative should include, at a minimum:

- Station identification;
- Date of storm event;
- Names of field personnel;
- Time precipitation started and ended (if known), times samples were taken, time monitoring ended; and
- Information regarding any problems encountered and changes to the sampling protocol that can affect the interpretation of the data.

After writing the narrative, graph the hydrologic data (flow and precipitation).

Examine the graphs for patterns in the timing and intensity of runoff relative to those of precipitation. After sampling a minimum of three or four storms, calculate summary statistics from the analytical results (Section A-3). Use these results to determine whether the data set is sufficiently robust to support statistical hypothesis testing. If not, additional monitoring at selected locations in order to obtain more data may be warranted.

Stormwater Discharge and Rainfall Information

Produce a hydrograph for each storm, displaying storm duration on the horizontal (H) axis and discharge rate on the vertical (Y) axis. Rainfall should be plotted on the same graph (or in a different graph on the same page). The collection times of the subsamples used for compositing should be noted on the horizontal axis of each plot. Analysis of these graphs for data gaps and outlying (i.e., extreme) data points may provide some information about the functioning of the automated equipment during the storm. Outliers should be rejected from the data set for the purpose of statistical analysis if the cause of their behavior can be identified (e.g., poor QA/QC of a particular data point, poor storm capture, etc.).

Typical Applications of Hypothesis Testing to Characterization Data

Typical applications of statistical testing procedures to discharge quality data include determining whether any of the following are significant:

- Differences between stations;
- Differences between monitoring years; and
- Correlations between different water quality parameters.

A-6 COMPARISON TO STATE AND FEDERAL WATER QUALITY OBJECTIVES

The validated analytical results for samples from piped or open channel drainage systems from an individual storm event can be compared to water quality criteria for the protection of aquatic life under acute (short-term) conditions. Although the pipe or open channel (in many cases) is not a receiving water body that supports beneficial uses, comparison to criteria can provide and indication of potential toxicity. For parameters other than metals, this will entail a simple comparison of the observed grab or flow-weighted composite concentration and the corresponding criterion. The toxicity of several trace metals increases as hardness decreases. Consequently, the acute criteria for most metals must be calculated for each sample based on the hardness measured in the sample. The equations to be used for these calculations are contained in the state water quality standards regulations (WAC 173-201A-040).

Surface water criteria have not been developed for some parameters on the priority pollutant list. Moreover, in many cases there are no state criteria for conventional parameters. It may be appropriate to compare the results for these parameters to other benchmarks, such as mean or median values from the Nationwide Urban Runoff Program

(USEPA 1983), or more recently collected local or regional data, to identify potential pollutants of concern.

If the initial statistical analysis indicates that the data set is adequate, statistical testing can be conducted to assess the probability that a water quality criterion will be exceeded at a given location. The procedure described on page 17.16 of Maidment (1992) can be used. A minimum of seven samples is generally required to achieve a meaningful result.

Pollutant loading estimates may provide an indication of the potential impact of a stormwater discharge on a receiving water body. The calculation of pollutant loads provides a direct quantitative measurement of the pollutants in stormwater discharge to the receiving water. Pollutant loadings can be calculated using either an estimate of flow in an average year (annual load), or flow measured during a specific storm event (instantaneous load). Loadings can be calculated using Schueler's Simple Model (described in USEPA 1992), the SUNOM generated by the Center for Watershed Protection statistical models, or one of several dynamic models. The simple model estimates the mean pollutant loading from a particular outfall or subbasin to a receiving water. A statistical-based models, such as the FWHA model (Driscoll et al. 1990), can be used to characterize the variability of pollutant loading and concentrations, including the expected frequency of exceeding water quality criteria. A dynamic model also can calculate the expected frequency of exceedances. In addition, a dynamic model can account for the variability inherent in stormwater discharge data including variations in concentration, flow rate, and runoff volume. Thus, it can be used to calculate the entire frequency distribution for the concentration of a pollutant and the theoretical frequency distribution (i.e., the probability distribution) for loadings from the outfall or subbasin. This enables the modeler to describe the effects of observed discharges on receiving water quality in terms of the frequency at which water quality standards are likely to be exceeded. Dynamic models include USEPA's Stormwater Management Model (SWMM) and Hydrologic Simulation Program (HSPF), the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM), and Illinois State Water Survey's Model QILLUDAS (or Auto-QI) (USEPA 1992).

Whatever method is used to estimate annual pollutant loadings, an estimate of the event mean concentration (EMC) should be used as input. Note that build-up/wash-off functions, which are available in SWMM and several other models, cannot accurately simulate all of the ways pollutants can enter stormwater; thus, the results should be interpreted with caution. The EMC is defined as the constituent mass discharge divided by the flow volume and is essentially the pollutant mass per unit of discharge volume. In stormwater monitoring programs, the EMC is estimated from the concentration of a constituent in a flow-weighted composite sample. Studies by Collins and Dickey (1992) demonstrate that the EMC derived from a flow-weighted composite sample does a good job of estimating the true event mean concentration for all but very short, intense storms. During short storms, the automated sampler cannot be programmed to collect a sufficient number of samples to ensure that the results are representative.

A-7 ASSESSING TRENDS IN STORMWATER DISCHARGE QUALITY

Power Analysis

Initial analyses can be used to determine whether statistical tests of hypotheses concerning a data set will be of sufficient power to reveal true differences between treatments (e.g., outfalls or years). Factors that influence the power of a test to detect a difference between treatments include:

- Magnitude of the trend to be detected
- Variability in the data set
- Number of independent samples per treatment
- Desired confidence interval for the estimate

The power of a test to detect a difference of a given magnitude (e.g., 20%) between treatments when it is truly present (equivalent to providing insurance against a "false negative") can be increased by increasing the number of observations in the data set. Most high-powered statistical packages for the personal computer provide the ability to conduct a power analysis or to create a power curve.

If the data are highly variable, the number of samples required to adequately ensure against a false negative test may require financial resources beyond the project scope. Clearly, where historical data are available, this type of analysis is of great benefit to project planning. Where historical data are not available, a power analysis can be conducted after the first year of sampling, preparatory to designing the monitoring program for successive years.

Time Trends. Several statistical methods, both parametric and nonparametric, are available for detecting trends. They include graphical methods, regression methods, the Mann-Kendall test, Sen's non-parametric estimator of slope, the Seasonal Kendall test (Pitt, 1994), and ANOVA. Preliminary evaluations of data correlations and seasonal effects should be made prior to trend analysis. Data correlations are likely if data are taken close together in time or space. Close data can be influenced by each other and do not provide unique information. Seasonal effects should be removed, or a procedure that is unaffected by data cycles should be selected (seasonal Kendall test). The correlation between concentration versus flow should be checked by fitting a regression equation to a concentration versus flow plot. The effect of any such correlation should be subtracted from the data prior to the trend analysis.

Graphical Methods

Plots of trends in constituent concentrations over time can be examined for seasonal or annual patterns:

- Sort the data set by station and sampling date (i.e., first station and oldest sampling data are the first line of data);

- For each station, select "date" as the x-variable and plot the parameter of interest on the y-axis; and
- Visually inspect the data for upward or downward trends and note any large "peaks" or "valleys."

Regression Methods

Linear least-squares regression on water quality versus time, with a t-test to determine if the true slope is not different from zero, can be used if the data are not cyclic or correlated and are normally distributed.

Mann-Kendall Test

This test is useful when data are missing . It can consider multiple data observations per time period, and enables examinations of trends at multiple stations and comparisons of trends between stations. Seasonal cycles and other data relationships (such as flow versus concentration correlation) affect this test and must be corrected. If data are highly correlated, the test can be applied to median values in discrete time groupings.

Sen's Nonparametric Estimator of Slope

This is a nonparametric test based on rank. It is not sensitive to extreme values, gross data errors, or missing data (Gilbert 1987).

Seasonal Kendall Test

This method is preferred to most regression methods if the data are skewed, serially correlated, or cyclic (Gilbert 1987). It can be used for data sets having missing values, tied values, censored values (below detection limits) and single or multiple data observations in each time period. Data correlations and dependence must be considered in the analysis (Pitt, 1994).

Analysis of Variance

ANOVA can be used to detect significant differences in stormwater quality at two or more monitoring events. Refer to Section A-4 for a detailed description of ANOVA.

A-8 ASSESSING THE EFFECTIVENESS OF BEST MANAGEMENT PRACTICES

Existing BMPs

The effectiveness of existing BMPs can be qualitatively evaluated by comparing sampling results for drainage basins with BMPs to results for basins without BMPs. After a minimum of three sampling events, an exploratory data analysis (Section A-2) can be conducted to determine whether the use of statistical methods to detect significant differences between sampling locations is appropriate. Alternatively, it may be necessary to collect more data (i.e., sample during additional storms) before statistical methods can be applied.

Statistical analysis of water quality data for locations with and without BMPs is performed using the ANOVA procedures described in Section A-3. As described above, the data set will consist of stormwater samples collected from each location during three or more storm events. Ideally, the locations being compared will be sampled during the same storm events.

Data on constituent concentrations or pollutant loadings from several locations with or without a BMP can be pooled for comparison. Pooling data under each treatment makes the data set more robust by capturing more of the potential variability while sampling the same number of storms. Pooled drainage basins should be similar in most respects. Data from markedly different drainage basins should not be pooled, even if both locations have the same BMP. Correlation analysis can be performed to determine if metals concentrations are highly correlated with TSS.

Future BMPs

To evaluate the effectiveness of BMPs not yet in place, water samples collected prior to BMP implementation can be quantitatively compared to samples collected at the same location after BMP implementation. If the data set appears to follow a normal or log-normal distribution and does not contain a high proportion of non-detects, the Student's t-Test should be used to determine whether "post-BMP" water quality differs significantly from "pre-BMP" water quality. If the data set does not appear to follow a normal distribution and/or contains a high proportion of non-detects, nonparametric methods should be used to test for significant differences.

APPENDIX A REFERENCES

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APPENDIX B
EXAMPLE HEALTH AND SAFETY PLAN

The information contained herein is for guidance only, and does not supersede or otherwise change any applicable state, local, or agency health and safety requirements or programs. A specific health and safety plan should be developed for each site. The example Health and Safety Plan contained herein is not intended to include every type of hazard that could be encountered; rather, it is intended to serve as a starting point for a site-specific analysis for a given project.

HEALTH AND SAFETY PLAN
STORMWATER MONITORING

Project No. XXXX

September 2000

EFFECTIVE DATES

[Insert date]

APPROVALS

________________________________	____________________
[Insert PM and Contractor name]	Date
________________________________	____________________
[Insert Health and Safety Officer]	Date

B-1 INTRODUCTION

[INSERT CLIENT] has retained [INSERT CONTRACTOR] to evaluate water quality monitoring equipment for measuring the constituents of highway stormwater runoff.

This Health and Safety Plan (HSP) identifies the general health and safety procedures for work to be conducted while monitoring stormwater for the [INSERT CLIENT] project. Implementation of this plan is the responsibility of the [INSERT CONTRACTOR] Project Manager. The [INSERT CONTRACTOR] Site Safety Officer (SSO) assists the [INSERT CONTRACTOR] Project Manager in carrying out this responsibility at the work site by enforcing the requirements of the Health and Safety Plan and by the authority to suspend work to protect worker health and safety. The [INSERT CONTRACTOR] Health and Safety Officer (HSO) may suspend or limit work, or direct changes in work practices, if the [INSERT CONTRACTOR] HSP and/or work practices used are deemed inadequate.

This HSP may not be used for work other than that described in Section B-4. It may not be modified or used beyond the effective date shown in the title page without the written approval of the [INSERT APPROPRIATE AUTHORITY] and the HSO. Portions of the HSP that deal with specific issues related to the sampling sites, such as addresses and route maps to hospitals, will be updated prior to beginning work at the sampling location. These additions to the plan will be submitted to the authorizing officers for approval.

This plan is to be followed by all [INSERT CONTRACTOR] personnel who will be participating in the sampling program. All personnel included in the sampling program shall be responsible for reading this plan and following its procedures.

B-2 PROJECT AND SAFETY PERSONNEL

The following outlines key project and safety personnel involved in the [INSERT CLIENT] Stormwater Monitoring project. This outline presents the names, titles, and specific responsibilities of these individuals in terms of project health and safety.

Title	Name and Phone Number	Responsibility
Health and Safety Officer	[INSERT H&S OFFICER] [PHONE NO.]	1) Interface with [INSERT CONTRACTOR] personnel and the project managers in matters of health and safety. 2) Develop or review, approve or disapprove project Health and Safety Plans. 3) Conduct staff training and orientation on health and safety related activities. 4) Appoint or approve site safety officers. 5) Monitor compliance with Health and Safety Plans and conduct site audits. 6) Assist project managers in obtaining required health and safety equipment.
[INSERT CONTRACTOR] Project Manager	[INSERT PROJECT MANAGER] [PHONE NO.]	1) Assure that the project is performed in a manner consistent with the [INSERT CONTRACTOR] Health and Safety Program. 2) Assure that the project Health and Safety Plan is prepared, approved, and properly implemented. 3) Provide the HSO with the information needed to develop the Health and Safety Plan. 4) Implement Health and Safety Plan. 5) Assure that adequate project resources are allocated to fully implement the project Health and Safety Plan. 6) Assure compliance with the Health and Safety Plan by contractor personnel. 7) Coordinate with the HSO on Health and Safety matters.

Title	Name and Phone Number	Responsibility
Site Safety Officer	[INSERT SITE SAFETY OFFICER] [PHONE NO.]	1) Direct health and safety activities on-site. 2) Report immediately all safety-related incidents or accidents to the HSO and project manager. 3) Assist project manager in all aspects of implementing Health and Safety Plans. 4) Maintain health and safety equipment on-site. 5) Implement emergency procedures as required. 6) Conduct health and safety briefings as needed.

B-3 SITE INFORMATION

[INSERT SITE-SPECIFIC INFORMATION]

B-4 WORK ACTIVITIES COVERED BY HEALTH AND SAFETY PLAN

One of the objectives of this project is to [INSERT PROJECT OBJECTIVE]. The majority of the field work will consist of crews collecting water samples for water quality analysis from the monitoring station during storms. In addition, some field work will be directed toward station set up and periodic station maintenance, which would occur during dry conditions. Access to some of the monitoring equipment may occur through storm sewer manholes. Other field work that crews could conduct includes setting up and implementing sampling programs (grab sampling and automatic samplers).

Field activities at the monitoring sites will include water quality sample collection (during storm events), *in situ* monitoring for select water quality parameters (during storm events), and general maintenance activities (ongoing). The hazards associated with all work performed at sampling stations include: (1) being involved in a vehicle accident while driving to or from a site: (2) being struck by a vehicle while working at a site; (3) falling into a stream or open manhole; (4) entering a confined space; (5) experiencing heat and cold stress; and (6) being exposed to hazardous materials or vapors.

[INSERT CONTRACTOR] will maintain water samplers and associated intake system and mounting hardware at all sites. All installation and maintenance procedures at sewer sampling stations will require entry into confined spaces. Confined spaces are large enough and so configured that an employee can enter and perform assigned work, but they have limited openings for entry and exit, and are not intended for continuous employee occupancy. Confined spaces may contain safety or health hazards; these must be identified and controlled or eliminated prior to entry. All [INSERT CONTRACTOR] employees who enter the confined space during installation and maintenance activities will have had confined-space entry training. Additionally, when confined space access is required, at least two trained individuals must be present (one to enter the space; one to observe).

Water sample collection during storm events will be performed by [INSERT CONTRACTOR]. Sample collection will involve one or more visits per site during storm events. It is anticipated that two field crews consisting of two people per crew will be adequate for all sites. The general tasks performed by a crew visiting any given site will consist of: (1) driving to the site; (2) establishing traffic control (if needed); (3) programming and interrogating flow monitor and/or sampler; (4) calibrating and installing continuous *in situ* water monitor in manhole; (5) removing and replacing sample bottles; (6) taking grab samples; and (7) diverting traffic. These activities do not require entry into storm sewers.

B-5 HAZARD ASSESSMENT

B-5.1 CHEMICAL HAZARDS

Although most of these sites are not known to contain hazardous materials, there is a potential for hazardous gaseous and/or liquid contaminants to be present as the result of industrial runoff and/or illicit storm sewer connections. The presence of chemicals and/or chemical vapors may result in (but is not limited to) one or more of the following threats: toxic conditions, oxygen displacement and explosion and/or fire. The risks associated with these threats include poisoning (acute and/or chronic), asphyxiation, and bodily injury.

B-5.2 CONFINED SPACES

As defined by the U.S. Occupational Safety and Health Administration (OSHA), storm sewers are classified as confined spaces. Regulations for entry into confined spaces are provided in the OSHA Confined Space Standard (Title 29 Code of Federal Regulations (CFR) 1910.146) and [INSERT RELEVANT LOCAL REGULATIONS]. The risks associated with confined spaces include dangerous atmospheres, engulfment, falls, falling objects, and bodily harm due to explosion. Confined Space Entry Procedures to be used during this project are presented in Section B-7.

B-5.2.1 Atmospheric Hazards

Atmospheric hazards that may be present within the storm sewers include oxygen deficiency and toxic or flammable gases. More sewer workers die each year from atmospheric causes than from all other causes combined. Each potential hazard and the recommended evaluation method is presented below:

Oxygen deficiency: Oxygen (O_2) deficiency can be caused by the aerobic decomposition of sewage and organic matter. Chemical and biological processes during the decomposition use the available oxygen. Oxygen deficient atmospheres can also result from displacement by gas such as methane or hydrogen sulfide, which may or may not be harmful, but cannot support life. Oxygen deficiency may be present in areas with little ventilation or air circulation or where biological or chemical processes are occurring. A confined space where water or sewage is enclosed for long periods, and where extensive oxidation of iron (rust) occurs has a high potential for being oxygen deficient.

The normal level of oxygen in the atmosphere is 20.8%. An atmosphere legally oxygen deficient contains less than 19.5% oxygen by volume. An atmosphere containing less than 16% oxygen is considered immediately dangerous to life and health (IDLH). Symptoms of oxygen deficiency include shortness of breath, dizziness, impaired vision, and loss of consciousness.

An atmosphere containing more than 23.5% oxygen by volume is an oxygen enriched atmosphere. This may increase the potential for fire or explosion.

Hydrogen Sulfide: Hydrogen sulfide (H_2S) is a dense, colorless gas that is the byproduct of sewage and organic material that has aerobically decayed. It has the characteristic odor of rotten eggs. Hydrogen sulfide is often present as a dissolved gas in sewage or can be trapped within sewer sediment and sludge. Disturbing the sediment or sludge can release the trapped or dissolved gas.

Initially, the gas anesthetizes the sense of smell, and cannot be detected by odor. Hydrogen sulfide prevents the bonding of oxygen to the hemoglobin molecule contained in the blood cells. Paralysis of the respiratory system is followed by unconsciousness and possibly death.

OSHA has established a ceiling concentration of 20 ppm for H_2S, with a 50 ppm, 10-minute maximum peak concentration. The IDLH concentration is 100 ppm.

Symptoms of hydrogen sulfide poisoning include inflammation of the eyes and lungs, dizziness, loss of coordination, weakness, breathing difficulty, and loss of consciousness.

Carbon Monoxide: Carbon monoxide (CO) is a colorless, odorless gas that acts as a chemical asphyxiant. It is a product of almost any kind of combustion or hydrocarbon oxidation.

The OSHA exposure limit as an 8-hour TWA is 50 ppm. The IDLH concentration is 1,200 ppm.

Symptoms of exposure include headache, dizziness, nausea, weakness, and confusion. In addition the skin becomes cherry red in color.

Methane: Methane (CH_4) is a colorless, odorless gas that is lighter than air. It is produced by the chemical decomposition of sewage and organic matter. Methane is both an asphyxiant and explosive. The lower explosive limit is reached when the concentration of methane reaches 5% of the total atmospheric composition.

B-5.3 PHYSICAL HAZARDS

B-5.3.1 Open Manholes and Manhole Lids

Manhole covers must be opened during water sample collection activities. Opening manholes requires the removal of heavy steel lids, which can easily cause injury if not opened using proper techniques. Failure to remove these lids in a safe manner can put the worker at risk of back injuries and/or crushed toes or feet. Specially designed manhole hooks used with proper lifting techniques provide the easiest and safest method to remove manhole covers.

Open manholes pose a threat to workers and the general public. Limited visibility, inattention, poor site control, slips, and/or trips could result in person falling into an open manhole. The risks of such a fall include bodily injury and/or death.

B-5.3.2 Open Water Hazards

High stream flows commonly associated with storm events present a threat to workers. Slippery conditions, stream-side vegetation, and unstable stream banks could cause a worker to fall into a stream. The risks of such a fall include hypothermia, bodily injury, and drowning.

B-5.3.3 Vehicle Traffic

Traffic hazards will be encountered when working at the side of or in a roadway. These hazards will be increased during times of reduced visibility such as during storm events and at night. The primary threats associated with working in or alongside roadways are workers being struck by passing vehicles or being involved in a vehicular collision. The risk associated with these threats is severe bodily injury and/or death.

B-5.4 BIOLOGICAL HAZARDS

Rodents, pathogenic microorganisms, and viruses are potential biological hazards of concern. The primary threats associated with these hazards are receiving bites and/or contracting disease. The threats associated with these hazards include flesh wounds and/or infections (acute and/or chronic).

B-6 GENERAL HEALTH AND SAFETY REQUIREMENTS

B-6.1 EMPLOYEE CLEARANCE

When [INSERT CONTRACTOR] personnel are directly involved in confined space entry activities, a minimum of two [INSERT CONTRACTOR] employees with an active safety and health clearance status will be present. Active health and safety clearance will consist of training and medical documentation. Entry supervisors, entrants, and attendants will be trained to adequately address all health and safety aspects associated with entry and be medically qualified for confined space entry work. All other field personnel involved in field and/or stormwater sampling activities must receive an on-site briefing from the Site Safety Officer before conducting field work.

B-6.2 SITE SAFETY MEETINGS

All personnel assigned to perform the work described in this HSP must be: (1) given a personal copy of this HSP by a Site Safety Officer; (2) briefed on the health and safety requirements of this HSP by a Site Safety Officer; and (3) must acknowledge receipt of and willingness to comply with the provisions of the plan by signing the attached compliance agreement. Individuals refusing to sign the agreement will not be permitted to conduct field work for this project. Completed agreements shall be provided to the [INSERT CONTRACTOR] Project Manager, who will file them with the [INSERT CONTRACTOR] HSO. Additional briefings should be scheduled and conducted by the Site Safety Officer as needed.

B-6.3 INCIDENT REPORTING

B-6.3.1 PURPOSE

All health and safety incidents shall be reported to [INSERT CONTRACTOR] management and health and safety staff. The prompt investigation and reporting of incidents will reduce the risk of future incidents, better protect [INSERT CONTRACTOR] employees, and reduce [INSERT CONTRACTOR] liability.

B-6.3.2 DEFINITIONS

A health and safety incident is any event listed below:

- Illness resulting from chemical exposure or suspected chemical exposure
- Physical injury, including both those that do and do not require medical attention to [INSERT CONTRACTOR] employees or [INSERT CONTRACTOR] subcontractors

- Fire, explosions, and flashes resulting from activities performed by [INSERT CONTRACTOR] and its subcontractors
- Property damage resulting from activities performed by [INSERT CONTRACTOR] and its subcontractors
- Vehicular accidents occurring on-site, while traveling to and from client locations, or with any non-personal vehicle
- Infractions of safety rules and requirements
- Unexpected chemical exposures
- Complaints from the public regarding [INSERT CONTRACTOR] field operations

B-6.3.3 REPORTING PROCEDURES

B-6.3.3.1 Reporting Format

Incident reports shall be prepared by completing Form HS-100. This form may be obtained from the [INSERT CONTRACTOR] HSO and is attached at the end of this Plan.

B-6.3.3.2 Responsible Party

Reports of incidents occurring in the field shall be prepared by the SSO or, in the absence of the SSO, the supervising field engineer, witness, or injured/exposed individual.

B-6.3.3.3 Filing

A report must be submitted to the HSO within 24 hours of each incident involving medical treatment. In turn, the HSO must distribute copies of the report to appropriate company personnel. When an injury or illness is reported, the HSO must deliver a copy of the report to the individual in charge of Human Resources so that a Worker's Compensation Insurance Report can be filed if necessary. Reports must be received within 48 hours of each qualifying incident.

B-6.3.3.4 Major Incidents

Incidents that include fatalities, hospitalization of employees or subcontractors, or involve injury/illness of the public shall be reported to the HSO and [INSERT CONTRACTOR] Project Manager as soon as possible. Any contact with the media should be referred to the [INSERT CONTRACTOR] Project Manager and appropriate Authority.

B-6.4 PROHIBITED ON-SITE ACTIVITIES

The following are prohibited on-site activities: (1) entering confined spaces without specific training and medical clearance; (2) conducting stormwater sampling without clearance from the Site Safety Officer; (3) eating and drinking without prior decontaminating (e.g., washing hands and face); and (4) smoking. Violations of these prohibitions will result in dismissal from the field crew.

B-7 SITE SPECIFIC HEALTH AND SAFETY REQUIREMENTS

B-7.1 SPECIAL MEDICAL TESTS

Personnel who enter confined spaces must have appropriate medical clearance, including clearance for use of respiratory protection.

B-7.2 SPECIAL TRAINING

Installation of water quality sampling and flow monitoring equipment in storm sewer systems, rating activities, and some station maintenance activities will require confined space entry. Confined space entry requires specific training. [INSERT CONTRACTOR] employees will be completing all confined space work.

B-7.3 PHYSICAL HAZARDS

B-7.3.1 Outfall Sites

Field personnel should not enter drainage channel conduits during a storm event. Rainy conditions can make pipes slippery, and thus increase the possibility of falling. A fall into a drainage pipe that is conveying flow may result in drowning. To minimize this possibility, each sampling crew will be equipped with an extendible sampling pole or similar device to be used for collecting samples from a location outside of the pipe. This same procedure applies to manhole sites.

B-7.3.2 Manhole Lids and Open Manholes

Monitoring sites may require opening manhole lids to gain access to the sampling equipment. Manhole lids are very heavy and bodily injury (e.g., broken foot or wrenched back) can easily occur if lids are not removed or replaced correctly. Each field crew will be given a manhole hook for removing manhole covers. The hook is placed through a hole in the manhole cover and acts as a lever to remove the lid. The lid is removed and replaced by lifting with the legs while keeping the back straight and then sliding the lid to the desired position. However, removal of the manhole lid creates a new hazard. A fall into an open manhole may result in serious injury or death. The area around an open manhole must be cordoned off from the general public by using barricades and/or traffic cones. All field crew members must be informed before a manhole is opened.

B-7.3.3 Work Site and Traffic Control

Work site control and work zones will be established each time a crew visits a sampling station. Field crews will use traffic control cones, warning signs, and vehicles to develop work zones and site control at sites where the safety of crews and the public may be threatened. An example of this would be the use of traffic cones to direct pedestrians away from an open manhole where vehicle traffic control is not required. Site-specific directions for proper vehicle and traffic control device placement in relation to a given sampling station will be added to this document as conditions warrant for the various sites. Modifications or additions to this traffic control section will be made by the Site Safety Officer who will then inform the [INSERT CONTRACTOR] Health and Safety Coordinator.

Traffic hazards pose the greatest risk to workers visiting sampling stations. Traffic hazards to both workers and motorists must be minimized at each sampling station. Standard traffic control measures that can be used to reduce traffic hazards are described below. However, sampling sites may be located in areas where standard traffic measures may not be applicable. In these cases, standard control measures will be modified to meet a given situation.

Warning signs (e.g., Utility Work Ahead, Lane Closed, etc.) will be erected on the roadway or shoulder and shall be removed upon termination of work. Portable signs will be erected vertically, with the bottom of the sign a minimum of 18 inches above the roadway. Portable signs will be illuminated at night and/or be accompanied by a flashing yellow light. Traffic cones or pylons will be placed on the roadway to divert traffic away from the manhole opening. These cones must have reflective striping in order to be visible at night. The cone taper distance from the manhole will be determined by the following equation when speed limit is 40 MPH or less:

$$L = (WS^2)/60$$

where L = pylon taper length in feet

W = width of desired closure or offset (feet)

S = posted speed limit (miles per hour)

(FHWA, 1988. Manual on Uniform Traffic Control Devices. FHWA-SA-94-027.)

Table B-1 shows taper lengths for various traffic speeds with 5 and 10-foot wide lane closure. A lane closure pertains only to traffic lanes and does not include shoulders or other areas outside the main traffic flow. Site plans have been developed with these criteria.

TABLE B-1. Traffic Cone Taper Lengths.

Width of Closure (feet)	Traffic Speeds (mph)	Cone Taper Length (feet)
5	25	52
	30	75
	35	102
	40	133
10	25	104
	30	150
	35	204
	40	267

B-7.4 HAZARDOUS MATERIALS IDENTIFICATION AND PROTECTION

Stormwater and stormwater sewer systems have the potential to contain hazardous materials and/or microorganisms and should be approached with caution. Industrial and commercial areas are of particular concern because of possible illegal dumping of wastes into the storm sewer system. Any unusual smells and/or discolored sample water are definitely causes for alarm. The following procedures are recommended to help protect field personnel from these hazards:

- ALL MANHOLES MUST BE CHECKED WITH A FOUR GAS METER (oxygen, LEL, carbon monoxide, and hydrogen sulfide) BEFORE THE MANHOLE IS OPENED. This is to determine whether gases are present that may affect persons at the surface when the manhole is opened. This test is conducted through a hole in the manhole lid.

- If dangerous gases are present (determined by gas meters and/or smell), crews will use the following responses:

  - If hazardous levels of non-explosive gases are indicated by the gas meter, crews will stop work and evacuate the area. (Note: Operate under the rule that if it smells bad, it is bad!). The SSO will be notified immediately.

- If explosive gases are detected in concentrations of 10% of the Lower Explosive Limit (LEL), no one, under any circumstances, will attempt to open the manhole. For methane, this represents a concentration of 0.5%. The SSO must be notified immediately.

- If field crews detect or suspect any dangerous situations, they must notify the SSO of their intended protective procedures.

- Field personnel should wear appropriate gloves when handling stormwater samples. It is important to realize that stormwater can contain dangerous constituents regardless of land use type. For example, stormwater typically has very high concentrations of bacteria in all areas including streams. All crew members who come into contact with stormwater must decontaminate. This is especially important prior to eating and drinking or smoking. All personnel must also decontaminate before leaving the site. Proper decontamination techniques will ensure that contamination will not spread to vehicles or other locations. Decontamination should include disposal of gloves and washing the hands and face with soap and water. Each crew shall carry 5-gallon containers of wash/drinking water. All crew members must be careful not to contaminate the container.

Procedures for entries will be determined by the anticipated level of hazard. The hazard levels are described in the following text.

Low Hazard Entries

Definition: Includes any stormwater system where there is clearly no potential for connection to a sewer system, and the stormwater system is dry. Under these conditions, no potential for exposure to unknown organics is anticipated. Entries must be completed when there is no precipitation forecasted.

Procedure: Use 4-gas meter to monitor all levels of the space. Verify that the instrument has been calibrated to alarm at the action level, and document all readings. Entry may proceed if explosive levels are below 10% of the LEL; oxygen content is between 19.5% and 22%; hydrogen sulfide is less than 5 ppm; carbon monoxide concentrations are below 15 ppm; and no other hazards are anticipated. Instrument readings will be taken periodically to ensure that conditions remain within specified limits. If any action level is exceeded, forced air ventilation will be provided until concentrations are reduced to acceptable levels. Ventilation of the space will be continuous during occupancy. No CSE permit is required. Fall protection is required for all entries with a vertical drop of greater than 6 feet. A ladder may be used in place of fall protection only if it is in full compliance with the OSHA standard.

Moderate Hazard Entries

*Definition***:** Includes any stormwater system where there is clearly no potential for connection to a sewer system, but the system contains liquids, and therefore may contain unknown organics. Entries must be completed when no precipitation is forecasted.

*Procedure***:** The standard confined space entry form will be used. The supervisor will check off requirements and sign for approval and termination of entry. Monitoring will be conducted with a flame ionization detector or photoionization detector with an 11.7 lamp. Emergency communications and use of an attendant will be required. Organic vapor and 4-gas meter monitoring results must be documented on the form prior to entry. Action levels for LEL, oxygen, hydrogen sulfide, and carbon monoxide will be the same as the low hazard entry. Acceptable levels for organic vapor will be less than 1 ppm above background. If any action level is exceeded, forced air ventilation will be provided until concentrations are reduced to acceptable levels. Ventilation of the space will be continuous during occupancy. Instrument readings will be taken periodically to ensure that conditions remain within specified limits. Fall protection requirements will be the same as the low hazard entry. The space must be ventilated prior to and during entry.

High Hazard Entries

Definition: This includes sewers, entries when there is a potential for precipitation, and any entries where additional hazards are anticipated.

Procedure: The confined space entry standards must be fully implemented. The HSO will coordinate with the project manager to prepare the entry permit.

It is very important to notify all members of the field crew when hazardous situations are encountered. In general, the notification process will consist of notifying the Site Safety Officer. This individual, will in turn, notify higher levels of [INSERT CONTRACTOR] management. However, if the SSO is not available the [INSERT CONTRACTOR] Project Manager must be contacted.

B-7.5 CONFINED SPACE ENTRY PROCEDURES

Storm sewers qualify as confined spaces as defined by OSHA, and are therefore subject to federal regulation. Procedures for confined space entry are given below. All personnel engaged in confined space entry will be required to follow the confined space entry procedures. **[NOTE: Contractor (or preparer of HSP) must ensure that procedures provided in the HSP are in compliance with current OSHA regulations.]**

B-7.5.1 PURPOSE

Entry into confined spaces always represents a potentially hazardous situation. Without proper planning, both entrants and rescuers may be at risk of death or injury. These risks can be minimized by following the approach outlined in this procedure.

B-7.5.2 DEFINITIONS

<u>Attendant</u>: A person who is assigned as standby to monitor a confined space process or operation, to provide support, and react as required.

<u>Biological Hazards</u>: Infectious agents presenting a risk or potential risk to the well-being of man or other animals, either directly through infection or indirectly through disruption of the environment.

<u>Blanking</u>: Inserting a solid barrier across the open end of a pipe leading into or out of the confined space, and securing the barrier in such a way to prevent leakage of material into the confined space.

<u>Confined Space</u>: An enclosed area that has the following characteristics (as defined by OSHA):

- is large enough and so configured that an employee can bodily enter and perform assigned work;
- is not designed for continuous human occupancy; and
- has limited or restricted means for entry and exit.

Examples of confined spaces include but are not limited to:

- tanks
- silos
- vessels
- pits
- sewers
- dam galleries
- pipelines
- tank cars
- boilers
- septic tanks
- utility vaults
- dam outlet works

Double Block and Bleed: A method used to isolate a confined space from a line, duct or pipe by physically closing two in-line valves on a piping system, and opening a "vented-to-atmosphere" valve between them.

Engulfment: The surrounding, capturing, or both, of a person by divided particulate matter or liquid.

Entry: Ingress by persons into a confined space, which occurs upon breaking the plane of the confined space portal with any part of the body; and all periods of time in which the confined space is occupied.

Hazard Evaluation: A process to assess the severity of known, real, or potential hazards at or in the confined space.

Hazardous Atmosphere: An atmosphere that may be, or is injurious to occupants by reason of: oxygen deficiency or enrichment; flammability; explosivity; or toxicity.

Hot Work: Work within a confined space that produces arcs, sparks, flames, heat, or other sources of ignition.

Isolation: A process of physically interrupting, or disconnecting, or both, pipes, lines and energy sources from the confined space.

LEL/LFL and UEL/UFL: Acronyms for "Lower Explosive Limit"/"Lower Flammable Limit" and "Upper Explosive Limit"/"Upper Flammable Limit."

Lockout/Tagout: The placement of a lock or tag on the energy-isolating device in accordance with an established procedure, indicating that the energy-isolating device shall not be operated until removal of the lock or tag in accordance with an established procedure. (The term "lockout/tagout" allows the use of a lockout device, a tag, or a combination of both.)

Non-Permit Confined Space (NPCS): A space that, by configuration, meets the definition of a confined space but after evaluation is found to have little potential for generation of hazards or has hazards that can bee controlled or eliminated by engineering controls.

Oxygen Deficient Atmosphere: An atmosphere containing less than 19.5% oxygen by volume.

Oxygen Enriched Atmosphere: An atmosphere containing more than 23.5% oxygen by volume.

PEL: An acronym for "Permissible Exposure Limit" which is the allowable air contaminant level established by the U.S. Department of Labor, Occupational Safety and Health Administration.

Permit Required Confined Space (PRCS): A confined space that after evaluation has actual or potential hazards that have been determined to require written authorization for entry.

Qualified Person: A person who by reason of training, education, and experience is knowledgeable in the operation to be performed and is competent to judge the hazards involved.

TLV: An acronym for "Threshold Limit Value."

Toxic Atmosphere: An atmosphere containing a concentration of a substance above the published or otherwise known safe levels.

B-7.5.3 REGULATORY REQUIREMENTS

[INSERT CONTRACTOR] will comply with OSHA Confined Space Standard (Title 29 CFR 1910.146) and any local regulations.

The American National Standards Institute (ANSI) has issued industry guidelines similar to the OSHA regulations as ANSI Z117.1-1989.

B-7.5.4 KEY ELEMENTS OF THE [INSERT CONTRACTOR] CONFINED SPACE ENTRY PROGRAM

1. Hazard Identification. Identify and evaluate each hazard of the permit spaces, including determination of severity.
2. Hazard Control. Establish and implement the means, procedures and practice by which the permit spaces can be entered safely.
3. Permit System. Establish a written permit system for the proper preparation, issuance and implementation of entry permits.
4. Employee Information. Signs shall be posted near permit spaces to notify employees what hazards may be present and that only authorized entrants may enter the permit spaces.
5. Prevention of Unauthorized Entry. Prevent unauthorized employee entry through such measures as training or by posting signs and barriers, as necessary.
6. Employee Training/Medical Surveillance. Train employees so that attendants, authorized entrants, and personnel authorized or in charge of entry can work safely in and around

permit space. Provide medial examinations as necessary for working in confined spaces and using respiratory protection.

7. Equipment. Provide, maintain and ensure the proper use of the equipment necessary for safe entry, including testing, monitoring, communication and personal protective equipment.

8. Rescue. Ensure that the procedures and equipment necessary to rescue entrants from permit spaces are implemented and provided.

9. Protection from External Hazards. Ensure that all pedestrian, vehicle or other barriers necessary to protect entrants from external hazards are provided.

10. Duty to Other Employers. Ensure that when [INSERT CONTRACTOR] employs subcontractors, [INSERT CONTRACTOR] provides the subcontractor with all available information on permit space hazards; on the OSHA Confined Space Standard; and on any other workplace hazards and emergency procedures of which the contractor needs to be aware.

B-7.5.5 CONFINED SPACE ENTRY PERMIT

A permit shall be used for all confined space entries. An example permit form HS200 is located in Appendix A. Permits must include the following:

1. the hazards of the permit space;
2. the measures for isolation of the permit space;
3. the measures, such as lockout/tagout, equipment and procedures for purging, inverting, ventilating and flushing, used to remove or control potential hazards;
4. acceptable environmental conditions, qualified with regard to the hazards identified in the permit space;
5. testing and monitoring equipment and procedures to verify that acceptable environmental conditions are being maintained during entry;
6. the rescue and other services that would be summoned in case of emergency and the means of communication with those services;
7. rescue equipment to be provided onsite, if necessary;
8. the personal protective equipment, such as respirators, clothing and retrieval lines, provided to ensure employee safety;

9. the identity of the permit space;
10. the purpose of the entry;
11. the date of the entry and the authorized duration; (a permit may be valid for up to one year, so long as all conditions under which the permit was issued are maintained).
12. a list of the authorized entrants;
13. a list of eligible attendants;
14. a list of individuals eligible to be in charge of the entry;
15. the signature, together with the name printed or otherwise legible, of the individual authorizing the entry, verifying that all actions and conditions necessary for safe entry have been performed.

The individual authorizing the entry shall sign or initial the permit before the entry begins, but not until all actions and conditions necessary for safe entry into the permit space have been performed.

Upon completion of the entry covered by the permit, and after all entrants have exited the permit space, the individual authorizing the entry shall cancel the permit. If the permit has been issued for more than one shift, the permit will be canceled when conditions change or the permit expires.

B-7.5.6 TRAINING REQUIREMENTS AND DUTIES OF PERSONNEL

B-7.5.6.1 Entrants

The individuals entering the confined space must:

1. know the hazards that may be faced during entry;
2. recognize the signs and symptoms of exposure to a hazard;
3. understand the consequences of exposure to a hazard;
4. maintain contact with the attendant;
5. notify the attendant when the entrants self-initiate evaluation of the permit space;
6. be aware of the personal protective equipment, such as retrieval lines, respirators or clothing, needed for safe entry and exit;
7. be provided with the necessary personal protective equipment;
8. use the personal protective equipment properly;

9. be aware of the external barriers needed to protect entrants from external hazards and of the proper use of those barriers; and

10. exit the permit space, unless it is physically impossible to do so, when

    a) the attendant orders evacuation;

    b) an automatic alarm is activated; or

    c) the authorized entrants perceive they are in danger.

B-7.5.6.2 Attendants

An attendant is stationed and remains outside the permit space(s) at all times during entry operations and must:

1. maintain a continuous, accurate count of all persons in the space;

2. know of and recognize potential permit space hazards, and monitor activities inside and outside the permit space to determine if it is safe for entrants to remain in the space;

3. maintain effective and continuous contact with authorized entrants during entry;

4. order authorized entrants to evacuate the permit space immediately when:

    a) the attendant observes a condition that is not allowed in the entry permit;

    b) the attendant detects behavioral effects of hazard exposure;

    c) the attendant detects a situation outside the space that could endanger the entrants;

    d) the attendant detects an uncontrolled hazard within the permit spaces;

    e) the attendant is monitoring entry in more than one permit space and must focus attention on the rescue of entrants from one of those spaces; or

    f) the attendant must leave the work station.

5. summon rescue and other emergency services as soon as the attendant determines \ that authorized entrants need to escape;

6. take the following actions, as necessary, when unauthorized persons approach or enter a permit space while entry is underway:

    a) warn unauthorized persons away from the space;

    b) request the unauthorized persons to exit immediately if they have entered the permit space; and

c) inform the authorized entrants and any other persons designated by the employer that unauthorized persons have entered the permit space.

7. No one may enter into the permit space to attempt rescue of entrants unless he/she is trained as a rescuer, emergency procedures are followed, and back-up assistance has arrived.

B-7.5.6.3 The Person Authorizing Entry

Individuals authorizing or in charge of entry must receive the appropriate training and be approved by the [INSERT CONTRACTOR] HSO to perform the assigned duties, as follows:

1. determine that the entry permit contains the requisite information before authorizing or allowing entry;
2. determine that the necessary procedures, practice, and equipment for safe entry are in effect before allowing entry;
3. determine, at appropriate intervals, that entry operations remain consistent with the terms of the entry permit, and that acceptable entry conditions are present;
4. authorize entry and terminate entry whenever acceptable entry conditions are not present; and
5. serve as authorized entrants or attendants for an entry if they have the proper training.

B-7.5.7 ATMOSPHERIC TESTING

Prior to entry, the atmosphere of a confined space must be tested:

1. oxygen content must be between 19.5 and 22%;
2. flammable gases must be less than 10% LEL ; and
3. toxic compounds must be below PELs; compounds of concern include:
    a) carbon monoxide,
    b) hydrogen sulfide, and
    c) any other acutely toxic compound suspected to be present.

Atmospheric testing should be done at all levels within the confined space (from bottom to top) and should be performed as frequently as appropriate during the actual entry. The permit shall specify the monitoring requirements.

B-7.5.8 PREPARATION OF A CONFINED SPACE FOR ENTRY

Prior to entry, a confined space must be made as safe as possible. This can include:

1. ventilating the space with fresh air for as long as possible, preferably by using forced ventilation or push/pull ventilation;
2. locking out and tagging out all electrical control switches, mechanical controls, pumps, etc. that could release energy or contaminants into the confined space;
3. disconnecting or capping all inlet pipes into the confined space; double blocking and bleeding can also be used on piping; and
4. assuring safe entry via ladder, tripod, or other mechanisms.

B-7.5.9 COMMUNICATION DURING ENTRY

The system of communication must be clearly established prior to entry. Voice, walkie-talkies, handlines, phone, or any appropriate system can be used. The system must be capable of communication rapidly and reliably in the event of an emergency.

B-7.5.10 EMERGENCY AND RESCUE PROCEDURES

Only rescuers trained in confined space rescue should attempt a rescue. If an emergency occurs, the attendant should summon assistance as rapidly as possible. A pre-arranged signal to summon assistance may be used, such as use of a horn, flashing light, or other alarm device. Emergency communication devices must be clearly identified prior to entry. Rescue teams should practice confined space rescue at least once every 12 months and at least one member of the rescue team must maintain current first-aid and CPR certification. Rescue teams brought in from the outside must be made aware of the hazards that they may confront in the specific confined space.

B-7.5.11 HAZWOPER SITE SAFETY AND HEALTH PLANNING PER TITLE 29 CFR 1910.120

Confined space entry permits and planning may be included as part of site safety and health plans. Such plans will require the normal [INSERT CONTRACTOR] Health and Safety Plan approvals.

B-7.5.12 CONFINED SPACE EQUIPMENT

The following equipment is required to be used during any confined space entry:

- safety harness with d-ring and lifeline;
- tripod and personnel winch, or other suitable means of rapidly removing personnel from a confined space;
- lighting equipment;
- flame ionization detector (FID) or photoionization detector (PID);
- combustible gas/O_2/H_2S/CO monitoring capability (four gas meter);
- blower with ducting; and
- cellular telephone or two-way radio (if visible or voice contact cannot be maintained with surface assistants).

B-7.6 PERSONAL PROTECTIVE EQUIPMENT

Protective equipment shall be used and shall consist of the following:

- hard-hat;
- reflective safety vest;
- rubber boots with steel toes;
- rain gear (when needed);
- nitrile or latex gloves;
- splash-proof goggles (if desired); and
- appropriate respiratory protection (to be used only by [INSERT CONTRACTOR] personnel trained in the proper use of this equipment and with medical clearance).

In addition, the following specific health and safety equipment will be present in each vehicle used for field work:

- first aid kit;
- fire extinguisher;
- drinking water;

- wash water and soap; and
- hoist for lifting water sampler.

It is the responsibility of field crew leaders to be sure their vehicles have these items before entering the field.

B-7.7 SITE ILLUMINATION

This project will likely require personnel to work at night. Portable lighting shall be used to achieve sufficient illumination. OSHA (29 CFR Part 1910) requires 5 foot-candles of illumination for the type of work covered by this plan. Vehicle lights, headlamps, and flashlights will be used to meet this requirement.

B-7.8 BIOLOGICAL HAZARDS

Field crews must protect themselves from biological hazards they may be exposed to during sampling activities. Bacteria and other micro-organisms pose the greatest threat since stormwater is known to contain high concentrations of these organisms. Crews should protect themselves by using disposable rubber gloves when handling stormwater samples. Crews should also avoid hand to mouth and hand to eye contact until they have had a chance to wash with soap and water. Eating, drinking, and smoking will not be allowed until proper decontamination has occurred.

There is also the possibility of exposure to either wild or domestic animals. Crews should avoid these animals since they may carry rabies or other diseases and they are capable of infecting serious wounds.

B-8 EMERGENCY RESPONSE PROCEDURES AND LOCATION OF NEAREST HOSPITALS

In the event of an injury, illness, or accident that may require the attention of a physician, the SSO must be notified immediately. If a person(s) is transported to a medical facility, the location of this facility must be given to the SSO. In emergency situations field personnel should call **911** for an emergency response team. Describe the injury or illness and answer all questions. All [INSERT CONTRACTOR] employees and subcontractor personnel must be familiar with the location of and route to the hospitals listed below. Figure B-8.1 shows the location of the two hospitals.

Hospital: [INSERT LOCAL HOSPITAL(S) AND ADDRESS(ES)]

Hospital: [INSERT LOCAL HOSPITAL(S) FIGURE]

B-9 FORMS AND CHECKLISTS

EMPLOYEE ACKNOWLEDGMENT

(Please sign, detach and return to [INSERT CONTRACTOR] Project Manager by [INSERT DATE])

I hereby certify that I have read and understand the safety and health guidelines contained in [INSERT CLIENT] Stormwater Monitoring Project Health and Safety Plan.

Employee Name			
Signature			Date
In case of emergency, please contact: 1.			
Name	Relationship	Phone Number	
2.			
Name	Relationship	Phone Number	
Received by:			
Site Safety Officer			
Signature			Date

SAMPLE FORM HS200
CONFINED SPACE ENTRY PERMIT
(page 1 of 2)

Project Name/No.______________________________

____

Location of Confined Space:

____

Purpose of Entry and Description of Work:

____

____

Possible Hazards:

____

____

Names of Authorized Entrants:

____

____

____

Names of Eligible Attendants:

____

____

____

Individuals to be In Charge:

____

____

____

Rescue Service Information:

Responding Team:

____

Address:

____

Phone No.:

____

Hazard Control Measures (e.g. Ventilation) Complied? ______ (SSO must initial prior to entry)

____

____

____

List of Rescue Equipment Required on Site Complied? ______ (SSO must initial prior to entry)

____

____

____

Communication Procedures and Equipment Complied? ______ (SSO must initial prior to entry)

____

____

____

Personal Protective Equipment Required Complied? ______ (SSO must initial prior to entry)

____

____

____

Lockout/Tagout Procedures Required

Complied? ______ (SSO must initial prior to entry)

____

____

Comments/Additional Information

____

____

____

SAMPLE FORM HS200
CONFINED SPACE ENTRY PERMIT
(page 2 of 2)

Test	**Location**	Reading	Acceptable Range
Oxygen	________________	____________ %	19.5-22 %
Flammability	________________	____________ % LEL	Less than 10 %
Toxics (Specify)			
____________	________________	____________	____________
____________	________________	____________	____________
____________	________________	____________	____________
____________	________________	____________	____________

For continuous or periodic monitoring, record results in [INSERT CONTRACTOR] **Health and Safety report.**

Entry Date ______________________

Duration: **Start Time** ______________________ **End Time** ______________________

Is hot work to be performed? Yes __________ No

Individual in charge of entry approval:

________________________ ________________________ _

Name Signature Date/Time

The individual responsible for entry verifies that all actions and conditions have been met for safe entry into the described space.

Permit Cancellation

All work is completed and all entrants are exited from the permit space.

____ _

Signature of Individual in Charge Date/Time

SAMPLE FORM HS-100

[INSERT CONTRACTOR] HEALTH AND SAFETY INCIDENT REPORT

Project Name: ______________________

Project Number: ______________________

Date of Incident: ______________________

Time of Incident: ______________________

Location: ______________________

____

TYPE OF INCIDENT (Check all applicable items)

☐ Illness ☐ Fire, explosion, flash

☐ Injury ☐ Unexpected exposure

☐ Property Damage ☐ Vehicular Accident

☐ Health & Safety Infraction

☐ Other (describe) ______________________

DESCRIPTION OF INCIDENT (Describe what happened and possible cause. Identify individual involved, witnesses, and their affiliations; and describe emergency or corrective action taken. Attach additional sheets, drawings, or photographs as needed.)

____

____

____

____

____

____

____

____

Reporter: ______________________ ______________________ ______________________

Print Name Signature Date

Reporter must deliver this report to the Health & Safety Officer within 24 hours of the reported incident for medical treatment cases and within five days for other incidents.

Reviewed by: ______________________ ______________________

Operating Unit Health & Safety Officer Date

Distribution by HSO:

- Health and Safety Manager
- Health and Safety Officer (file)
- [INSERT CONTRACTOR] Project Manager
- Personnel Office (medical treatment cases only)

APPENDIX C
EXAMPLE STANDARD OPERATING PROCEDURES FOR FIELD SAMPLING

This appendix contains an example of a Standard Operating Procedure (SOP) developed for field sampling conducted for FHWA during the development of this manual. Due to the objective of this field work, duplicate sampling equipment was used at this site. Typically only one set of equipment for each function will be used at a site. This document is provided as an example SOP that could serve as a starting point for a site-specific SOP. Additional documents that should be developed prior to initiating field sampling may include:

- Health and Safety Plan
- Sampling Equipment Checklist
- Stormwater Station Maintenance Log
- Station Visit Checklist
- Field Data Log
- Work Permit for Confined Space
- Set-up/Shut-down Checklist
- Chain of Custody
- Rainfall Station Record

C-1 INTRODUCTION

C-1.1 GENERAL

This Monitoring Plan describes the approach, implementation schedule, and procedures that were used for monitoring stormwater discharges from highway runoff in Portland, Oregon. The monitoring location in Portland was selected by the project team for the Federal Highway Administration (FHWA) project titled *Evaluation of Water Quality Monitoring Equipment for Measurements of the Constituents of Highway Stormwater Runoff*.

C-1.2 SITE DESCRIPTION

C-1.2.1 Stormwater

The selected Northwest monitoring site is an Oregon Department of Transportation (ODOT) stormwater drain, located in Portland, Oregon. The sampling site is a stormwater drain pipe approximately 18 feet below ground, which is accessed through a manhole located in the Oregon Convention Center's exhibitor parking lot adjacent to an elevated section of Interstate 5 (I-5). The drainage area is approximately 23.1 acres and consists of approximately 0.96 miles of the I-5 corridor. The average daily traffic volume on this section of I-5 is approximately 100,000 cars. The drain pipe is a 36-inch concrete conduit, with a bottom slope of 0.017 feet at the monitoring point. Due to the fact that some perforated pipes drain into this system, the flow at this site may include some groundwater; however, groundwater flow is expected to be minimal because there is no observed base flow during dry weather.

C-1.2.2 Precipitation

Rainfall monitoring will be conducted on the rooftop of the three-story ODOT management building, which lies within a 1/2 mile of the stormwater monitoring site. Unlike the stormwater monitoring site that is situated below an elevated highway, the ODOT building offers an excellent location for precipitation monitoring. The roof of the building is flat and has no significant obstructions to interfere with the measurement of rainfall.

C-1.3 MONITORING OBJECTIVE

The objectives of the work performed at the Northwest monitoring site are as follows:

- evaluate the installation and operation of state-of-the-art water quality detection and sampling equipment for use in characterizing highway stormwater runoff quality;
- evaluate the operation and necessity of auxiliary equipment, such as rainfall instrumentation and flow measurement devices, with regards to monitoring stormwater quality;
- assess the effect of climatic and other physical conditions of the site on sampling equipment and sampling methods; and
- formulate recommendations for installation and adaptation of stormwater sampling equipment.

C-1.4 SCOPE OF WORK

Highway stormwater monitoring will be conducted at the Northwest site using previously selected equipment. The equipment will be installed at the site and modifications to the equipment will be made as necessary to conduct sampling and monitoring. The equipment performance and sampling methodologies will be qualitatively assessed during the sampling of three storm events. Additionally, consideration will be given to methods for collecting and shipping samples for analysis of constituents that require special handling.

C-1.5 EXPECTED RESULTS/INFORMATION

The monitoring conducted at the Northwest site will result in a constituent characterization of the site's highway runoff for three storm events. The flow weighted composite samples obtained from two automated samplers will be tested for the parameters listed in Section C-9. Individual bottles will also be analyzed for key parameters to provide insight on the "first flush" effect with regard to highway runoff. In addition to this water quality data, the *in situ* YSI 6000 meter will provide an almost continuous picture of the stormwater's dissolved oxygen, pH, turbidity, conductivity, temperature, salinity, and total dissolved solids. It is expected that the YSI meter will show how the values for these specific water quality parameters change over the duration of a storm event, which may indicate the variability of the parameters.

Data for this site's flow meters will also be obtained, which will aid in the comparison of the two flow monitoring units. Based on preliminary data received, this project expects that the ISCO flow monitor, using Manning's equation, will provide slightly more accurate results than the area velocity method employed by the American Sigma flow meter. This expected performance would not be verified during the field monitoring because the true flow in the drain pipe will not be known. It will be possible, however, to compare whether the two measurements display the same general relationships as in the USGS study (e.g., one method consistently records smaller peak flows).

The precipitation monitoring station will provide initial data for comparing the performance of the two rain gauges with respect to wind conditions. The optical rain gauge is expected to be more accurate than the tipping bucket under most wind conditions. This project will attempt to identify wind conditions that significantly affect the performance of the tipping bucket gauge.

Possibly the most useful information obtained from the monitoring of the Northwest site will be qualitative data obtained during monitoring. This information could include:

- problems encountered with equipment installation;
- reliability of equipment during operation;
- maintenance required to maintain equipment readiness;
- common problems encountered with storm monitoring; and
- an indication of the parameter variability in flow-weighted composite stormwater samples collected from side by side collection equipment.

This information will be essential in assessing the performance and practicality of the stormwater monitoring equipment tested in this project.

C-2 MONITORING STATION INSTALLATION AND REMOVAL

C-2.1 MONITORING EQUIPMENT

A listing of FHWA monitoring equipment that will be used or installed at the monitoring location is provided in Table 2-1.

TABLE 2-1
FHWA STORMWATER MONITORING EQUIPMENT

Equipment Manufacture	Description
AUTOMATED SAMPLERS	
ISCO	6700 Portable Samples Samplink Software w/Manual (2) Wall Battery Charger Lead Acid Battery (2) Rabid Transfer Device (RTD) RTD Power Cable Four Sets of 1.8 Liter Glass Bottles Low Flow Strainer Pump Tubing (5) Flowmeter/Interrogation Cable Equipment Platform Desiccant Bag
American Sigma	900 Max Portable Sampler Gel Battery (2) Charger Assy. 1.9 Liter Glass Bottles (32) Retainer for 8-Bottle Configuration Distributor Arm Assy. 100" Teflon Lined Tubing (3/8" ID) Low Flow Strainer Remote Pump w/Cables and Tubing Kit Streamlog II Software DTUI Assy. 4-20 mA Interface Multi-Purpose Cable Sampler - PC Cable 15" to 42" Mounting Band (2) Suspension Harness - Sampler Desiccant - Sampler Manual – Sampler
Norton Plastics	Norwell Teflon Lined Tubing, 250 ft.

TABLE 2-1
(Concluded)

Equipment Manufacturer	Description
FLOW METERS	
ISCO	Bubbler Flow Module Bubbler Line, 25' Bubbler Tube Extension Flow Data Book Manual - Flow Meter
American Sigma	950 AV Flow Meter Probe/Bubble Tube Cable Flow Meter - PC Cable Suspension Harness - Flow Meter Power Relay w/Cable Desiccant - Flow Meter Manual - Flow Meter
IN-SITU WATER QUALITY MONITOR	
YSI	600 Final Assy. 6030 Probe DO/Cond/Temp 6031 pH Probe Kit 6063 Cable, PC Interface 6035 Reconditioning Kit 6026 Turbidity Probe 6040 Maintenance Kit Carrying Case
DATA LOGGER	
Handar	Data Logger 555A 555 Software Universal Mounting Hardware Voice Modem Modem Assy. Internal Battery Cable Assy. Data Acquisition, Programming, and Software Manual Solar Panel Assy.
RAIN GAGES	
Scientific Technology, Inc.	Model: ORG-115-DA Optical Rain
American Sigma	Tipping Bucket Rain Gage
WIND SENSOR	
Handar	453 Wind Speed/Direction Sensor Cable Assy. 30'
ACCESSORIES	
Masterflex Pump	Low Voltage (DC) Motor 1/2 hp. Pump Head Adapter Short Shaft Pump Head Tubing size 82 (2)
Cargo Trailer	10'x4'x6' Enclosed Trailer
API-LIRCO	100 NTU Turbidity Standard
Dell Latitude XP Notebook Computer	100 MHz, DX4, 8MB RAM, 540 MB Hard

C-2.1.1 Rain Gauges

The station will be equipped with two different types of rain gauges: tipping bucket (American Sigma) and optical (Scientific Technologies, Inc.). The tipping bucket is a commonly used rain gauge that measures the rainfall volume in 0.01-inch increments. The optical rain gauge represents the cutting edge of precipitation gage technology. This gauge measures rainfall intensity (rate) and is typically used when high resolution and accuracy is required. A dedicated data logger will record data from these gauges at selected intervals (5 to 15 minutes).

C-2.1.2 Flow Monitoring Hardware/Software and Equipment Control

At the monitoring site, both flow meters (ISCO and American Sigma) will measure the depth of flow using bubbler technology. In the case of the ISCO sampler, the flow is calculated using the measured water depth and Manning's equation. In addition to measuring depth, the American Sigma 950-AV flow meter will also measure the peak velocity. The 950-AV computes the flow as the cross-sectional area multiplied by the average velocity. The cross-sectional area of water is obtained from the measured water depth and the geometry of the pipe. The average velocity is based on 90% of the peak velocity.

Each flow meter has site-specific software for hardware control. This software interfaces with the manufacturer's software installed on a laptop computer. This enables flow monitor operation to be programmed during a storm event and expedites data retrieval. Each flow monitor unit will be programmed to send a signal to activate the water quality sampler when a redefined cumulative volume of flow is exceeded.

C-2.1.3 Water Quality Samplers/Monitors

The monitoring station will be equipped with two automatic water quality samplers, an ISCO and American Sigma, each of which can be configured for either discrete or composite sampling. For stormwater monitoring, the samplers will be configured to fill sample bottles for composite sampling by collecting samples per calculated flow volumes.

The ISCO system consists of the 6700 Sampler with eight 1.9-liter glass bottles, distributor arm and bottle carrier/insert in a standard 19.875-inch wide base. Options included with the water quality sampler are a lead acid battery, a 120V AC battery charger, Teflon (3/8-inch ID) suction line and a low flow suction strainer.

The American Sigma 900 Max portable water quality sampler is equipped with a rain gauge input, a 3-channel data logger, and a remote pump receptacle. It will be assembled with eight 1.9-liter bottles, a bottle retainer and distributor arm. Options for this unit consist of a gel-cell battery and charger, Teflon (3/8-inch ID) suction line with low flow suction strainer, and a remote pump assembly.

One in situ water quality monitor (YSI 6000) will be used. The YSI 6000 is capable of continuously measuring, deriving, and logging dissolved oxygen, pH, turbidity, conductivity, temperature, salinity, and total dissolved solids data. The base unit (sonde) is equipped with various probes for monitoring specific parameters. Some of these sensors must be kept submerged in water at all times. A pump and reservoir system has been designed for the site to ensure that the probes are immersed in water even when no base flow at the site exists. After the storm event starts and flow enters the drain pipe, the pump is triggered and stormwater is pumped to a reservoir. The sonde will be immersed in the reservoir and will monitor the pumped stormwater.

C-2.2 INSTALLATION CONFIGURATION PLAN

The installation of equipment will occur at two sites, the Portland stormwater monitoring location and the roof of the ODOT management building. The installation plan for these two sites is described below.

C-2.2.1 Stormwater

The automatic water quality samplers (an ISCO 6700 portable sampler and an American Sigma 900 Max portable sampler) will be installed above ground in an equipment trailer. A 3/8-inch diameter Teflon suction line for each sampler will be installed in the stormwater drainage conduit. The ISCO flow module and American Sigma 950 AV Flow Meter will also be located in the trailer. The ISCO bubbler probe and Sigma velocity probe will be installed in a location that provides the most stable hydraulic conditions within the drainage pipe. Typically, the most ideal location is just upstream from the location of the manhole, because construction of the manhole may have altered the original shape of the pipe at this point, thus changing the hydraulic characteristics of the channel.

The sensor installation consists of mounting the depth and velocity sensors from the two flow units to expansion rings, which are sized and expanded in the pipe for a tight fit. The expansion ring facilitates easy removal of the sensors for maintenance or movement to another site. The water sampler intake tubing and strainer will be mounted at the invert of the pipe just downstream of the sensing equipment ring.

The YSI 6000 sonde will be inserted in a reservoir system that is mounted along with a small peristaltic pump to a platform that is suspended in the manhole access pipe. A peristaltic pump will supply stormwater via a ½-inch diameter Teflon tube to the inner reservoir where the water quality parameters will be measured by the YSI 6000 sonde. Based on the pump size (approximately 1.5 gpm) the residence time of the inner reservoir will be around 30 seconds. The inner reservoir will be allowed to overflow into the outer reservoir, which will drain back via a ¾-inch hose to the stormwater drain. The intake tubing for the pump will be mounted in the storm drain conduit with the water sampler intakes. The pump supplying water to the YSI meter will be activated, when flows are sufficient, by a relay switch located in the American Sigma flow meter. Four deep cycle marine batteries contained in the equipment trailer will supply power for this pump.

C-2.2.2 Precipitation

The precipitation gauges and wind sensor will be mounted to a plywood base using 1-inch water pipe. An equipment enclosure housing the Handar 555 data logger will also be mounted to the platform. This data logger unit will be wired and set-up to receive input from both rain gauges and the wind sensor. The entire rain and wind monitoring station will be anchored to the roof of the ODOT management building.

C-2.3 EQUIPMENT CALIBRATION

Calculation of flow in the closed conduit is based either on the depth of flow, or the depth and velocity of flow. To verify sensor readings both depth and velocity of flow are tested upon installation by means independent of the flow sensor. Depth measurements are verified with a scaled wading rod or similar device. In order to verify and adjust the velocity sensor, concurrent measurements are taken with a hand-held electromagnetic velocity meter.

The YSI meter will be calibrated against standards provided with the sensors. The reservoir that will provide the measurement point for the unit will be filled with water and installed in the reservoir after the unit is calibrated.

During installation of the rain monitoring station, the tipping bucket gauge will be calibrated to tip after 0.01 inch of water has accumulated in the tipper cup. The gauge will be adjusted using a graduated cylinder to measure and pour the exact water amount necessary into the gauge to initiate a tip. Both sides of the tipping cup will be calibrated in this manner.

C-3 STORMWATER SAMPLING PERSONNEL

Stormwater sampling personnel have been organized in a linear manner to form a chain of command. The links in this chain consist of: 1) Task Manager; 2) Storm Event Coordinator; and 3) Field Team members, which include a Team Leader and an Assistant. Figure 3-1 shows the overall organization of the stormwater personnel. The responsibilities for each of these positions are given below.

C-3.1 PERSONNEL ORGANIZATION AND RESPONSIBILITIES

Task Manager. The Task Manager finalizes decisions regarding storm selection and allocation of personnel resources and has overall responsibility for all stormwater sampling.

Storm Event Coordinator. The Storm Event Coordinator is responsible for programming and operating the flow monitoring equipment, tracking and directing Field Team activity, and coordinating with the laboratory. The Storm Event Coordinator must be available to answer technical questions from the field crew during an event and must ensure that field crews have all of the necessary equipment.

Field Team Leader. The Field Team Leader is responsible for station set up, sample collection (grab and composite), station shut-down, transporting the samples to the laboratory, and completing all applicable documentation (logs, checklists, etc.). They are to be assisted by the Field Team Assistant.

Field Team Assistant. The Field Team Assistant provides support to the Field Team Leader.

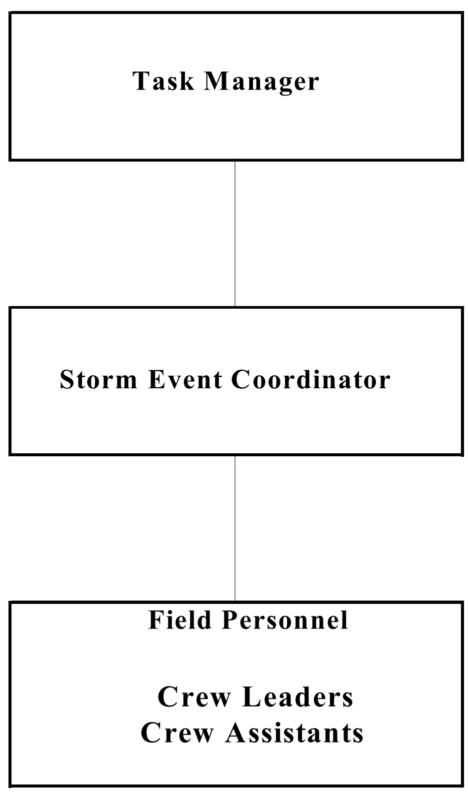
C-3.2 GENERAL FIELD TEAM RESPONSIBILITIES

Field teams are responsible for the following tasks:

- field equipment and sample bottle organization;
- sampling station set up;
- basic equipment maintenance;
- sampler programming and operation;
- field measurement of water quality parameters;
- grab sample collection;
- composite sample collection;

- bottle replacement (when necessary);
- record keeping and field notes;
- field Quality Assurance and Quality Control; and
- sample labeling and transfer to the analytical laboratory

FIGURE 3-1
PORTLAND I-5 SITE, STORMWATER MONITORING
PERSONNEL ORGANIZATION



Listed below are some general procedures that must be followed when working on this project. Additional details on each of these procedures are located elsewhere in this manual.

1. All field personnel must wear hard hats, traffic vests, and steel-toed boots when outside the vehicle.

2. Traffic control must be set up before conducting any work at a sampling site where personnel are exposed to traffic. Standard traffic control measures include parking vehicles to shield personnel from traffic and using hazard lights.

3. All manholes must be checked with a 4-gas meter (oxygen, methane, carbon monoxide, and hydrogen sulfide) before opening and while working within manholes.

4. Manhole covers and samplers containing full bottles can be very heavy. Personnel must be careful when lifting to avoid injury and spilled samples (i.e., keep back straight and lift with legs).

5. Station logs, data sheets, and checklists must be completed prior to leaving the sites.

6. All electronic equipment should be kept as dry as possible.

7. The person who is assigned to be the field leader will be responsible for answering the phone and making phone calls. Therefore, the assistant should be responsible for all of the driving.

8. All field personnel will comply with the Health and Safety Plan for the FHWA project.

This manual contains instructions for operating equipment used in the FHWA Stormwater Program. It is the responsibility of URS to update this manual as changes are made in the equipment or standard operating procedures.

C-4 PRE-STORM MOBILIZATION

This section describes the chain of events that must take place prior to water quality sampling of a storm event at the Portland stormwater monitoring site. An objective of the FHWA project is to monitor three storm events within a two-month period at each of the four monitoring locations. Criteria for selecting storm events that will be monitored are provided in this section along with a method for forecasting the runoff produced by the storm.

C-4.1 STORM SELECTION

Frequency and timing of sample collection depends upon how the data will be used. This project has two unique objectives: to learn more about the nature of highway stormwater runoff, and to assess various monitoring equipment technologies. Because of these objectives and the short monitoring period (two months), the period between monitored storm events will be shorter than would normally be used in a long-term stormwater monitoring project.

Storms will be considered for sampling if they are forecast with a 70% or greater confidence by the National Weather Service in Portland to produce a minimum of 0.30 inches of rain in an 8- to 24-hour period. Further, the storm must have been preceded by a 24-hour dry period of 0.1 inch of rain or less.

Weather conditions will be monitored daily by the Storm Event Coordinator. If a forecast suggests that a storm satisfies the selection criteria, the Storm Coordinator will recommend to the Task Manager that the field team be mobilized for station set-up and monitoring. The Task Manager will decide based upon the size, certainty, and timing of the storm whether monitoring of the event will be conducted.

It is the intent of this project to monitor three storms at the Portland site that meet the criteria listed above. However, due to the short time frame for monitoring at the site these criteria may be adjusted if weather conditions dictate, in order to reach the overall goal of monitoring three storm events.

C-4.2 RUNOFF ESTIMATION

Runoff volume estimation is necessary before monitoring to program the sampling equipment to collect representative flow-weighted composite samples. The runoff volume for the catchment is determined from the predicted rainfall amount, watershed area, and the runoff coefficient. The runoff coefficient is defined as the fraction of the total rainfall volume (the amount of rainfall over the watershed area) that becomes stormwater runoff. In general, runoff coefficients are approximately equal to the percent impervious area. The runoff coefficient used for the Portland site is 0.2.

The Storm Event Coordinator will estimate the storm's runoff volume, which will be used in programming the water quality samplers. The Field Crew will program the samplers to collect a sample after each time approximately 5% of the runoff volume has passed by the sensors. Therefore, the water quality sampler is programmed to collect about 20 samples over the entire storm. Each time the sampler is triggered to collect a sample a pre-specified volume of stormwater will be deposited into one of the bottles. If the storm is larger than expected, full bottles in the samplers may need to be replaced with empty bottles.

C-4.3 FIELD TEAM PREPARATION

Mobilization of the Field Team will be made as soon as possible after a storm is selected for monitoring. The Field Team will assemble at the URS warehouse and assemble the necessary equipment for monitoring.

Each Field Team Leader must complete the **Sampling Equipment Checklist** before leaving the warehouse. This check confirms that all equipment is available and in proper working order. Only a calibrated gas meter may be used. The calibration procedure for the meter is located in the warehouse.

Prior to arriving at the station, the Field Teams must purchase ice. One standard 5-pound bag (available at convenience markets) is required for each sampler. Two additional bags will be required for the grab sample coolers.

The storm coordinator is responsible for making sure that all of the necessary bottles are available prior to the event. This may involve contacting the analytical laboratory and making arrangements for bottle delivery to the URS warehouse.

C-5 STATION SET UP & OPERATION

C-5.1 COMPOSITE SAMPLER / FLOW METER SET UP

C-5.1.1 Accessing Samplers

The composite samplers must be accessed whenever the bottles are loaded or removed and whenever the sampler is programmed. The samplers are stored in the locked trailer next to the manhole. Access is gained by unlocking a padlock and opening the rear door of the trailer. The samplers do not need to be removed from the enclosure to perform the sampling activities. The trailer houses the ISCO 6700 Portable Sampler, American Sigma 900 Max Portable Sampler, and the American Sigma AV-950 area velocity flow meter.

C-5.1.2 Sampler Inspection

Once the samplers have been accessed, they should be inspected for typical problems and programmed for sampling. The Storm Event Coordinator is responsible for scheduling the field work such that the field crews can visit each site two to six hours before the storm event. Field crews are responsible for completing the **Stormwater Station Maintenance Log** for each sampler and performing basic maintenance, if necessary. The steps involved in the inspection process include:

1. Gaining access to sampler as described in Section C-5.1.1.

2. Checking the intake tubing for kinks or twists and clamps for tightness and condition.

3. Checking all electrical connections for tightness.

4. Inspecting the sampler humidity indicator located on the control panel.

5. Checking the pump tubing for cracks and working out any pinches or replacing the tubing.

6. Performing any required basic maintenance and completing the **Stormwater Station Maintenance Log**.

C-5.1.3 Sampler Bottle Loading/Replacement

Although loading bottles into the sampler is relatively simple, it is crucial that no mistakes are made. To avoid mistakes, field crews must strictly adhere to the **Station Visit Checklist**. The steps involved in loading (or replacing) composite sampler bottles are as follows:

1. Gain access to sampler and perform maintenance check.

2. If replacing bottles, obtain clearance from Storm Event Coordinator before halting sampler program or removing any bottles from the sampler.

3. Remove sampler control section from base section by releasing the three latches on the sampler body and lifting upward using the handles. Set this assembly aside, being careful not to twist or entangle the intake tubing and electrical cables.

4. Place eight clean 1.9 liter glass sample bottles w/lids (lids will be removed later) in base, being careful to align the middle of the first bottle with the first bottle indicator on the inside of the sampler base.

5. Attach the retainer assembly to secure the bottles.

6. Fill the base with crushed ice, one 5-pound bag.

7. Remove sample bottle lids as the sampler control section is replaced. It is suggested that one person hold the control section a few inches over the base section while another person reaches into the base and removes each of the lids. The person removing lids should have clean nitrile gloves to minimize contamination of clean sample bottles.

8. Put bottle lids in a clean zip-loc bag. Place the zip-loc bag on top of the crushed ice in the center of the sampler base. Be sure that the zip-loc bag does not interfere with the sampler distributor arm or obstruct the bottle openings.

9. Latch control section to base section.

10. Complete the applicable sections of the **Station Visit Checklist**. If making a bottle replacement, complete the applicable sections of the **Field Data Log**.

C-5.1.4 Sampler Programming and Operation

Both the ISCO and the American Sigma samplers are programmed to collect 24 - 600 ml samples and deliver them to 8 - 1900 ml bottles. Each bottle receives three consecutive samples before the sampler begins to fill the next bottle. The ISCO sampler receives its triggers on a flow-weighted basis from a calculation the sampler unit performs. The ISCO sampler is equipped with a bubbler flow module that measures depth of flow in the pipe, which allows the sampler to calculate the flow rate using Manning's equation. The American Sigma sampler receives its flow-weighted triggers from a 950-AV (area-velocity controller), which is a separate unit housed in the trailer. The 950-AV uses depth of flow, velocity, and pipe geometry to calculate a flow rate in the pipe.

The samplers and 950-AV must be properly calibrated and programmed in order to successfully collect a full set of composite stormwater samples. Field Teams will be responsible for checking the sampler's calibration, reviewing program parameters, and making sure that the program is running each time a sampler is visited.

C-5.2 CONTINUOUS WATER QUALITY MONITOR SET UP

C-5.2.1 Accessing the YSI System

Between monitored storm events, the YSI sonde and four 6-volt deep cycle marine batteries that provide 12 volts of power for the pump that supplies water to the YSI sonde reservoir are stored in the trailer (the YSI sonde should be stored in its protective case). Both the trailer and the manhole will need to be accessed to set up the YSI sonde for operation. Prior to accessing the manhole, field crews must complete a **Work Permit for Confined Space**.

C-5.2.2 YSI System Inspection

After gaining access to the trailer and the manhole, several YSI system components need to be inspected prior to calibrating the meter and installing it in the manhole. Field crews should conduct the following:

1. Install in the trailer the four, charged pump batteries. Connect the power leads for the YSI pump to the batteries.

2. Visually inspect the pump wiring in the trailer for cuts.

3. From above ground, use a flashlight to visually inspect the reservoir system, pump, tubing, and electrical wiring for the YSI system components mounted in the manhole.

4. Remove the YSI sonde from the storage case, remove the meter's calibration storage cup and inspect the probes for visual damage. Ensure the membrane over the dissolved oxygen probe is free of tears.

5. Complete the **Stormwater Station Maintenance Log**.

C-5.2.3 YSI Sonde Calibration and Operation

The YSI sonde is equipped with three probes to measure conductivity, pH, turbidity, and dissolved oxygen. It is necessary to calibrate the meter for all of these measurements prior to sampling a storm event. To calibrate the meter, follow the general steps outlined below.

1. After accessing and inspecting the YSI sonde, remove the waterproof cap from the sonde connector and connect the PC interface cable. Connect the DB-9 end of the cable to a serial port on the laptop computer.

2. Remove and retain the two allen screws at the very bottom of the sonde guard. Remove the bottom plate of the sonde guard (not the entire guard). This allows the calibration solutions access to the probes with minimal displacement of fluid within the calibration cup. Additionally, carry-over from one solution to the next is reduced.

3. Have 2 liters of fresh tap water readily accessible for rinsing the sonde between calibration solutions, 500 ml each of pH 4 and pH 10 calibration solution, 500 ml of conductivity standard, 500 ml of turbidity standard, and a separate liter of fresh tap water for calibration.

4. Conduct sonde calibration according to the manufacture's instructions.

After calibration of the meter is complete, place the sonde in unattended run mode. Install the sonde in the manhole as follows:

1. Disconnect the laptop computer from the sonde and reinstall the sonde guard that was removed in item 2 above.

2. Ensure the sonde reservoir (mounted on the platform in the manhole) is filled with water prior to installing the sonde in the manhole. It is essential to keep the probes on the sonde wet. If the reservoir is empty, it can be filled from above using the PVC pipe and funnel located in the trailer. **Do not climb down into the manhole to fill the reservoir.** Once there is flow in the pipe, the pump is energized via a relay in the AV-950 flow meter to pump stormwater into the reservoir.

3. Lower the sonde in to the manhole. Use the 25-foot PC interface cable connected during calibration and lower the meter down into the reservoir located on the platform in the manhole. Tie off the PC interface cable near the top of the manhole and reinstall the manhole cover.

4. Complete the applicable sections of the **Station Visit Checklist.**

The YSI meter should now be in operation. It will not begin to record parameter measurements for stormwater until there is water in the pipe and the pump changes out the water in the reservoir.

C-6 STORMWATER SAMPLE COLLECTION

C-6.1 AUTOMATED SAMPLERS

After calibrating and placing the ISCO and American Sigma samplers in run mode, both units will collect samples from the stormwater drain automatically when the pre-defined trigger volume is exceeded. Provided there is sufficient flow in the drain pipe and the samplers do not malfunction, each sampler should collect and distribute a total of 24 - 600 ml samples among the eight 1.9 liter sample bottles contained in the base of the sampler. Bottle one in the sampler will be filled with the first three 600-ml samples collected (samples 1, 2, and 3). Bottle two will be filled with the next three 600-ml samples (samples 4, 5, and 6). The remaining six bottles will be filled following the same sequence. If the storm is short or if there are mechanical problems with the sampler, some bottles may not be filled.

C-6.2 GRAB SAMPLING

Grab samples will be collected for the analysis of oil and grease and petroleum hydrocarbons. The collection of grab samples is necessary for assessing the presence of oil and grease because these constituents float on the surface of the water. The amount of oil and grease in the stormwater would be underestimated if the samples collected by the automated samplers were used for analysis because the automated samplers collect samples near the invert of the drain pipe.

C-6.2.1 Grab Sample Collection

Grab samples will be collected directly into a large-mouth 1-liter amber sample bottle. Two 1-liter samples will be collected approximately one hour after the start of the storm event. Follow the general procedures for sample collection outlined below:

1. Insert the sample bottle into the protective grab sample harness and remove the bottle lid.

2. Connect a rope to the sample harness and lower the harness and bottle into the pipe/channel to collect the stormwater from mid-channel at mid-depth.

3. Collect both 1-liter samples in this manner and complete applicable sections of the **Field Data Log.**

C-7 QUALITY ASSURANCE CONTROL

The measurement of chemical constituents at the trace level is often difficult due to inherent properties of environmental samples, field sampling techniques, and analysis techniques. In order to assess and maximize data quality, a strict Quality Assurance and Quality Control (QA/QC) Plan will be implemented as an integral part of the monitoring program. The QA/QC program is designed to enable an evaluation and validation of the analytical data for representativeness, accuracy, and precision. The following text includes separate descriptions for the field and laboratory portions of the QA/QC program.

C-7.1 FIELD QA/QC PROCEDURES

Field QA/QC samples will be collected for one storm event to be determined by the Storm Event Coordinator. QA/QC samples require special labeling and tracking procedures. All duplicate samples will be treated as "blind field" duplicates, which are given a fictitious station identification and collection time. Therefore, it is very important to record the true duplicate station location and collection time on the **Field Data Log**. All equipment blanks will be labeled as "equipment blanks." The specific field procedures for conducting these tests are presented as follows.

Equipment Blanks - Composite sampler equipment blanks will be obtained by letting the sampler fill a complete set of bottles with clean de-ionized (DI) water. One set of blanks will be collected for each sampler during one storm event. Equipment blanks will be collected during set up, prior to the beginning of the storm event. This process is detailed below:

1. Access the sampler, complete inspection, and check calibration.
2. Detach the intake tubing from the sampler and attach a short piece of new or de-contaminated Teflon-lined tubing to the pump tubing and rinse the system for at least 15 seconds with DI water using the sampler pump.
3. Load the sampler with sample bottles.
4. Fill each sample bottle with DI water by pressing "pump sample" 3 times. Move to the next bottle by pressing "bottle advance." Label sample bottles as "equipment blanks."

Duplicates - Grab sample duplicates will require one of the Field Teams to fill an additional set of grab sample bottles during one storm event for QA/QC. These bottles will be labeled with a fictitious site identification and/or time. Record true location and/or times in the **Field Data Log**. This duplicate sample will be analyzed to assess sampling and analytic precision.

C-7.2 LABORATORY QA/QC

The laboratory contracted will perform all chemical analyses requested. In addition to performing the analysis, the laboratory will make every effort to meet holding times and target detection limits for each analysis. The following laboratory QA/QC procedures will be followed for the sampling program.

Standards - Calibration standards with known concentrations will be prepared and used in the laboratory to obtain instrument calibration curves in accordance with the provisions of the various method specifications.

Method Blanks - Analyte-free water will be processed through all sample preparation procedures and analyzed as a method blank. One such method blank will be analyzed per storm event. This will provide an indication as to whether contamination is occurring as a result of laboratory procedures.

Replicates - The laboratory will perform replicate sample analysis twice for each sampler. The Storm Coordinator will determine the analysis sequence. The intention will be to have a replicate analyzed from each of four sampling sites designated in Task B of the project. Replicate samples are two aliquots taken from the same sample container and analyzed independently. After compositing at the analytical lab, the total sample volume will be divided equally in half and each half will be analyzed separately. Because the laboratory must composite the samples before dividing, this is not a blind replicate.

Matrix Spike - For metals analysis, the laboratory will perform a matrix spike to provide a measure of accuracy for the method used in a given matrix. A matrix spike analysis is performed by adding a predetermined quantity of stock solutions of certain analytes to a sample matrix prior to sample extraction/digestion and analysis.

C-7.3 DATA REDUCTION, VALIDATION, AND REPORTING

Results of precision and contamination checks (described above) will be reviewed by a chemist after each storm event. Summary results of the QA/QC program will be included in the storm reports (see Section C-11). In the event that data quality objectives are not met, data will be qualified as necessary in the final data report.

C-8 POST STORM PROCEDURES

C-8.1 STATION SHUT DOWN

When the Storm Event Coordinator makes the final determination that storm sampling is complete, Field Team(s) will perform station shut-down and other post-storm procedures. The station shut-down procedures include the following tasks:

1. Remove and label sample bottles from the samplers. These samples will be grouped with the rest of the composite bottles and taken to the analytical laboratory for analysis.

2. Record the number and timing of samples taken by the sampler on a **Field Data Log**.

3. Download all storm data to the lap top computer following the data retrieval instruction for the YSI Sonde, the ISCO sampler and American Sampler, and flow meter.

4. Remove the PC data cable and properly stow the sonde in its calibration cup and protective case after retrieving the data from the YSI sonde.

5. Remove the batteries from the samplers and the trailer. Transport the batteries to the warehouse and set-up for charging.

6. Complete the shut-down section of the **Set-up/Shut-down Checklist**.

7. Organize all **completed** field sheets and checklists and transfer them to the Storm Event Coordinator. Teams will be required to submit the following items:

    a. Sampling Equipment Checklist

    b. Work Permit for Confined Spaces (manhole stations only)

    c. Stormwater Station Maintenance Logs

    d. Station Visit Checklist

    e. Field Data Logs

    f. Chain of Custody Forms

C-8.2 TRANSPORTING SAMPLES TO ANALYTIC FACILITY

Field Team Leaders are responsible for the labeling and transfer of samples from the field stations to the analytical laboratory. The bottles must be securely packed with blue ice in coolers for shipment to the lab facility. The transfer process involves the completion of **Chain of Custody** sheets.

C-8.2.1 Sample Labeling

Sample labels must be filled out completely. The following information should be entered on every label:

1. Date and time collected (24-hour clock using Pacific Standard Time).

2. Station identification (I01 for ISCO & S01 for Sigma).

3. Total number of sample bottles for each analysis and the number of each container (e.g., 1/ 8, 2/ 8, etc.).

4. Initials of Field Team.

Note: The sample information should be written on the label before applying it to the bottle. Also, the bottle should be dried with a paper towel before applying the label.

C-8.2.2 Chain of Custody

The **Chain of Custody** sheets track the sample containers and specify how the sample is to be analyzed. Field crews will use a Chain of Custody form provided by the analytical laboratory to record the necessary information. The analytical laboratory will not accept any samples without a completed Chain of Custody form.

The following organizational scheme has been developed to minimize confusion during the sample Chain of Custody process:

1. Each Field Team Leader will check the bottle labels and assemble all samples in an orderly manner.

2. Each Field Team Leader will complete the Chain of Custody forms.

3. The Field Team Leaders and/or Storm Event Coordinator will then ship via Federal Express each set of sample bottles in a cooler with the appropriate Chain of Custody Form to General Testing at 710 Exchange Street, Rochester, NY 14608.

C-9 CHEMICAL ANALYSIS AND METHODS

This section of the monitoring plan provides a general description of parameters to be analyzed in stormwater samples and the methods used by the lab for the analysis.

C-9.1 GENERAL BOTTLE ANALYSIS

The laboratory will perform testing on three different sample types: individual bottle samples, grab samples, and composite samples.

Individual bottle analysis consists of drawing a sample from each of the eight bottles for both samplers and analyzing that sample for a select group of parameters commonly found in highway runoff. This analysis will provide information on how constituent concentrations change over the course of the storm event.

The water remaining in eight bottles from the ISCO sampler will then be composited in a glass container, and the water remaining in eight bottles from the American Sigma sampler will be composited in a separate container. The composite samples for each sampler will be analyzed for a set of parameters that are more extensive than the analysis performed on the individual bottles. This analysis will provide the study with a storm average of parameter concentrations.

The collected grab samples will be analyzed for oil and grease (O&G) and total petroleum hydrocarbons (TPH). O&G represents a broad group of pollutants including animal fats and petroleum products. TPH is the subset of O&G that represents the non-polar hydrocarbons from petroleum products (e.g., gas and engine oil for automobiles).

C-9.1.1 Parameters and Methods for Analysis

Table 9-1 provides a list of the parameters to be analyzed for each sample type along with USEPA analysis method used, the target detection limit, cost to perform the analysis, and the maximum holding time for the parameter. The total laboratory costs for monitoring the three storm events in Portland is estimated in Table 9.1 to be $3,500. This includes costs for QA/QC, shipping, and bottle cleaning.

TABLE 9-1
PARAMETER ANALYSIS LIST FOR PORTLAND FHWA MONITORING

PARAMETER	USEPA METHOD NUMBER	TARGET DETECTION LIMIT	UNIT PRICE	Holding Times
COMPOSITED SAMPLE ANALYSIS				
TSS	160.2	4 ppm	9.00	7 days
Hardness	130.2	1 ppm	11.70	6 months
Phosphorus, Total	365.1	0.05 ppm	13.50	28 days
Kjeldahl Nitrogen, Total	351.2	0.1 ppm	18.00	28 days
Nitrate + Nitrite	353.2	0.05 ppm	31.50	48 hours
Ammonia	350.1	0.1 ppm	9.00	28 days
Cadmium (total & dissolved)	213.2	0.2 ppb	36.00	6 months
Cooper (total & dissolved)	220.2	1.0 ppb	12.60	6 months
Lead (total & dissolved)	239.2	0.2 ppb	36.00	6 months
Zinc (total & dissolved)	289.2	1.0 ppb	12.60	6 months
	Unit Cost per Sample per Event Extended Cost per Event Cost per Site (3 events)		189.90 379.80 1139.40	
GRAB SAMPLES				
Oil & Grease	413.2	0.5 ppm	36.00	7 days
TPH	418.1	0.5 ppm	36.00	7 days
	Cost per Event Cost per Site		72.00 216.00	
INDIVIDUAL BOTTLE ANALYSIS				
TSS	160.2	4 ppm	9.00	7 days
Copper	220.2	1.0 ppb	12.60	6 months
	Cost per Bottle Cost per Event (16 bottles) Cost per Site (3 events)		21.60 345.60 1036.80	

Total Costs for Sampling at a Site	
QA/QC	$500
Shipping	$500
Cleaning 6 sets of Bottles	$150
Individual Bottle Analysis	$1,037
Grab Samples Analysis	$216
Composite Sample Analysis	$1,139
Total Laboratory Costs	$3,542

C-9.2 GENERAL DESCRIPTION OF PARAMETERS

Total Suspended Solids (TSS) - Rivers and streams in their natural state carry sediment loads. The conditions under which suspended solids are considered a pollutant are a matter of definition. In general, suspended solids are considered a pollutant when they significantly exceed natural concentrations and have a detrimental effect on water quality and/or beneficial uses of the water body. Portions of the suspended solids will settle out of the water column depending on the size of the particle and the velocity of the water. These settled solids can blanket the bottom of water bodies and damage invertebrate populations; cover gravel spawning beds; clog the gill structures of young trout and salmon; change the pattern of the channel; and in some cases lead to the reduction of channel capacity. Suspended sediments may also result in stress to fish by causing alterations in behavior and movement patterns because fish will often avoid turbid areas. Sediment that remains suspended in the water column diminishes light penetration into the water body, reducing the depth of the zone where primary production occurs and hence reducing the amount of food available for fish. Suspended sediments near the surface can also cause an increase in water temperature because they have a greater tendency to absorb heat, they scatter light (as measured by turbidity), and they reduce water clarity. Both suspended and settled solids are also of concern because they are associated with toxins (toxic metals and organics tend to sorb onto particulate matter).

In addition to natural erosion, sources of sediment can include runoff from construction sites, agricultural activities, logging activities, and any other operations where the ground surface is disturbed. Increased flows resulting from development are also responsible for erosion in excess of natural background levels.

Hardness - Hardness is a measure of specific types of ions that are dissolved in water. In fresh water it is usually defined as the sum of the calcium and magnesium concentrations. It is important in stormwater because the biological availability, and therefore toxicity, of some metals is directly related to the hardness of the water. For example, the freshwater acute and chronic criteria for cadmium, chromium, copper, lead, nickel, silver, and zinc are hardness-dependent. When hardness values are relatively low, the bioavailability of these metals is relatively high.

Phosphorus - Phosphorus is used as a nutrient by algae and higher aquatic plants, and excess may be stored for use within plant cells. With decomposition of plant cells, some phosphorus may be released immediately through bacterial actions for recycling within the biotic community, while the remainder may be deposited with sediments.

Three forms of phosphorus have been somewhat routinely analyzed in stormwater runoff water quality studies. These include total phosphorus, soluble phosphorus, and orthophosphate. Orthophosphate represents the inorganic phosphorus that is most immediately biologically available. Soluble phosphorus includes orthophosphate and a fraction of the organic phosphorus. The majority of soluble phosphorous is usually orthophosphate. Total phosphorus includes other forms of phosphorous that may not be as readily biologically available, in addition to the orthophosphate and soluble phosphorus. Total phosphorus and orthophosphate are generally recommended for inclusion in stormwater monitoring programs, however, due to the short holding time for orthophosphate (48 hours) this project has elected not to analyze for this parameter.

Nitrogen (Total Kjeldahl Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen) - Nitrogen is used as a nutrient by algae and higher aquatic plants, and excess may be stored for use within plant cells. With decomposition of plant cells, some nitrogen may be released immediately through bacterial action for recycling within the biotic community, while the remainder may be deposited with sediments.

Nonpoint sources of nitrogen include fertilizers, municipal/industrial wastewater, septic tanks, leachate from waste disposal in dumps or sanitary landfills, atmospheric fallout, nitrite discharges from automobile exhausts and other combustion processes, natural sources such as mineralization of soil organic matter, and farm-site fertilizers and animal wastes.

Three forms of nitrogen have been analyzed extensively in stormwater runoff water quality studies. These are nitrite plus nitrate ($NO_2 + NO_3$), ammonia nitrogen (NH_3), and total Kjeldahl nitrogen (TKN). The latter, named after the analytical test procedure, provides a measure of ammonia and organic nitrogen forms that are present. The first ($NO_2 + NO_3$) provides a measure of the inorganic nitrogen. There is usually very little nitrite in stormwater. Nitrate (NO_3) is very mobile and is usually difficult to treat utilizing stormwater BMPs. Ammonia nitrogen can be toxic to aquatic life depending on the pH and temperature of the receiving water. These three forms of nitrogen are important to characterize nitrogen forms in stormwater and for conducting receiving water assessments.

Total and Dissolved Metals (Cadmium, Copper, Lead, Zinc) - Heavy metals may be washed into streams (via stormwater runoff) or they may be naturally released in small quantities by the weathering of rock. Sources of metals in stormwater runoff include combustion of fossil fuels, disposal of car batteries, tires (cadmium and zinc), brake pads (copper), metal recyclers, metal corrosion, pigments for paints, solder, fungicides, pesticides, herbicides, and wood preservatives.

When metals are released into the environment in larger than “natural” or background concentrations, they can be highly toxic to freshwater aquatic species.

Information regarding the percentage of metals in the dissolved and particulate phases is useful for selecting control measures. For example, control measures designed to remove particulates from flows will not be effective at removing metals if a large portion of the metals are in the dissolved phase (or if they are sorbed to particulates that are so small that it is difficult to remove them by settling).

Heavy metals tend to have relatively low solubilities. However, they are often found in the water column as they form soluble complexes with humid materials or as they become attached to suspended particles. Heavy metals have been identified consistently as the most significant toxics found in urban stormwater and often exceed water quality criteria for aquatic life.

Stormwater quality studies conducted at many urban locations have indicated that cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) are almost always present, and are at concentrations that tend to be elevated relative to other heavy metals. They can also be used as surrogates for other heavy metals, as they tend to display the range of transport characteristics for heavy metals. However, other heavy metals should be analyzed if there are known sources of significant quantities of these metals in influent flows to the storm system.

Oil & Grease and Total Petroleum Hydrocarbons (TPH) - Oil and grease represents a broad group of pollutants including animal fats and petroleum products. Accurately measuring oil and grease is very difficult due to its affinity for coating sampling bottles and sampling tubes, and its highly non-uniform distribution in the water column (except in the most turbulent and well mixed conditions). With the proper sampling techniques and preservatives, total oil and grease can be measured. However, other tests provide more insight regarding the sources of oil and grease, including total petroleum hydrocarbons (TPH) and polar oil and grease. TPH is the subset of oil and grease that represents the non-polar hydrocarbons from petroleum products (e.g., gas and engine oil for automobiles). Polar oil and grease is the subset of oil and grease that represents polar hydrocarbons from natural organics such as animal by-products (e.g., animal and vegetable fats in refuse from restaurants). If completed, the TPH evaluation is the most appropriate measure of human induced sources of petroleum oil and greases.

C-10 RAINFALL STATION OPERATION

This section provides the general set-up and data retrieval guidelines for the rainfall and wind monitoring equipment.

C-10.1 STATION SET UP

The rainfall monitoring station consists of the tipping bucket and optical rain gauges, a wind speed and wind direction sensor, and a data logger with a solar panel power supply. Field Crews will install the gauge on top of the ODOT building, as described in Section C-2. Rain and wind monitoring will be initiated upon station set up and will continue until stormwater monitoring is completed at the Portland site. Instruction for wiring and operating the Handar 555 data logger will be provided.

Field crews must visit the monitoring station weekly to download the data collected by data logger. Whenever the site is visited and the data logger is accessed the Field crew must complete the **Rainfall Station Record**. The field team leader will provide this form to the storm coordinator after each visit to the site.

C-11 DATA REPORTING

All data collected as part of this monitoring study should be stored in electronic format for easy retrieval, data interpretation, and graphing. Data collected as part of the sampling program should include rainfall data, runoff volumes, runoff coefficients, field analytical data, laboratory analytical data, and QA/QC results.

Following each sampling event, a storm report should be prepared that summarizes the results of the sampling. This report should include the date of the storm, the antecedent dry period, the total rainfall, a description of the storm, and a description of the equipment operation. Hydrographs and trigger times and analytical data for each sampler should be included. The storm reports will provide a basis for summarizing the project results at the completion of monitoring.