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Urban Stormwater
BMP Performance Monitoring

A Guidance Manual for Meeting the National
Stormwater BMP Database Requirements

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Prepared by

GeoSyntec Consultants
Urban Drainage and Flood Control District

and

Urban Water Resources Research Council (UWRRC) of ASCE

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TABLE OF CONTENTS

List of Tables viii
List of Figures x
Acknowledgements and Disclaimer xi

1 INTRODUCTION 1
- 1.1 Scope 1
  - 1.1.1 State of the Practice 2
  - 1.1.2 The Need for Guidance 2
  - 1.1.3 National Stormwater Best Management Practices Database 2
- 1.2 Format and Content of This Document 2

2 BMP MONITORING OVERVIEW 4
- 2.1 Context of BMP Monitoring in the Regulatory Environment 4
- 2.2 BMP Monitoring Goals 5
- 2.3 Physical and Chemical Characteristics of Stormwater Runoff 7
- 2.4 Stormwater Quality Monitoring Challenges 8
- 2.5 Complexities Specific to BMP Monitoring 9
  - 2.5.1 Considerations for Evaluating BMP Effectiveness 10
    - Load Versus Water Quality Status Monitoring 10
    - Consideration of Parameters for Monitoring 12
- 2.6 BMP Types and Implications for Calculation of Efficiency 13
- 2.7 Relationship Between Monitoring Study Objectives and Data Analysis 14
- 2.8 Physical Layout and Its Effect on Efficiency and Its Measure 15
- 2.9 Relevant Period of Impact 16
  - 2.9.1 Concentrations, Loads, and Event Mean Concentrations 17
    - 2.9.1.1 Concentrations 17
    - 2.9.1.2 Loads 17
    - 2.9.1.3 Event Mean Concentrations 18
  - 2.9.2 Measures of BMP Efficiency 18
    - 2.9.2.1 Historical Approaches 21
      - Efficiency Ratio 21
        - Definition 21
        - Assumptions 23
        - Comments 23
        - Example 24
      - Summation of Loads 24
        - Definition 24
        - Assumptions 24
        - Comments 25
        - Example 25
      - Regression of Loads (ROL) 25
        - Definition 25

Assumptions 26
Comments..27
Mean Concentration 29
Definition..29
Assumptions 29
Comments..30
Efficiency of Individual Storm Loads 30
Definition..30
Assumptions 31
Comments..31
Summary and Comparison of Historical Methods 32
2.9.2.2 Other Methods and Techniques 32
"Irreducible Concentration" and "Achievable Efficiency" 32
Percent Removal Relative to Water Quality Standards..........................36
"Lines of Comparative Performance©" 37
Multi-Variate and Non-Linear Models..40
2.9.2.3 Recommended Method 40
Effluent Probability Method..40
2.9.2.4 Reference Watershed Methods 43
2.9.3 BMPs and BMP Systems...44

3 DEVELOPING A BMP MONITORING PROGRAM 45
3.1 Phase I – Determine Objectives and Scope of BMP Water Quality Monitoring Program 46
3.1.1 Monitoring and Literature Review to Assess BMP Performance............47
3.1.2 Monitoring to Assess Compliance with Surface Water quality criteria 49
3.1.3 Criteria for the Protection of Aquatic/Marine Life 49
3.1.4 Human Health 50
3.1.5 Application of Water quality criteria to Stormwater 50
3.1.6 Groundwater and Sediment Standards..51
3.1.7 Scope of Work for BMP Monitoring Program 51
3.1.8 Information Needs to Meet Established Goals of BMP Monitoring 55
3.2 Phase II – Develop BMP Monitoring Plan 56
3.2.1 Recommendation and Discussion of Monitoring Locations....................56
Integration of BMP Monitoring into a Municipal Monitoring Program 57
Sampling from a Well Mixed Location..58
3.2.1.1 Upstream 59
3.2.1.2 Downstream 60
3.2.1.3 Intermediate Locations...60
3.2.1.4 Rainfall...61
Site Proximity..61
Number of Gauges..62
3.2.1.5 Groundwater 62
3.2.1.6 Sediment Sampling 63
3.2.1.7 Dry Deposition..63
3.2.1.8 Modeling Methods 64

Estimates of Water Quality Parameters....64
Estimates of Flow....67
Estimates of Rainfall....67
3.2.2 Recommendation and Discussion of Monitoring Frequency....68
3.2.2.1 Statistical Underpinnings of Study Design....68
3.2.2.2 Factors Affecting Study Design....69
Number of Samples....69
Determining the Number of Observations Needed....70
3.2.3 Recommendation and Discussion of Water Quality Parameters and Analytical Methods....76
3.2.3.1 Selecting Parameters....76
3.2.3.2 Dissolved vs. Total Metals....79
3.2.3.3 Measurements of Sediment Concentration....79
3.2.3.4 Analytical Methods....81
3.2.4 Recommendation and Discussion of Monitoring Equipment and Methods....83
3.2.4.1 Equipment....83
Data Loggers....83
Power Requirements....87
Flow....89
Volume-Based Methods....91
Stage-Based Methods....91
Manning's Equation....92
Other Empirical Stage-Flow Relationships....93
Stage Based Method Using Weirs and Flumes....93
Stage-Based Variable Gate Meters....94
Velocity-Based Methods....94
Tracer Dilution Methods....95
Constant Injection Rate Tracer Dilution Studies....95
Total Recovery Tracer Dilution Studies....95
Pump Discharge Method....95
3.2.4.2 Automatic Sampling Techniques....96
Selection of Primary Flow Measurement Device....96
Types of Primary Flow Measurement Devices....96
Weirs....97
Flumes....97
Considerations for Selection of Primary Flow Measurement Device....99
Range of Flows....99
Flow Rate....100
Accuracy....100
Cost....100
Head Loss and Flow Characteristics....101
Sediment and Debris....101
Construction Requirements....101
Selection of Secondary Flow Measurement Device....102
Float Gauge....103
Bubbler Tube....103

Ultrasonic Depth Sensor 104
Pressure Probe 105
Ultrasonic “Uplooking” 106
Radar/Microwave 106
Equipment for Measuring Velocity 107
Methods Suitable for Calibration 107
Tracer Studies 108
Rotating-Element Current Meters 108
Pressure Sensors 108
Acoustical Sensors 108
Float-and-Stopwatch Method 109
Deflection (or Drag-Body) Method 109
Methods Most Suitable for Continuous Velocity Monitoring 109
Ultrasonic (Doppler) Sensors 109
Electromagnetic Sensors 110
Acoustic Path 111
Water Quality Sample Collection Techniques 111
Grab Samples 111
Composite Samples 112
Automatic Sampling 114
Automatic Sampling Equipment 115
Overland Flow Sampler 118
In-situ Water Quality Devices, Existing Technology 119
In-situ Water Quality Devices, Future Technologies 121
Ion-Selective Electrodes 121
On-Line Water Quality Analyzers 121
Particle Size Analyzers 122
In-situ Filtration and Extraction System 123
Remote Communications with Automatic Equipment 123
Manual Sampling 124
Manual Grab Sampling Equipment 125
Manual Composite Sampling Equipment 125
3.2.4.3 Error Analysis and Measurement Accuracy 126
3.2.5 Recommendation and Discussion of Storm Criteria 127
3.2.5.1 Storm Characteristics 127
3.2.6 Recommendation and Discussion of QA/QC 129
3.2.6.1 Sampling Methods 132
Contamination/Blanks 133
Reconnaissance and Preparations 134
Site Visits 134
Laboratory Coordination 134
Sample Containers/Preservation/ Holding Times 135
Recommended Field QA/QC Procedures 135
Field Blanks 135
Field Duplicate Samples 135
Field Sample Volumes 136

Chain of Custody 136
Recommended Laboratory QA/QC Procedures 136
Method Blanks 136
Laboratory Duplicates 136
Matrix Spike and Spike Duplicates 136
External Reference Standards 136
3.2.7 Recommendations for Data Management 137
3.2.7.1 Database Requirements 137
Analysis of Database Links 138
Analysis of Outlying Records 138
Sample Comparisons Between Original Documents and Final Data Set 139
Digital Conversion of Data 139
Double Data Entry and Optical Character Recognition 139
3.3 Phase III - Implementation of Monitoring Plan 139
3.3.1 Training of Personnel 139
3.3.2 Installation of Equipment 140
3.3.3 Testing and Calibrating Equipment 141
3.3.4 Conducting Monitoring 141
3.3.5 Coordinate Laboratory Analysis 143
3.4 Phase IV - Evaluation and Reporting of Results 144
3.4.1 Validate Data 144
3.4.2 Evaluate Results 144
3.4.2.1 Preliminary Data Evaluation 145
3.4.2.2 Definitive Evaluations 145
3.4.3 Report Results 146
3.4.3.1 National Stormwater BMP Database Requirements 147
3.4.3.2 Standard Format Examples 156
General Test Site Information 156
Watershed Information 159
Structural BMP Information 164
Non-Structural BMP Information 166
Detention Basin Design Data 169
Retention Pond Design Data 172
Percolation Trench and Dry Well Design Data 175
Media Filter Design Data 178
Grass Filter Strip Design Data 181
Wetland Channel and Swale Design Data 183
Porous Pavement Design Data 186
Infiltration Basin Design Data 189
Hydrodynamic Device Design Data 192
Wetland Basin Design Data 194
Monitoring Station Information 198
Precipitation Data 201
Flow Data 203
Water Quality Data 205
3.4.3.3 On-line Information 207

References 208
Index 214

APPENDIX A
APPENDIX B
APPENDIX C
APPENDIX D

List of Tables

Page

Table 2.1: Objectives of BMP implementation projects and the ability of comprehensive water quality monitoring studies to provide information useful for determining performance and effectiveness 6
Table 2.2: Examples of water quality parameters and relevant monitoring period 17
Table 2.3: Summary of historical, alternative, and recommended methods for BMP water quality monitoring data analysis....20
Table 2.4: Example of ER method results for TSS in the Tampa Office Pond 24
Table 2.5: Example of SOL method results for TSS in the Tampa Office Pond....25
Table 2.6: Example of ROL method results for TSS in the Tampa Office Pond. 27
Table 2.7: Example of Individual Storm Loads Method results for TSS in the Tampa Office Pond....32
Table 2.8: Comparison of BMP efficiency methods.....32
Table 2.9: “Irreducible concentrations” as reported by Scheuler, 2000. 33
Table 2.10: Example TSS results for typical ER Method....33
Table 2.11: Example TSS results for demonstration of Relative Efficiency approach.....35
Table 2.12: Example of percent removal relative to receiving water quality limits approach....36
Table 3.1: Typical urban stormwater runoff constituents and recommended detection limits 79
Table 3.2: Flow measurement methods.... 91
Table 3.3: Equipment for measuring depth of flow 103
Table 3.4: Velocity measurement methods suitable for calibration....108
Table 3.5: National Stormwater BMP Database requirements for all BMPs 149
Table 3.6: National Stormwater BMP Database requirements for structural BMPs....150
Table 3.7: National Stormwater BMP Database requirements for Non-structural BMPs 150
Table 3.8: National Stormwater BMP Database requirements for individual structural BMPs 151
Table 3.9: National Stormwater BMP Database requirements for non-structural BMPs and structural BMPs that are based on minimizing directly connected impervious areas 156
Table 3.10: National Stormwater BMP Database requirements for structural BMPs that are based on minimizing directly connected impervious areas 157
Table 3.11: General test site form data element descriptions 158
Table 3.12: Watershed form data elements description....160
Table 3.13: Structural BMP form data elements description....165
Table 3.14: Non-structural BMP form data elements description 167
Table 3.15: Detention Basin design form data elements list....170

Table 3.16: Retention Pond design form data elements list 173
Table 3.17: Percolation trench and dry well design form data elements list 176
Table 3.18: Media filter design form data elements list..179
Table 3.19: Grass filter strip form data elements list..182
Table 3.20: Wetland channel and swale form data elements list..184
Table 3.21: Porous pavement form data elements 187
Table 3.22: Infiltration basin form data elements list.. 190
Table 3.23: Hydrodynamic device form data elements.. 193
Table 3.24: Wetland basin form data elements list.. 195
Table 3.25: Monitoring station form data elements 199
Table 3.26: Precipitation form data elements 202
Table 3.27: Flow form data elements..204
Table 3.28: Water quality form data elements.. 206
Table A.1: Example of inputs for estimation of errors in flow measurement Devices.. A-5
Table A.2: Summary of examples demonstrating the propagation of errors in flow measurement.. A-7
Table D.1: Relationships of log-normal distributions.. D-1

List of Figures

Page

Figure 2.1 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1990)..........28
Figure 2.2 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1993-1994)…………...28
Figure 2.3 ROL plot for use in calculating efficiency for TSS using the Tampa Office Pond (1994-1995)..........29
Figure 2.4 Removal Efficiency (ER Method) of TSS as a function of influent concentration..........38
Figure 2.5 Removal Efficiency (ER Method) of total phosphorous as a function of influent concentration..........38
Figure 2.6 Removal Efficiency (ER Method) of total zinc as a function of influent concentration..........39
Figure 2.7 Percent removal as a function of influent concentration for randomly generated, normally distributed influent and effluent concentrations. 39
Figure 2.8 Probability plot for Suspended Solids..........42
Figure 2.9 Probability plot for Total Dissolved Solids..........42
Figure 2.10 Probability plot for Chemical Oxygen Demand..........42
Figure 3.1 Nomograph relating coefficient of variation of a samples set to the allowable error in the estimate of the population mean..........71
Figure 3.2 Number of samples required using a paired sampling approach to observe a statistically significant percent difference in mean concentration as a function of the coefficient of variation (power of 80% and confidence of 95%)..........75
Figure 3.3 Data logger with weatherproof housing..........84
Figure 3.4 Data logger without housing..........85
Figure 3.5 Data logger summary..........88
Figure 3.6 Parshall flume..........98
Figure 3.7 H-flume..........98
Figure 3.8 Bubbler flow meter..........104
Figure 3.9 Ultrasonic-depth sensor module..........105
Figure 3.10 Pressure transducers..........106
Figure 3.11 Area velocity sensors module..........110
Figure 3.12 Automatic sampler..........116
Figure 3.13 VOC sampler..........117
Appendix B Figures: Number of samples required for various powers, confidence intervals, and percent differences..........B-1

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1 Introduction

1.1 Scope

Existing guidance is available for assessing the effectiveness of stormwater best management practices (EPA 1997; FHWA 2000). However, few existing documents provide targeted practical assistance in conducting and reporting data from a water quality based monitoring program that results in data that are useful for assessing BMP effectiveness on a broader scale.

This guidance has been developed by integrating experience gleaned from field monitoring activities conducted by members of ASCE's Urban Water Resource Research Council and through the development of the ASCE/EPA National Stormwater Best Management Practices Database. The manual is intended to help achieve stormwater BMP monitoring project goals through the collection of more useful and representative rainfall, flow, and water quality information. Many of the recommended protocols (particularly those for reporting monitoring, watershed, and design information) are directly related to requirements of the National Stormwater Best Management Practices Database.

This manual is intended to improve the state of the practice by providing a recommended set of protocols and standards for collecting, storing, analyzing, and reporting BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs. This manual provides insight into and guidance for strategies, approaches, and techniques that are appropriate and useful for monitoring BMPs.

This document addresses methods that were in use at the time it was written. As the state of the practice and the design of monitoring equipment progress, new monitoring approaches and techniques, more sensitive devices, and equipment based on new technologies will likely be employed. Although the technology may change somewhat from that described herein, 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 primarily on the collection, reporting, and analysis of water quantity and quality measurements at the heart of quantitative BMP efficiency projects. It 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, or other activities that in many circumstances may be as, or more, useful for measuring and monitoring water quality for assessing BMP efficiency.

1.1.1 State of the Practice

Many studies have assessed the ability of stormwater treatment BMPs (e.g., wet ponds, grass swales, stormwater wetlands, sand filters, dry detention, etc.) to reduce pollutant concentrations and loadings in stormwater. Although some of these monitoring projects conducted to date have done an excellent job of describing the effectiveness of specific BMPs and BMP systems, there is a lack of standards and protocols for conducting BMP assessment and monitoring work. These problems become readily apparent for persons seeking to summarize the information gathered from a number of individual BMP evaluations. Inconsistent study methods, lack of associated design information, and reporting protocols make wide-scale assessments difficult, if not impossible. (Strecker et al. 2001; Urbonas 1998) For example, individual studies often include the analysis of different constituents and utilize different methods for data collection and analysis, as well as report varying degrees of information on BMP design and flow characteristics. The differences in monitoring strategies and data evaluation alone contribute significantly to the range of BMP "efficiency" that has been reported in literature to date.

1.1.2 The Need for Guidance

Municipal separate storm sewer system owners and operators need to identify effective BMPs for improving stormwater runoff water quality. Because of the current state of the practice, however, very little sound scientific data are available for making decisions about which structural and non-structural management practices function most effectively under what conditions; and, within a specific category of BMPs, to what degree design and environmental static and state variables directly affect BMP efficiency. This guidance addresses this need by helping to establish a standard basis for collecting water quality, flow, and precipitation data as part of a BMP monitoring program. The collection, storage, and analysis of this data will ultimately improve BMP selection and design.

1.1.3 National Stormwater Best Management Practices Database

The National Stormwater BMP Database (Database) serves two key purposes: (1) to define a standard set of data reporting protocols for use with BMP monitoring efforts; and (2) to assemble and summarize historical and future BMP study data in a standardized format. The software consists of a data entry module for reporting data on new BMP studies and a search engine module to allow users to retrieve data. The Database is a user-friendly, menu-driven software program developed in a run-time version of Microsoft® Access 97 and Access 2000. The software has been distributed on CD-ROM and is now also accessible via the Internet at www.bmpdatabase.org.

1.2 Format and Content of This Document

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

Section 2 provides an overview of BMP monitoring. Discussion is provided on the context of BMP monitoring, difficulties in assessing BMP performance, and understanding the relationship between BMP study design and the attainment of monitoring program goals. Useful analysis of data collected from BMP monitoring studies is essential for understanding and comparing BMP monitoring study results. A summary of historical and recommended approaches for data analysis is provided in this section to elucidate the relationship between the details and subtleties of each analysis approach and the assessment of performance.

Section 3 discusses the specifics of developing a monitoring program, selecting monitoring methods and equipment, installing and using equipment, implementing sampling approaches and techniques, and reporting information consistent with the National Stormwater Best Management Practices Database.

In addition, four appendices have been included in this guidance document. The first appendix describes methods for calculating expected errors in field measurements. The second provides detailed information about the number of samples required to obtain statically significant monitoring data. The third appendix includes charts for estimating the number of samples required to observe a statically significant difference between two populations for a various levels of confidence and power. The final appendix is a table for estimating arithmetic descriptive statistics based on descriptive statistics of log-transformed data.

2 BMP Monitoring Overview

This section provides an overview of BMP monitoring program context and execution, including a discussion of approaches used for quantifying BMP efficiency.

2.1 Context of BMP Monitoring in the Regulatory Environment

BMP monitoring is conducted by researchers, public entities, and private companies for meeting both regulatory and non-regulatory needs. This section briefly discusses some of the regulatory programs that drive BMP monitoring programs.

A number of environmental laws exist for implementation of stormwater and BMP monitoring programs including:

- <u>The Clean Water Act (CWA) of 1972:</u>

    Section 208 of 1972 CWA requires every state to establish effective BMPs to control nonpoint source pollution. The 1987 Water Quality Act (WQA) added section 402(p) to the CWA, which requires that urban and industrial stormwater be controlled through the National Pollutant Discharge Elimination System (NPDES) permit program.

    Section 303(d) of WQA requires the states to list those water bodies that are not attaining water quality standards including designated uses and identification of relative priorities among the impaired water bodies. States must also develop TMDLs (Total Maximum Daily Loads) that quantify the pollutant load or the impairing pollutants that will bring the waterbody back into attainment.

- <u>The Endangered Species Act:</u>

    The Endangered Species Act of 1973 protects animal and plant species currently in danger of extinction (endangered) and those that may become endangered in the foreseeable future (threatened). It provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through Federal action and by encouraging the establishment of state programs.

- <u>Coastal Zone Act Reauthorization Amendments (CZARA) of 1990</u>:

    CZARA was passed to help address nonpoint source pollution in coastal waters. Each state with an approved coastal zone management program must develop and submit to the EPA and National Oceanic and Atmospheric Administration (NOAA) a Coastal Nonpoint Pollution Control Program (CNPCP), which provides for the implementation of the most economically achievable management measures and BMPs to control the addition of pollutants to coastal waters.

CZARA does not specifically require that states monitor implementation of management measures and BMPs. They must, however, provide technical assistance to local governments and the public in the implementation of the management measures and BMPs, which may include assistance to predict and assess the effectiveness of such measures.

CZARA also states that the EPA and NOAA shall provide technical assistance to the states in developing and implementing the CNPCP, including methods to predict and assess the effects of coastal land use management measures on coastal water quality and designated uses:

1. Protection of stream and water body designated use (meet fishable and swimmable goals)

2. Antidegradation policies designated to protect water quality when the water quality already is higher than existing standards

3. Other state, county, and local regulations or ordinances

As regulations and the application and enforcement thereof change over time, details about the above environmental laws and their implications for specific sites and watersheds are best obtained from current EPA, state, county, and local resources.

2.2 BMP Monitoring Goals

BMP monitoring projects are initiated to address a broad range of programmatic, management, regulatory, and research goals. Goal attainment is often focused on the achievement of water quality objectives downstream of the BMP. However, there are many other objectives that have been established as part of BMP implementation projects that cannot be measured using a water quality monitoring approach alone. Table 2.1 below describes the relationship between BMP implementation objectives and the ability of water quality monitoring studies to address the attainment of these objectives.

Studies directed at addressing the efficiency of BMPs in attaining water quality goals are usually conducted to obtain information to help answer 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 efficiency vary from pollutant to pollutant?

- How does this normal efficiency vary with large or small storm events?
- How does this normal efficiency vary with rainfall intensity?
- How do design variables affect efficiency?
- How does efficiency vary with different operational and/or maintenance approaches?
- Does efficiency improve, decay, or remain stable over time?
- How does this BMP's efficiency compare with the efficiency of other BMPs?

The ability of a specific BMP monitoring program to answer these questions and ultimately address the desire to measure goal attainment is a vital planning stage component of setting up a meaningful BMP monitoring program.

Table 2.1: Objectives of BMP implementation projects and the ability of comprehensive water quality monitoring studies to provide information useful for determining performance and effectiveness

Category	**Goals of BMP Projects**	**Ability to Evaluate Performance and Effectiveness**
Hydraulics	• Improve flow characteristics upstream and/or downstream of BMP	-
Hydrology	• Flood mitigation, improve runoff characteristics (peak shaving)	✓
Water Quality	• Reduce downstream pollutant loads and concentrations of pollutants	✓
	• Improve/minimize downstream temperature impact	✓
	• Achieves desired pollutant concentration in outflow	✓
	• Removal of litter and debris	-
Toxicity	• Reduce acute toxicity of runoff	✓
	• Reduce chronic toxicity of runoff	✓
Regulatory	• Compliance with NPDES permit	-
	• Meet local, state, or federal water quality criteria	✓[1]
Implementation Feasibility	• For non-structural BMPs, ability to function within management and oversight structure	-
Cost	• Capital, operation, and maintenance costs	-
Aesthetic	• Improve appearance of site	-
Maintenance	• Operate within maintenance, and repair schedule and requirements	-
	• Ability of system to be retrofit, modified or expanded	-
Longevity	• Long-term functionality	✓
Resources	• Improve downstream aquatic environment/erosion control	-
	• Improve wildlife habitat	-
	• Multiple use functionality	-
Safety, Risk and Liability	• Function without significant risk or liability	-
	• Ability to function with minimal environmental risk downstream	-
Public Perception	• Information is available to clarify public understanding of runoff quality, quantity and impacts on receiving waters	✓

✓ can be evaluated using water quality monitoring as primary source of information

✓[1] can be evaluated using water quality monitoring as the primary source of information combined with a secondary source of comparative data

\- cannot be directly evaluated using water quality monitoring, but in some cases may be supported by work associated with collecting water quality information (i.e., detailed flow data)

2.3 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 event being sampled. Stormwater also can include dry weather flows such as pavement washing, pavement cutting wash water, or irrigation. Loads from dry weather flows, in some cases, can greatly exceed wet weather loads over the course of a year and must be taken into account.

Stormwater quality tends to be extremely variable (EPA 1983; Driscoll et al. 1990). The intensity (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 given 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.

In addition, the complexity of introducing a structural management practice can greatly affect hydraulics and constituent concentrations in complex ways. For example, flows from detention facilities are often not confined only to the period of wet weather, as drain time can be significant.

Numerous studies conducted during the late 1970s and early 1980s show that stormwater runoff from urban and industrial areas are a potentially significant source of pollution (EPA 1983; Driscoll et al. 1990). As a result, federal, state and local regulations have been promulgated to address stormwater quality (see Section 2.1 above).

The impacts of hydrologic and hydraulic (physical as opposed to chemical) changes in watersheds are increasingly being recognized as significant contributors to receiving waters not meeting beneficial criteria. These impacts include stream channel changes (erosion, sedimentation, temperature changes) as well as wetland water level fluctuations.

2.4 Stormwater Quality Monitoring Challenges

Information collected on the efficiency and design of BMPs serves a variety of goals and objectives as discussed in Section 2.2. The principal challenge facing persons implementing BMP monitoring programs is the great temporal and spatial variability of stormwater flows and pollutant concentrations. Stormwater quality at a given location varies greatly both between storms and during a single storm event, and thus a small number of samples are not likely to provide a reliable indication of stormwater quality at a given site or the effect of a given BMP. Therefore, collection of numerous samples is generally needed in order to accurately characterize stormwater quality at a site and BMP efficiency (see Section 3.2.2).

Collecting enough stormwater samples to answer with a high level of statistical confidence many of the common questions regarding BMP efficiency is generally expensive and time-consuming. 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 one begins a BMP monitoring program, it is critical to clearly identify and prioritize the goals of the project, determine the type and quality of information needed to attain those goals, 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 consider the following options to obtain useful results within your resource limitations (e.g., funds, personnel, time):

- A phased approach wherein you address only a subset of the overall geographic area, or only the most important stormwater questions.

- Limiting the number of constituents evaluated as an alternative to reducing the number of samples collected.

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

The key question should be: "Will the information provided from the monitoring program I am considering (and would be able to implement) significantly improve my understanding of the effectiveness of the BMP being monitored?" If the answer is no, reconsider the monitoring program.

2.5 Complexities Specific to BMP Monitoring

Monitoring BMPs introduces a number of specific difficulties into the already complex task of monitoring stormwater runoff water quality.

In many ways a structural BMP system is best viewed as an environmental unit process with a large number of static and state variables affecting functionality of the process. For example, static variables that can directly affect BMP system function include:

- BMP design (e.g., length, width, height, storage volume, outlet design, upstream bypass, model number, etc.)
- Geographical location.
- Watershed size.
- Percent imperviousness.
- Vegetative canopy.
- Soil type.
- Watershed slopes.
- Compaction of soils.

State variables that directly affect BMP function may include:

- Rainfall intensity.
- Flow rate.
- Season.
- Vegetation.
- Upstream non-structural controls.
- Inter-event timing.
- Settings for control structures such as gates, valves, and pumps.
- Maintenance of the BMP.

The inconsistent use of language in reporting BMP information can compound the difficult task of assessing physically complex systems. In order to provide a consistent context for discussion of monitoring approaches in this guidance, the following definitions are provided:

- Best Management Practice (BMP) - A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters.

- BMP System - A BMP system includes the BMP and any related bypass or overflow. For example, the efficiency (see below) can be determined for an offline retention (Wet) Pond either by itself (as a BMP) or for the BMP system (BMP including bypass).

- Performance - measure of how well a BMP meets its goals for stormwater that the BMP is designed to treat.

- Effectiveness - measure of how well a BMP system meets its goals in relation to all stormwater flows.

- Efficiency - measure of how well a BMP or BMP system removes or controls pollutants.

Researchers often want to determine efficiency of BMPs and BMP systems and to elucidate relationships between design and efficiency. Efficiency has typically been quantified by “percent removal”. As is discussed in the following sections, “percent removal” alone is not a valid measure of the functional efficiency of a BMP (Strecker et al. 2001). As a result the definition of “efficiency” in this manual can mean any measure of how well a BMP or BMP system removes or controls pollutants and is not restricted by the historical use of the term referring to “percent removal.”

2.5.1 Considerations for Evaluating BMP Effectiveness

Load Versus Water Quality Status Monitoring

The choice between monitoring either (a) the status or condition of the water resource or (b) the pollutant load and event mean concentrations discharged to the water resource should be made with care (Coffey and Smolen 1990). Monitoring of loads and event mean concentrations is focused on obtaining quantitative information about the amount of pollutants transported to the receiving water from overland, channel and pipe, tributary, or groundwater flow. Load and concentration monitoring can be used to evaluate pollutant export at a stormwater BMP.

Water Quality Status Monitoring

Water quality status can be evaluated in a number of ways, including:

- Evaluating "designated use" attainment[1].
- Evaluating Water Quality Standards violations.
- Assessing ecological integrity.
- Monitoring an indicator parameter.

Monitoring water quality status includes measuring a physical attribute, chemical concentration, or biological condition, and may be used to assess baseline conditions, trends, or the impact of treatment on the receiving water. Monitoring water quality status may be the most effective method to evaluate the impact of the management measure implemented, but sensitivity may be low (Coffey and Smolen 1990). When the probability of detecting a trend in water quality status is low, load monitoring may be necessary.

When deciding between measuring load or water quality status (i.e., it is not clear whether abatement can be detected in the receiving resource), a pollutant budget may help to make the decision (Coffey and Smolen 1990). The budget should account for mass balance of pollutant input by source, all output, and changes in storage. Sources of error in the budget should also be evaluated (EPA 1993a).

Pollutant Load and Event Mean Concentration Monitoring

Load monitoring requires considerable effort and should include the protocols that are the primary intent of this document. Because of potentially high variability of discharge and pollutant concentrations in watersheds impacted by both point and non-point sources, collecting accurate and sufficient data from a significant number of storm events and base flows over a range of conditions (e.g., season, land cover) is important. This manual describes several methods for collecting and analyzing meaningful pollutant loading and event concentration data. Most of these methods are also applicable to water quality status monitoring where specific chemical concentrations must be monitored.

Monitoring for designated use attainment or standards violations should focus on those parameters or criteria specified in state water quality standards. Where the monitoring objective includes relating improvements in water quality to the pollution control activities, it is important that the parameters monitored are connected to the management

[1] See Clean Water Act, Section 303(c)(2)

measures implemented. For violations of standards, the choice of variable is specified by the state water quality standard (EPA 1993a).

Consideration of Parameters for Monitoring

Many studies have been conducted to assess the effectiveness of stormwater treatment BMPs to reduce pollutant concentrations and loads in stormwater runoff. Unfortunately, inconsistent study methods and reporting make assessment and comparison of BMP efficiency studies difficult. The studies often analyze different constituents with varying methods for data collection and analysis. These differences can contribute considerably to the range of BMP effectiveness observed (Strecker 1994).

Several protocols for parameter selection have been used in the past. The most widely applied was developed as a part of the Nationwide Urban Runoff Program (NURP). NURP adopted consistent data collection techniques and analytical parameters so that meaningful comparisons of gathered data could be made. NURP adopted the following constituents as "standard pollutants characterizing urban runoff" (EPA 1983):

- SSC – Suspended Solids Concentration
- BOD – Biochemical Oxygen Demand
- COD – Chemical Oxygen Demand
- CU – Copper
- Pb – Lead
- Zn – Zinc
- TP – Total Phosphorous
- SP – Soluble Phosphorous
- TKN – Total Kjeldahl Nitrogen
- NO_2 + NO_3 – Nitrate + Nitrite

The following factors were considered for including a parameter in the list of recommended monitoring constituents (Strecker 1994):

- The pollutant has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment.

- The analytical test used can be related back to potential water quality impairment.

- Sampling methods for the pollutant are straight forward and reliable for a moderately careful investigator.

- Analysis of the pollutant is economical on a widespread basis.

- Treatment is a viable option for reducing the load of the pollutant.

Similar considerations should go into the planning of water quality constituents and analytical methods to be used in monitoring the effectiveness of stormwater BMPs. The NURP parameters are a starting point and may or may not represent constituents of concern for discharges from specific BMPs. As mentioned previously, there is often a tradeoff between the breadth and depth of a monitoring program given a fixed cost and, as a result, narrowing the list of constituents monitored can dramatically improve the ability to quantify the efficiency of the BMP.

Large volumes of data have been collected over the past 20 years on the performance of many structural stormwater BMPs, with most of the data relating to the performance of detention basins, retention ponds, and wetlands. Less data are available on the effectiveness of other types of BMPs (Urbonas 1994). Many of the reported results do not demonstrate a clear relationship between the efficiency of similar BMPs among the sites in which they were investigated. Sufficient parametric data has generally not been reported with the performance data to permit a systematic analysis of the data collected (Urbonas 1994).

There are a number of important parameters that need to be measured and reported whenever BMP performance is monitored (Urbonas 1994). A detailed discussion on this subject is provided in Section 3.4 of this manual.

2.6 BMP Types and Implications for Calculation of Efficiency

The issues involved in selecting methods for quantifying efficiency, performance, and effectiveness are complex. It would be difficult, at best, to find one method that would cover the data analysis requirements for the widely varied collection of BMP types and designs available. When analyzing efficiency, it is convenient to classify BMPs according to one of the following four distinct categories:

- BMPs with well-defined inlets and outlets whose primary treatment depends upon extended detention storage of stormwater, (e.g., retention (wet) and detention (dry) ponds, wetland basins, underground vaults).

- BMPs with well-defined inlets and outlets that do not depend upon significant storage of water, (e.g., sand filters, swales, buffers, structural “flow-through” systems).

- BMPs that do not have a well-defined inlet and/or outlet (e.g., full retention, infiltration, porous pavement, grass swales where inflow is overland flow along the length of the swale).

- Widely distributed (scattered) BMPs where studies of efficiency use reference watersheds to evaluate effectiveness, (e.g., catch basin retrofits, education programs, source control programs).

Any of the above can also include evaluations where the BMP's efficiency was measured using before and after or paired watershed comparisons of water quality.

The difficulty in selecting measures of efficiency stems not only from the desire to compare a wide range of BMPs, but also from the large number of methods currently in use. There is much variation and disagreement in the literature about what measure of efficiency is best applied in specific situations, however it is generally accepted that event mean concentrations and long-term loading provide the best means for observing the effects of the BMP respectively on acute and chronic pollution.

It has been suggested that intra-storm monitoring could be used to establish paired inflow/outflow samples during the storm based upon average travel times. However, this method would only be valid if a BMP were functioning as a perfect plug-flow reactor, which is rarely the case.

2.7 Relationship Between Monitoring Study Objectives and Data Analysis

In selecting a specific method for quantifying BMP efficiency, it is helpful to look at the objectives of previous studies seeking such a goal. BMP studies are usually conducted to obtain information regarding one or more of the following objectives:

- What degree of pollution control does the BMP provide under typical operating conditions?

- How does effectiveness vary from pollutant to pollutant?

- How does effectiveness vary with various input concentrations?

- How does effectiveness vary with storm characteristics such as rainfall amount, rainfall density, and antecedent weather conditions?

- How do design variables affect performance?

- How does effectiveness vary with different operational and/or maintenance approaches?

- Does effectiveness improve, decay, or remain stable over time?
- How does the BMP's efficiency, performance, and effectiveness compare to other BMPs?
- Does the BMP reduce toxicity to acceptable levels?
- Does the BMP cause an improvement in or protect downstream biotic communities?
- Does the BMP have potential downstream negative impacts?

The monitoring efforts implemented most typically seek to answer a small subset of the above questions. This approach often leaves larger questions about the efficiency, performance and effectiveness of the BMP, and the relationship between design and efficiency, unanswered. This document recommends monitoring approaches consistent with protocols established as part of the National Stormwater Best Management Practices Database project and useful for evaluating BMP data such that some or all of the above questions about BMP efficiency can be assessed.

2.8 Physical Layout and Its Effect on Efficiency and Its Measure

The estimation of the efficiency of BMPs is often approached in different ways based on the goals of the researcher. A BMP can be evaluated by itself or as part of an overall BMP system. The efficiency of a BMP when bypass or overflow are not considered may be dramatically different than the efficiency of an overall system. Bypasses and overflows can have significant effects on the ability of a BMP to remove constituents and appreciably reduce the efficiency of the system as a whole. Researchers who are interested in comparing the efficiency of an offline wet pond and an offline wetland may not be concerned with the effects of bypass on a receiving water. On the other hand, another researcher who is comparing offline wet ponds with online wet ponds would be very interested in the effects of the bypass. Often in past study reports detailed information about the bypass flows is not available. In some cases, comprehensive inflow and outflow measurements allow for the calculation of a mass balance that can be used to estimate bypass flow volumes. Estimations of efficiency of a BMP system can be based on these mass balance calculations coupled with sampling data.

The effect of devices in series is often neglected in the analyses of BMPs. BMPs are often used in conjunction with a variety of upstream controls. For example detention ponds often precede wetlands, and sand filters typically have upstream controls for sediment removal such as a forebay or a structural separator or settling device. Depending on the approach used to quantify BMP efficiency, the effects resulting from upstream controls can have a sizable impact on the level of treatment observed.

The efficiency of a BMP system or a BMP can be directly affected by the way in which an operator chooses to physically manage the system. This is the case where parameters of a design can be adjusted (e.g., adjustments to the height of an overflow/bypass weir or gate). These adjustments can vary the efficiency considerably. In order to analyze a BMP or BMP system thoroughly, all static and state variables of the system must be known and documented for each monitoring period. The protocols established for the National Stormwater Best Management Practices Database (Database) provide a framework for reporting the static and state variables thought to most strongly contribute to BMP efficiency and provide flexibility for non-standard situations.

2.9 Relevant Period of Impact

The period of analysis used in carrying out a monitoring program is important. The period used should take into account how the parameter of interest varies with time. This allows for observation of relevant changes in the efficiency of the BMP on the time scale in which these changes occur. For example, in a wetland it is often observed that during the growing season effluent quality for nutrients improves. The opposite effect may be observed during the winter months or during any period where decaying litter and plant material may contribute significantly to export of nutrients and, potentially, other contaminants. Therefore, monitoring observations may need to be analyzed differently during different seasons. This variation of performance and more specifically efficiency on a temporal scale is extremely important in understanding how a specific BMP functions.

In addition to observing how factors such as climate affect BMP efficiency as a function of time, it is important to relate the monitoring period to the potential impact a given constituent would have on the receiving water. For example, it may not be useful to study the removal of some heavy metals (e.g., mercury) for a short period of record when the negative impacts of such a contaminant are generally expressed over a long time scale (accumulation in sediments and biota). Likewise, some parameters (e.g., temperature, BOD, DO, pH, TSS and metals) may have a significant impact in the near term.

Toxicity plays a major role in evaluating the type of monitoring conducted at a site as well as the time period that should be used to analyze efficiency. Specific constituents that are acutely toxic may require a short-term analysis on an "intra-storm" basis. Where dilution is significant and/or a constituent is toxic on a chronic basis, long-term analysis that demonstrates removal of materials on a sum of loads or average EMC basis may be more appropriate. Many contaminants may have both acute and chronic effects in the aquatic environment. These contaminants should be evaluated over both periods of time. Similarly, hydraulic conditions merit both short and long-term examination. Event peak flows are examples of short-term data, while seasonal variations of the hydrologic budget due to the weather patterns are examples of long-term data. Examples of water quality parameters and their relationship to the time scale over which they are most relevant are given in Table 2.2.

Table 2.2: Examples of water quality parameters and relevant monitoring period

Time Scale for Analysis	**Water Quality Parameter**
Short-term	BOD, DO
Long-term	Organics, Carcinogens
Both Short- and Long-term	Metals, TSS, Nitrogen, Phosphorous, Temperature, pH, Pesticides

2.9.1 Concentrations, Loads, and Event Mean Concentrations

A variety of tools are available for assessing and quantifying the amount of pollutant conveyed to and from a BMP. Three primary measures are used most commonly: concentrations of stormwater at some point in time, the total load conveyed over a specified duration, or the event mean concentration (EMC).

2.9.1.1 Concentrations

Concentrations measured at a point in time can be useful for BMP efficiency evaluation in a number of circumstances. Concentrations resulting from samples collected at specific times during an event allow the generation of a pollutograph (i.e., a plot of the concentration of pollutants as a function of time). The generation of pollutographs facilitates the analysis of intra-event temporal variations in runoff concentration. For example, pollutographs can be used to determine if the "first-flush" phenomenon was observed for a specific event. Detailed concentration data is one of the approaches for assessing concentrations of pollutants that have acutely toxic effects, particularly where runoff from storm events constitutes a significant proportion of downstream flow. Under some circumstances, reduction of peak effluent concentrations may be more important than event mean concentration reduction. The cost of implementing a monitoring program that collects sufficient data to evaluate the temporal variation in runoff and BMP effluent concentration can be high. The trade-off between collecting data from a larger number of events versus collecting detailed concentration data from intra-storm periods often limits the utility of studies that collect detailed concentration data. This type of detailed monitoring is best focused on outflow monitoring rather than inflow and outflow.

2.9.1.2 Loads

Loads are typically calculated by the physical or mathematical combination of a number of individual concentration measurements, which have been assigned by some means an associated flow volume. A variety of methods are available for estimation of loads. The method employed is dependent on the sampling and flow measurement techniques used. Sampling approaches include collection of either timed samples, flow weighted samples, or some combination of both. Likewise, flow can be collected continuously, intermittently, or modeled from other hydrologic information such as rain gauge information, or gauging conducted in a nearby watershed. Many BMP monitoring studies focus efforts on water quality sample collection and neglect flow measurement. *Accurate flow measurement or well-calibrated flow modeling is essential for loading determination.*

Loads are often most useful for assessing the impact of a BMP where receiving waters are lakes or estuaries where long-term loadings can cause water quality problems outside of storms. Where the effluent flow rate from a particular BMP is small compared to the flow rate of the receiving water body, potential downstream impairments are typically not dependent on concentrations, but the absolute load of pollutant reaching the receiving water. For example, loads are the central issue in BMP studies that have direct links to receiving water bodies that are regulated under the Total Maximum Daily Load (TMDL) program, particularly where the concern is pollutants deposited in slow moving systems.

Dry weather flows can also contribute substantially to long-term loading. In addition, “on-line” BMPs (ponds and possibly filters) that have appreciable dry weather flows passing through them, may have reduced “capacity” for storage of wet weather pollutants. For example, pond performance may also be affected by the amount of water in the pond before the event, and filters may have some of their adsorption capacity consumed by pollutants and other constituents during dry weather flows.

2.9.1.3 Event Mean Concentrations

The term event mean concentration (EMC) is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event. It is defined as the total constituent mass divided by the total runoff volume. The calculation of EMCs from discrete observations is discussed in detail in Section 2.5.3. When combined with flow measurement data, the EMC can be used to estimate the pollutant loading from a given storm. The EMC approach to understanding BMP efficiency is primarily aimed at wet weather flows.

Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event. Collection of EMC data has been the primary focus of the National Stormwater Best Management Practices Database Project.

2.9.2 Measures of BMP Efficiency

The efficiency of stormwater BMPs (how well a BMP or BMP system removes pollutants or results in acceptable effluent quality) can be evaluated in a number of ways. An understanding of how BMP monitoring data will be analyzed and evaluated is essential to establishing a useful BMP monitoring study. The different methods used to date are explained in this section to illustrate historical approaches and provide context for the method recommended in this manual (Effluent Probability Method), which is presented at the end of this section. The following table (Table 2.3) summarizes all of the methods examined by this guidance.

Table 2.3: Summary of historical, alternative, and recommended methods for BMP water quality monitoring data analysis

Category	**Method Name**	**Recommendation**	**Comments**
Historical Methods	Efficiency Ratio (ER)	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Most commonly used method to date. Most researchers assume this is the meaning of "percent removal". Typical approach does not consider statistical significance of result.
	Summation of Loads (SOL)	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Utilizes total loads over entire study. May be dominated by a small number of large events. Results are typically similar to ER method. Typical approach does not consider statistical significance of result.
	Regression of loads (ROL)	Do not use	Very rarely are assumptions of the method valid. Cannot be universally applied to monitoring data.
	Mean Concentration	Do not use	Difficult to "track" slug of water through BMP without extensive tracer data and hydraulic study. Results are only for one portion of the pollutograph.
	Efficiency of Individual Storm Loads	Do not use	Storage of pollutants is not taken into account. Gives equal weight to all storm event efficiencies
Alternative Methods	Percent Removal Exceeding Irreducible Concentration or Relative to WQ Standards/Criteria	Not recommended – May be useful in some circumstances	Typically only applicable only for individual events to demonstrate compliance with standards.
	Relative Efficiency	Not recommended – May be useful in some circumstances	Typically only applicable only for individual events to demonstrate how well a BMP perfoms relative to how well it would perform if it
	"Lines of Comparative Performance©"	Do not use	Spurious self-correlation. Method is not valid.
	Multi-Variate and Non-Linear Models	Possible future use	Additional development of methodology based on more complete data sets than are currently available.
Recommended Method	**Effluent Probability Method**	**Recommended Method**	**Provides a statistical view of influent and effluent quality. This is the method recommended in this guidance manual. Benefits over other approaches that are described in this section of the Guidance.**

2.9.2.1 Historical Approaches

A variety of pollutant removal methods have been utilized in BMP monitoring studies to evaluate efficiency. This section describes and gives examples of methods employed by different investigators. Historically, one of six methods has been used by investigators to calculate BMP efficiency:

- Efficiency ratio
- Summation of loads
- Regression of loads
- Mean concentration
- Efficiency of individual storm loads
- Reference watersheds and before/after studies

Although use of each of these methods provides a single number that summarizes efficiency of the BMP in removing a particular pollutant, they are not designed to look at removal statistically, and thus, do not provide enough information to determine if the differences in inflow and outflow water quality measures are statistically significant.

<u>Efficiency Ratio</u>

Definition

The efficiency ratio is defined in terms of the average event mean concentration (EMC) of pollutants over some time period:

$$ER = 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} = \frac{\text{average inlet EMC - average outlet EMC}}{\text{average inlet EMC}}$$

EMCs can be either collected as flow weighted composite samples in the field or calculated from discrete measurements. The EMC for an individual event or set of field measurements, where discrete samples have been collected, is defined as:

$$EMC = \frac{\sum_{i=1}^{n} V_i C_i}{\sum_{i=1}^{n} V_i}$$

where,

V: volume of flow during period i
C: average concentration associated with period i
n: total number of measurements taken during event

The arithmetic average EMC is defined as:

$$\text{average EMC} = \frac{\sum_{j=1}^{m} EMC_j}{m}$$

where,

m: number of events measured

In addition, the log mean EMC can be calculated using the logarithmic transformation of each EMC. This transformation allows for normalization of the data for statistical purposes.

$$\text{Mean of the Log EMCs} = \frac{\sum_{j=1}^{m} Log\left(EMC_j\right)}{m}$$

Estimates of the arithmetic summary statistics of the population (mean, median, standard deviation, and coefficient of variation) should be based on their theoretical relationships (Appendix A) with the mean and standard deviation of the transformed data. Computing the mean and standard deviation of log transforms of the sample EMC data and then converting them to an arithmetic estimate often obtains a better estimate of the mean of the population due to the more typical distributional characteristics of water quality data. This value will not match that produced by the simple arithmetic average of the data. Both provide an estimate of the population mean, but the approach utilizing the log-transformed data tends to provide a better estimator, as it has been shown in various investigations that pollutant, contaminant, and constituent concentration levels tend to be well described by a log-normal distribution (EPA 1983). As the sample size increases, the two values converge.

Assumptions

This method:

- Weights EMCs from all storms equally regardless of relative magnitude of storm. For example, a high concentration/high volume event has equal weight in the average EMC as a low concentration/low volume event. The logarithmic data transformation approach tends to minimize the difference between the EMC and mass balance calculations.

- Is most useful when loads are directly proportional to storm volume. For work conducted on nonpoint pollution (i.e., inflows), the EMC has been shown to not vary significantly with storm volume. Accuracy of this method will vary based on the BMP type.

- Minimizes the potential impacts of smaller/"cleaner" storm events on actual performance calculations. For example, in a storm by storm efficiency approach, a low removal value for such an event is weighted equally to a larger value.

- Allows for the use of data where portions of the inflow or outflow data are missing, based on the assumption that the inclusion of the missing data points would not significantly impact the calculated average EMC.

Comments

- This method is taken directly from non-point pollution studies and does a good job characterizing inflows to BMPs but fails to take into account some of the complexities of BMP design. For example, some BMPs may not have outflow EMCs that are normally distributed (e.g., media filters and other BMPs that treat to a relatively constant level that is independent of inflow concentrations).

- This method also assumes that if all storms at the site had been monitored, the average inlet and outlet EMCs would be similar to those that were monitored.

- Under all circumstances this method should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences in mean EMCs are statistically significant (it is better to show the actual level of significance found, than just noting if the result was significant, assuming a 0.05 level).

Example

The example calculations given below are for the Tampa Office Pond using arithmetic average EMCs in the efficiency ratio method.

Table 2.4: Example of ER Method results for TSS in the Tampa Office Pond

Period of Record	Average EMC In	Average EMC Out	Efficiency Ratio
1990	27.60	11.18	59%
1993-1994	34.48	12.24	64%
1994-1995	131.43	6.79	95%
ER is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)			

Summation of Loads

Definition

The summation of loads method defines the efficiency based on the ratio of the summation of all incoming loads to the summation of all outlet loads, or:

$$\mathrm{SOL} = 1 - \frac{\text{sum of outlet loads}}{\text{sum of inlet loads}}$$

The sum of outlet loads are calculated as follows:

$$\text{sum of loads} = \sum_{j=1}^{m}\left(\sum_{i=1}^{n} C_i V_i\right) = \sum_{j=1}^{m} EMC_j \cdot V_j$$

Assumptions

- Removal of material is most relevant over entire period of analysis.
- Monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants.
- Any significant storms that were not monitored had a ratio of inlet to outlet loads similar to the storms that were monitored.

- No materials were exported during dry periods, or if they were, the ratio of inlet to outlet loads during these periods was similar to the ratio of the loads during the monitored storms.

Comments

- A small number of large storms typically dominate efficiency.

- If toxics are a concern then this method does not account for day-to-day releases, unless dry weather loads in and out are also accounted for. In many cases long-term dry weather loads can exceed those resulting from wet weather flows.

- Under all circumstances this method should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences in loads are statistically significant (it would be better to show the actual level of significance found, rather than just noting if the result was significant, assuming a 0.05 level).

Example

The example calculations given in Table 2.5 are for the Tampa Office Pond using a mass balance based on the summation of loads.

Table 2.5: Example of SOL Method results for TSS in the Tampa Office Pond.

Period of Record	**Sum of Loads In (kg)**	**Sum of Loads Out (kg)**	**SOL Efficiency**
1990	134.60	39.67	71%
1993-1994	404.19	138.44	66%
1994-1995	2060.51	130.20	94%
SOL Efficiency is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)			

Regression of Loads (ROL)

Definition

The regression of loads method as described by Martin and Smoot (1986) defines the regression efficiency as the slope (b) of a least squares linear regression of inlet loads and outlet loads of pollutants, with the intercept constrained to zero. The zero intercept is specified as an "engineering approximation that allows calculation of an overall efficiency and meets the general physical condition of zero loads-in (zero rainfall) yield zero loads-out". The equation for the ROL efficiency is:

$$\text{Loads out} = b \bullet \text{Loads in} = b - \frac{\text{Loads out}}{\text{Loads in}}$$

The percent reduction in loads across the BMP is estimated as:

$$\text{Percent Removal} = 1 - b = 1 - \frac{\text{Loads out}}{\text{Loads in}}$$

Due to the nature of stormwater event monitoring, it is rare that all of the assumptions for this method are valid, particularly requirements for regression analysis. The example calculations and plots provided in this section are from one of the better studies available at the time this manual was written, and as can be seen from the ROL plots, the data does not meet the requirements for proper simple linear regression analysis.

Assumptions

- Any significant storms that were not monitored had a ratio of inlet to outlet loads similar to the storms that were monitored. The slope of the regression line would not significantly change with additional data.

- No materials were exported during dry periods, or if they were, the ratio of inlet to outlet loads during these periods was similar to the ratio of the loads during the monitored storms.

- The data is well represented by a least squares linear regression, that is:

    - The data is “evenly” spaced along the x-axis.

    - Using an analysis of variance on the regression, the slope coefficient is significantly different from zero (the p value for the coefficient should typically be less than 0.05, for example).

    - A check of the residuals shows that the data meets regression requirements. The residuals should be random (a straight line on probability paper) and the residuals should not form any trend with predicted value or with time (i.e., they form a band of random scatter when plotted).

Comments

- A few data points often control the slope of the line due to clustering of loads about the mean storm size. Regressions are best used where data is equally populous through the range to be examined. This is readily observed in the examples that follow (See Figures 2.1 through 2.3).

- The process of constraining the intercept of the regression line to the origin is questionable and in some cases could significantly misrepresent the data. It may be more useful to apply the *Regression of Loads* method over some subset of the data without requiring that the intercept be constrained to the origin. The problem with this alternative approach is that a large number of data points are required in order to get a good fit of the data. Often a meaningful regression cannot be made using the data that was collected. This is well illustrated by the very low R^2 values in the table below. Forcing the line through the origin, in these cases, provides a regression line even where no useful trend is present.

- There is sufficient evidence that this first order polynomial (straight line) fit is not appropriate over a large range of loadings. Very small events are much more likely to demonstrate low efficiency where larger events may demonstrate better overall efficiency depending on the design of the BMP.

Table 2.6: Example of ROL Method results for TSS in the Tampa Office Pond.

Period of Record	**Slope of Regression Line**	**R^2**	**Percent Removal**
1990	0.21	0.06	79%
1993-1994	0.18	-0.06	82%
1994-1995	0.05	0.46	95%

Percent Removal is rounded, but the other numbers were not (to prevent introduction of any rounding errors in the calculations)

The regressions used to arrive at the above slopes are given in Figures 2.1-2.3.

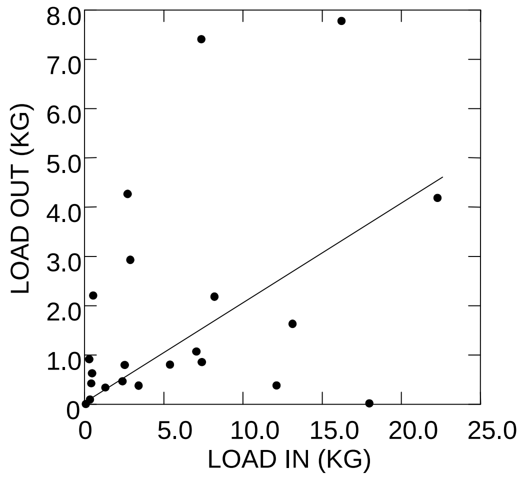

Figure 2.1: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1990) (Slope = 0.2135, R^2 = 0.0563, Standard Error in Estimate = 2.176, one point is considered an outlier with a Studentized Residual of 3.304). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

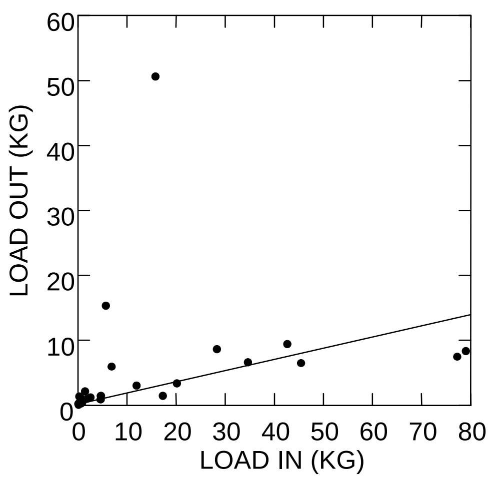

Figure 2.2: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1993-1994) (Slope = 0.1801, R^2 = -0.0562, Standard Error in Estimate = 10.440, one point is considered an outlier with a Studentized Residual of 13.206 and one point has a high Leverage of 0.323). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

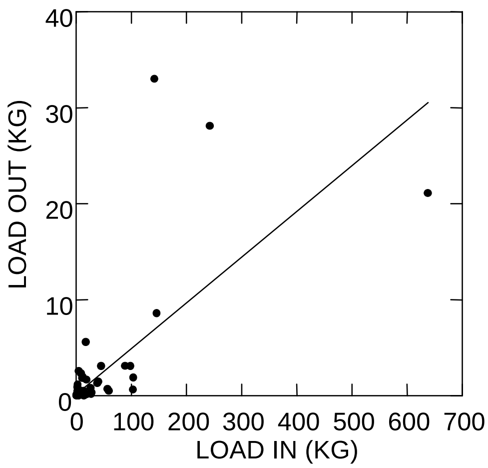

Figure 2.3: ROL Plot for use in Calculating Efficiency for TSS using the Tampa Office Pond (1994-1995) (Slope = 0.0492, R^2 = 0.4581, Standard Error in Estimate = 5.260, three points are considered outliers (Studentized Residuals of 3.724, 8.074, and –4.505, the point to the far right on the graph has large Leverage (0.724) and Influence, Cook Distance = 36.144). All points were used for regression. Method is not valid due to failure of simple linear regression assumptions.

Mean Concentration

Definition

The mean concentration method defines the efficiency as unity minus the ratio of the average outlet to average inlet concentrations. The equation using this method is:

$$\text{Mean Concentration} = 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

This method does not require that concentrations be flow weighted. This method might have some value for evaluating grab samples where no flow weighted data is available or where the period of record does not include the storm volume.

Assumptions

- The flows from which the samples were taken are indicative of the overall event.

Comments

- This method might be useful for calculating BMP's effectiveness in reducing acute toxicity immediately downstream of the BMP. This is due to the fact that acute toxicity is measured as a threshold concentration value of a specific constituent in the effluent at or near the point of discharge.

- This methods weights individual samples equally. Biases could occur due to variations in sampling protocols or sporadic sampling (i.e., collecting many samples close in time and others less frequently). The sample collection program specifics are not accounted for in the method and estimated efficiencies are often not comparable between studies.

- There is appreciable lag time for most BMPs between when a slug of water enters a BMP and when the slug leaves the BMP. Unless this lag time is estimated (e.g., through tracer studies) results from this approach can be quite inaccurate. Results of this method may be particularly difficult to interpret where lag time is ignored or not aggressively documented.

- This method does not account for storage capacity. Typically BMPs will have an equal or lesser volume of outflow than of inflow. On a mass basis this affects removal, since volume (or flow) is used with concentration to determine mass for a storm event,

$$1 - \frac{\mathrm{C}_{\mathrm{out}} V_{out}}{C_{in} V_{in}} \geq 1 - \frac{\text{average outlet concentration}}{\text{average inlet concentration}}$$

where,

C_{in}: Concentration In
C_{out}: Concentration Out
V_{in}: Volume In
V_{out}: Volume Out

In this respect, it is often more conservative (i.e., lower removal efficiency stated) to use a concentration rather than mass-based removal approach.

<u>Efficiency of Individual Storm Loads</u>

Definition

The Efficiency of Individual Storm Loads (ISL) method calculates a BMP's efficiency for each storm event based on the loads in and the loads out. The mean value of these individual efficiencies can be taken as the overall efficiency of the BMP. The efficiency of the BMP for a single storm is given by:

$$\text{Storm Efficiency} = 1 - \frac{Load_{out}}{Load_{in}}$$

The average efficiency for all monitored storms is:

$$\text{Average Efficiency} = \frac{\sum_{j=1}^{m} \text{Storm Efficiency}_j}{m}$$

where,

m: number of storms

Assumptions

- Storm size or other storm factors do not play central roles in the computation of average efficiency of a BMP.

- Storage and later release of constituents from one storm to the next is negligible.

- The selection of storms monitored does not significantly skew the performance calculation.

Comments

- The weight of all storms is equal. Large storms do not dominate the efficiency in this scenario. The efficiency is viewed as an average performance regardless of storm size.

- Some data points cannot be used due to the fact that there is not a corresponding measurement at either the inflow or the outflow for a particular storm, and thus efficiency cannot always be calculated on a storm-by-storm basis. This is not true for the ER method, however it is a limitation of the Summation of Load Method.

- Storm by storm analysis neglects the fact that the outflow being measured may have a limited relationship to inflow in BMPs that have a permanent pool. For example, if a permanent pool is sized to store a volume equal to the average storm, about 60 to 70 percent of storms would be less than this volume [from studies conducted using SYNOP (EPA 1989)].

Table 2.7: Example of Individual Storm Loads Method results for TSS in the Tampa Office Pond.

Period of Record	Efficiency
1990	29%
1993-1994	-2%
1994-1995	89%

Summary and Comparison of Historical Methods

The table below shows the results of the various historical methods shown above for calculating efficiency for the Tampa Office Pond. The four methods demonstrated (mean concentration method was not applicable to data available from the Tampa Office Pond study) vary widely in their estimates of percent removal depending on the assumptions of each method as discussed above.

Table 2.8: Comparison of BMP efficiency methods.

	Method			
Design	**Efficiency Ratio (ER)**	**Summation of Loads (SOL)**	**Regression of Loads (ROL)**	**Efficiency of Individual Storms**
1990	59%	71%	79%	29%
1993-1994	64%	66%	82%	-2%
1994-1995	95%	94%	95%	89%

2.9.2.2 Other Methods and Techniques

"Irreducible Concentration" and "Achievable Efficiency"

As treatment occurs and pollutants in stormwater become less concentrated, they become increasingly hard to remove. There appears to be a practical limit to the effluent quality that any BMP can be observed to achieve for the stormwater it treats. This limit is dictated by the chemical and physical nature of the pollutant of concern, the treatment mechanisms and processes within the BMP, and the sensitivity of laboratory analysis techniques to measure the pollutant. This concept of "irreducible concentration" has significant implications for how BMP efficiency estimates are interpreted. However, it is possible to get concentrations as low as desired, but in most cases achieving extremely low effluent concentrations may not be practical (i.e., would require treatment trains or exotic methods). For example, colloids are typically viewed as "never" being able to be removed in a pond (settling is the primary mechanism for treatment in ponds), despite the fact that they could be further removed through chemical addition.

The term "irreducible concentration" (C*) has been used in stormwater literature (Schueler 2000) to represent the lowest effluent concentration for a given parameter that can be achieved by a specific type of stormwater management practice. Schueler examined the effluent concentrations achieved by stormwater management practices from published studies for several parameters. From this research, the following estimates of "irreducible concentrations" for TSS, Total Phosphorous, Total Nitrogen, Nitrate-Nitrogen, and TKN for all stormwater management practices were proposed:

Table 2.9: "Irreducible concentrations" as reported by Scheuler, 2000.

Contaminant	Irreducible Concentration
TSS	20 to 40 mg/L
Total Phosphorous	0.15 to 0.2 mg/L
Total Nitrogen	1.9 mg/L
Nitrate-Nitrogen	0.7 mg/L
TKN	1.2 mg/L

Recent research (ASCE 2000) indicates that achievable effluent concentrations vary appreciably between BMP types. For example, in many cases, well-designed sand filters can achieve lower effluent concentrations of TSS than well-designed detention facilities or grassed swales. However, sand filters have issues with long-term maintenance of flow treatment volumes.

The typical approach to reporting the ability of a BMP to remove pollutants from stormwater entails comparing the amount of pollutant removed by the BMP to the total quantity of that pollutant. The concept of irreducible concentration, however, suggests that in some cases it may be more useful to report the efficiency of the BMP relative to some achievable level of treatment (i.e. express efficiency as the ability of the BMP to remove the fraction of pollutant which is able to be removed by a particular practice.)

The following example illustrates this approach. Suppose that two similar BMPs have been monitored and generated the following results for TSS:

Table 2.10: Example TSS results for typical ER Method

Percent TSS Removal Using Absolute Scale		
	BMP A	**BMP B**
Influent Concentration	200 mg/L	60 mg/L
Effluent Concentration	100 mg/L	30 mg/L
Efficiency Ratio	50%	50 %

Clearly, the effluent from BMP B is higher quality than that from BMP A, however comparing percent removals between BMPs alone would indicate that both BMPs have an equal efficiency. Methods have been suggested for quantifying the dependence of BMP efficiency on influent concentration. The following section presents one such method advanced by Minton (1998).

In order to account for the dependence of BMP efficiency on influent concentration, Minton (1998) suggests a method of evaluating BMP efficiency that would recognize the relationship between influent concentration and efficiency. The relationship is summarized as follows:

$$\text{Achievable Efficiency} = (C_{influent} - C_{limit}) / C_{influent}$$

where,

$C_{influent}$: Influent Concentration of Pollutant; and
C_{limit} : The lower attainable limit concentration of the BMP (e.g., "irreducible concentration" or value obtained from previous monitoring of effluent quality)

For example, if a BMP had a lower treatment limit of TSS at 20mg/L concentration, then at an influent TSS concentration of 100 mg/L, it would be assigned an equivalent performance of 80%, while at an influent TSS concentration of 50 mg/L the equivalent performance would be 60%.

This method relies on the ability to determine the lower attainable limit concentration, which is analogous to the "irreducible concentration" for a specific BMP, however effluent quality is best described not as a single value, but from a statistical point of view (See the Effluent Probability Method).

The Achievable Efficiency may be useful in better understanding the results of the ER method in cases where the influent concentration is lower than is typically observed.

Alternately, a single factor (dubbed the Relative Efficiency here) can be used to report how well a BMP is functioning during some period relative to what that BMP is theoretically or empirically able to achieve (as defined by the Achievable Efficiency).

As shown below, the Relative Efficiency can be found by dividing the Efficiency Ratio by the Achievable Efficiency, thus yielding an estimate of how well the BMP performed relative to what is "achievable".

$$\text{Relative Efficiency} =$$

$$\frac{\text{Efficiency Ratio}}{\text{Achievable Efficiency}} = \frac{[(C_{influent} - C_{effluent})/C_{influent}]}{[(C_{influent} - C_{limit})/C_{influent}]}$$

Or simplifying:

$$\text{Relative Efficiency} = (C_{influent} - C_{effluent})/(C_{influent} - C_{limit})$$

If applied to the example presented earlier in this section, the following results are obtained:

Table 2.11: Example TSS results for demonstration of Relative Efficiency approach.

	BMP A	**BMP B**
Influent Concentration	200 mg/L	60 mg/L
C_{limit}	20 mg/L	20 mg/L
Effluent Concentration	100 mg/L	30 mg/L
Relative Efficiency	56%	75 %

For this example, the results indicate that BMP B is achieving a higher level of treatment than BMP A and this approach may be more useful as a comparative tool than the Efficiency Ratio for some data sets. The Relative Efficiency for a BMP's effectiveness is still influenced by influent concentration but less so than is the Efficiency Ratio.

As $C_{influent}$ approaches C_{limit} the Relative Efficiency goes to infinity, which is not a very meaningful descriptor. However, if the influent concentration is near the "irreducible concentration" for a particular pollutant, very little treatment should occur and $C_{influent}$ - $C_{effluent}$ should approach zero. $C_{effluent}$, at least theoretically, should always be higher than C_{limit} and the numerator of the equation should approach zero faster than the denominator. If $C_{influent}$ is less than C_{limit}, the Relative Efficiency approach should not be used. As is always the case, any of the percent removal efficiency approaches (including the Efficiency Ratio Method) should not be employed if there is not a statistically significant difference between the average influent and effluent concentrations.

If this method is used to represent data from more than one event (i.e., mean EMCs are calculated) it should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences are statistically significant (it would be preferred to show the actual level of significance found, instead of just noting if the result was significant, assuming a 0.05 level).

Percent Removal Relative to Water Quality Standards

From a practical or programmatic perspective, it may be more useful to substitute the water quality limit for the "irreducible concentration" as a measure of how well the BMP is meeting specific water quality objectives. A measure of efficiency can be calculated to quantify the degree to which stormwater BMPs employed are meeting or exceeding state or federal water quality criteria or standards for the runoff they treat.

Standards are enforceable regulations established within the context of an NPDES permit or a TMDL and are usually specific to the receiving water. Water quality criteria are more general guidelines expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular beneficial use.

By showing that stormwater is being treated to a level that is higher than standards require or criteria recommend, a permitee may be able to demonstrate to regulators or stakeholders that their current stormwater management practices are adequate for a particular constituent of concern. The equation to calculate the Percent Removal Relative to Receiving Water Quality Limits is as follows:

Percent Removal Relative to Receiving Water Quality Limits =

$$(C_{influent} - C_{effluent})/(C_{influent} - C_{standard/criterion})$$

The following example illustrates the application of this approach for reporting efficiency:

Table 2.12: Example of percent removal relative to receiving water quality limits approach.

	BMP A
Influent Concentration (EMC)	1.65 ug/l
$C_{standard/criterion}$	0.889 ug/l
Effluent Concentration (EMC)	0.635 ug/l
Percent Removed Relative to Established WQ Limits	133 %

The results indicate that the BMP for the given event is meeting the water quality standard or criterion for dissolved lead. In fact the BMP is functioning to remove in excess of the amount needed to bring the influent concentration below the water quality limit (as indicated in the example by a value greater than 100%). Use of this method is only recommended for specific event analysis. As mentioned for previous analyses, if this approach is taken for a series of events it should be supplemented with an appropriate non-parametric (or if applicable parametric) statistical test indicating if the differences are statistically significant (it would be better to show the actual level of significance found, than just noting if the result was significant, assuming a 0.05 level)

<u>“Lines of Comparative Performance©”</u>

For many stormwater treatment BMPs, the efficiency of the BMP decreases as a function of the influent concentration. Methods have been recommended that integrate this concept into efficiency evaluations. The “Lines of Comparative Performance©” (Minton 1999) is one such method.

In this method, plots of percent removal as a function of the influent concentration for each storm are generated for each pollutant monitored. The results of these plots are overlain on plots of data collected from studies of similar BMPs within a region.

“Lines of Comparative Performance©” are generated for the data from similar BMPs based on best professional judgment by examining the likely “irreducible concentration” for a particular pollutant, the detection limit for that pollutant, and knowledge of expected maximum achievable efficiency for a BMP type.

This method has primarily been suggested as an approach to evaluate the efficiency of innovative and “unapproved” stormwater technologies. “To be accepted, the performance data points of an unapproved treatment technology must fall above and to the left of the ‘Line of Comparative Performance©’.”

This approach has several major problems. The most significant flaw is the use of “spurious” self-correlation. Plots such as those shown in Figures 2.4 through 2.6 can be generated using random, normally distributed influent and effluent concentrations as seen below in Figure 2.7. As such, **it is strongly recommended that this approach not be employed** in BMP monitoring evaluation studies. This approach may lead to overly complicated analysis methodologies without providing additional useable information on BMP functionality.

Figures 2.4-2.6 below show work conducted by Minton in the development of the Achievable Efficiency approach.

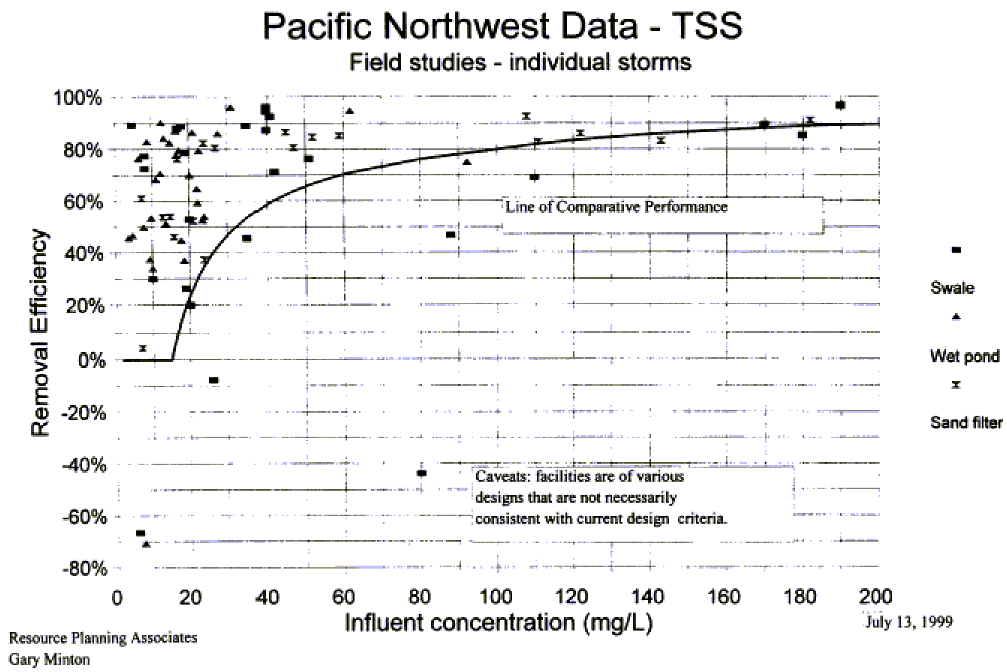

Figure 2.4: Removal Efficiency (ER Method) of TSS as a Function of Influent Concentration (Minton 1999)

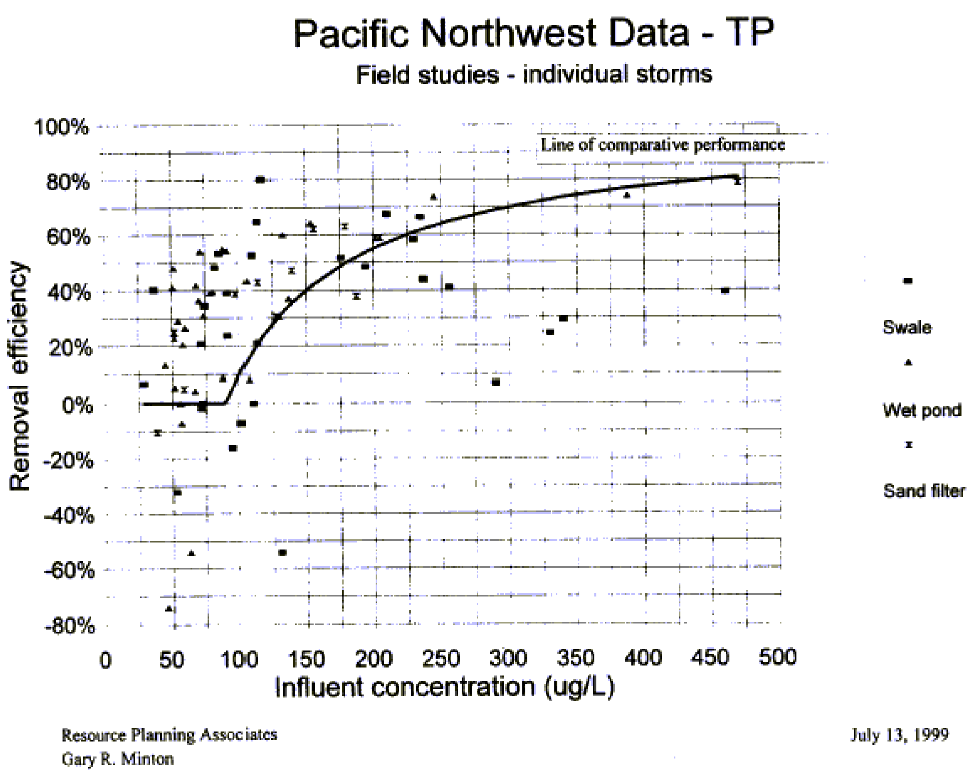

Figure 2.5: Removal Efficiency (ER Method) of Total Phosphorous as a function of influent concentration (Minton 1999)

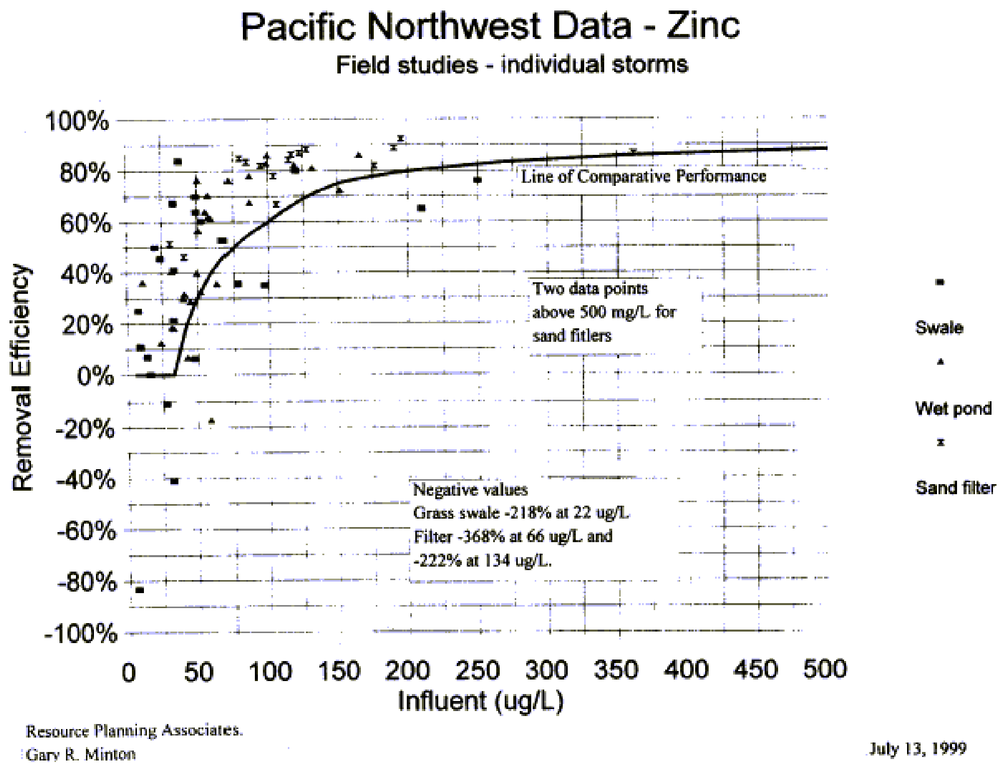

Figure 2.6: Removal Efficiency (ER Method) of Total Zinc as a Function of Influent Concentration (Minton 1999)

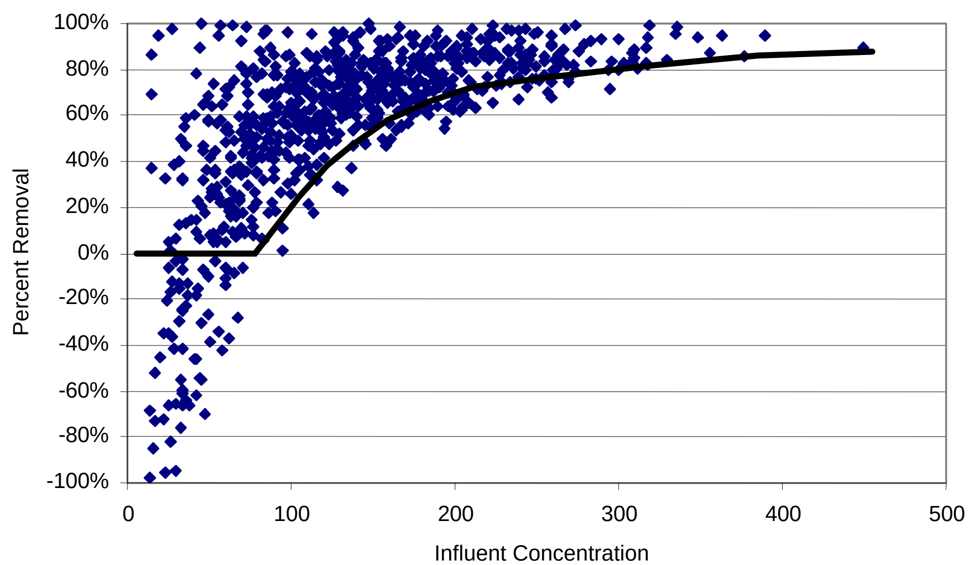

Figure 2.7: Percent removal as a function of influent concentration for randomly generated, normally distributed influent and effluent concentrations. Any number of similar charts can be generated from randomized data.

An alternate method which does not include the serious problems associated with the "Lines of Comparative Performance©", but presents relatively the same information can be generated using a simple plot of effluent concentration as a function of influent concentration with "rays" (or curves on a log plot) originating from the plot origin for several levels of control (e.g., 0, 25, 50, 75, and 90%). The plot may need to be a log-log plot for data with a large range of values typical of stormwater monitoring data.

Multi-Variate and Non-Linear Models

Reporting efficiency as a percent removal that is calculated based on the difference between influent and effluent concentrations will always make a BMP that treats higher strength influents appear to be more efficient than one treating weaker influents if both are achieving the same effluent quality. A more useful descriptor of efficiency would take into consideration that weaker influents are more difficult to treat than concentrated ones. A multi-variate equation that includes corrections to compensate for this phenomena or a non-linear model may be worth considering for reporting efficiency.

A model that approaches pollutant removal in a manner similar to the reaction rates for complex physical and chemical batch and plug-flow processes may be useful. To date calibration of such a model for all but the most elementary situations (e.g., settling of solids in relatively simplistic flow regimes) is difficult given the complexity of the real-world problem. As more high quality data becomes available, other approaches to evaluating BMP efficiency may become apparent.

Currently, effluent quality, as discussed below, is the best indicator of overall BMP performance.

2.9.2.3 Recommended Method

The following method is recommended for use in analyzing new and existing monitoring studies.

Effluent Probability Method

The most useful approach to quantifying BMP efficiency is to determine first if the BMP is providing treatment (that the influent and effluent mean EMCs are statistically different from one another) and then examine either a cumulative distribution function of influent and effluent quality or a standard parallel probability plot.

Before any efficiency plots are generated, appropriate non-parametric (or if applicable parametric) statistical tests should be conducted to indicate if any perceived differences in influent and effluent mean event mean concentrations are statistically significant (the level of significance should be provided, instead of just noting if the result was significant, assume a 95% confidence level).

Effluent probability method is straightforward and directly provides a clear picture of the ultimate measure of BMP effectiveness, effluent water quality. Curves of this type are the single most instructive piece of information that can result from a BMP evaluation study. The authors of this manual strongly recommend that the stormwater industry accept this approach as a standard "rating curve" for BMP evaluation studies.

The most useful approach for examining these curves is to plot the results on a standard parallel probability plot (see Figures 2.8-2.10). A normal probability plot should be generated showing the log transform of both inflow and outflow EMCs for all storms for the BMP. If the log transformed data deviates significantly from normality, other transformations can be explored to determine if a better distributional fit exists. Figures 2.8-2.10 show three types of results that can be observed when plotting pollutant reduction observations on probability plots. The data was taken from the Monroe St. wet detention pond study in Madison, WI, collected by the USGS and the WI DNR. Figure 2.8 for suspended solids (particulate residue) shows that SS are highly removed over influent concentrations ranging from 20 to over 1,000 mg/L. A simple calculation of "percent removal" (ER Method) would not show this consistent removal over the full range of observations. In contrast, Figure 2.9 for total dissolved solids (filtered residue) shows poor removal of TDS for all concentration conditions, as expected for this wet detention pond. The "percent removal" (ER Method) for TDS would be close to zero and no additional surprises are indicated on this plot. Figure 2.10, however, shows a wealth of information that would not be available from simple statistical numerical summaries, including the historical analysis approaches described in this manual. In this plot, filtered COD is seen to be poorly removed for low concentrations (less than about 20 mg/L), but the removal increases substantially for higher concentrations. Although not indicated on these plots, the rank order of concentrations was similar for both influent and effluent distributions for all three pollutants (Burton and Pitt 2001).

Water quality observations do not generally form a straight line on normal probability paper, but do (at least from about the 10th to 90th percentile level) on log-normal probability plots. This indicates that the samples generally have a log-normal distribution as described previously in this document and many parametric statistical tests can often be used (e.g., analysis of variance), but only after the data is log-transformed. These plots indicate the central tendency (median) of the data, along with their possible distribution type and variance (the steeper the plot, the smaller the COV and the flatter the slope of the plot, the larger the COV for the data). Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities (or differences) in the data sets. Most statistical methods used to compare different data sets require that the sets have the same variances, and many require normal distributions. Similar variances are indicated by generally parallel plots of the data on the probability paper, while normal distributions would be reflected by the data plotted in a straight line on normal probability paper. (Burton and Pitt 2001)

Probability plots should be supplemented with standard statistical tests that determine if the data is normally distributed. These tests, at least some available in most software packages, include the Kolmogorov-Smirnov one-sample test, the chi-square goodness of fit test, and the Lilliefors variation of the Kolmogorov-Smironov test. They are paired tests comparing data points from the best-fitted normal curve to the observed data. The statistical tests may be visualized by imagining the best-fit normal curve data (a straight line) and the observed data plotted on normal probability paper. If the observed data crosses the fitted curve data numerous times, it is much more likely to be normally distributed than if it only crosses the fitted curve a small number of times (Burton and Pitt 2001).

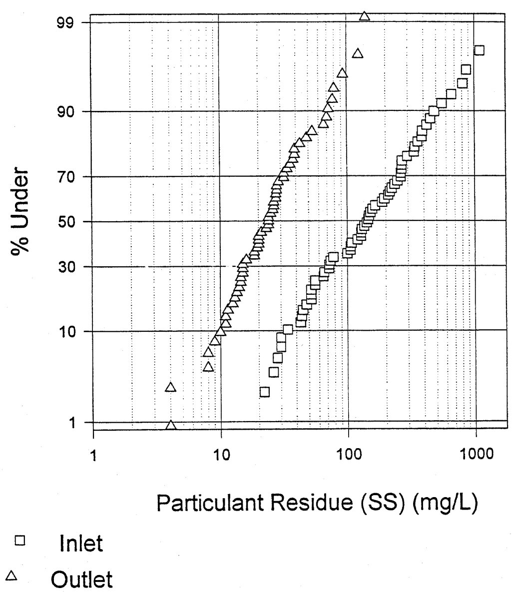

Figure: 2.8: Probability plot for Suspended Solids

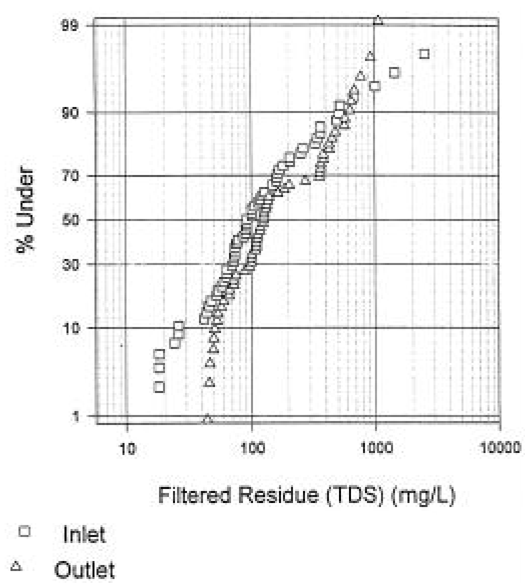

Figure: 2.9 Probability plot for Total Dissolved Solids

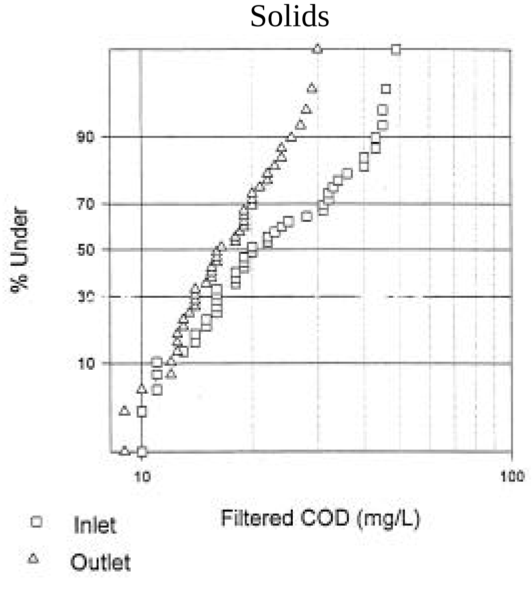

Figure: 2.10: Probability plot for Chemical Oxygen Demand

(Originally by Burton and Pitt 2001)

2.9.2.4 Reference Watershed Methods

Many BMPs do not allow for comparison between inlet and outlet water quality parameters. In addition, it is often difficult or costly, where there are many BMPs being installed in a watershed (e.g., retrofit of all catch basins), to monitor a large number of specific locations. A reference watershed is often used to evaluate the effectiveness of a given BMP or multiple BMPs of the same type. The database allows for a watershed and all associated data to be identified for use as a reference watershed. One of the primary reasons for using a reference watershed is that for some BMPs there is no clearly defined inlet or outlet point at which to monitor water quality. Such is the case with many non-structural BMPs, porous pavements, and infiltration practices.

The difficulty in determining the effectiveness of a BMP using a reference watershed approach stems from the large number of variables typically involved. When setting up a BMP monitoring study, it is advantageous to keep the watershed characteristics of the reference watershed and the test watershed as similar as possible. Unfortunately, finding two watersheds that are similar is often quite difficult, and the usefulness of the data can be compromised as a result. In order to determine the effectiveness of a BMP based on a reference watershed, an accurate accounting of the variations between the watersheds, and operational and environmental conditions is needed. The Database explicitly stores some of the key parameters required for normalization of watershed and environmental conditions.

The most obvious parameter used to normalize watershed characteristics is area. If the ratio of land uses and activities within each watershed is identical in both watersheds then the watershed area can be scaled linearly. The loads found at each downstream monitoring station for each event can be scaled linearly with area as well. Difficulty arises when land use in the reference watershed is not found in the same ratio. In this case, either the effects of land use must be ignored or a portion of the load found for each event must be allocated to a land use and then scaled linearly as a function of the area covered by that land use. In many cases, the differences in land use can be ignored, (e.g., between parking lots with relatively small, but different unpaved areas). The effect of the total impervious area is relevant and should always be reported in monitoring studies. The ratio of the total impervious areas can be used to scale event loads. Scaling the loads based on impervious areas would be best used where the majority of pollutants are from runoff from the impervious areas (e.g., parking lots), or the contaminant of interest results primarily from deposition on impervious surfaces, (e.g., TSS in a highly urban area). Methods that attempt to determine BMP performance from poorly matched watersheds yield poor results at best. As the characteristics of the two watersheds diverge, the effect of the BMP is masked by the large number of variables in the system; the noise in the data becomes greater than the signal.

The analysis of BMPs utilizing reference watersheds also requires incorporation of operational details of the system, (e.g., frequency of street sweeping, type of device used, device setup). Monitoring studies should always provide the frequency, extent, and other operational parameters for nonstructural BMPs. If the BMP is an alteration of the frequency of a certain practice, the system can be viewed in two ways, (1) as a control/test system, or (2) as a series of data aimed at quantifying the continuous effect of increasing or decreasing BMP frequency. In the first case, the BMP can be analyzed in a manner similar to other BMPs with reference watersheds. In the second case, the loads realized at the monitoring stations need to be correlated with the frequency using some model for the effectiveness of the practice per occurrence.

2.9.3 BMPs and BMP Systems

Overflow and bypassing of treatment BMPs affect the long-term performance of the pollution control measure. Many types of BMP structures, such as detention or filtration basins, are designed to treat specific volumes of stormwater runoff. Runoff volumes (or flows) exceeding the designed storage volume or maximum flow rate are bypassed untreated or partially treated. In order to accurately assess the long-term efficiency of the BMP system, the bypass flow needs to be taken into consideration. Ideally, a third flow monitor should be installed to measure by-passed flow directly (Oswald and Mattison 1994).

If monitoring data is not cost effective or physically difficult to collect, estimates of bypass can be made using inflow / outflow water balance calculations or modeled from local rainfall data, watershed hydrology, and BMP system hydraulics. The volume treated by a BMP for each event can be compared to a measured or modeled runoff volume yielding the volume of bypass.

Estimates of BMP system efficiency should always be calculated for the entire BMP system (in addition to the BMP). Mass balance checks should be performed in all cases to help verify monitoring data and/or modeled flow rates.

3 Developing a BMP Monitoring Program

This chapter describes the steps involved in developing and implementing a monitoring program to evaluate BMP effectiveness. Regardless of the scope and objectives, designing a monitoring plan generally involves four phases:

Phase 1: Determine the objectives and scope of your monitoring program
Phase 2: Develop the monitoring plan in view of your objectives
Phase 3: Implement the monitoring plan
Phase 4: Evaluate and report the results of monitoring

The activities associated with each phase are listed below.

<u>Phase 1: Determine Objectives and Scope</u>

- Identify permit requirements and/or information needs
- Compile and review existing information (maps, drawings, results from prior sampling, etc.) relevant to permit requirements and/or information needs
- Develop monitoring program objectives and scope

<u>Phase 2: Develop Monitoring Plan</u>

- Select monitoring locations
- Select monitoring frequency
- Select parameters and analytical methods
- Select monitoring methods and equipment
- Select storm criteria (i.e., size, duration, season)
- Develop mobilization procedures
- Prepare a quality assurance/quality control plan
- Prepare a health and safety plan
- Prepare a data management plan

<u>Phase 3: Implement Monitoring Plan</u>

- Install equipment (and modify channels, if applicable)
- Test and calibrate equipment
- Conduct training
- Conduct monitoring (collect samples)
- Conduct analyses (field and/or laboratory)

Phase 4: Evaluate and Report Results

- Validate chemical data quality
- Evaluate results
- Report the results

Several of the steps in developing a monitoring program are dependent on one another. Consequently, earlier steps may need to be revisited and refined throughout the planning process. For example, if it is determined in Phases 2 or 4 that monitoring more storms is needed to achieve objectives, revisiting the "select monitoring location" task and selecting a lower number of sampling locations and/or a different analytical scheme may be needed to keep within the schedule and budget.

Determine Key Study Parameters

Key parameters of the monitoring project are determined using the information gathered in the previous steps of the systematic planning process. Key study parameters include site selection, number of monitored storm events and their temporal distribution, characteristics of target storm events, types of samples (composite, grab, etc.), and analytical constituents. The better these characteristics are understood, the more efficiently the monitoring data can be collected (Caltrans 1997).

The planned number of sites and monitoring events are often constrained by fiscal factors, such as the cost of sample collection and analysis. For this reason, the list of analytical constituents is often considered in the early stages of project planning (see Section 3.2.3), so that costs of the appropriate sample collection and analysis can be factored into the expected cost per monitoring event. The analytical constituents are often prescribed by regulatory or legal mandate.

3.1 Phase I – Determine Objectives and Scope of BMP Water Quality Monitoring Program

It is particularly important that the objectives of a BMP monitoring program be clearly stated and recorded. The process of writing them down generally results in careful consideration being given to the possible options. Written objectives help avoid misunderstandings by project participants, are an effective way of communicating with sponsors, and provide assurance that the monitoring program has been systematically planned.

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?

- Does this BMP help achieve compliance with water quality standards?

Many BMP monitoring programs have been established to satisfy requirements prescribed by permits to monitor the effectiveness of BMPs, but often the wording of such requirements is vague. Local program-specific objectives are likely to provide the soundest basis for planning a BMP monitoring study.

A well-designed BMP monitoring program may help address specific monitoring questions, thereby enabling better decisions regarding allocation of resources to address stormwater quality issues. The ultimate use of the monitoring results should be kept in mind throughout the monitoring program planning process.

3.1.1 Monitoring and Literature Review to Assess BMP Performance

Typically, structural BMPs have well-defined boundaries and are 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.

It is assumed that many stormwater quality management programs will consider the possibility of implementing some structural BMPs by experimenting with them on a pilot-scale by testing and demonstrating their performance, their costs, and their practical implications before committing to larger-scale implementation. Programs that already have structural BMPs in place may also test their performance for a variety of reasons.

Before obtaining BMP performance data or establishing the objectives and scope of the BMP monitoring program, it is useful to investigate other regional BMP monitoring programs to learn from their successes and/or failures in implementing the BMP, establishing their objectives and scope of their BMP monitoring program, and obtaining meaningful results. This research will also provide some level of foresight in developing a meaningful monitoring program that will produce results that will be useful in achieving project goals and comparable to other programs.

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 are not implemented. Some of the guidance provided in this manual and referred to in literature citations is intended 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 their usefulness for evaluating the effectiveness of stormwater wetlands. 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 conceptual and strategic aspects of monitoring (e.g., Strecker 1994; Urbonas 1993) could be of particular value during the planning stage. In addition, EPA and ASCE's Urban Water Resources Research Council have compiled a National Stormwater Best Management Practices Database (ASCE 1999) (on the world wide web at http://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. Review of the protocols established for the database is useful in determining what and how information should be collected.

It is also valuable to review the monitoring methods and findings of other reported programs because they may contain transferable concepts (or even data). In considering the use of data collected elsewhere, critical attention must be given 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 errors that are often introduced by assuming (rather than determining) that certain pollutants are associated with certain sediment fractions.

These associations of pollutants with particles are very important (in fact they are the reason why most BMPs are effective), but they vary dramatically from place to place and must be determined based on careful local studies of relevant factors. When reviewing data from relatively early studies, it is important to remember that state of the art of analyses has advanced considerably in the past decade or so. For example, many data entries that report "non-detect" may not be relevant.

3.1.2 Monitoring to Assess Compliance with Surface Water quality criteria

A main objective of BMP monitoring is to determine if the BMP helps reduce concentrations of constituents of concern and therefore achieves compliance with water quality criteria set forth by state and federal regulations.

Water quality standards may include bacteria, dissolved oxygen, temperature, pH, turbidity, and toxic organic and inorganic compounds in marine and freshwater bodies. The water quality standards for toxic compounds (e.g., metals, pesticides) are intended to protect aquatic organisms, terrestrial animals, and humans who drink the water and/or consume shellfish and fish from the waterbody. In addition, the water quality bacterial standards are intended to guard against human health risks associated with recreational activities such as swimming, wading, boating, fishing, and shellfish consumption.

State water quality standards often include the federal water quality criteria for the protection of human health and aquatic life (40 CFR 131.36). Federal water quality criteria may include a number of additional compounds not listed in state water q
uality standards.

Note that water quality criteria are guidelines, whereas water quality standards are enforceable regulations. In this section, water quality criteria are 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.

3.1.3 Criteria for the Protection of Aquatic/Marine Life

Criteria for the protection of aquatic and marine life were developed based on laboratory toxicity tests of representative organisms using test solutions spiked with pollutants to simulate exposure. In order to apply the results of these tests, EPA has classified aquatic life standards as either "acute" or "chronic" based on the length of time the organisms are exposed to the 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. EPA suggests one hour as the shortest exposure period, which 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. EPA derives chronic criteria from longer term (often greater than 28-day) tests that measure survival, growth, reproduction, or in some cases, bioconcentration. For chronic criteria, EPA recommends the criteria be applied to an averaging period of 4 days. That is, the 4-day average exposure should not exceed the chronic criteria.

water quality criteria 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 too often.

3.1.4 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 non-carcinogens, exposure periods are more chemical specific and depend on the particular endpoint and toxic effect.

EPA 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 are the calculated water-column concentrations that would produce a one in a million (10^{-6}) lifetime cancer risk if water were consumed by humans and a given amount of organisms, like fish or shellfish, living in that water was eaten every day. The second set of criteria is based on consumption of organisms alone (the water is not consumed by humans). These standards apply to saltwater or other water that is not a drinking water source but does support a fishery, and that is used as food. The standard for carcinogenic compounds in the consumption of organisms only criteria 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 waterbody (without drinking the water).

3.1.5 Application of Water quality criteria to Stormwater

The water quality criteria 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 water quality criteria is usually conducted in a receiving water body (rather than in the stormwater conveyance system that discharges into it) in order to provide a direct measure of whether the beneficial uses of the waterbody are impaired or in jeopardy.

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

The variable nature of stormwater quality further complicates comparison to water quality standards. Stormwater quality varies both between and during storm events, 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 water quality standards can provide valuable information for stormwater management. Water quality standards can be used as screening criteria, or "benchmarks," for assessing stormwater quality problems and establishing management priorities. Direct comparisons with the water quality criteria 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 water quality standards exceedances within storm sewer systems can help prioritize additional investigations and/or implementation of control measures. Frequent 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.

3.1.6 Groundwater and Sediment Standards

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 in order 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.

3.1.7 Scope of Work for BMP Monitoring Program

Once monitoring objectives have been defined, the scope of the monitoring program must be determined. It is important to balance information needs with the resources available, and to consider alternative means for obtaining information. To that end, consider the following:

- How accurate or representative do the monitoring results need to be in order to support forthcoming management decisions?

If objectives include determination of stormwater quality trends or evaluation of BMP effectiveness, numerous storms may need to be monitored in order to account for the variability inherent in stormwater quality data. It can be difficult and expensive to obtain truly definitive stormwater data. For example, one of the City of Fresno's monitoring programs (15 storms per year) has a 20% probability of detecting a 20% change in stormwater quality at a confidence level of 95%. This monitoring program was expected to cost about $1.55 million over 10 years, which was about 21% of Fresno's total budget for stormwater management during that period. To attain an 80% probability of detecting a 20% change at a 95% confidence limit, the monitoring cost would have risen to about $5.84 million, or 41% of the total stormwater management budget (Harrison 1994).

Note that the BMPs necessary to reduce stormwater contamination from built-out areas by 20% would probably be costly and challenging to implement. Cave and Roesner (1994) estimated that typical non-structural BMPs are likely to result in stormwater pollutant reductions on the order of 5%-10%, while structural measures may reduce some stormwater pollutants by 50%-90%. They suggested that a fully implemented municipal stormwater management program is likely to result in pollutant load reductions of 25% or less for built-out areas. This number, however, has been cited by others to be closer to 40% (Bannerman 2001).

Devoting large amounts of time and money to achieve a high level of accuracy may not be the best use of stormwater program resources. It might be more cost effective to spend less on trend monitoring and more on source identification, sediment monitoring, and/or control measures. In some cases, a simple, screening-type monitoring program may be sufficient to meet needs.

- Are sufficient staff and financial resources available to obtain the needed information at the desired level of accuracy? If not, can additional resources be obtained?

This is a critical consideration. BMP monitoring is generally expensive and time-consuming. This question can be addressed by developing an overview of monitoring required and reviewing general cost information of other programs.

In assessing personnel resources, consider staff size, technical background, physical condition, and ability (and willingness) to respond to storm events with little advance notice. These factors are discussed below.

<u>Staff Size</u>. Few organizations can afford to have many personnel whose sole responsibility is stormwater monitoring. In most cases, monitoring duties are assigned to

certain people in addition to their regular responsibilities. Back-ups are needed in case the designated personnel are sick, on vacation, or otherwise unavailable when a storm monitoring event occurs. The assigned people must be able and willing to drop what they are doing and mobilize for a storm event on short notice. In some organizations, personnel are not allowed to perform work that is not specified in their job descriptions. Insurance and liability may also be considerations. Because of these staffing issues, some agencies elect to hire contractors to perform monitoring.

<u>Technical Expertise</u>. Some technical expertise is needed to properly conduct monitoring, especially if automated equipment is used. Special training is required for any personnel that enter confined spaces, such as manholes, to collect samples. In addition, the person directing a monitoring program should be familiar with how the results will be used, so that effective decisions are made regarding storm selection, when to cancel a monitoring event, etc.

<u>Physical Condition/Health</u>. Stormwater monitoring can be physically demanding. Monitoring personnel may be required to work in slippery or otherwise challenging conditions at night.

<u>Ability to Respond to Storm Events</u>. Storms often occur outside of normal working hours when it is more difficult to contact and mobilize monitoring personnel.

If resources are not sufficient to sample enough storms and/or enough locations to meet tentatively identified program objectives, monitoring program objectives and scope should be scaled back until they are commensurate with resources. This can sometimes be accomplished by using a phased approach where only one or two areas or questions are addressed at a time so that useful results can be obtained within budget limitations. Supplementing existing resources should also be considered. It may be worthwhile to contact neighboring municipalities or facilities to find out if they are willing to pool their resources in order to fund a joint BMP monitoring program. If objectives cannot be met with the available resources, possible alternatives to stormwater monitoring should be considered (discussed below), or monitoring resources should be allocated to additional pollution control measures.

- Can some of the information needed be obtained without conducting BMP monitoring?

Because of the typically high cost of BMP monitoring, it may be desirable to evaluate alternative means for addressing some information needs (assuming that BMP monitoring is not required to comply with a permit). Depending on the situation, sediment sampling, biological sampling, and/or visual surveys of the stormwater conveyance system may be cost-effective alternatives to stormwater quality monitoring. Literature reviews may also help address some stormwater management issues.

- Who is going to use the monitoring data and what is the intended use?

Develop specific monitoring objectives and scope based on answers to these questions. At this point, the objectives should still be considered flexible because they may need to be re-considered and revised as the monitoring program is developed.

3.1.8 Information Needs to Meet Established Goals of BMP Monitoring

Generally, the more information that is available, the easier it is to design a practical monitoring program. For BMP monitoring programs, compile and review the following information, if available:

- Results from prior surface water and groundwater quality studies, other BMP monitoring studies in the local area, sediment quality studies, aquatic ecology surveys, dry weather reconnaissance, etc.
- Drainage system maps.
- Land use maps (or general plan or zoning maps).
- Aerial photographs.
- Precipitation and streamflow records.
- Reported spills and leaks.
- Interviews with public works staff.
- Literature on design of structural BMPs to understand functionality and pollutant removal processes.

For BMPs monitored in industrial areas, the following information may also be relevant:

- BMP performance data for similar industries in region.
- Facility map(s) showing locations of key activities or materials that could be exposed to stormwater.
- Lists of materials likely to be exposed to stormwater.
- Reported spills and leaks.
- Interviews with facility staff and others who are knowledgeable about the facility.

In addition to gathering information about the study area and BMP design, some forethought should be given to the expected data characteristics and subsequent data analysis methods in order to optimize collection of data within the limitations of the proposed study and ensure that useful results will be provided to fulfill study objectives (Caltrans 1997).

Essential data characteristics include the type of data to be collected (e.g., constituents and concentrations), the variables affecting the data (e.g., antecedent conditions, rainfall intensity, site type and location) and the expected variability of the data (derived from previous studies when available). Statistical techniques such as power analysis can then be used to determine key study parameters, such as the number of monitoring locations and storm events to be monitored (Caltrans 1997).

Prior to the initiation of environmental sampling, a strategy should be developed for analysis of the data, directed to answering the specific study questions. The selected data analyses technique(s) may influence the types and quantities of data required to satisfy study objectives. The analysis methods applied to data collected for BMP evaluations or characterization studies typically involve straight-forward statistical operations.

3.2 Phase II – Develop BMP Monitoring Plan

3.2.1 Recommendation and Discussion of Monitoring Locations

The number of locations to be monitored depends on program objectives, permit requirements (if applicable), the size and complexity of the drainage basin(s), and the resources (time, personnel, funds) allocated to monitoring. In addition, the frequency of sampling at each location must be considered. Depending on objectives, resources, and logistical considerations, many locations may be sampled infrequently, or fewer locations more frequently. The former approach is generally better for evaluating place-to-place variability; the latter approach is generally better for evaluating storm-to-storm variability and for characterizing the monitoring location more accurately. If the effectiveness of a specific structural BMP needs to be evaluated, monitoring locations should be located immediately upstream and downstream of the structure.

In general, choose monitoring sites that facilitate representative sampling and flow measurement. Consider the criteria listed below in the selection of monitoring sites:

- The contributing (upgradient) catchment should be completely served by a separate storm drain system or, if it is served by a combined sewer system, carefully consider the possibility that stormwater samples would be contaminated by sanitary sewage.

- The storm drain system should be sufficiently well understood to allow a reliable delineation and description of the catchment area (e.g., geographic extent, topography, land uses).

- For monitoring stations that will be used to measure flow in open channels, the flow measurement facilities need to be located where there is suitable hydraulic control so that reliable rating curves (i.e., stage-discharge relationships) can be developed. In other words, the upstream and downstream conditions must meet the assumptions on which the measurement method is based.

- Where possible, stations should be located in reaches of a conveyance where flows tend to be relatively "stable" and "uniform" for some distance upstream (approximately 6 channel widths or 12 pipe diameters), to better approach "uniform" flow conditions. Thus, avoid steep slopes, pipe diameter changes, junctions, and areas of irregular channel shape due to breaks, repairs, roots, debris, etc.

- Locations likely to be affected by backwater and tidal conditions should be avoided since these factors can complicate the reliable measurement of flow and the interpretation of data.

- Stations in pipes, culverts, or tunnels should be located to avoid surcharging (pressure flow) over the normal range of precipitation.

- Stations should be located sufficiently downstream from inflows to the drainage system to better achieve well-mixed conditions across the channel and to favor the likelihood of "uniform" flow conditions.

- Stations should be located where field personnel can be as safe as possible (i.e., where surface visibility is good and traffic hazards are minimal, and where monitoring personnel are unlikely to be exposed to explosive or toxic atmospheres).

- Stations should be located where access and security are good, and vandalism of sampling equipment is unlikely.

- Stations should be located where the channel or storm drain is soundly constructed.

- If an automated sampler with a peristaltic pump is to be used, and the access point is a manhole, the water surface elevation should not be excessively deep (i.e., it should be less than 6 meters, or 20 feet, below the elevation of the pump in the sampler, and preferably less than 4.5 meters or 15 feet deep).

- If automated equipment is to be used, the site configuration should be such that confined space entry (for equipment installation, routine servicing, and operation) can be performed safely and in compliance with applicable regulations.

Each potential sampling station should be visited, preferably during or after a storm to observe the discharge. A wet-weather visit can provide valuable information regarding logistical constraints that may not be readily apparent during dry weather.

Integration of BMP Monitoring into a Municipal Monitoring Program

In most cases, it is not practical to monitor water quality at every BMP within a municipality. Therefore, most municipal monitoring programs are designed to yield estimates of effluent water quality for other similar BMPs by extrapolating data collected at a small number of locations.

Many municipal stormwater monitoring programs use stations that monitor relatively small, homogeneous land use catchments (so called "single land use" or upland stations). Data from a study site may then be extrapolated to other catchments within the project area that are thought to have similar sources and pollutant-generating mechanisms. This approach may also be useful for BMP monitoring studies. However, extrapolations should be interpreted with caution because it is difficult to ascertain the degree to which catchments and BMP functionality are truly similar. Also, previous studies have shown that stormwater quality within a given land use category can vary considerably; thus, the correlation between land use and stormwater quality, and thus the utility of a particular BMP, may not be as strong as is typically assumed.

Other municipal programs use stations that sample relatively large catchments representing a composite of land uses. These stations are typically located in streams or other stormwater conveyances at the lower end of a watershed and are sometimes referred to as "mixed land use" stations or "stream stations." If possible, choose stream stations that receive runoff from catchments with a land use composition similar to that of the project area as a whole. This will make it easier to apply BMP monitoring results to similar watersheds. A geographic information system (GIS) can be very helpful in characterizing land uses and identifying stormwater monitoring locations.

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 (see Section 3.2.1). The added cost of a weir or flume, as opposed to less sophisticated flow measurement methods, is almost always worthwhile because measurement errors propagate through various aspects of the analysis. Propagation of errors due to inaccurate measurement is discussed in detail in Section 3.2.4.3.

It is often difficult to identify large, homogeneous land use catchments that satisfy all of the above criteria. As a result, compromises will typically need to be made. Refer to basic texts on hydraulics and flow measurement and the instructions provided by monitoring equipment manufacturers to guide judgment.

Sampling from a Well Mixed Location

The location of a permanent sampling station is probably the most critical factor in a monitoring network that collects water quality data. If the samples collected are not representative of the water mass, the frequency of sampling as well as the mode of data interpretation and presentation becomes inconsequential. The following paragraphs describe the theory of mixing within a river cross-section, which is applicable to stormwater flows within stormwater conveyance systems. Typically these calculations are not needed for stormwater monitoring design, but they are presented here to bring attention to the need to be aware of mixing problems, particularly in wide conveyances. (Saunders 1983)

The representativeness of a water quality sample is a function of the uniformity of the sample concentrations in a river’s cross sectional area. Wherever the concentration of a water quality variable is independent of depth and lateral location in a river's cross section, the river at that point is completely mixed and could serve as a desirable sampling location (Saunders 1983).

Well mixed zones in a river for representative water quality sampling can be defined, given that several assumptions will apply. By assuming that a pollutant distribution from an instantaneous point source is normally distributed on both the lateral and vertical transect and applying classical image theory, a theoretical distance from an outfall to a well mixed zone in a straight uniform river channel is a function of 1) mean stream velocity, 2) location of the point source and 3) the mean lateral and vertical turbulent diffusion coefficients (Saunders 1983).

There are several models available that are functions of the mixing coefficients, which have been shown to apply for predicting a zone of relatively complete mixing. Ruthven (1971) derived an expression for a mixing distance utilizing the solution to the steady-state, two-dimensional advection and dispersion equation. Assuming that complete vertical mixing is assured in a relatively short distance, he established a relationship from the two-dimensional solution to predict the mixing distance to a point where the concentration variation in the cross section does not exceed ten percent. The approach taken by Ruthven is shown in the following equation:

$$L \geq 0.075 \frac{w^2 u}{D_y} \qquad \text{Equation 3.1}$$

where,

- L: mixing distance
- w: width of channel
- u: mean stream velocity
- D_y: lateral turbulent diffusion coefficient

The distance needed for complete mixing using the above approach results in great distances for most situations. In addition, many upstream discharges normally exist and it is rarely possible to get far enough below all of them. Because of the distance required for complete mixing, there is often a need to composite samples across wide streams.

Extensive discussion on this subject can be found in Fischer et al. (1979).

3.2.1.1 Upstream

Monitoring stations established upstream of a BMP can give results that reveal the influent concentration or load of pollutants before they flow through the BMP. Upstream water quality is indicative of concentrations and pollutant loads that would be observed downstream if no BMP were implemented. It is important to monitor only waters that flow into the BMP to be able to use the resultant data to compare upstream water quality with downstream locations. Upstream monitoring locations can also be useful to determine bypass water quality. Where bypass is present, accurate flow measurement is highly important. Where sufficient funds are available and the physical layout of the control structures allow, bypass and flow to the BMP should be monitored directly. In situations where direct measurement is not practical, modeling of bypass flows can be substituted, particularly where the hydraulics of the bypass structure are well known or can be calibrated to flow rates. Typically a mass balance approach is used to model bypass flow rates and volumes.

Upstream monitoring stations should be located far enough away from the BMP to ensure that samples are independent of the BMP. Immediately upstream from a BMP, contributing runoff could be affected by backflow, slope, vegetation, etc. Upstream monitoring should be representative of conditions that existed before the BMP was implemented.

3.2.1.2 Downstream

Monitoring stations established downstream of a BMP can indicate water quality of flows that are treated by the BMP. Downstream monitoring is essential for establishing:

- That the BMP provides a measurable and statistically significant change in water quality.
- That the BMP provides effluent of sufficient quality to meet water quality criteria.
- A comparison of effluent concentrations with similar BMPs to determine if the BMP is achieving typical effluent water quality.

Monitoring stations should be located immediately downstream so that BMP effluent is sampled before it is introduced into the receiving waters or is exposed to factors that may affect constituent concentrations. Where bypass is present and one wants to understand the efficiency of the BMP in addition to the BMP system, it is important to monitor water quality of the bypass flows and the effluent separately. In some cases where influent water quality is not expected to be appreciably different than bypass water quality, upstream data may be used to determine water quality. This approach does not, however, obviate the need for accurate estimates of bypass flow rates and/or volumes from monitoring or flow modeling. In some cases, bypass flows may be very difficult to separate from treated effluent (e.g., in hydrodynamic devices).

3.2.1.3 Intermediate Locations

BMPs are often designed as a group of devices or chambers that target specific processes. For example, a filter might have a settling chamber to quickly remove large settlable solids before flowing into the filter media chamber. A treatment train approach is sometimes taken to combine various BMPs in order to maximize removal of specific constituents. Intermediate monitoring locations in the interior of the BMP are useful for investigating how various sections of the BMP are working and establishing mid-BMP concentrations. Monitoring stations are also useful in between treatment train BMPs to assess effectiveness of each individual BMP in addition to monitoring upstream/downstream stations to determine overall BMP efficiency.

Intermediate monitoring locations should be located either interior to the BMP or in between BMPs linked in a treatment train. For interior monitoring, such as in the middle of a wetland or detention pond, stations should be established in a location that is representative of the BMP. For example, monitoring within a wetland should be done in the middle section, where the slopes, vegetation, channel width, etc., are uniform and similar to the rest of the wetland, avoiding any microcosms of unique vegetation, basins, or slopes. To monitor in between treatment train BMPs, stations should be established to capture effluent from the upstream BMP or inflow to the downstream BMP, or both. Monitoring should not be conducted in a place where backflow or mixing is occurring, as these processes do not allow for isolated sampling of direct BMP discharge or inflow. During high flow conditions, this may be difficult because many BMPs overflow, reducing the distinction and separation between BMPs. Intermediate treatment train BMP monitoring stations need to be carefully evaluated to determine if samples taken during high flows are representative of water quality of flow between the BMPs and not backflow or some other phenomena.

3.2.1.4 Rainfall

Rainfall monitoring can be an essential piece of the monitoring puzzle. Rainfall data may help determine when to start sampling as well as provide information to calculate rainfall characteristics such as intensities. The importance of accurate rainfall data, however, decreases as the accuracy and reliability of flow information is improved. Rainfall data are relatively inexpensive to collect and therefore, even in cases where rainfall data may not be required for a detailed analysis of BMP efficiency, it is usually worthwhile to monitor for validation of flow monitoring results.

Site Proximity

Rainfall gauges should be established as close as possible to the monitoring stations. In many regions, rainfall is highly variable within a small area due to orographic effects, elevation, and proximity to water bodies. The US Geological Survey, National Weather Service, and many municipalities have networks of rain gauges, some with real-time rain data available over the Internet. These established stations are convenient to use if they are in close proximity to the monitoring site, or as a general estimate of rainfall if they are not in close proximity to the monitoring site.

Rain gauges may need to be installed near the site to obtain accurate rainfall data where established gauges are not available. Proper installation and maintenance of the rain gauge is as important as gauge proximity to the monitoring site. 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 the rain gauge in close proximity to other monitoring equipment to provide required connections for recording of rainfall depths and/or representative records.

Number of Gauges

The number of precipitation gauges installed in a system directly affects the quality of precipitation data. Generally, the higher the number of precipitation gauges, the better the estimate of 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.

In addition to the network of rain gauges accessed for monitoring, it is also useful to install manual rain gauges at the monitoring site to check accuracy, consistency and proper functioning among different gages. It is not difficult to discover a gauge that produces different rainfall data than that observed at the site due to the location of the gauge at a different elevation or microclimate, improper installation or placement, or natural interferences (birds resting on the gauge, for example).

3.2.1.5 Groundwater

Although most BMPs are designed to treat surface water runoff, some BMPs also promote groundwater infiltration. BMPs incorporating infiltration should not process large quantities of certain constituents (petroleum products, pesticides, solvents, etc.) that could be mobilized in groundwater or pose a drinking water hazard to those who rely on downstream wells.

Groundwater monitoring wells should be established if contamination of groundwater is suspected. Groundwater flow, direction and elevation as well as soil types should be established before monitoring sites are chosen. Monitoring stations should be located sufficiently down gradient from the BMP where infiltrated water from the BMP is accessible. A series of monitoring stations could be established: a station upstream of the BMP, one a short distance downstream from the BMP, another a longer distance downstream, and another even further downstream from the BMP. This will indicate if there is any contribution of constituents to the groundwater from the BMP, and where there is a contribution, if the concentrations decrease with increasing distance from the BMP.

3.2.1.6 Sediment Sampling

Many constituents either settle out of the water column or prefer not to be in the water column (due to hydrophobicity) and become incorporated in the sediment. Sediment can store significant amounts of certain constituents, such as BTEX, PCBs, metals, and microbes. During high flows, these sediments are stirred up and can release their potentially high concentrations of accumulated constituents. Many BMPs are designed to remove the sediment from runoff, theoretically removing the associated constituents as well.

Sediment sampling can determine concentrations of constituents not necessarily found through water column monitoring. Sediments can be sampled upstream and downstream of BMPs as well as internal to the BMP to assess removal and effluent efficiencies as well as internal accumulation of sediment and associated constituents.

When sampling for suspended sediments in the water column, it is important to take the sample well below the surface of the water, ideally in the middle portion of the water column where the average concentration of suspended sediment is found. When sampling sediment from the creek bed or internal to the BMP (e.g., sampling the filter media or detention pond bottom sediments) sediments should be collected minimizing disturbance or resuspension of the sediment bed so that the original settled material is captured in the sample apparatus. Depth of sediment sample should also be noted as constituent concentrations can vary with depth.

3.2.1.7 Dry Deposition

Many constituents are quite volatile, including mercury, BTEX, PCBs, and some pesticides. Atmospheric deposition has been pointed to as a significant source of certain constituents to water bodies in some areas. These constituents are continuously being deposited out of the atmosphere either by coming into contact with the surface and sorbing to it, settling out of the air, or through rainfall. Constituents are deposited onto surfaces, such as roads, rooftops, and driveways and then incorporated into runoff during storm or low flow events. Therefore, atmospheric deposition may contribute some material to those BMPs that are exposed to the atmosphere, such as detention ponds and wetlands.

In order to assess the contribution of atmospheric deposition to constituent concentrations and to isolate influent and effluent concentrations, dry deposition can be monitored in conjunction with BMP monitoring. Pans can be set out near BMPs to capture dry deposition of these volatile constituents much in the same way that rainfall gauges are installed to capture rainfall. After a period of time the deposited material can be analyzed to determine constituent concentrations. It is recommended that dry deposition sampling should only be conducted as a follow-up investigation where sufficient evidence indicates that dry deposition may be contributing appreciably to stormwater pollution.

It is important to note that very little of the total watershed dry deposition actually contributes to stormwater runoff. The only contributions to water quality impairment that currently can be directly attributed to dry deposition fall on the receiving waters themselves (such as PCBs and DDT measurements for the Great Lakes) (Pitt 2001). Otherwise, most is incorporated in soils or may not wash off paved areas during rains. Fugitive dust from nearby sources is usually comprised of relatively large material that is poorly washed off, while particulates from regional air pollution sources (particularly power generation and autos) are mostly very small and are typically incorporated in soils; however, these smaller particles are much more easily washed off from pavements and might be a quantifiable source of pollutants where depositional rates are relatively large compared to other sources.

3.2.1.8 Modeling Methods

When monitoring is not feasible due to a limited budget or lack of sampling staff, estimates of water quality parameters, flow, and rainfall can be made using various models and assumptions. The use of modeling to estimate these parameters may limit usability of the data depending on the validity of the assumptions made, the accuracy of the model itself, and accuracy of the information input into the model.

Estimates of Water Quality Parameters

Certain water quality parameters can be estimated by monitoring instead for related parameters that are simpler or less expensive. These related or surrogate parameters are statistically correlated to the more complicated or expensive parameters. Some common surrogate parameters and represented parameters are:

Surrogate Parameter	Parameter Represented by Surrogate
Turbidity	TSS
Fecal Coliform	Pathogens
Chemical oxygen Demand (COD)	Biological Oxygen Demand (BOD)

In addition to monitoring for surrogate parameters at each monitoring site, water quality models can be used to estimate constituent concentrations at monitoring sites using available monitoring data, upstream land use, hydrology, geology, and history to calculate a mass balance for each constituent. Water quality models are a tool for simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and finally to receiving waters. Both single-event and continuous simulation may be performed on catchments having storm sewers and natural drainage for prediction of flows, stages and pollutant concentrations. Each water quality model has its own unique purpose and simulation characteristics. It is advisable to thoroughly review downloading and data input instructions for each model.

The applicability and usefulness of these models is dependent upon a number of assumptions. The degree of accuracy of these assumptions determines the usefulness of the output data. For example, one assumption could be based on certain types of land use contributing certain constituents to the catchment runoff. The constituents associated with each land use have been well studied by many monitoring programs, but are still highly variable, depending on specific activities on each parcel, history of spills, age of infrastructure, climate, and many other factors. Although modeling of water quality parameters is a useful tool to estimate parameter concentrations, model results should not be interpreted as exact data. Confirmation of water quality model results should be done by monitoring a few storms and/or a few sites, then running the model with the observed conditions as input variables and comparing the results.

A variety of modeling tools are available for modeling water quality these include, but are not limited to, the following:

- Enhanced Stream Water Quality Model, Windows (QUAL2E)

Simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources.

- AQUATOX: A Simulation Model for Aquatic Ecosystems

AQUATOX is a freshwater ecosystem simulation model. It predicts the fate of various pollutants, such as nutrients and organic toxicants, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. AQUATOX is a valuable tool for ecologists, water quality modelers, and anyone involved in performing ecological risk assessments for aquatic ecosystems.

- SWMM: Storm Water Management Model

The EPA's Storm Water Management Model (SWMM) is a large, complex model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage/treatment units, and finally to receiving water. Both single-event and continuous simulation may be performed on catchments having storm sewers, combined sewers, and natural drainage for prediction of flows, stages and pollutant concentrations (EPA 1995). See http://www.ccee.orst.edu/swmm/ for more information on this model.

- HSPF: Hydrologic Simulation Program – Fortran

The HSPF Model is an EPA developed application for simulation of watershed hydrology and water quality. The HSPF model uses historical rainfall, temperature and solar radiation data; land surface characteristics such as land use patterns; and land management practices to simulate the processes that occur in watersheds. The result of this simulation is a continuous recreation of the quantity and quality of runoff from urban or agricultural watersheds. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. The HSPF model incorporates the watershed-scale Agricultural Runoff Model (ARM) and Non-Point Source (NPS) models into a basin-scale analysis framework that includes pollutant transport and transformation in stream channels.

- WASP5: Water Quality Analysis Simulation Program

The Water Quality Analysis Simulation Program (WASP) is a generalized framework for modeling contaminant fate and transport in surface waters. WASP5 is the latest of a series of WASP programs. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using the WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination (James 2001).

- SLAMM: Source Loading and Management Model

The Source Loading and Management Model (SLAMM) was developed to assist water and land resources planners in evaluating the effects of alternative control practices and development characteristics on urban runoff quality and quantity. SLAMM only evaluates runoff characteristics at the source areas In the watershed and at the discharge outfall; it does not directly evaluate receiving water responses. However, earlier versions of SLAMM have been used in conjunction with receiving water models (HSPF) to examine the ultimate effects of urban runoff.

SLAMM is different from other urban runoff models. Beside examining land development practices and many source area and outfall control practices, it contains two major areas of improvements. These are corrected algorithms for the washoff of street dirt and the incorporation of small storm hydrology. Without these corrections, it is not possible to appropriately predict the outfall responses associated with source area controls and development practices. (James 2001)

Estimates of Flow

Flows entering and leaving a BMP may be useful to model if actual monitoring is prohibitive. Flow can be estimated at varying levels of detail using approaches ranging from simple spreadsheets to complex hydraulic simulations of extensive urban drainage networks. Many of the water quality models presented in the previous section are also the best choices for modeling flows.

The simplest approach is to use the volumetric runoff coefficient approach described below.

- Volumetric Runoff Coefficient

The Volumetric Runoff Coefficient is an empirical relationship that provides an estimate of total volume of runoff based on total volume of rainfall according to the following equation:

Volume of Runoff = Volume of Rainfall x Rv - Depression Storage

where,

Rv: Volumetric Runoff Coefficients

This method is usually applied to smaller catchments such as parking lots, rather than entire watershed areas.

Where monitoring data have been collected for some calibration period such that an accurate estimate of the volumetric runoff coefficient and depression storage for the watershed can be made, this approach coupled with accurate rainfall data may provide one of the least expensive methods for determining total volume of flow from a watershed on a storm-by-storm basis.

Estimates of Rainfall

If a nearby rainfall gauge is not available, rainfall at the monitoring site can be approximated using available gauges that are located as close as possible and at similar elevation. A network of gauges in an area can be analyzed to relate latitude, longitude, and elevation to rainfall. The grid of gauges can be expanded and extrapolated to an area lacking any gauges, provided that enough rainfall gauges exist.

Although raw rainfall data are often sufficient for monitoring needs, statistical evaluation of the data is often more useful. For example, if rainfall is needed to estimate runoff, most of the rainfall less than 0.1 inch will infiltrate into the ground and not produce any runoff. These small events could be eliminated from the data set to allow for a more accurate account of actual runoff. Two statistical analysis tools used extensively in separating and filtering continuous rainfall records, include:

- SYNOP

SYNOP is a statistical rainfall analysis program that converts hourly data into descriptive statistics for individual storm events and provides annual rainfall statistics. The program takes an hourly precipitation record from a station, organizes the data into rainfall events, and computes the statistics of the storm event parameters. When a complete hourly record has been organized into a sequence of individual storm events, the mean and standard deviation may be determined for each of the event parameters (EPA 1989).

- SWMM

The SWMM model will conduct a complete statistical analysis almost identical to the SYNOP tool. In most cases, SWMM is the preferred analysis tool as it is based on the same basic approach as SYNOP and it lacks some minor bugs present in SYNOP.

3.2.2 Recommendation and Discussion of Monitoring Frequency

The number of storms to be monitored each year (i.e., monitoring frequency) is an important consideration in planning your monitoring program. Budget and staff constraints generally limit the number of storms, locations, and parameters to be monitored. Program objectives should be weighed in light of available resources to determine the best mix of monitoring frequency, locations, and parameters.

The cost of learning more (i.e., conducting more intensive monitoring) should be compared to 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 the system. Clearly, there is a need for balance here, because endless studies should not be substituted for control actions.

In general, however, many measurements (i.e., many samples during many events) are necessary to obtain enough data to be confident that actual BMP performance 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.

3.2.2.1 Statistical Underpinnings of Study Design

Four factors influence the probability of identifying a significant temporal and/or spatial change in water quality:

1) Overall variability in the water quality data.

2) Minimum detectable change in water quality (difference in mean concentration).

3) Number of samples collected.

4) Desired confidence level from which to draw conclusions.

Statistical analysis may be conducted to estimate how many events need to be monitored to achieve a desired confidence in a conclusion (i.e., power analysis). Performing a power analysis requires that the magnitude of detectable change, the confidence level, and the statistical power or probability of detecting a difference are defined. Typically, the confidence level and power are at least 95% and 80%, respectively, meaning that there is a 5% probability of drawing an incorrect conclusion from the analysis and a 20% probability that a significant change will be overlooked.

The power analysis often shows that many samples are needed to yield a power of 80% to 90% (i.e., discern a small change). In fact, Loftis et al. (2001) report that achieving a power of 80% requires double the data required for a power of 50%, and a power of 90% requires triple the data required for a power of 50%. The exponential increase in data required to achieve higher statistical power reinforces the need for careful consideration of the minimum detectable change required (and amount of data required) to achieve project objectives. In some cases, project objectives require quantification of small changes in concentration (e.g., inefficient BMPs or BMPs receiving relatively clean influent), which may call for larger power, but in many cases, less power (i.e., few samples) may be sufficient. If available resources prohibit the frequent monitoring of all locations, then reducing the number of locations or parameters tested may provide sufficient data to resolve slight differences in concentration at a more reasonable cost. Statistical confidence in the results of the monitoring program(collecting samples from a significant number of events) should be assigned a higher importance than collecting information from a larger number of locations or testing a multitude of water quality parameters.

3.2.2.2 Factors Affecting Study Design

Based on a review of existing studies, it is apparent that much BMP research in the past has not considered several key factors. The most frequently overlooked factor is the number of samples required to obtain a statistically valid assessment of water quality. This section focuses on estimating the number of samples required prior to beginning monitoring activities.

<u>Number of Samples</u>

Stormwater quality may vary dramatically from storm to storm. Therefore, monitoring a large number of storms is required if the objective of the program is to obtain accurate estimates of stormwater pollution in a given catchment (e.g., to determine whether water quality is changing over time or whether a given BMP is effective). However, staff and budget constraints typically limit monitoring to either a limited sampling methodology incorporating a smaller set of parameters for many storms, or a more detailed monitoring approach including a larger set of parameters for a few storms.

Determining the Number of Observations Needed

Typically a large portion of the costs associated with conducting a BMP monitoring program are related to collection and analysis of water quality samples. It is imperative that samples are not only collected in a manner consistent with the guidelines, but also that an adequate number of samples are collected for statistical validation. Estimates of the number of samples required to yield statistically valid monitoring results are also useful for making decisions about the nature and extent of monitoring efforts prior to implementation. Often goals for a monitoring effort (e.g., to demonstrate that a specific BMP is achieving a given level of removal of a constituent) may not be consistent with fiscal limitations of the project. This section provides a method for estimating the number of samples required for obtaining a statistically valid estimate of both the mean event mean concentration at a single sampling station and the percent difference observed at two stations.

As mentioned above, four factors affect predictions as to whether a sampling program will collect an adequate number of samples to provide a useful estimate of the mean station EMC:

1) Allowable level of error in estimates of mean (i.e., variance)

2) Level of statistical confidence in estimates of the mean

3) Number of samples collected

4) Variability in population trends

A variety of methods are available for estimating the number of observations required to predict the range surrounding a sample mean that contains the population mean. EPA (1993b) presents a nomograph relating the coefficient of variation (COV, defined as the ratio of the sample standard deviation to the sample mean) to the allowable error in the estimate of the population mean as a fraction of the sample mean. This nomograph is given in Figure 3.1 for normally distributed data and a statistical confidence of 95%.

Figure 3.1 can be generated using Equation 3.2 below. The number of samples required (n) is a function of the allowable error in the data mean (E) and the standard deviation (s), (or in the case of Figure 3.1, the COV) (Cochran 1963).

$$n = \frac{4(s)^2}{(E)^2} \qquad \text{Equation 3.2}$$

where,

n: number of samples
s: sample standard deviation
E: allowable error in the data mean

This approach is useful for estimating the number of samples required when sampling at a single location where an acceptable upper bound for the error is known. However, Equation 3.2 does not provide an estimate of the number of samples required to determine if the mean concentrations from two sample sets are statistically significantly different.

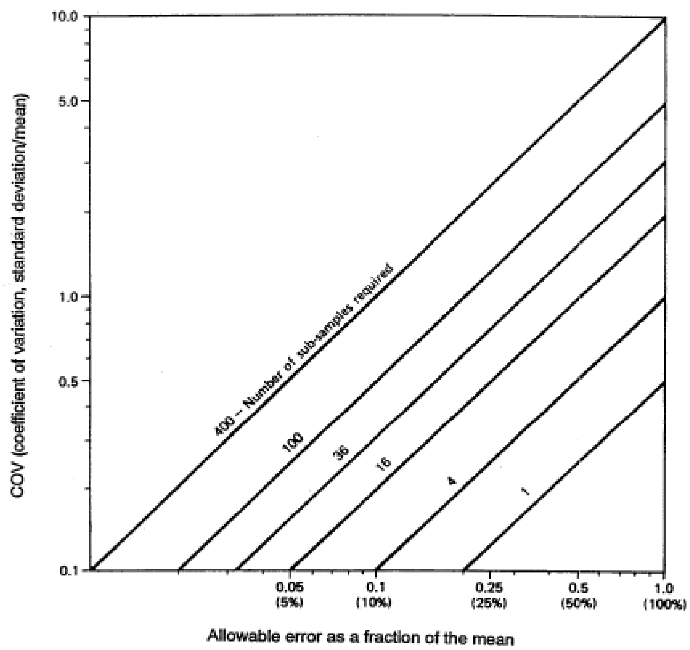

Figure 3.1: Nomograph relating coefficient of variation of a sample set to the allowable error in the estimate of the population mean (Pitt 1979).

Consideration of the number of samples required to draw statistically significant conclusions from data is often ignored until after monitoring work has been completed. However, there is great benefit to performing this analysis before initiating a monitoring program, particularly where the variability of the data is expected to be quite high because resources may be better spent on control measures than verification of BMP efficiency.

Appendix C expands the approach described in EPA (1993b) to the analysis of the number of samples required to conclude that there is a statistically significant difference between means calculated from sample data selected at random from two populations.

Appendix C provides a straightforward method for estimating the number of samples required to determine, with some degree of confidence, that observed means (such as the EMCs resulting from a BMP monitoring program) are statistically significant.

One assumption of the approach provided in Appendix C is that measured influent and effluent concentrations are normally distributed having a mean equal to the EMC.

Collection of water quality sample data at the inflow and outflow of a structural BMP allows for the determination of a mean EMC and the variance of the data (or log-mean and log-variance for log-normally distributed data). The mean and variance (square of the standard deviation) are the first and second moments of the distribution, respectively. These moments completely describe a normal distribution; thus, using the mean and variance of the distribution corresponding to any probability can be determined. Additionally, probabilities are additive so that confidence intervals between any two probabilities can be determined simply by calculating values of the distribution corresponding to the upper and lower probabilities of the confidence interval (i.e., confidence limits). The most common application is to determine the range of values surrounding the mean that falls within a specified 95% confidence interval (i.e., probabilities of 2.5% and 97.5%, which are the mean plus/minus 1.96 times the standard deviation).

One test that can be used to evaluate whether the means of two data sets (e.g., influent and effluent) are statistically different is a hypothesis test (e.g., student t-test), which is basically a test that quantifies the overlap of two confidence intervals surrounding the mean. The mean values will be considered different if there is little (as defined by the t-statistic distribution) overlap between the confidence intervals. This document presents hypothesis testing with the assumption that data sets are large (i.e., are composed of 30 or more values). Given this assumption, the Z-statistic can be used in place of the t-statistic, which eliminates the need to incorporate the degrees of freedom of a data set into hypothesis analysis. However, for analysis of small data sets, users should use the t-statistic in place of the Z-statistic (and refer to the student t-test in a standard statistics text). An iterative solution is required to determine the number of samples needed if the t-statistic, due to its dependence on the number of measurements, is used in place of the Z-statistic (Gilbert 1987).

The confidence interval about the mean for normally distributed data is defined as:

$$\left(\overline{C} - Z_{a/2}\frac{s}{\sqrt{n}}, \quad \overline{C} + Z_{a/2}\frac{s}{\sqrt{n}}\right) \qquad \text{Equation 3.3}$$

where,

$\overline{C}$ = mean concentration

σ = standard deviation for the population of the concentrations

$Z_{\alpha/2}$ = Z-statistic obtained from a standard normal distribution table n = number of measurements

The confidence interval corresponds to a significance level (α), where $(1 - \alpha)$x100% is the probability that $\overline{C}$ will fall within the confidence interval. As α increases, the confidence interval will become larger (all other variables remaining the same). If the population standard deviation (σ) is unknown, which is typically the case, then σ can be estimated using the sample standard deviation (s). Prior to the collection of field data, the standard deviation typically is estimated from existing data sets either from local or nationally published data on expected quality of stormwater runoff.

The confidence interval is often used to show the likely range containing the population mean, and for comparing the means for two populations (i.e., influent and effluent). However, the confidence interval formula contains the number of samples in the data sets, and therefore the equation can be solved for the number of samples needed to achieve a desired confidence interval for an expected difference in population means. The derivation of this formula is provided in Appendix C. As Appendix C shows, the resulting equation is (see the appendix for variable definitions):

$$n = \left[\frac{\left(Z_{a/2} + Z_{b/2} \right) \times COV \times \left(2 - \%removal \right)}{\%removal} \right]^2 \qquad \text{Equation 3.4}$$

$$n = 2\,[(Z_{1-\alpha} + Z_{1-\beta})/(\mu_1 - \mu_2)]^2 \sigma^2 \qquad \text{Equation 3.5}$$

This assumes that the sample sets have identical n, COV, $Z_{\alpha/2}$, and $Z_{1-\beta}$. Assuming the COVs of the sample sets are equal is a significant assumption because it mandates that s_{in}/s_{out} equals $\overline{C}_{in}/\overline{C}_{out}$. This assumption allows for the generation of a simple nomograph showing iso-sample number lines on a plot of COV versus percent difference in the means (see Figure 3.2). If the influent and effluent COVs are not assumed to be equal, *n* can be found from Equation 3.6 below:

$$n = Z_{a/2} \left[\frac{COV_{in} + COV_{out}\left(1 - \%removal\right)}{\%removal} \right]^2 \qquad \text{Equation 3.6}$$

Where COV is defined for influent and effluent data sets.

$Z_{\alpha/2}$ is a function of the desired level of certainty. For example, to determine a confidence interval with 95% certainty (significance level $\alpha = 0.05$), $Z_{\alpha/2}$ equals 1.96. Values for $Z_{\alpha/2}$ are tabulated in most statistical texts.

As an example of the application of the confidence interval, consider the case where the researcher wants to determine if a mean influent concentration is greater than a mean effluent concentration (assuming effluent concentrations are lower than influent concentrations). To do this, the 95% confidence interval of the influent and effluent EMCs are calculated. If the upper confidence limit (i.e., 97.5 percentile) of the effluent is less than the lower confidence limit of the influent (2.5 percentile), then the mean influent concentration is not equal to the mean effluent concentration, with 95% confidence.

As mentioned above, the Equation s derived in Appendix C allow for the solution of the COV, percent removal, or *n* in terms of the other two variables. Solving for the required COV for an estimated percent removal and *n* is shown in Figure 3.2 (for 95% confidence limits and a power of 80%). The primary use of Figure 3.2 is to estimate the *n* required to have 95% confidence in a hypothesis test given estimates of COV and percent removal. It is recommended that Figure 3.2 be used to provide a reasonable estimate of the number of samples (i.e., events) needed to quantify whether or not a BMP achieves an anticipated level of performance (i.e., measured by percent removal). It can be seen from Figure 3.2 that as the relative difference between influent and effluent mean event mean concentrations becomes small, the number of required monitored events becomes quite large.

Variations of the plot presented in Figure 3.2 are provided in Appendix B for a variety of different confidence intervals, powers, and percent differences. These plots were developed by Pitt and Parmer (1995).

Many commonly used statistical tests (e.g., parametric analysis of variance) are based on the assumption that the data are sampled at random from a normally distributed population. Thus, prior to applying the methods outlined in this section, the limitations imposed by assumed normality of sample data sets should be fully understood. Several methods can be used to determine the normality of a data set (or of data that is transformed to be normally distributed). Some of these tests are the W-test, Probability Plot Correlation Coefficient (PPCC), and graphical methods; all are useful for the analysis of stormwater quality data.

As mentioned previously, researchers have found that stormwater quality data is generally best fit by a log-normal distribution (EPA 1983; Driscoll et al. 1990; Harremoes 1988; Van Buren et al. 1996) and theoretical justification for using a log-normal distribution is provided by Chow (1954). Although, Van Buren et al. (1997) and Watt et al. (1989) found that pond effluent and/or soluble constituents in stormwater may be better fit using a normal distribution.

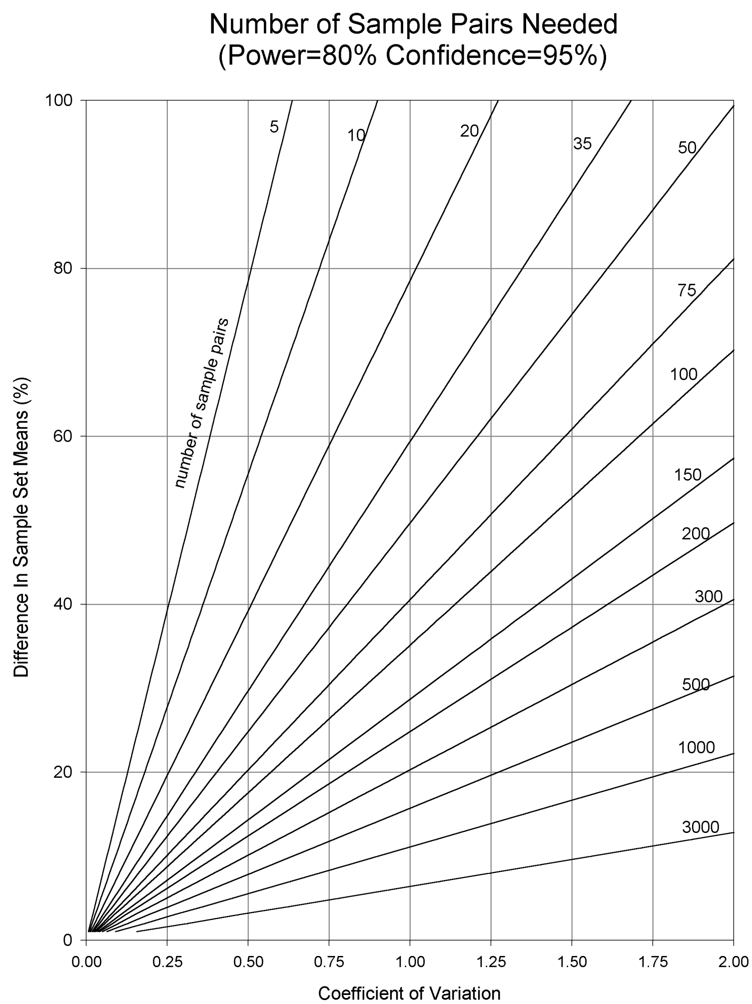

Figure 3.2 Number of samples required using a paired sampling approach to observe a statistically significant percent difference in mean concentration as a function of the coefficient of variation (power of 80% and confidence of 95%)

The following are some properties of the lognormal distribution. If a sample (a data set of N observations) is drawn from an underlying population that has a lognormal distribution, the following apply:

1. The natural logarithm of log-normally distributed data is normally distributed with a log-mean (μ_{lnK}) and log-standard deviation (σ_{lnK}) computed from the natural log-transformed data.

2. The arithmetic statistical parameters of the population (mean, median, standard deviation, coefficient of variation) should be determined from the theoretical relationships (see Appendix D) between these values and the mean and standard deviation of the transformed data.

A few mathematical formulas based on probability theory summarize the pertinent statistical relationships for log-normal probability distributions. These formulas provide the basis for forward and reverse conversions between arithmetic properties of untransformed data (such as measurements of concentration, flow, and load) and properties of transformed data (values that fall on a normal distribution so that statistical moments and probabilities can be defined). Appendix D, presents these formulas.

3.2.3 Recommendation and Discussion of Water Quality Parameters and Analytical Methods

3.2.3.1 Selecting Parameters

Stormwater runoff may contain a variety of substances that can adversely affect the beneficial uses of receiving water bodies. To select the parameters to be analyzed for a given monitoring location, consider the following:

- Permit requirements (if any). Monitoring to comply with a permit may specify the parameters that must be measured in stormwater discharges. However, monitoring for additional parameters may help attain overall program objectives.

- Land uses in the catchment area. Land use is a major factor affecting stormwater quality. Developing a list of the pollutants commonly associated with various land uses is helpful for deciding what to look for when monitoring.

- Existing monitoring data (if any) for the catchment area. Previous monitoring data can be helpful in refining the parameter list. However, if there is uncertainty about the monitoring methods and/or analytical data quality, or if the existing data pertain to baseflow conditions or only one or two storms, caution should be used in ruling out potential pollutants. For example, an earlier study may have used outdated analytical methods which had higher detection limits than current methods.

- Beneficial uses of the receiving water. Information on water quality within a stormwater drainage system often is used to indicate whether discharges from the system are likely to adversely affect the receiving water body. For example, if a stormwater system discharges to a lake, consider analyzing for nitrogen and phosphorus because those constituents may promote eutrophication.

- Overall program objectives and resources. The parameter list should be adjusted to match resources (personnel, funds, time). If program objectives require assessing a large number of parameters (based on a review of land uses, prior monitoring data, etc.), consider a screening approach where samples collected during the first one or two storms are analyzed for a broad range of parameters of potential concern. Parameters that are not detected, or are measured at levels well below concern, can then be dropped from some or all subsequent monitoring events. To increase the probability of detecting the full range of pollutants, the initial screening samples should be collected from storms that occur after prolonged dry periods.

A recommended list of constituents (along with recommended method detection limits for comparing stormwater samples to water quality criteria) for BMP monitoring has been developed and is presented in Table 3.1 below. Refer to Strecker (1994), Urbonas and Stahre (1993), and the ASCE Database website (http://www.bmpdatabase.org/) for 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 has been identified as prevalent in typical urban stormwater at concentrations that could cause water quality impairment (NURP 1983; FHWA 1990; and recent Municipal NPDES data).

- The analytical result 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.

- Controlling the pollutant through practical BMPs, rather than trying to eliminate the source of the pollutant (e.g., treating to remove pesticide downstream instead of eliminating pesticide use).

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.

The base list represents 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).

Table 3.1: Typical urban stormwater runoff constituents and recommended detection limits

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
Nutrients		
Orthophosphate	mg/L	0.05
Phosphorus – Total	mg/L	0.05
Total Kjeldahl Nitrogen (TKN)	mg/L	0.3
Nitrate – N	mg/L	0.1
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.

3.2.3.2 Dissolved vs. Total Metals

Different metal forms (species) show different levels of toxic effects. In general, metals are most toxic in their dissolved, or free ionic form. Specifically, EPA 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 water quality criteria, it is advised that the dissolved metals fraction 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 with little sediment 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 that acts as adsorption sites for pollutants to attach to. 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 than those for stormwater. Hardness affects the bio-availability of heavy metals, further complicating the ecological impact of dissolved heavy metals.

If loads to the receiving waters are of concern (e.g., 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 assess the relative load from different sources. Finally, total recoverable metals data together with dissolved metals data can be used to assess potential metals sediment issues.

3.2.3.3 Measurements of Sediment Concentration

A variety of methods have been employed in stormwater quality studies for quantifying sediment concentration. The most frequently cited parameter is "TSS" or total suspended solids. The "TSS" label is used, however, to refer to more than one sample collection and sample analysis method. The "TSS" analytical method originated in wastewater analysis as promulgated by the American Public Health Association.

The USGS employs the suspended-sediment concentration (SSC) method (ASTM 2000), which was originally developed for the Federal Interagency Sedimentation Project (USGS 2001). SSC data is often described as TSS data, when in many cases results from the two methods may be significantly different. The difference between methods is sample size – the SSC method analyzes the entire sample while the TSS method uses a sub-sample. The process of collecting a representative sub-sample containing larger sediment particles is problematic as large sediment particles (e.g., sand) often settle quickly. Differences between the results obtained from SSC and TSS analytical methods become apparent when sand-sized particles exceed 25% of the sample sediment mass (Gray et al. 2000). Gray demonstrates that at similar flow rates, sediment discharge values from SSC data can be more than an order of magnitude larger than those from TSS data (USGS 2001) due primarily to larger particles that are often missed in the TSS method. "The USGS policy on the collection and use of TSS data establishes that TSS concentrations and resulting load calculations of suspended material in water samples collected from open channel flow are not appropriate" (USGS 2001).

It is recommended that both TSS (for comparison to existing data sets) and SSC be measured.

The discrepancies in sampling methodologies currently employed in the field highlight the importance of particle size distribution (PSD) analysis as an essential component of any BMP monitoring study. PSD data provide the information necessary to meaningfully interpret the ability of a BMP to remove suspended materials. However, PSD methods are varied and include (USGS 2001):

- Dry sieve.
- Wet sieve.
- Visual accumulation tube (VA).
- Bottom withdrawal tube.
- Pipet.
- Microscopy.
- Coulter counter.
- Sedigraph (x-ray sedimentation).
- Brinkman particle pize analyzer.
- Laser diffraction spectroscopy.

- Light-based image analysis.

The investigator must select and use a consistent and appropriate method.

Specific gravity (SG) of sediments is also an important component in determining the settleability of sediments and is recommended for sediment analysis by ASTM (1997). For BMP studies where PSD data are being collected, SG provides additional useful information about the ability of a particular BMP to remove sediment.

In addition, settling velocities of sediments are highly important and can be either measured directly or calculated theoretically from SG and PSD data. Settling velocities give the most useful information for quantifying BMP sediment removal efficiency.

The difficulty of collecting accurate sediment samples underscores the need to fully understand the conditions under which sediment data were collected and analyzed. Regardless of the analytical methods used, the sampling methodology often introduces the largest bias to sediment data.

3.2.3.4 Analytical Methods

After the parameters have been selected, the analytical methods to be used to measure them must be chosen. Select analytical methods that will provide results of sufficient quality to support the intended uses of the data. To determine the quality of data necessary for a program, consider the following:

- Appropriate analytical levels. EPA guidance suggests tailoring the analytical level to the intended use of the data. EPA has defined five analytical levels:

  I. Field screening and analysis using portable instruments

  II. Field analysis using more sophisticated portable analytical instruments, possibly set up in a portable laboratory at the site

  III. Analysis performed at an off-site analytical laboratory using EPA Contract Laboratory Program (CLP) or equivalent methods, but without the validation or documentation procedures required for CLP

  IV. CLP routine analytical services and complete data reporting packages

  V. Analysis by non-standard methods (to achieve very low detection limits or measure a specific parameter not included in standard methods)

  Stormwater samples are generally analyzed using Levels I, II, or III. Levels IV and V are not used very often for stormwater projects because these levels are intended for situations requiring low detection limits and high confidence, such as human or ecological risk assessments or Superfund/MTCA investigations.

- Appropriate methods should be selected for the chemicals of concern. These are the most significant contributors to human health or environmental risk at the site. Chenicals of concern are generally the most toxic, mobile, persistent, and/or frequently occurring chemicals found at the site. Commonly occurring chemicals of concern in stormwater runoff include metals (cadmium, copper, lead, and zinc), polycyclic aromatic hydrocarbons (PAHs), and organo-phosphate insecticides (e.g., diazinon and chloropyrifos). The latter are included because recent studies in the San Francisco Bay area found that diazinon accounted for much of the observed aquatic toxicity in urban runoff (Cooke and Lee 1993). Other chemicals (e.g., organochlorine pesticides and PCBs) should be included if there is reason to believe they are present. Note that the potential toxicity of some metals in freshwater systems is affected by the hardness of the water; thus, water quality standards for cadmium, copper, chromium, lead, nickel, silver, and zinc are calculated based on water hardness. For this reason, total hardness should be measured if metals are measured at sites where fresh water quality standards may apply.

- Level of concern. This term refers to the chemical concentration that is of concern. Typically, state or federal water quality criteria for protection of aquatic life or human health are used as the default level of concern for water sample results, and sediment quality criteria are used as the level of concern for sediment sample results. For pollutants that do not have state or federal water or sediment quality standards, the Risk-based Concentration Table developed by EPA Region III (EPA 1994a,b) can be used as levels of concern for water and soil sample results.

- Required detection limit/practical quantitation limit. The level of concern directly affects the data quality requirements because the sampling and analysis methods used must be accurate at the level of concern. Sampling variability is often difficult to control, especially in stormwater. The relative accuracy of most laboratory methods decreases as concentrations approach the detection limits. For these reasons, the practical quantitation limit (5 to 10 times the detection limit) should be below the level of concern, if possible.

If the objective is to conduct a screening study to identify chemicals that appear to be present at levels of concern, consider analyzing for a wide range of constituents using analytical methods with low detection limits. An initial screening analysis can generally reduce the number of chemicals analyzed in subsequent studies by eliminating those that were detected below their corresponding levels of concern.

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, total organic carbon), then it may be possible to use less costly monitoring approaches 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 worthy of consideration. 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 as indicators. For example, fecal coliform are bacteria often used as proxies for pathogens and as an indicator of fecal contamination. Total organic carbon 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). The important consideration is 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 (e.g., temperature or pH data). Such information may turn out to be valuable to the overall stormwater program at some time in the future and/or to others programs.

3.2.4 Recommendation and Discussion of Monitoring Equipment and Methods

BMP monitoring can be done using a variety of equipment and methods. The type of equipment and methods used often directly affect the usability of the data collected. Both options and recommended approaches for monitoring are provided in this section.

3.2.4.1 Equipment

Equipment used to monitor BMPs includes a variety of data loggers, primary devices (e.g., flumes, weirs, and nozzles), secondary devices (e.g., bubblers, pressure transducers, and ultrasonic devices), automatic samplers, manual sampling devices, and rain gauges. These devices and their uses are described below.

Data Loggers

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 capabilities (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 their internal circuitry from water and dust hazards. They are designed to operate at extreme temperatures, from as low as -55°C to as high as 85°C (-67°F to 185°F). In addition, most models can be securely mounted in remote locations, providing protection from wind and rain, wildlife, and vandalism.

Figure 3.3: Data Logger with Weatherproof Housing (Handar)

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 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.

Figure 3.4: Data Logger Without Housing (Campbell Scientific)

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: 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.

Programmability

Most data loggers can be programmed to record data at user-selected intervals. 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 flow rates and event timing and duration. Data loggers can also record data simultaneously for several different intervals (15 minutes, storm event, daily).

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, 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 functionality would be 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 varies 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 commonly available spreadsheet or word processing files, while others require the use of their particular vendor-developed software for data analysis and manipulation.

Data Capacity

Memory type and capacity vary greatly between instruments. Standard capacity varies between models and vendors from 8K or less, 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 may 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, (i.e., 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, backup power is supplied by a lithium battery, 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 important to realize that data may be lost if it is not downloaded before it is written over.

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.

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. As indicated earlier, data loggers can be equipped with an internal modem for telecommunications, allowing a user to download data from a remote host PC without having to visit 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, baud rates can be selected by the user. 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.

Power Requirements

In general, data loggers are energy efficient devices. Most are powered by an internal battery, with the option of using external electrical power, if available. Some can also be equipped to use solar power.

Data loggers powered by internal batteries often offer a choice of cell type. Some models offer the choice of rechargeable cells or standard 12 volt alkaline cells, while others offer either alkaline or lithium batteries. The choice of power source and model selection, depends upon several factors, including site accessibility, distance, and amount of data to be recorded.

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. In addition, since alkaline batteries must be replaced and discarded frequently, the use of alkaline batteries may actually be more expensive than using rechargeable batteries. Although rechargeable batteries offer less battery waste and 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 power can be used by the data logger. Under extreme conditions, it may not be feasible to use a data logger powered by alkaline batteries.

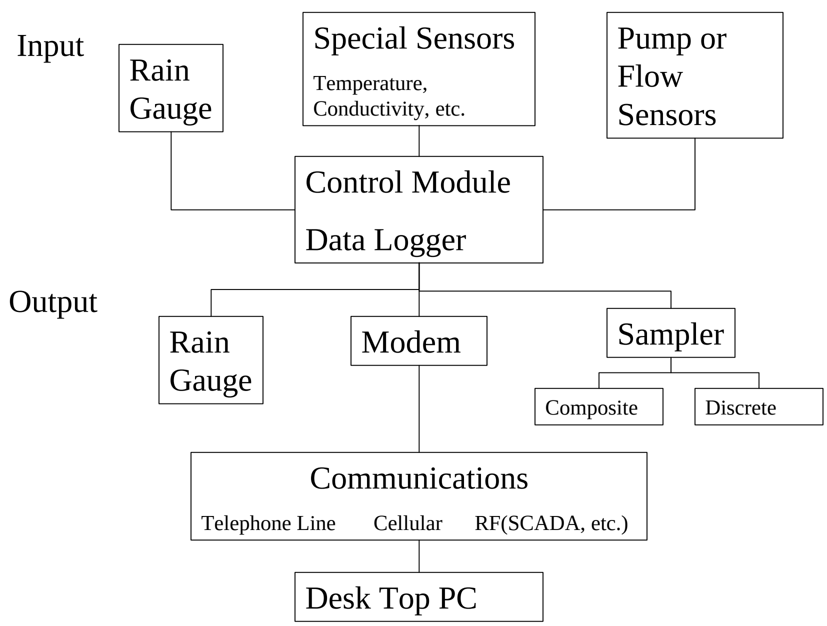

Figure 3.5: Data Logger Summary

Flow

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 flow 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 flow 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 flow).
- 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 flow rate changes (uniform vs. varied flow).

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

Typically, stormwater flow through BMPs will fit the open channel flow configuration. However, some BMPs are drained by pipe systems, which may be flowing, full at times. Therefore, methods used for measuring flow in full pipes will also be discussed.

Table 3.2 summarizes available flow measurement methods, the requirements for their use, typical BMP use, and required equipment. Each of these methods is discussed in more detail in the following sections.

Table 3.2: Flow Measurement Methods

Method	**Major Requirements For Use**	**Typical BMP Use**	**Required Equipment**
Volume-Based	▪ Low flow 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 BMPs	ISCO Variable Gate Meter
Velocity-Based	▪ None	▪ Automatic sampling	Depth measurer and velocity meter
Tracer Dilution	▪ Adequate turbulence and mixing length	▪ Typically used for calibrating equipment	Tracer and concentration meter
Pump-Discharge	▪ All runoff into one pond	▪ Not typically used for BMPs	Pump

Volume-Based Methods

The concept behind volume-based flow measurement is simple: one collects all the flow over a short period of time, measures the volume, and divides the collected volume by the length of the time period:

$$Q = V/T \qquad \text{Equation 3.7}$$

where,

Q: flow, 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 flow. At higher rates of flow, collection of all the runoff from typical BMP conveyances (an essential component of the method) will probably become infeasible. This method is most useful for conducting limited research and for calibrating equipment.

Stage-Based Methods

Flow 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 flow 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 flow 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 flow rate of the flow stream.

Manning's Equation

The variables required for the Manning Equation (Equations 3.8 and 3.9) 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, which takes into account channel material, age, and physical condition.

$$Q = \frac{1}{n} AR^{2/3}S^{1/2} \qquad \text{Equation 3.8}$$

$$Q = \frac{1.486}{n} AR^{2/3}S^{1/2} \qquad \text{Equation 3.9}$$

where, Q: flow, 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	where, Q: flow, 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

The Manning Equation truly applies only to steady and uniform flow but can provide a fairly accurate estimate of flow 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 twenty 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; 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 flow rates 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 flow rate of 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 flow rate to vary with time, either gradually or rapidly. Depending on the frequency with which the depth of flow is measured, rapid fluctuations in flow rate will be missed and the total runoff volume from a storm event will be miscalculated.

Other Empirical Stage-Flow Relationships

Another empirical relationship used to estimate flow is the Chézy Equation (Gupta 1989):

$$Q / A = C\sqrt{RS} \qquad \text{Equation 3.10}$$

where,

- Q: flow, 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: flow coefficient, $m^{1/2}/s$ ($ft^{1/2}/s$)

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

$$C = \frac{R^{1/6}}{n} \qquad \text{Equation 3.11}$$

where,

- n: Manning’s Roughness Coefficient

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 flow (Ponce 1989). Therefore, when considering applying these equations to a natural channel, one should first evaluate the alluvial material in the channel and the magnitude of flows expected. It may be desirable to select another flow measurement approach for natural channels with highly varied surfaces and flow rates.

Stage Based Method Using Weirs and Flumes

The accuracy with which flow is estimated can be improved by using a weir or flume to create an area of the channel where the hydraulics is 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 flow rate using a known empirical equation (for examples, see Stevens 1991).

Stage-Based Variable Gate Meters

A relatively new development in flow metering technology is ISCO Inc.'s (Lincoln, NE) 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. 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 flow 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. The insert may be useful for sampling very small catchment areas. Again, problems with debris accumulation can occur.

Velocity-Based Methods

The continuity method is a velocity-based technique for estimating flow rate. Each determination requires the simultaneous measurement of velocity and depth of flow.

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

$$Q = A_i * V_i \qquad \text{Equation 3.12}$$

where,

Q: flow, 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 flow rate. That is, 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 flow.

Although this method is useful for calibrating equipment, it is more sophisticated and expensive than the stage-flow 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 and can be found in 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 flow. For example, chloride ion can be injected into fresh water, and 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 flow 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 flow is measured at a downstream point over time. After some time period has passed, the tracer becomes completely mixed in the flow so that the downstream concentration reaches steady state. Flow 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 flow are taken at a downstream point until the plume has entirely passed. Flow 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 flow runs into a natural or manmade basin from several directions or as overland flow. If the pump is precalibrated, 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 not usually encountered in the field as the only available monitoring method, pumps are not discussed further in this manual.

3.2.4.2 Automatic Sampling Techniques

Selection of Primary Flow Measurement Device

This section provides an overview of the process of selecting a primary flow measurement device.

Changes to surface hydrology due to urbanization result primarily from the increases in impervious areas (roofs, streets, parking lots, etc.) and the increased hydraulic conveyance of the flow channels. The naturally occurring channels are often straightened, deepened, and lined in addition to the installation of storm sewers, drains, and gutters. Without detention storage, the resulting hydrograph has a higher peak discharge and shorter duration. This necessitates the ability of a primary flow device to accurately measure large discharge rates for storm events with high precipitation intensities. Due to the highly variable nature of storm events, low runoff rates will result from the smaller storm events. Analysis of long-term rainfall records indicates that smaller storm events generally account for the majority of stormwater runoff and resulting pollutant loads. Therefore it is essential that the primary device selected is also capable of accurately measuring the lower range of the expected flows. The potential for a wide range of flow rates resulting from stormwater runoff makes the assessment of the required range of discharge rates an important consideration for selection of a flow measurement device.

Flow measurements are critical to monitoring stormwater BMPs. Accurate flow measurements are necessary for accurate composting of samples used to characterize storm runoff and for the estimation of volumes (including pollutant loads) treated in the BMP. Many methods are available to estimate the flow in open channels: volume-based methods, velocity-based methods, empirical equations, and tracer-dilution methods. While these methods are all valid ways to measure the flow in open channels, they are not potentially as accurate as the use of a primary flow measurement device. Researchers monitoring flows pertaining to stormwater BMP effectiveness are encouraged to use primary flow devices where possible.

Types of Primary Flow Measurement Devices

Primary flow measurement devices fall into the general categories of flumes and weirs. Primary flow measurement devices allow for accurate measurement of discharge rates by creating a channel geometry in which the hydraulics are controlled (control section). Primary devices are calibrated (i.e., in the laboratory or by the manufacturer) to relate the stage at a predetermined point in the control section to the discharge rate using a known empirical equation (for examples, see Stevens 1998). These types of measurement devices are called depth (or stage) based methods because the discharge through the device is directly related to the depth (stage or head) of the flow. The relationship between the depth of flow and the discharge is called the rating. Tables referred to as rating curves are available for all standard flumes and weirs.

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 common are the rectangular, trapezoidal (or Cipolletti weir), and triangular weirs. The weir opening (i.e., the rectangular, trapezoidal, or triangular opening) is called the "notch." Each type of weir has a specific discharge equation for determining the flow rate through the weir.

Weirs are generally low in cost, easy to install (relative to flumes), and can be quite accurate when used correctly. A weir can be used to regulate flow in a natural channel with irregular geometry, a situation where Manning's Equation, for example, would not provide reliable estimates for the flow rate. However, a weir will back water up in channels by creating a partial dam. Weirs are generally used for flow measurements with relatively large head available to establish free-flow conditions over the weir. A weir is intended to back up water 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-flow relationship for the weir will apply.

Sediments and debris that accumulate behind a weir can alter the hydraulic conditions, changing the empirical relationship between flow depth and discharge rate. Weirs are often not a good choice where representative suspended sediment samples are desired. Weirs should be inspected regularly and accumulated sediment or debris removed. If high amounts of sediment or debris occur in the flow, then use of a flume may be more appropriate as they generally avoid sedimentation problems.

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.

Because the velocity of water accelerates as it passes through a flume, the problem of sedimentation associated with weirs (see below) 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; however, where applicable, flumes can provide accurate results and significantly reduced maintenance.

The most common types of flumes are the Parshall, the Palmer-Bowlus, the HS, H, and HL flumes and the trapezoidal flume.

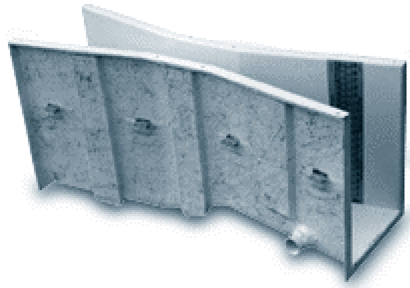

Figure 3.6: Parshall flume (Plati-Fab Inc.)

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-flow relationships have been established for a variety of flume configurations (USGS 1980; Gupta 1989; Stevens 1991).

Figure 3.7: H-flume (Tracom Inc.)

Considerations for Selection of Primary Flow Measurement Device

Consideration should be given to the following items when selecting a primary flow measurement device.

Range of Flows

Triangular thin-plate weirs have a large range in their ability to measure flows because of the 2.5-power relationship between flow depth and flow rate. That is, relative to other devices, flow increases quite rapidly as a function of head. The range of flow rates that can be measured accurately can vary by a factor (ratio of largest flow to smallest flow rate) of 200 for fully contracted weirs to around 600 for partially contracted 90^{o} notches that can utilize the allowable range of head (ASTM 1995).

For rectangular thin-plate weirs, the range is typically about a factor of 90 and increases to about 110 for full-width weirs. These ranges depend somewhat on the crest length to channel width ratio. These results are based on a minimum head of 0.1 ft (0.03 m) and a suggested (although not absolute) maximum head of 2 ft (0.6 m). However, the range-ability of smaller rectangular weirs can be significantly less (ASTM 1995).

The range in flow measurement for Parshall flumes varies widely with size. The range of Palmer-Bowlus and other long-throated flumes depends on the shape of the throat cross-section and increases as the shape varies from rectangular toward triangular. For typical Palmer-Bowlus flumes of trapezoidal section, the range of flow rates that can be measured accurately generally varies by a factor of 30. The USGS has developed and tested a modified Palmer-Bowlus flume (USGS 1985) for use in circular pipes that carry highway stormwater runoff. This flow can occur under either open or pressurized channel flow. This flume has been designed to measure the discharge under pressurized flow by using two bubbler sensors, which detect the hydraulic pressure change between upstream and downstream locations on the flume. This system was found to be one of the most accurate after calibration is performed. However the range between low and high flows that can be measured accurately using a Palmer-Bowlus flume is not as large as some other types of devices.

In cases in which there is a need for measurement of extreme flow ranges along with sediment transport capability, which is often the case for stormwater runoff, the H, HS, or HL flumes should be considered. The range of flows that can be measured accurately using H-type flumes can exceed three orders of magnitude; for example, a 3 ft H flume can measure flows between 0.0347 cfs at 0.10 ft of head to 29.40 cfs at 2.95 feet of head.

For some cases when low flows are expected to occur for an extended period but will ultimately be superseded by much larger flow rates, the interim use of removable small flumes inserted inside larger flumes can provide a method for accurate measurement of the range of flows.

Flow Rate

As mentioned in the beginning of the section, one of the most important factors influencing the selection of a primary device is the flow capacity necessary to accommodate runoff. Small and moderate flows are generally best measured with thin-plate weirs, with the triangular notches most appropriate for the smallest flows (ASTM 1995). Small Parshall and Palmer-Bowlus flumes are also available to measure low flows. The flumes do not have issues related to sediment passage and head loss as do thin-plate weirs, but this comes at some sacrifice in potential accuracy (ASTM 1995). Flumes and broad-crested weirs are generally the best choices for the measurement of large discharges.

Accuracy

Weirs are generally recognized as more accurate than flumes (Grant and Dawson 1997). A properly installed weir can typically achieve accuracies of 2 to 5% of the rate of flow, while flumes can typically achieve accuracies of 3 to 10% (Spitzer 1996). The ASTM cites lower errors for weirs ranging from about 1 to 3% and Parshall and Palmer-Bowlus flumes with typical accuracies around 5%. However, the overall accuracy of the flow measurement system is dependant on a number of factors, including proper installation, proper location for head measurement, regular maintenance, the accuracy of the method employed to measure the flow depth, approach velocities (weirs), and turbulence in the flow channel (flumes). It should be noted, however, that the largest source of error in flow measurement of stormwater results from inaccuracies related to low flow or unsteady flow. Improper construction, installation, or lack of maintenance can result in significant measurement errors. A silted weir or inaccurately constructed flume can have associated errors of ±5 to 10% or more (Grant and Dawson 1997). Circumstances present in many stormwater monitoring locations can result in errors well in excess of 100%.

Potential inaccuracies in the method used to measure the depth of flow will tend to increase the error in flow measurement as the flow depth approaches the minimum head. For primary devices operating near minimum head, even a modest error can have a significant effect on the measured flow rate. Therefore, it is important to select sizes or combinations of primary devices that avoid prolonged operation near minimum head (Spitzer 1997).

Cost

The important factor of cost consideration should include manufacturing, installation, and operational costs. Weirs are often considerably less expensive to fabricate than flumes due to simpler design and material requirements (Grant and Dawson 1997). Weirs are also usually easier and less expensive to install, although installation of flumes designed for insertion into a pipe (e.g. Palmer-Bowlus and Leopold-Lagco) are generally straightforward. Despite the higher initial costs of flumes, the relatively low maintenance requirements may outweigh this with time (Grant and Dawson 1997). Consideration should be given to the expected sediment loads in the flow to be measured for likely accumulation and maintenance requirements for weir installations.

Head Loss and Flow Characteristics

The head difference that is required for a weir or flume to operate properly may be an important selection criterion. Examples include, when the elevation difference is not adequate to maintain the required flow or when the upstream channel cannot contain the backwater.

For the same flow conditions, thin plate weirs typically require the largest head difference, Parshall flumes require an intermediate amount of head, and the long-throated flumes require the least (ASTM 1995).

Weirs are typically gravity fed and must be operated within the available head of the system. Flumes also require a certain head range in which the discharge liquid level is low enough that it does not exert back pressure on the liquid in the throat of the flume, otherwise the flume will be in a submerged condition, and two head measurements will be required to determine the flow rate.

Operation of a weir is sensitive to the approach velocity, often necessitating a stilling basin or pond upstream of the weir to reduce the fluid velocity. Operation of a flume is sensitive to turbulence or waves upstream from the entrance to the flume, which can require a section of straight channel upstream of the flume.

Sediment and Debris

Flumes tend to be self-cleaning because of the high flow velocity and the lack of any obstruction across the channel (Spitzer 1997). A flume is therefore generally more suited to flow channels carrying solids than is a weir.

Debris accumulation is likely to occur behind a weir especially due to the presence of a stilling basin to reduce flow velocities to an acceptable rate. Debris accumulation behind a weir can affect flow measurement. This requires periodic inspection and maintenance to remove debris. To allow periodic removal of deposits, it is recommended that the weir bulkhead be constructed with an opening beneath the notch to sluice accumulated sediments (Spitzer 1997).

Flumes, while typically not susceptible to problems due to sedimentation, can have debris accumulate in the throat portion of the flume and require periodic maintenance (although generally less frequently than weirs).

Construction Requirements

The Parshall flume is usually the most difficult device to construct due to the relatively complex shape and the possible need to excavate the channel floor to accommodate the sharp downward slope of the throat. Because this flume is an empirical device it is necessary to closely follow the design specifications (ASTM 1995). The discharge coefficients for long-throated flumes can be obtained theoretically which allows for some departure from the prescribed dimensions. Many types of flumes are available in prefabricated sizes up to several feet in width.

Weirs are generally easier to construct than flumes. The most difficult task is the fabrication of the notch edges, which require a sharp edge so the nappe is free flowing.

Selection of Secondary Flow Measurement Device

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 BMP sites are described below. Table 3.3 summarizes available equipment for measuring depth of flow, major requirements for use, and typical use within a BMP monitoring program.

Table 3.3: Equipment for measuring depth of flow

Method	Major Requirements For Use	Typical Use in a BMP Monitoring Program
Visual Observations	Small number of sites and events to be sampled. No significant health and safety concerns	Manual sampling
Float Gauge	Stilling well 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
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	Highly controlled systems. Typically not useful in the field	Automatic sampling
Pressure Probe	Open channel flow. No organic solvents or inorganic acids & bases	Automatic sampling

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 flow rate. The data can also be used as input to appropriate software to compute the flow 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 flow. 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:

$$P = \rho h \qquad \text{Equation 3.13}$$

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 flow. 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.

Figure 3.8: 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 flow 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, interpreted by the flow meter as a drop in flow rate. These instruments therefore, should not be used in channels where the slope of the bottom exceeds 5-7 percent. Sediments and organic material can also 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 are also 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.

Figure 3.9: 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 can also 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 in Portland, Oregon to measure the depth of flow at an urban stormwater sampling site 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, mounted at the bottom of the channel, that measures the hydrostatic pressure of the overlying water. 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.

Figure 3.10: Pressure transducers (In-Situ Inc.)

Submerged probes are not adversely affected by wind, turbulence, foam, steam, or air temperature gradients. However, because contaminants in the water may interfere with 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 a vendor, this equipment is not recommended for stormwater applications because the sensor is likely to become covered by sediments 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 large concern during stormwater monitoring.

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

Equipment for Measuring Velocity

Use of the continuity equation for measuring flow requires the estimation of average velocity as well as depth. The velocity of flow may be measured using visual methods (i.e., the float-and-stopwatch and the deflection, or drag-body methods), tracer studies, the use of instruments such as rotating-element current meters and 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 described (more details are available in USGS 1980). More extensive discussions, including advantages and disadvantages related to sampling activities, are provided for the ultrasonic and electromagnetic sensors.

Methods Suitable for Calibration

The most important aspect of any calibration method is its ability to obtain accurate results with a high degree of certainty and repeatability. A variety of methods have been employed in the past. The most common methods are described in this section. Table 3.4 summarizes the available methods.

Table 3.4: Velocity measurement methods suitable for calibration

Method	Comments
Tracer Studies	**Recommended Method**. Where applicable, one of the best calibration methods. Requires complete mixing of tracer with flows.
Rotating-Element Current Meters	Useful for larger flows that do not rapidly vary with time. Typically useful for large systems with appreciable flows. Low flows are difficult to monitor.
Pressure Sensors	Not useful for velocities above 1.5-1.8 m/sec or in pipes with steep slopes (>5%).
Acoustical Sensors	Not applicable to most monitoring locations. Large flow rates are typically required. Base flow required to observe complete storm hydrograph. Typically applicable only to large channels.
Float-and-Stopwatch	Rarely accurate enough for calibration purposes. Not recommended for most situations.
Deflection (or Drag-Body) Method	Rarely accurate enough for calibration purposes. Not recommended for most situations.

Tracer Studies

Tracer methods have been developed to measure flow 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 flow. 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 flow measurement, but 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 flow 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 flow 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 base flow to provide the medium in which the sound wave travels. If there is no base flow, the lower portions of the rising and falling limbs of the hydrograph will be lost.

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 and styrofoam balls 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 flow 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.

Methods Most Suitable for Continuous Velocity Monitoring

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.

Figure 3.11: 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 solids 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 flow.

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 flow measurement, data logging, and automated sampling, and when properly calibrated, this system is capable of greater accuracy than one relying on a stage-flow (i.e., Manning's 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 solids loadings are expected. A built-in conductivity probe senses when there is no flow 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 flow 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 base flow present. It is not practical for smaller diameter conveyances with no base flow, which may be found at a BMP site. Additionally, stormwater conduits for BMP runoff can be 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 BMP monitoring situations.

Water Quality Sample Collection Techniques

Grab Samples

The term "grab sample" refers to an individual sample collected within a short period of time at a particular location. Analysis of a grab sample provides a "snapshot" of stormwater quality at a single point in time. Grab samples are suitable for virtually all of the typical stormwater quality parameters. In fact, grab samples are the only option for monitoring parameters that transform rapidly (requiring special preservation) or adhere to containers, such as oil and grease, TPH, and bacteria.

The results from a single grab sample generally are not sufficient to develop reliable estimates of the event mean pollutant concentration or pollutant load because stormwater quality tends to vary dramatically during a storm event. Nevertheless, grab sampling has an important role in many stormwater monitoring programs for the following reasons:

- A single grab sample collected during the first part of a storm can be used to characterize pollutants associated with the "first flush." The first part of a storm often contains the highest pollutant concentrations in a storm runoff event, especially in small catchment areas with mostly impervious surfaces, and in storms with relatively constant rainfall. In such cases, the first flush may carry pollutants that accumulated in the collection system and paved surfaces during the dry period before the storm. Thus, the results from single grab samples collected during the initial part of storm runoff may be useful for screening-level programs designed to determine which pollutants, if any, are present at levels of concern. However, this strategy may be less effective in areas subject to numerous low-intensity, long duration storms with short inter-event times, because "first flush" effects are less obvious under such weather conditions.

- Some measurable parameters, such as temperature, pH, total residual chlorine, phenols, volatile organic compounds (VOCs), and bacteria transform or degrade so rapidly that compositing can introduce considerable bias. (Note: Grab sampling is the typical method for VOCs because VOCs can be lost through evaporation if samples are exposed to air during compositing. However, as discussed in Section 3.2.1 some automated samplers can be configured to collect samples for VOC analysis with minimal losses due to volatilization).

- Some pollutants, such as oil and grease and TPH, tend to adhere to sample container 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, obtain this information from a series of grabs analyzed individually).

To estimate event mean concentrations or pollutant loads, you could collect a series of grab samples at short time intervals throughout the course of a storm event. There are several different approaches for obtaining information from a series of grab samples. One approach would be to analyze each grab sample individually. If the samples are analyzed individually, the results can be used to assess the rise and fall of pollutant concentrations during a storm and to estimate event mean concentrations of pollutants. This approach can be particularly useful if the monitoring objective is to discern peak pollutant concentrations or peak loading rates for assessing short-term water quality impacts. Analyzing each grab separately adds significantly to laboratory costs; consequently, this approach is rarely used except when program objectives require detailed information about changes in constituent concentrations over the course of a storm.

Composite Samples

Another approach is to combine appropriate portions of each grab to form a single composite sample for analysis, 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 your program encompasses more than a few storm events. For these reasons, many monitoring programs have found that the use of automated monitoring equipment and methods are more appropriate for compiling composite samples than manual monitoring. If detecting peak concentrations or loading rates is not essential, composite sampling can be a more cost-effective approach for estimating event mean concentrations and pollutant loads. A composite sample is a mixture of a number of individual sample "aliquots." The aliquots are collected at specific intervals of time or flow during a storm event and combined to form a single sample for laboratory analysis. Thus, the composite sample integrates the effects of many variations in stormwater quality that occur during a storm event. Composite samples are suitable for most typical stormwater quality parameters, but are unsuitable for parameters that transform rapidly (e.g., fecal coliform, residual chlorine, pH, volatile organic compounds) or adhere to container surfaces (e.g., oil and grease).

The two basic approaches for obtaining composite samples are referred to as time-proportional and flow-proportional. A time-proportional composite sample is prepared by collecting individual sample "aliquots" of equal volume at equal increments of time (e.g., every 20 minutes) during a storm event, and mixing the aliquots to form a single sample for laboratory analysis. Time-proportional samples do not account for variations in flow; pollutant concentrations in sample aliquots collected during the portion of the storm with lower flows are given the same "weight" as sample aliquots collected during higher flows. Consequently, time-proportional composite samples generally do not provide reliable estimates of event mean concentrations or pollutant loads, unless the interval between sample aliquots is very brief and flow rates are relatively constant.

Flow-weighted composite samples are more suitable for estimating event mean concentrations and pollutant loads. The event mean concentration is discussed in detail in Section 2.5.3. A flow-weighted composite sample can be collected in several ways (EPA 1992):

1. Constant Time - Volume Proportional to Flow Rate - Sample aliquots are collected at equal increments of time during a storm event, and varying amounts of each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the flow rate at the time the aliquot was collected. This type of composite sample can be collected using either manual or automated techniques.

2. Constant Time - Volume Proportional to Flow Volume Increment - Sample aliquots are collected at equal increments of time during a storm event, and varying amounts from each aliquot are combined to form a single composite sample. The amount of water removed from each aliquot is proportional to the volume of flow since the preceding aliquot was collected. This type of compositing is generally used in conjunction with an automated monitoring system that includes a continuous flow measurement device. It can be used with manual sampling in conjunction with a continuous flow measurement device, but this combination is uncommon.

3. Constant Volume - Time Proportional to Flow Volume Increment - Sample aliquots of equal volume are taken at equal increments of flow volume (regardless of time) and combined to form a single composite sample. This type of compositing is generally used in conjunction with an automated monitoring system that includes a continuous flow measurement device.

Select the flow-weighted compositing method most suitable for your program based on the monitoring technique (manual or automated) and equipment you plan to use. Compositing Methods 2 and 3 are more accurate than Method 1 because Methods 2 and 3 use the total volume of flow based on continuous flow measurement to scale the sample volume; in contrast, Method 1 uses a single instantaneous rate measurement to estimate the flow over the entire sampling interval. However, if you intend to use manual methods, compositing Method 1 is generally the most practical choice. If automated equipment is to be used, Method 3 is generally preferred because it minimizes the need for measuring and splitting samples, activities that can increase the chance for sample contamination. If you plan to use automated methods, review the equipment manufacturer's specifications and instructions to select the compositing method most appropriate for that particular make and model.

Storm events affect stream flows for variable lengths of time depending on the storm duration and antecedent conditions and catchment characteristics. Runoff may persist for a period of a few hours to one to 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 water quality criteria 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 water quality criteria 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 which are relatively small (a few acres), it is recommended one or more one-hour composite samples be collected during the first few hours of flow 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), peak total metals concentrations are generally 1.5 times the flow-weighted composite concentrations (WCC 1993). Results from monitoring a smaller, highly impervious industrial catchment with the 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.

Automatic Sampling

Automated monitoring involves sample collection using electronic or mechanical devices that do not require an operator to be on-site during actual stormwater sample collection. It is the preferred method for collecting flow-weighted composite samples. Automated monitoring is generally a better choice than manual monitoring at locations where workers could be exposed to inadequate oxygen, toxic or explosive gases, storm waves, and/or hazardous traffic conditions. Also, automated methods are better than manual methods if you are unable to accurately predict storm event starting times. Automated samplers can be set so that sampling operations are triggered when a pre-determined flow rate of storm runoff is detected. Conversely, manual monitoring relies on weather forecasts (and considerable judgment and good luck) to decide when to send crews to their monitoring stations. It is very difficult to predict when stormwater runoff is likely to begin; consequently, manual monitoring crews may arrive too early and spend considerable time waiting for a storm that begins later than predicted, or they may arrive too late and miss the "first flush" from a storm that began earlier than predicted. If the automated equipment is set to collect flow-weighted composite samples using the constant volume-time proportional to flow method, it reduces the need to measure samples for compositing.

If you have determined that field-measured "indicator" parameters (e.g., turbidity, conductivity, dissolved oxygen, pH) are sufficient for your monitoring objectives, consider using electronic sensors and data loggers. Using electronic sensors and data loggers, you can obtain near-continuous measurements of indicator parameters at reasonable cost.

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 very valuable by protecting against inappropriate BMP applications. Therefore, the cost of using automated systems is often justifiable.

Automatic 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 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 which can be analyzed individually or composited. Some automated samplers offer multiple bottle configurations that can be tailored to program objectives.

Important features of automated samplers include:

- Portability.

- Refrigeration.

- Volatile organic compound (VOC) sample collection (if needed).

- Alternative power supplies.

Figure 3.12: Automatic sampler (American Sigma Inc.)

Portable samplers are smaller than those designed for fixed-site use, facilitating installation in 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.

Figure 3.13: VOC sampler (ISCO)

An automated sampler designed for VOCs is currently available from ISCO. The bladder pump used by this instrument minimizes physical disturbance of the sample (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 EPA 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 BMP sampling, for each of the types of samplers described above, 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 to the channel bottom. However, if high solids 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 with peristaltic pumps has shown that their reliability in drawing a consistent sample volume is greatly reduced as the static suction head (i.e., distance between the flow stream 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 flow stream to ensure reliable sample collection.

The degree to which sampler lift affects the concentration of total suspended solids and other pollutant parameters (especially coarser materials) is not well known. 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 by the USGS (FHWA 2001), it was found that suspended solids 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 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. This chamber can cause sample cross-contamination, as it cannot be flushed as the tubing can.

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 for certain types of BMPs (upstream of catch basins). 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 seals 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 no other methods for collecting this flow. However, this sampler is not capable of taking flow or time-weighted composites or of sampling the entire flow 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. 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

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 also 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. USGS determined that between 12 and 16 individual samples resulted in a mean that was within 10 to 20 percent of the actual event mean concentration (FHWA 2001). In-situ monitoring devices offer a possible solution to obtaining a continuous record of water quality; however, at this time, 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 one minute or less intervals. 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 flow. 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:

Physical parameters
Temperature
Turbidity

Chemical parameters
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 solids concentrations and other factors, studies have found that they are not practical for field application (FHWA 2001). 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 downloading 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 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 flow 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 complexed forms. For example, depending on the target parameter, a nitrate-selective electrode will not measure the concentration of nitrite in the flow. 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 in the field of computers 20 years ago: large machines requiring a controlled laboratory environment were operated by highly trained specialists. 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 processes 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 and 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 or BMP monitoring. The “ChemScan” analyzer, manufactured by Biotronics Technologies, Inc., is reported to adjust automatically for changes in the turbidity of the flow and fouling of the optical windows, features which 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 is required to be submerged. Currently it is not applicable for stormwater monitoring.

Research is currently being conducted on applying ultrasonics for particle size analysis. However, it is presently not available for 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 flow passes through. 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 prefilter for suspended solids can be attached if levels high enough to clog the resin filter are anticipated. Pollutants trapped in the prefilter can also be extracted and analyzed.

These systems can be programmed so that samples of the flow 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 prefilter may become clogged as a large volume of water passes through it. Metals can be lost from the filter if the pH drops to 6.0 or lower, 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 BMP monitoring sites.

Remote Communications with Automatic Equipment

The ability to remotely access the memory and programming functions of automated samplers 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 because many of the technical aspects of equipment set-up and shut-down 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 limited. 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 are developing systems that address the problems described above.

Manual Sampling

Manual monitoring involves sample collection and flow measurement by personnel using hand-operated equipment (e.g., bailer, bottle). For a monitoring program that is modest in scope (i.e., relatively few sampling sites and storm events), manual methods for obtaining grab and composite samples may be preferable to those employing automated equipment. Also, if your program requires monitoring large streams, you may need to use manual methods in order to collect cross-section composites. The principal advantages to manual sampling are its relatively low capital cost and high degree of flexibility. In addition to the capital outlay required for the purchase of automated samplers, other costs, such as installation, training personnel to use the samplers correctly, and field maintenance and operations (replacing batteries, interrogating data loggers, retrieving and cleaning sample jars) can be substantial.

Manual sampling is usually preferred under the following circumstances:

- When 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.

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

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

However, manual monitoring may not be feasible if:

- Monitoring personnel are not available after normal working hours.

- Monitoring personnel have strict job descriptions that do not include sampling.

- The organization's insurance policy doesn't cover stormwater monitoring activities.

- Managers and monitoring personnel are not able to deal with sick days, vacations, and competing priorities.

Manual sampling is generally less practical than automated monitoring for large-scale programs (e.g., monitoring programs involving large numbers of sites or sampling events over multiple years). It is difficult to collect true flow-weighted composites using manual methods. Under these circumstances, labor costs and logistical problems can far outstrip those associated with automated equipment. For the same reason, manual sampling is seldom practiced if specific program objectives require that samples be composited over the entire duration of a storm, which is recommended for BMP monitoring.

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

Manual Grab Sampling Equipment

Manual sampling techniques and equipment have been reviewed in more detail by Stenstrom and Strecker (1993). 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 flow is too deep and/or not well mixed enough to be sampled in its entirety (Martin et al. 1992). However, stormwater BMPs often drain relatively small catchments and contain fairly shallow flows. Collection of depth-integrated samples at these sites is not usually performed.

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 flow 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.

3.2.4.3 Error Analysis and Measurement Accuracy

Every measurement has an unavoidable uncertainty due to the precision of the measuring tool, the accuracy of the calibration, and the care with which the measurement is made. If all other sources of error are minimized or removed, then the uncertainty in the measurement is generally on the same order of the smallest numerical value that can be estimated with the measuring instrument. The true value is typically contained in the range of values reflecting the experimental uncertainty of the measurement. Calculating the mean of multiple measurements if the measurement errors are random in nature and not systematic can provide a better estimate of the true value.

Indeterminate (random) errors result from instrument precision, calibration, and inaccuracies in the measuring process. The size and magnitude of indeterminate errors cannot be determined (hence the name) and result in different values from a measuring process when the process is repeated. There are several ways indeterminate errors can be introduced, including operator error, variation in the conditions in which the measuring process is conducted, and the variability of the measuring instrument.

Determinate (systematic) errors have an algebraic sign and magnitude and result from a specific cause introducing the same error into every measurement. Determinate errors are more serious than indeterminate errors because taking the average of multiple measurements cannot reduce their effects. This is because determinate errors have the same sign and magnitude, which prevents positive and negative errors from off setting each other. Causes of this type of error can include operator bias, (consistent) operator error such as incorrect reading of the instrument, or improper calibration of the measuring instrument.

Expressing Errors

Absolute and relative methods are the standard forms for expressing errors. Absolute error is expressed as a range of values reflecting the uncertainty in the measurement and is reported in the same units as the measurement. Measured values followed by the ± sign express the absolute error.

Relative (or fractional) error is expressed as the ratio of the uncertainty in the measurement to the measurement itself. This is difficult to estimate, because it is a function of the true value of the quantity being measured, which is unknown, otherwise the error estimate would be zero. Typically this error estimate utilizes the measured value as the “true” value.

The type of measurement and instrumentation can provide an indication of the appropriate form of expressing the error. For example, a pressure probe used to measure depth of flow is likely to have the accuracy of the instrument expressed as a relative percent, while readings on a staff gauge would have an absolute error related to the markings on the gauge. In these instances the reported depth measurements would be expressed in the same manner as the precision of the measuring instrument.

Propagation of Errors

Quite often, measurements taken of one or more variables are used in equations to calculate the value of other variables. For example, to calculate the area of a rectangle, the length and width are usually measured. For a cube, the length, width, and height are measured to calculate the volume. Each measurement has a potential error associated with it and, as a result, the variable calculated from the individual measurements will also contain some error. The magnitude of the error in the calculated variable can be of a different order than the error associated with any one of the measurements depending on the algorithm that describes their relationship.

A detailed discussion of the propagation of errors and methods for calculating estimates of errors as a result of propagation are provided in Appendix A.

3.2.5 Recommendation and Discussion of Storm Criteria

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

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

- To estimate performance on the basis of differences of relatively noisy data sets (i.e., inlet versus outlet data). This intensifies the value of large volumes of credible data (not just a few samples from portions of a few storms).

- To characterize the water quality of dry weather flows for some BMPs with significant wet storage and/or base flows. 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 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 your methods to be consistent with available resources. The types of storms to be monitored and optimal temporal distribution of monitoring events also should be considered during project planning (Caltrans 1997).

3.2.5.1 Storm Characteristics

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 percent 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 as they are really not representative in many cases. 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.

Because the initial objective of the monitoring is to consider a "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 for your situation, you can develop site-specific storm event criteria by analyzing long-term rainfall records using EPA’s SYNOP or another appropriate analytical program such as EPA’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 in order to generate reliable population statistics is beyond the resources of most agencies. For this reason, it is recommended a "worst case" approach be taken. Often permits require that you monitor "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.

3.2.6 Recommendation and Discussion of QA/QC

Prior to sample collection, you should prepare a Quality Assurance/Quality Control (QA/QC) plan that describes the sample collection and laboratory analysis procedures. The first step in preparing a QA/QC plan is to determine the data quality objectives (DQOs) appropriate to your program. Ideally, the QA/QC plan should be prepared by someone with a good understanding of chemical analytical methods, field sampling procedures, and data validation procedures. Select an analytical laboratory that has been accredited to perform the analyses required for your program. The analytical laboratory should provide its input to ensure the plan is realistic and consistent with the laboratory's operating procedures.

It is recommended that the QA/QC plan should summarize the project organization, data quality objectives, required parameters, field methods, and laboratory performance standards for the measurements. A typical QA/QC plan for stormwater monitoring may include the following sections:

1. Project Description

2. Project Organization and Responsibility

3. Data Quality Objectives

4. Field Methods
    - sample collection methods
    - field QA procedures such as equipment cleaning and blanks
    - collection of field duplicate samples
    - sample preservation methods
    - type of bottles for subsampling

5. Laboratory Procedures
    - constituents for analysis
    - laboratory performance standards (e.g., detection limits, practical quantitation limits, objectives for precision, accuracy, completeness)
    - analysis method references
    - frequency and type of laboratory QA samples (e.g., laboratory duplicates, matrix spikes and spike duplicates, laboratory control samples, standard reference materials)
    - data reporting requirements
    - data validation procedures
    - corrective actions

It is important that you develop your QA/QC plan in concert with your field personnel and your analytical laboratory. If you have not already done so, you should visit the monitoring locations to verify that the selected monitoring methods are feasible. Inform your managers of any modifications to either the DQOs or laboratory performance standards due to field or laboratory constraints.

Potential Sources of Error

This section describes some potential sources of error that can occur in the process of sampling or transferring monitoring results to a database. These common errors can be specifically addressed in the QA/QC plan to increase awareness and potentially reduce their occurrence.

In many cases error is introduced in the process of transferring or interpreting information from the original data records. These errors most likely result from typographical errors or format and organizational problems. In most cases, water quality data are returned from the lab in some tabular format. Data are then entered into a database, typically with separate records for each monitoring station and each storm event. The inconsistency of data formats between monitoring events can considerably increase the potential for errors in entering data into the database and subsequently interpreting and using the processed (digital) data.

Where errors in data are present in the processed information, format is often a causative factor. In some circumstances interpretation of the data presented is not possible due to missing explanations of the data format; in these cases, data should be excluded. It has been found that missing records typically have to do with inadvertent skipping of a column or row of data. Errors in data or parameter type, that were not typographical, typically resulted from misalignment of rows or columns. Supporting information and useful summaries of parameters, such as characteristics of the watershed, are often included as text in a general information column, or in a report or record external to the water quality database. In addition to making the extraction of this supporting information laborious, checking for errors in information not formatted succinctly can also be quite cumbersome.

In addition to these "paper" errors, many other opportunities abound for introduction of other errors, including errors in interpretation and reporting of supporting information (e.g., misreading of maps, poor estimates of design, watershed, and environmental parameters, etc.) and reporting of information from previous studies that may have been originally incorrect.

In addition to potential reporting errors, all field collected and/or laboratory analyzed data on flow and water quality are subject to random variations that cannot be completely eliminated. These variations are defined as either "chance variations" or "assignable variations." Chance variations are due to the random nature of the parameters measured; increased testing efforts and accuracies cannot eliminate these variations. Although assignable variations cannot be eliminated altogether, these variations can be reduced and the reliability of the data increased. Assignable variations are those errors that result from measurement error, faulty machine settings, dirty containers, etc. Increasing both the length of a study and/or the number of storms sampled can reduce the assignable variations and increase the reliability of the data (Strecker 1992). Many monitoring studies take place over relatively short periods and have a small number of monitored storms during those periods. Thus the resultant data sets are often susceptible to both of these types of variations in addition to any reporting errors.

Prepare Health and Safety Plan

As part of the QA/QC plan, the health and safety of personnel involved in the monitoring program should be considered. Aside from ensuring quality results and efficient implementation of monitoring procedures, human health and safety are a priority.

The health and safety of field personnel should be considered throughout development of your monitoring program. You should select monitoring locations and methods that have the lowest potential for health and safety problems. You should then prepare a health and safety plan. The first step is an assessment of the physical and chemical hazards likely to be associated with each monitoring activity. Some of the potential considerations include:

- Wet (and possibly cold) weather conditions.
- Physical obstructions that complicate access to the site and sample collection point (e.g., steep slopes, dense blackberry bushes).
- Traffic hazards.
- Manholes (i.e., confined space entry, including toxic, explosive, or otherwise unsafe conditions).
- Flooding and fast moving water.
- Dim lighting.
- Slippery conditions.
- Contact with water that could be harmful (e.g., caustic, pathogenic).
- Lifting and carrying heavy and bulky pieces of equipment, including carboys and sample bottles filled with water.

Based on the hazard assessment, identify the appropriate equipment and procedures to protect field personnel from the potential hazards you have identified. Also, consider adjusting your monitoring locations and/or methods if necessary to minimize the risk of health and safety problems.

3.2.6.1 Sampling Methods

Proper sampling methods are essential in conducting a BMP monitoring program in order to ensure resulting data are meaningful and representative of the water and other media being processed by the BMP. Sampling methodologies and techniques that maintain and confirm the integrity of the sample are discussed below.

Grab Sample Collection Techniques

During moderate flow events, grab samples can be collected at some stations simply by approaching the water to be sampled and directly filling up the bottles, being careful not to loose any preservative already contained in the bottle. It is important also to be aware of surface conditions of the sampled water body, avoiding layers of algae and debris and areas of dense vegetation if possible. The bottle cap should be handled carefully, making sure not to introduce any extraneous dirt, water, debris or vegetation while filling the bottle; bottle caps should not be placed on the ground facing downward.

Low flow events may not provide sufficient flows to allow filling of bottles directly. In this case, sample collectors may be used to collect the low flow runoff and transfer the water into the sample bottles. These sample collectors are typically cup to bucket sized containers with a wide mouth and no neck, allowing the collector to be placed close to the bottom surface of the flow path and then filled with the small depth of flow. Sample collectors must be compatible in material with the sample bottles and the constituents to be analyzed. Sample collectors made of stainless steel, teflon or glass could be considered after investigating the compatibility of these materials with each constituent to be analyzed. After each sample bottle has been filled, and before the next monitoring site is to be sampled, the sample collector should be rinsed thoroughly with deionized water to prevent cross-contamination between sites. At least four rinses with deionized water are necessary, followed by filling the sample collector several times with new monitoring site runoff before finally using the collector to fill the sample bottles.

During high flow events, runoff may be unsafe to approach directly to collect the sample. Modified sample collectors can be designed to allow remote sampling. Many stainless steel buckets or cookware (asparagus cookers) have handles to which ropes may be tied at a length that allows the sample collector to be lowered into the runoff and raised back up after filling with water. These sample collectors with rope are ideal to use if sampling a creek from a bridge or sampling an outfall from a creek bank. In addition, modified sample collectors will work well to sample runoff in a manhole, eliminating the need to enter the confined space during higher flows. The advantage of the rope and bucket device is that a significant length of rope can be attached to the sample bucket to allow for sampling from great heights, yet the rope can be coiled and stored compactly. If a sturdier sampling device is needed, sample collectors may be attached to a pole using tape or rope and lowered into the runoff. Again, cross-contamination between sample sites should be prevented by rinsing the sampling collector with deionized water and new sample water several times.

Contamination/Blanks

Control over sample contamination is critical when attempting to measure concentrations of compounds at the parts-per-billion level. 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 if 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 in order 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 (EPA 1993a,b) 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 likely not necessary for stormwater runoff samples, some of the laboratory procedures should be employed. For example, 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.

Reconnaissance and Preparations

Reconnaissance and preparation is an important component of any field sampling program. Proper reconnaissance will help field operations to 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.
- 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.

Sample Containers/Preservation/ Holding Times

EPA recommends that samples be collected and stored in specific types of sample container materials (e.g., plastic, glass, Teflon). For analysis of certain parameters, 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. 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 as well as precision and accuracy goals and qualified according to EPA functional guidelines for data validation (EPA 1988).

If composite sampling procedures are to be used to collect one large sample that will be subsampled into smaller containers, the composite sample bottle should be compatible with all of the constituents to be subsampled. In general, the use of glass containers will allow subsampling 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 should be collected for field and laboratory QA/QC samples. As a general guide, if one station is to be used for both field and laboratory QA/QC measurements, four times the normal volume of water should be collected.

Recommended Field QA/QC Procedures

Listed below are the recommended quality control samples and field procedures.

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 be routinely 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 often not done due to 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 EPA-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.

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 concentrations 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.

3.2.7 Recommendations for Data Management

A monitoring program may generate a considerable amount of information in a wide variety of forms. Before you begin monitoring, you should establish procedures for managing the data you expect to generate and for presenting the results.

Data management is an important component of your overall stormwater quality program. You need to be able to store, retrieve, and transfer the diverse hard copy and electronic information generated by your monitoring program. Before you begin monitoring, you should establish:

- A central file to accommodate the hard copy information your program is expected to generate and practical dating and filing procedures to help ensure that superseded information is not confused with current information.

- A database to accommodate digital information such as results of laboratory analyses, information recorded by data loggers (e.g., flow, precipitation, in-situ water quality measurements), maps in CAD or GIS, spreadsheets, etc. It is recommended that data be stored and reported according to the protocols described in Section 4 of this Manual.

In many cases, the laboratory can provide the analytical results in an electronic format (i.e., an "Electronic Data Deliverable" or EDD) that you can input directly to your database. This can save time and reduce the potential for data entry errors. You should work with the analytical laboratory to determine if electronic data transfer makes sense for your program.

If you do not have one, you may want to consider instituting an electronic filing system to help ensure that draft reports (including text, tables, and graphics) and unvalidated analytical data can be easily distinguished from final reports and validated data.

After data from the field and/or laboratory have been received and the originals have been stored in the project file, they may be routed to designated staff members who will perform one or more of the activities. These activities include data validation, calculations and analysis, and data presentation.

Data reports should be reviewed for completeness as soon as they are received from the laboratory. Reports should be checked to ensure all requested analyses were performed and all required QA data are reported for each sample batch. 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.

3.2.7.1 Database Requirements

This section provides general guidance on storing data and is based on QA/QC procedures developed for the ASCE/EPA National Stormwater Best Management Practices Database.

Databases provide a significant level of control over the types of data that are valid for a particular field. These "rules" limit the format and structure of individual fields. For example any field where a date is present should be entered in the mm/dd/yyyy format. In addition, drop down boxes with lookup tables of relevant values can be used extensively in a database in order to maintain consistency between records.

Additional fields can be included on forms in order to allow comments to be provided in each data table. Water quality information can be entered in a tabular format where one row is used for each sample and one column for each constituent. Macros can then be written to parse the tabular format into a one-record-per-constituent format similar to that used in the National Stormwater Best Management Practices Database (Database).

Analysis of Database Links

In creating a complex database, records are often linked between tables. Once all data have been entered into a database, a check of the established links should be done between the tables storing event data for flow, precipitation, and water quality. The start and stop date and time of each water quality record can be checked against the date and time of the linked flow and precipitation event. This can be conducted using a combination of database queries by identifying dates that do not pair up. All dates that do not match should be flagged and the links should be checked by hand. This process ensures internal consistency between the separate tables in the database. Where any errors are encountered, the original document should be consulted.

Analysis of Outlying Records

An analysis of the data contained in database tables can be done to identify outlying values that resulted from typographical errors during data entry (e.g., wrong decimal place), unit errors (e.g., mg instead of μg), and incorrectly assigned STORET Codes. Two types of outlying records can appear in the database: data entry errors (i.e., manifestations of the data extraction process) and real outlying values (i.e., values present in a study's original documents). The efforts conducted during outlier analysis seeks to identify and correct data entry errors. The assumption in looking for outlying errors is that recorded water quality parameter values lie within an expected reasonable range. Values that are outside of this range may be incorrectly entered into the database and deserve close attention. This method is particularly useful for identifying errors in units.

The usefulness of identification of outliers varies from constituent to constituent. For example any mistyped entries are easily identified in pH or temperature data. If one digit is off in pH or temperature data it is quite obvious, and, thus, there is a greater degree of confidence in the quality of the data based on an outlier analysis of pH or temperature than for other water quality parameters. Unfortunately, on the other end of the scale are other parameters such as Fecal Coliform. Even an error in excess of two orders of magnitude is not readily identified in a series of Fecal Coliform records, and thus an outlier analysis provides little or no additional information about the quality of Fecal Coliform records.

Sample Comparisons Between Original Documents and Final Data Set

Finally, to better quantify the quality of the data stored in a data set, sample comparisons can be made of the data set with the original source documents. A percentage of all records can be checked in order to assess data quality. All errors identified in these documents should be flagged and corrected. The sample comparisons conducted provide insight into overall quality of the data entry process.

Digital Conversion of Data

In the event that data is provided in a digital format that is different from the designated ASCE/EPA BMP Database format (see Section 3.4 of this Guidance), conversion of the data is necessary. Data can be easily imported between database, spreadsheet, and word processing software in more recent versions of most software. However, this data should be carefully evaluated and checked for transition errors. Often, different programs will automatically round numbers to a certain decimal and then truncate the remaining digits. Evaluation and comparison between the original document or database and the converted data is recommended for all records to ensure that the quality of the data is maintained.

Double Data Entry and Optical Character Recognition

Before data entry begins, both digital and hard copy data extraction/entry forms should be created along with instructions for the data entry process. These forms should be based directly on the database table structure. This methodology will allow the data collection and entry process to take place in a consistent, uniform environment.

To improve the quality of data entry during any process that requires hand entry of large data sets, it is typically necessary to implement a double entry procedure with automated flagging and formal correction of all inconsistencies. This method should be considered as a potential part of any data entry protocols. This is one of the few systematic methods for ensuring very small error rates. In circumstances where significant understanding of the source of the data is required on the part of the data entry personnel, the cost of this approach could be prohibitive.

In some cases, optical character recognition (OCR) can be used effectively to increase the speed of data entry. In cases where OCR is used, all results should be hand checked to ensure data quality. The data resulting from OCR typically contains a smaller number of errors compared to hand entered data, depending on format of data.

3.3 Phase III - Implementation of Monitoring Plan

3.3.1 Training of Personnel

Each member of the monitoring team must receive whatever training is necessary to properly perform his or her assigned roles. Generally, the first step is for each team member (including back-up personnel) to review the monitoring plan and health and safety plan. Next, the team members attend an initial orientation session that includes a "dry run" during which team members travel to their assigned stations and simulate monitoring, sample documentation, packaging, etc., under the supervision of the instructor (usually the principal author of the monitoring plan). Health and safety precautions should be reinforced during the dry run. Periodic "refresher" orientation sessions should be conducted after long dry periods, or when the monitoring team composition changes.

3.3.2 Installation of Equipment

If you plan to use manual monitoring techniques, equipment installation may be unnecessary. If you plan to use automated monitoring methods, you must install the sampling and flow measurement equipment at the monitoring locations. Equipment installation procedures vary depending on the specific equipment and the configuration of the monitoring location. Follow the equipment manufacturer's instructions for installation. Some general recommendations for equipment installation are listed below:

- Personnel must follow the health and safety plan when installing equipment. Some monitoring locations may require use of protective clothing, traffic control, combustible gas meters, and special training in confined space entry procedures.

- Bubbler tubes, pressure transducers, and velocity sensors typically are mounted on the bottom of the channel in the middle of the channel cross-section, facing upstream. Ultrasonic depth sensors typically are mounted above the water surface.

- In most cases, the automated sampler intake tube is mounted facing upstream and parallel to the flow in order to reduce any flow distortion that could bias the sampling of suspended solids. The intake often is covered with a strainer to prevent clogging.

- Probes, sensors, and intake lines usually are anchored to the pipe or channel. The intake tubing should be anchored throughout its length so that it will not bend, twist or crimp under high flows.

- Weirs and flumes must be secured to the bottom of the pipe or channel. If the monitoring location is in a swale, the weir or flume cutoff walls must be buried in each bank so that the structure extends all the way across the channel and all flow is directed through the weir or flume.

- If not installed inside a manhole vault, the flow meter and automated sampler should be placed in a sturdy shelter to protect the equipment from vandalism and other damage.

- If batteries are used as the power supply, install fresh batteries at the frequency recommended by the manufacturer or before each anticipated storm monitoring event.

3.3.3 Testing and Calibrating Equipment

Water quality probes (e.g., pH, conductivity), automated samplers, and flow meters must be periodically calibrated in order to ensure reliable operation and credible results. Typical calibration procedures are summarized in this section; however, you should always follow the manufacturer's instructions when calibrating a specific monitoring device.

Calibration of pH meters, conductivity meters, dissolved oxygen meters, and other water quality instruments generally involves two steps:

1. Use the instrument to measure a known standard and determine how much the instrument's measurement differs from the standard.

2. Adjust the instrument according to the manufacturer's instructions until it provides an accurate measurement of the standard.

Automated sampling equipment should be calibrated after installation to ensure it pumps the correct volume of sample. The condition of the sampler pump and intake tubing, the vertical distance over which the sample must be lifted, and other factors can affect the volume drawn. Therefore, you should test the sampler after installation and adjust the sampler programming if necessary to be sure the system consistently draws the correct sample volume.

Flow meters can be affected by the hydraulic environment in which they are placed; consequently, they should be calibrated after installation to ensure accuracy. Because sediments, debris, and other materials carried by stormwater can damage or clog bubbler tubes and pressure transducers used for depth measurements, they must be frequently inspected and calibrated by checking the flow depth with a yard stick or staff gauge. Ultrasonic velocity sensors and other instruments that measure flow rate must also be inspected and checked against velocity measurements made using a current meter.

3.3.4 Conducting Monitoring

After you have completed the advance preparations described above, you are ready to begin monitoring.

The general steps for automated monitoring are:

1. Perform routine inspection and maintenance to help ensure that the equipment will function properly when a storm event occurs.

2. Keep track of precipitation. After each storm, check the local rainfall records (or preferably a rain gauge at or near the center of the basin) to see if the amount of precipitation and the antecedent dry period met your pre-determined criteria.

- If the storm did not meet your criteria, remove the sample bottles from the sampler and replace them with clean bottles. Empty the sample bottles and arrange for them to be cleaned.

- If the storm criteria were met, remove the sample bottles. Check them to be sure they received the proper amount of sample. Check the sampling times against the storm duration to see how much of the storm was sampled. If this meets your criterion, complete the sample labels, chain-of-custody form and other field documentation, then deliver the samples to the laboratory for analysis.

3. If the sampler overfilled or underfilled the sample bottles, refine the sampler programming.

4. Reset the sampler and inspect all of its systems for possible damage or clogging so that it will be ready to sample the next storm.

The general steps for manual monitoring are:

1. The monitoring team leader or another designated person tracks the weather forecasts.

2. When the weather forecasts indicate that a potentially acceptable storm is approaching, the monitoring team leader contacts the monitoring team and the analytical laboratory. If any of the primary team members are unavailable, the monitoring team leader arranges for back-ups. The team members check their instructions, communications protocols, monitoring equipment, and supplies to ensure they are ready.

3. The monitoring team leader contacts NOAA (or some other meteorological service, if better information is available) to get updated forecasts as the storm approaches. When the forecasts indicate that the storm is likely to start within the next few hours, and it still appears likely to meet the storm selection criteria, the team leader directs the team members to proceed to their assigned monitoring stations so that they arrive before the predicted start time. The team leader also alerts the lab that samples are likely to be delivered soon.

4. The team members travel to their assigned locations and start collecting samples and taking flow measurements as soon as possible after stormwater runoff begins. They fill out the sample labels, chain-of-custody forms, and other field documentation.

5. During monitoring, the team members may contact the team leader (usually by cellular phone) to ask questions, notify him or her of changing conditions, receive direction, etc.

6. After samples have been collected, they are shipped or delivered to the analytical laboratory.

7. If the lab is to prepare flow-weighted composite samples, the monitoring team members must use the flow data they collected to determine the amount of each sample to be used

to form the composite. Usually, the team will calculate the amounts using a spreadsheet and fax the completed spreadsheet to the lab.

If you are using manual methods, you will need to maintain a vigilant "weather watch." This is essential if you wish to monitor the initial runoff from a storm event. You need some advance notice of an impending sampling event in order to have enough time to contact the monitoring team, arrange for back-ups if the primary members are unavailable, notify the analytical laboratory, work out communications protocols, pick up ice, and travel to the monitoring locations. Also, if your are able to obtain reasonably accurate estimates of storm start times, you can reduce the amount of stand-by time for your monitoring team. Finally, a close weather watch can help reduce the risk of a "false start" which can occur when a predicted storm fails to materialize or turns out to be a brief shower.

3.3.5 Coordinate Laboratory Analysis

Most stormwater monitoring programs involve laboratory analysis. Exceptions include (1) field screening programs that rely solely on visual observations and field test kits, and (2) programs that rely on "in-situ" monitoring of indicator parameters (e.g., pH, dissolved oxygen, turbidity) using probes and data loggers.

It is a good idea to involve laboratory personnel in identifying the analytical methods establishing communications protocols and QA/QC protocols. Typically, the laboratory will provide the pre-cleaned sample bottles and distilled/deionized water used for monitoring.

Your mobilization protocols should include notifying the laboratory when a storm monitoring event appears imminent. They should also include contacting the laboratory shortly after the monitoring event to ensure that the samples were received in good condition and to answer any questions the lab may have regarding the analyses to be conducted. Also, it is a good idea to periodically contact the laboratory while the analyses are being conducted. Frequent communication with the laboratory helps reduce the risk of incorrect analysis and other potential unpleasant "surprises."

3.4 Phase IV - Evaluation and Reporting of Results

3.4.1 Validate Data

You should evaluate the quality or adequacy of the laboratory analytical results before you interpret the results. This evaluation is known as "data validation" or data quality review. The basic steps are listed below.

1. Check that all requested analyses were performed and reported. Check that all requested QA/QC samples were analyzed and reported.

2. Check sample holding times to ensure that all samples were extracted and analyzed within the allowed sample holding times.

3. Check that the laboratory's performance objectives for accuracy and precision were achieved. This includes a check of method blanks, detection limits, laboratory duplicates, matrix spikes and matrix spike duplicates, laboratory control samples, and standard reference materials.

4. Check that field QA/QC was acceptable. This includes a check of equipment blanks, field duplicates, and chain-of-custody procedures.

5. Check that surrogate recoveries were within laboratory control limits.

6. Assign data qualifiers as needed to alert potential users of any uncertainties that should be considered during data interpretation.

If the laboratory and field performance objectives were achieved, further data validation is not generally needed. Specifics of the instrument calibration, mass spectral information, and run logs are not usually recommended for review unless there is a suspected problem or the data are deemed critical. If performance objectives were not achieved (e.g., due to contaminated blanks, matrix interference, or other specific problems in laboratory performance), the resulting data should be qualified. EPA functional guidelines for data validation (EPA 1994a,b) should be used as a guide for qualifying data.

3.4.2 Evaluate Results

After the chemical data have been validated, you should perform a preliminary data evaluation. The main purpose of the preliminary evaluation is to determine whether you have obtained enough information of sufficient quality to meet BMP assessment goals. If the answer is no, you should continue monitoring until you have collected sufficient information. If the answer is yes, you should proceed with the definitive evaluations that are best suited to your specific objectives.

3.4.2.1 Preliminary Data Evaluation

After the analytical results have been validated, consider graphing the flow and rainfall data vs. time for each storm event in order to produce a storm hydrograph (flow rate versus storm duration). It is often helpful to plot rainfall volume versus storm duration on the same graph. In addition, you should denote the times when the grab or composite samples were collected. This information can be very helpful in interpreting the chemical results.

Generally, stormwater quality variability is so high that statistical evaluation is not worthwhile until you have monitored several events (at least four). You should conduct an initial statistical analysis using the validated chemical data. This analysis will provide summary statistics that indicate how well your sample results represent stormwater quality at a given site. Summary statistics include sample mean, variance, standard deviation, coefficient of variation, coefficient of skewness, median, and kurtosis. Stormwater quality typically exhibits a lognormal distribution (EPA 1983; WCC 1989). Therefore, you should calculate these descriptive statistics based on an assumed lognormal distribution. Non-detects should be included in calculating the initial statistics using a maximum likelihood estimator approach.

The initial statistical analysis can help you determine whether it will be useful to statistically test various hypotheses regarding the existing data set. For example, if the standard deviations are several times larger than the means (i.e., the coefficient of variation is 3 or more), hypothesis testing may not be worthwhile. You may need to conduct additional monitoring to compensate for the observed variability and allow statistically significant differences to be discerned.

3.4.2.2 Definitive Evaluations

If your initial statistical analysis indicates that your samples are representative of water quality at the site(s) in question, you should conduct additional statistical analyses (or perhaps modeling) as needed to answer the key questions about your stormwater catchment area.

Consider the initial statistics when selecting the statistical procedure(s) you will use to answer the key questions about your stormwater catchment area. For example, if the data set does not appear to follow a normal or lognormal distribution, or if the data set contains a high proportion (i.e., >15%) of non-detects, non-parametric tests may be more appropriate than parametric tests.

The results of your monitoring program may also serve as input to a water quality model. Loadings can be calculated using SUNOM (previously the simple model, Schueler 1987), 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 dynamic model takes into account the variability inherent in stormwater discharge data including variations in concentration, flow rate, and runoff volume. A dynamic model can therefore 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. Thus, the modeler can describe the effects of observed discharges on receiving water quality in terms of the frequency by which water quality standards are likely to be exceeded. Dynamic models include EPA's

Stormwater Management Model (SWMM) and Hydrologic Simulation Program Fortran (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) (EPA 1992).

3.4.3 Report Results

The results of your monitoring program should be presented in one or more reports. The appropriate report frequency and content depends on your monitoring program objectives and your audience. If you are monitoring to comply with a permit, the permit will generally specify the minimum frequency and content of the reports.

Most monitoring programs involve two types of reports: status (or progress) reports and final reports. To determine the appropriate frequency of status reports, consider your monitoring frequency and objectives, particularly any permit requirements. Many programs produce status reports on a quarterly or semi-annual basis. A typical status report may contain the following information:

- Summary of work accomplished during the reporting period
- Summary of findings
- Summaries of contacts with representatives of the local community, public interest groups, or state federal agencies
- Changes in key project personnel
- Projected work for the next reporting period

You should prepare more comprehensive reports at the end of the monitoring program (for short-term programs) or at the end of each year (for multi-year programs). Consider including the above-listed information and the following information in your annual or final report:

- Executive summary
- Monitoring program background and objectives
- Monitoring station descriptions, analytical parameters, analytical methods, and method reporting limits
- Summary descriptions of the conditions and stations, equipment inspections and calibrations, etc.
- Sample collection, precipitation, and flow measurement methods

- Flow, precipitation, and water quality results and data validation information
- Qualitative and statistical data evaluations/hypothesis testing as required for your specific program objectives (see Section 3.4.2 and Appendix I)
- Summary and conclusions, including any caveats or qualifying statements that will help the reader understand and use the reported information in the appropriate context
- Recommendations regarding management actions (e.g., changes in monitoring program, implementation of BMPs)

3.4.3.1 National Stormwater BMP Database Requirements

This section is designed to provide guidance for consistent reporting of results collected from BMP monitoring studies. The protocols described are based on those specified in the National Stormwater Best Management Practices Database, which has been developed by the Urban Water Resources Research Council of ASCE under grant funding from EPA to serve as a tool for data organization and reliable comparison of BMPs. Minimum requirements for acceptance in the National Database are outlined in this section, and standard format examples that can be used as templates for reporting results of stormwater monitoring studies are provided.

The National Stormwater BMP Database was developed to provide a scientifically sound tool for the determination of the effectiveness of BMPs under various conditions for a range of design parameters. The data fields included in this database have undergone intensive review by many experts and encompass a broad range of parameters including test site location, watershed characteristics, climatic data, BMP design and layout, monitoring instrumentation, and monitoring data for precipitation, flow and water quality. In order to effectively compare the performance of different BMPs under a variety of conditions, a set of "required" database fields were identified. These "required" fields are considered the minimum requisites for acceptance into the National Stormwater BMP Database. The database requirements vary with the different types of BMPs, and special requirements exist for unique hydraulic conditions. Database requirement categories and fields are as follows:

1) Information required for all BMPs (Table 3.5)

   - General Test Site Information
   - Watershed Information
   - Monitoring Station Information
   - Precipitation Data
   - Flow Data
   - Water Quality Data

Table 3.5: National Stormwater BMP Database requirements for all BMPs

Data Element	Description
General Test Site Information	
BMP Test Site Name	Name that site is known by locally.
City	City closest to test site.
State	State where test was performed.
Zip Code	Zip code of the test site.
Country	Country where the test site is located.
Altitude	Altitude to nearest 100 ft or 30 m.
Sponsoring and Monitoring Agencies for Test Site	
Address	Includes monitoring and sponsoring agency name and contact information.
Watershed Information	
Subject Watershed Name	Name that watershed is referred to locally.
Total Watershed Area	Topographically defined area drained by system.
Percent (%) Impervious Area	Total percent of impervious surface in watershed.
Regional Climate Station (US)	Regional climate station in US that is most relevant to test site.
Land Use Information	Description of land uses (only required for non-structural BMPs).
Monitoring Stations	
Station	User-defined name for subject monitoring station.
Identify Upstream BMP	BMP upstream of the monitoring point (if any).
Identify Relationship to Upstream BMP	Identify the relationship of the monitoring station to the upstream BMP (i.e. inflow, outflow or not applicable).
Identify Downstream BMP	BMP downstream of the monitoring point (if any).
Identify Relationship to Downstream BMP	Identify the relationship of the monitoring station to the downstream BMP (i.e. inflow, outflow or not applicable).
Monitoring Instrumentation	
Monitoring Station Name	Select monitoring station where the instrument is located.
Precipitation Data	
Monitoring Station Name	Identify monitoring station where precipitation event was monitored.
Storm Runoff and Base Flow Data	
Monitoring Station Name	Select monitoring station where flow event was monitored.
Type of Flow	Base flow or stormwater runoff.
Flow Start Date	Month, day and 4-digit year (e.g. 01/01/1998).
Total Bypass Volume (if any)	Total runoff volume minus runoff volume influent to BMP.
Total Storm Flow Volume into or from BMP	Total runoff volume minus the bypass volume.
Dry Weather Base Flow Rate	Flow rate during dry-weather conditions.

(Table continued on the following page)

Water Quality Sampling Event	
Monitoring Station Name	Select monitoring station where samples were collected.
Related Flow-Event	Select flow data corresponding to water quality data.
Date Water Quality Sample Collected	Month, day and 4-digit year the water quality sample was collected.
What Medium Does the Instrument Monitor	e.g. Groundwater, surface runoff.
Water Quality Parameters	STORET water quality parameters analyzed.
Value	Value of measured constituent.
Unit	Units of measured constituent.
Qualifier	Select STORET qualifier code.

2) Data required for structural BMPs (Table 3.6)

Table 3.6: National Stormwater BMP Database requirements for structural BMPs

Data Element	Description
Structural BMP Information	
Structural BMP Name	Common name by which BMP is referred to locally.
Structural BMP Type	Select the type of BMP being monitored at the site (drop-down list).
Date Facility Was Put Into Service	Month, day and 4-digit year facility became operational.
Number of Separate Inflows	Number of inflows into the facility.
Describe the Type and Design of Each BMP Outlet	Description of the outlet configuration (i.e. Perforated riser).
Is the BMP Designed to Bypass When Full?	Select "Overflow" or "bypass" characteristics of BMP.
BMP Drawing	Plan view and profile of BMP (in bitmap format for database).

3) Information required for non-structural BMPs (Table 3.7)

Table 3.7: National Stormwater BMP Database requirements for non-structural BMPs

Data Element	Description
Non-structural BMP Information	
Non-structural BMP Type	Type of non-structural BMP (e.g. educational, maintenance practices, etc.).
Non-structural BMP Name	The name by which the non-structural BMP is referred to locally.
Date Test Began	Month, day and 4-digit year.
Describe the Quantity or Measure of the BMP Being Practiced	Measure of the educational, maintenance, recycling or source control BMP.

4) Individual structural BMP requirements (Table 3.8) for:

- Detention Basins.
- Grass Filter Strips.
- Infiltration Basins.
- Media Filters.
- Porous Pavement.
- Retention Ponds.
- Percolation Trenches and Dry Wells.
- Wetland Channels and Swales.
- Wetland Basins.
- Hydrodynamic Devices.

Table 3.8: National Stormwater BMP Database requirements for individual structural BMPs

Data Element	Description
Detention Basin Design Data	
Water Quality Detention Volume	The volume of runoff that is captured and released over time.
Water Quality Detention Area (when full)	The area of water surface in basin at full water quality detention volume.
Water Quality Detention Basin Length	Distance between inflow and outflow (average for multiple inflows).
Detention Basin Bottom Area	Area of the bottom of the detention basin, including bottom stage area.
Brim-full Volume Emptying Time	Emptying time of water quality detention volume.
Half Brim-full Volume Emptying Time	Emptying time of lower half of water quality detention volume.
Bottom Stage Volume (if any)	The volume of the lower “bottom stage” of the detention basin.
Bottom Stage Surface Area	The surface area of the lower “bottom stage” of the detention basin.
Is there a Micro Pool?	“Yes” or “No” indication of micropool.
Forebay Volume	Volume of the forebay portion of the detention basin.
Forebay Surface Area	Surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	List and description of types of vegetation on the basin sides and bottom.
Flood Control Volume (if any)	Volume in excess of water quality detention volume.
Design Flood Return Periods	Design return period if basin is designed for flood control.
Grass Filter Strip Design Data	
Grass Strip Length	Length of strip in the direction of flow.
Grass Strip Slope	Slope of the strip along the flow path.
Flow Depth During 2-Year Storm	Design depth of flow during the 2-year peak flow.
2-Year Peak Flow Velocity	Design flow velocity during the 2-year peak flow.
Describe Grass Species and Densities	List of grass species and their densities.
Is Strip Irrigated?	“Yes” or “no” indication of irrigation.

(Table continued on the following page)

Infiltration Basin Design Data	
Capture Volume of Basin	The design runoff capture volume of the basin.
Surface Area of Capture Volume (When Full)	The area of the water surface in the infiltration basin, when full.
Infiltrating Surface Area	The plan area of the surface used to infiltrate the water quality volume.
Depth to Seasonal High Groundwater Table	Depth from basin bottom to seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth from basin bottom to impermeable layer, if is present.
List of Plant Species	List of plant species and densities on infiltrating surface.
Describe Granular Material on Infiltrating Surface (if any)	Description of granular material depth and porosity.
Media Filter Design Data	
Permanent Pool Volume, Upstream of Filter Media (if any)	Volume of the permanent pool, if pool is part of filter basin.
Permanent Pool Surface Area	Area of water surface of permanent pool.
Permanent Pool Length	Distance between inflow and outflow (average for multiple inflows).
Surcharge Detention Volume	The design water quality detention volume, including the volume above the filter.
Surcharge Detention Volume Surface Area	The surface area of the design water quality capture volume.
Surcharge Detention Volume's Design Drain Time	The drain time (in hours) of the water quality capture volume.
Surcharge Detention Volume Design Depth	Depth of water quality capture volume.
Media Filter Surface Area	Surface area of the media filter.
Angle of Sloping or Vertical Filter	Inclination of filter in degrees above the horizontal plane.
Number of Media Filter Layers	Number of layers of different filter material in BMP.
Describe Depth and Type of Each Filter Media Layer	Description of the type and depth of media used in the filter.

(Table continued on the following page)

Porous Pavement Design Data	
Porous Pavement Surface Area	Surface area of porous pavement.
Depth to Seasonal High Groundwater Table	Depth from pavement surface to seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth from pavement surface to impermeable layer, if present.
Infiltration Rate	Rate of infiltration for site soils under saturated conditions.
Type of Granular or Other Material Used Below Pavement	Description of the type and depth of each granular material layer under the porous pavement.
Porosity of Granular Material (%)	The volumetric portion of the filter material that is not occupied by solid matter, expressed as a percent of the total filter volume.
Total Storage Volume Above Pavement (if any)	The volume of water stored in depressions or as a result of attenuation (if any) above the porous pavement surface.
Estimated Drain Time of the Storage Volume Above the Pavement (if any)	Drain time of holding areas above pavement, if any.
Total Storage Volume Under Pavement (if any)	Net available volume of pore spaces in the granular materials beneath the porous pavement.
Estimated Drain Time of Storage Volume Under Pavement	Total emptying time for water stored in granular materials.
Does Porous Pavement Have Underdrains?	“Yes” or “no” indication of presence of underdrains.
Retention Pond Design Data	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Area of water surface of permanent pool.
Permanent Pool Length	Length of the permanent pool measured along the axis between the inflow and outflow. For more than one inflow, take an average.
Littoral Zone Surface Area	The surface area of the bank above the permanent pool that is periodically covered with water during a storm event.
Water Quality Surcharge Detention Volume (when full)	Water quality detention volume above permanent pool.
Water Quality Surcharge Area (when full)	The surface area (plan view) of the water quality surcharge detention volume.
Water Quality Surcharge Basin Length	Length of the water quality surcharge pool measured along the axis between the inflow and outflow. For more than one inflow, take an average.
Brim-full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim-full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.
Forebay Volume	Volume of the forebay portion of the detention basin.
Forebay Surface Area	Surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	List and description of vegetation on basin sides and floor.
Flood Control Volume (if any)	Volume in excess of the retention basin water quality surcharge detention volume.
List Design Flood Return Period (in years)	Design return periods if pond was designed for flood control.

(Table continued on the following page)

Percolation Trench and Dry Well Design	
Percolation Trench/Well Surface Area	The surface area of the top of the percolation trench/well.
Percolation Trench/Well Length	Length of percolation trench or diameter of the well.
Percolation Trench/Well Depth	The depth of trench or well that is exposed to permeable soils.
Depth to Seasonal High Groundwater Table	Depth below the bottom of the trench or well to the seasonal high groundwater table.
Depth to Impermeable Layer (if any)	Depth below the bottom of the trench or well to impermeable layer, if impermeable layer is present.
Depth and Type of Each Soil Layer Adjacent to and Below Trench/Well	Description of the stratification and the depth of each layer of soils at the BMP site.
Type of Gradation of Granular Materials Used in Trench/Well	Description of the type and depth of granular material used in the trench or well.
Was Geotextile Used Above Granular Trench Fill?	"Yes" or "no" indication of geotextile use above granular fill.
Was Geotextile Used on the Side of Granular Fill?	"Yes" or "no" indication of geotextile use on sides of granular fill.
Was Geotextile Used on the Bottom of Granular Fill?	"Yes" or "no" indication of geotextile use below granular fill.
Give Porosity (%) of the Granular Fill	The volumetric portion of the granular material that is not occupied by solid matter, expressed as a percent of the total volume.
Total Storage Pore Volume in Trench	Volume of available pore space in the trench or well.
Describe Type of Geotextile Used	Description of types and locations of geotextile fabrics.
Hydraulic Conductivity of Adjacent Soil	Hydraulic conductivity of the soils adjacent to the trench or well.
Groundwater Flow Gradient	Slope of the local groundwater table without influence from the BMP.
Wetland Channel and Swale Design Data	
Length of Channel/Swale	Length of channel or swale from stormwater inflow to outflow point.
Longitudinal Slope of Channel/Swale	Measured slope between grade control structures in swale.
Bottom Width of Channel /Swale	Average width between side slopes.
Side Slope of Channel Swale	Average slope of swale sides.
2-Year Flow Design Depth in Channel/Swale	Average depth of water in channel/swale during 2-yr flow.
2-Year Peak Design Flow Velocity	Design velocity for 2-yr flow.
Type of Plant Species in Wetland Zone or Swale	List and description of plant species, percent of cover and densities.

(Table continued on the following page)

Wetland Basin Design Data	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Surface area of permanent pool.
Permanent Pool Length	Length of the permanent pool of water, measured at the water surface along the axis of the inflow and outflow (average for multiple inflows).
Water Quality Surcharge Detention Volume (when full)	Water quality detention volume above permanent pool.
Water Quality Surcharge Area (when full)	The surface area of the water quality surcharge detention volume.
Water Quality Surcharge Basin Length	Water quality surcharge basin length, measured at the water surface along the axis of the inflow and outflow (average for multiple inflows).
Brim-full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim-full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.
Forebay Volume	Volume of the forebay portion of the detention basin, when full.
Forebay Surface Area	Water surface area of the forebay portion of the detention basin.
Describe Vegetation Cover Within Basin	Description of types of vegetative cover within the basin.
Flood Control Volume (if any)	Volume in excess of the water quality detention volume.
List Design Flood Return Period (in years)	Design return period if basin is designed for flood control.
Wetland Surface Area	The surface (plan view) area of the total wetland.
Percent of Wetland Pond with 12 inches Depth	Percent of wetland surface area with less than 12 inches of standing water.
Percent of Wetland Pond with12-24" Depth	Percent of wetland surface area with 12-24 inches of standing water.
Percent of Wetland Pond with 24-48" Depth	Percent of wetland surface area with 24-48 inches of standing water.
Percent of Wetland Pond with >48" Depth	Percent of wetland surface area with greater than 48 inches of standing water.
Percent of Wetland Basin's Area That is Meadow Wetland	Percent of wetland surface area with meadow wetlands (no standing water).
List All Known Plant Species in the Wetland	List of plant species, percent of cover and densities.
Hydrodynamic Devices	
Volume of Permanent Pool	Volume of permanent pool in structure.
Permanent Pool Surface Area	Surface area of the permanent pool.
Permanent Pool Length	Distance between inflow and outflow (average for multiple inflows).
Water Quality Surcharge Detention Volume (when Full)	Water quality detention volume above permanent pool.
Inlet Chamber Volume (if any)	Volume of the inlet chamber portion of the hydrodynamic device.
Brim Full Emptying Time for Surcharge	Emptying time of water quality detention volume down to the permanent pool.
Half Brim Full Emptying Time for Surcharge	Emptying time of lower half of surcharge detention volume down to the permanent pool.

5) Requirements for non-structural and structural BMPs that are based on minimizing directly connected impervious areas (Table 3.9).

Table 3.9: National Stormwater BMP Database requirements for non-structural BMPs and structural BMPs that are based on minimizing directly connected impervious areas

Data Element	Description
Watershed Information	
Total Length of Grass-Lined Channel	Total length of natural and grass-lined channels in watershed.
Total Watershed Area Disturbed	Total watershed area that is actively disturbed or under construction.
Percent Irrigated Lawn and/or Agriculture in Watershed	Percent of lawn or agricultural areas that are irrigated.
Percent of Watershed Served by Storm Sewers	The percent of watershed served by storm sewers.
Average Runoff Coefficient	Based on area-weighted average.
Soil Type	NRCS soil type.
Type of Vegetation	Type of vegetation predominant in pervious area.
Roads and Parking Lots	
Total Paved Roadway Area	Total area of paved roads, streets and alleys in watershed..
Total Length of Curb/Gutter on Paved Roads	Total length of curb/gutter on paved roads.
Total Unpaved Roadway Area	Total unpaved roadway area.
Total Length of Curb/Gutter on Unpaved Roads	Total length of curb/gutter on unpaved roads.
Percent of Paved Roads Draining to Grass Swales/Ditches	Percent of paved roads draining to swales/ditches.
Percent of Unpaved Roads Draining to Grass Swales/Ditches	Percent of unpaved roads draining to swales/ditches.
Type of Pavement on Roads, Streets and Alleys	Description of type of pavement (i.e. concrete, asphalt, etc.).
Total Paved Parking Lot Area	Total area of paved parking lots in the watershed.
Total Length Curb/Gutter on Paved Lots	Total length curb/gutter on paved lots.
Total Unpaved Parking Lot Area	Total unpaved parking lot area.
Total Length Curb/Gutter on Unpaved Lots	Total length of curb/gutter on unpaved lots.
Percent Paved Lot Area Draining to Grass Swales	Percent of paved lot area draining to swales.
Percent Unpaved Lot Area Draining to Grass Swales	Percent of unpaved lot area draining to swales.
Type of Pavement in Parking Lots	Type of pavement in parking lots.

6) Requirements for structural BMPs that are based on minimizing directly connected impervious areas (Table 3.10)

Table 3.10: National Stormwater BMP Database requirements for structural BMPs that are based on minimizing directly connected impervious areas

Data Element	Description
Watershed Information	
Storm Sewer Design Return Period	Most common design return period for the storm sewers in the watershed.
Average Watershed Slope	Average unit less slope of the watershed (i.e. ft/ft, in/in).
NRCS Hydrologic Soil Group	Dominant NRCS hydrologic soil group.

3.4.3.2 Standard Format Examples

The purpose of this section is to provide standard format examples that can serve as a guidance tool for developing monitoring plans and promoting consistent reporting and documentation of stormwater monitoring studies. These forms include, but are not limited to, the required data entry fields for the National Stormwater BMP Database. The database requirements were used as a guideline for development and organization of forms because of its ability to aid in consistently evaluating BMP effectiveness under different conditions. The following sections provide standardized document formats that can be used as a template when performing a BMP monitoring study. Each form is categorized based on the sub-sections presented in the National Stormwater BMP Database.

General Test Site Information

The general test site information form provides data to aid in the identification of the testing location. Location information is important because it enables identification of the general climatic conditions under which a BMP was evaluated. Data reported on this form also provides a cross-link with other national EPA databases. The general test site information form includes data about the sponsoring and monitoring agencies conducting the study and georeferencing information for exact identification of the site location. A detailed description of the data element fields for the general test site information form is available in Table 3.11. The General Test Site Information form, Form A, follows:

Table 3.11: General test site form data element descriptions

Data Element	Description
BMP Test Site Name[1]	Name that the site is known by locally (e.g., Shop Creek, First Bank).The site may contain more than one BMP, but ONLY if the watersheds tributary to these BMPs are virtually identical.
City[1]	City closest to the test site. The site does not have to be within the city limits.
County	County in which test site is located.
State[1]	State where test was performed (2 characters).
Zip Code[1]	Zip code of the test site.
Country[1]	Country where the test site is located (2 characters).
Time Zone	Time zone in which the BMP test site is located off-set in hours from Greenwich Mean Time. For example, in the United States, Eastern Time is -5, Central Time is -6, Mountain Time is -7 and Pacific Time is -8.
Georeferencing Information	
USGS Quadrangle Map Name	U.S. Geological Survey (USGS) 7.5-minute map on which the site can be located. This information should be provided for U.S. sites only.
Principal Meridian	Local or international meridian from which the degrees of longitude locating the BMP test site are measured.
Range	Range identifies the site distance and direction (east or west) from the selected principal meridian. For example, Range 60 West (R60W). This information can be found on a U.S. Geological Survey quadrangle map (U.S. sites only).
Township	Townships are located by their distance and direction (north or south) from a selected baseline. For example, Township 2 North (T2N) (U.S. sites only).
Section	Section is a land area usually containing one square mile (640 acres) that can be identified on a U.S. Geological Survey quadrangle map. There are 36 sections in a given township and range numbered from 1 to 36 (U.S. sites only) .
Quarter-Quarter-Quarter section	Quarter-Quarter-Quarter section should be provided to locate the BMP test site on a U.S. Geological Survey quadrangle map. U.S. sites only.
Latitude	Latitude is the North-South coordinate that locates the project to the nearest second on the globe relative to the equator. The degree, minute and second measures of the latitude can be obtained from a U.S. Geological Survey Quadrangle Map.
Longitude	The East-West coordinate that locates the project to the nearest second on the globe relative to the selected principal meridian. The degree, minute and second measures of the latitude can be obtained from a U.S. Geological Survey (USGS) Quadrangle.
Altitude[1]	Elevation above mean sea level provided to the nearest 100 feet from a U.S. Geological Survey quadrangle map or to the nearest 30 meters for studies outside of the United States.
Sponsoring and Monitoring Agency Information	
Agency Type[1]	Agency type, such as city, county, state, industry, federal, special district, council of governments, authority, consultant, or other.
Address[1]	Address information including agency name, department (if any), street or post office address, city, state, zip code, country, phone, fax and e-mail.

[1] – National Stormwater BMP Database requirement for all BMPs

Form A

GENERAL TEST SITE INFORMATION

Test Site Name ______________________________

City ____________ County ____________ State ____________

Zip Code ____________ Country ____________ Time Zone ____________

Georeferencing

Township ____________ Range ________ Principal Meridian ______

USGS Quadrangle Map ____________________ Altitude ______ Section _____

Quarter Sections: Quarter ______ Quarter-Quarter _____ Quarter-Quarter-Quarter _____

Latitude: Degrees _____ Minute _____ Seconds ______

Longitude: Degrees _____ Minute _____ Seconds ______

Sponsoring Agency

Sponsor's Name ______________________________

Sponsoring Agency's Description ______________________________

Address ______________________ City ____________

______________________ State ____________

____

Zip Code ________ Country ____________

Phone ____________ Fax ____________ E-Mail ____________

Monitoring Agency

Monitoring Agency Name ______________________________

Monitoring Agency Description ______________________________

Address ______________________ City ____________

______________________ State ____________

____

Zip Code ________ Country ____________

Phone ____________ Fax ____________ E-Mail ____________

Comments

Watershed Information

The watershed form contains important information about the physical and relational characteristics of the watershed where the BMP was monitored. Watershed characteristics play a significant role in the quantity and type of pollutants in stormwater runoff. The form includes information on the physical characteristics of the watershed, parking lots and roads, streams and land uses. This information plays a significant role in comparing BMP performance under various watershed conditions. If multiple watersheds were examined at a single test site then additional watershed information forms can be completed for each watershed. Table 3.12 provides descriptions of the watershed form data elements, and the watershed form is presented as Form B.

Table 3.12: Watershed form data elements description

Data Elements	Description
Subject Watershed Name[1]	Name by which the watershed is referred to locally.
Hydrologic Unit Code	The U.S. Geological Survey (USGS) 8-digit hydrologic unit code (HUC) which represents a geographic area containing part or all of a surface drainage basin or distinct hydrologic feature.
EPA Reach Code	EPA-designated RF1 or RF3 river reach with which the station is associated. Sites will either have an RF1 code or an RF3 code, but not both.
Unit System (S.I. or U.S. Standard)	The unit system used for measurement for the study. The unit system should be consistent for all reported data.
Physical Characteristics	
Total Watershed Area[1]	Topographically defined area drained by an urban system, channel, gulch, stream, etc., such that all outflow is directed to a single point.
Total Length of Watershed	Length of the watershed along the main drainage path to the furthest point on the watershed divide.
Total Length of Grass-Lined Channel [5]	Total length of grass-lined and natural channels in the watershed. This is the portion of the storm drainage network in the watershed that is not conveyed in concrete channels, storm sewers or pipes.
Total Watershed Area Disturbed [5]	Total watershed area that is actively disturbed or under construction. This parameter may be useful in indicating the types and levels of pollutant loads in stormwater.
Percent (%) Irrigated Lawn and/or Agriculture in Watershed [5]	Percent of watershed area that is irrigated.
Percent (%) Total Impervious Area in Watershed[1]	The percent of the total watershed that is impervious can be determined as the total impervious area divided by the total area of the watershed. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and macadam or other surfaces that similarly impede the natural infiltration of urban runoff. Rainfall on impervious areas can cause rapid overland flow to drainage inlets.
Percent (%) of Total Impervious Area (above) that is Hydraulically Connected	Parameter calculated by dividing the hydraulically connected impervious area by the total impervious area. An example of hydraulically connected impervious area includes building rooftops that drain onto paved areas.
Percent (%) of Watershed Served by Storm Sewers[5]	The percentage of watershed area served by storm sewers (typically higher in urbanized areas than in rural areas).

(Table continued on the following page)

Data Elements	Description
Storm Sewer Design Return Period (yrs)[6]	Most common design storm return period for the storm sewers in the watershed provided in years. For example, most storm sewers in the watershed may be designed to handle flows generated by the 25-year storm.
Average Watershed Slope[6]	Average unitless slope of the watershed (i.e., ft fall/ft run or m fall/m run--unitless). Slope for each linear reach can be determined as the elevation difference for the reach divided by the length of the reach, and the average slope for the watershed can be calculated as a weighted sum of the slopes of individual reaches.
Average Runoff Coefficient[5]	Rational Method runoff coefficient. If data permits, calculate the average of individual storm runoff coefficients using each storm's runoff volume divided by its rainfall volume. Otherwise determine as area-weighted average for watershed land uses.
NRCS Hydrologic Soil Group[6]	Dominant Natural Resource Conservation Service (NRCS--formerly Soil Conservation Service) hydrologic soil group--A, B, C, or D.
Soil Type[5]	NRCS soil type--(c)lay (s)ilt, s(a)nd. Clay particles are smaller than 0.002 millimeters (mm) in diameter. Silt particles are between 0.002 and 0.05 mm in diameter. Sand particles range from 0.05 mm to 2.0 mm.
Type of Vegetation[5]	Type of vegetation predominant in pervious areas (i.e. grass turf, dry land grasses, etc.).
Roads	
Total Paved Roadway Area[5]	Total area of paved roads, streets and alleys in the watershed. Associated paved shoulders should be included in this area.
Total Length Curb/Gutter on Paved Roads[5]	Total length of curb & gutter along paved roads, streets, and alleys.
Total Unpaved Roadway Area[5]	Total area of unpaved roads, streets, and alleys in the watershed. Unpaved shoulders should be included in this area.
Total Length Curb/Gutter on Unpaved Roads[5]	Total length of curb & gutter along unpaved roads, streets, and alleys.
% Paved Roads Draining to Grass Swales/Ditches[5]	Parameter calculated by dividing the length of paved roads, etc., draining to grass swales and ditches by the total length of paved roads, streets and alleyways in the watershed.
% Unpaved Roads Draining to Grass Swales/Ditches[5]	Percentage of unpaved roads, street and alley areas draining to grass swales/ditches that can be calculated by dividing the length of unpaved roads, etc., draining to grass swales and ditches by the length of unpaved roads, streets and alleyways in the watershed.
Type of Pavement on Roads, Streets and Alleys[5]	Pavement Type. Can be (C)oncrete,(A)sphalt, or a Mix of (B)oth.
Parking Lots	
Total Paved Parking Lot[5] Area	Total area of all paved parking lots within the watershed.
Total Length Curb/Gutter on Paved Lots[5]	Total length of curb & gutter along paved parking lots.
Total Unpaved Parking Lot Area[5]	Total area of all unpaved parking lots within the watershed.
Total Length Curb/Gutter on Unpaved Lots[5]	Total length of curb & gutter along unpaved parking lots.
% Paved Lot Area Draining to Grass Swales[5]	Percentage of parking lot areas draining to grass swales or ditches. This can be calculated by dividing the total parking lot area draining to swales by the total parking lot area.

(Table continued on the following page)

Data Elements	Description
% Unpaved Lot Area Draining to Grass Swales[5]	Percentage of unpaved parking lot areas draining to grass swales or ditches. This can be calculated by dividing the total unpaved parking lot area draining to swales by the total unpaved parking lot area.
Type of Pavement in Parking Lots	Can be (C)oncrete,(A)sphalt, or a Mix of (B)oth. Additionally, provide the percentages of porous concrete, porous asphalt and porous modular pavement present relative to the total paved parking lot area.
Land Uses	
Land Use Information[3]	Should be provided for each land use present in the watershed. The percent of each land use in the watershed, categorized according to % Light Industrial, % Heavy Industrial, % Multi-family Residential, % Office Commercial, % Retail, % Restaurants, % Automotive Services, % Rangeland, % Orchard, % Vegetable Farming, etc.

[1] – National Stormwater BMP Database requirement for all BMPs
[3] – National Stormwater BMP Database requirement for all Non-Structural BMPs
[5] – National Stormwater BMP Database requirement for Non-Structural and Structural BMPs that are based on minimizing directly connected impervious areas
[6] – National Stormwater BMP Database requirement for Structural BMPs that are based on minimizing directly connected impervious areas

Form B

WATERSHED INFORMATION

Watershed Name ____________________

Hydrologic Unit Code (8-digit) ____________ EPA Reach Code (RF1 or RF3) ________

Unit System (S.I. or U.S. Standard) ________

Physical Characterstics

Total Watershed Area ________ Total Length of Watershed ________

Total Length of Grass-Lined Channels ________

Total Disturbed Area ________

% Irrigated Lawn and/or Agriculture ________ % Total Impervious Area in Watershed ______

% of Total Impervious Area that is Hydraulically Connected ________

% of Watershed Served by Storm Sewers ______ Storm Sewer Design Return Period ________

Average Watershed Slope ________ Average Runoff Coefficient _____

Hydrologic Soil Group ________ Soil Type ________

Type of Vegetation

Roads

Total Paved Roadway Area ________ Total Unpaved Roadway Area ________

Total Length of Curb and Gutter on Paved Roads ________

Total Length of Curb/Gutter on Unpaved Roads ________

% Paved Roads Draining to Grass Swales/Ditches ________

% Unpaved Roads Draining to Grass Swales/Ditches ________

Type of Pavement on Roadways ________

Sheet 1 of 2

WATERSHED INFORMATION

Parking Lots

Total Paved Parking Lot Area ____________ Total Unpaved Parking Lot Area ____________

Total Length of Curb and Gutter on Paved Roads ________________

Total Length of Curb/Gutter on Unpaved Parking Lots ____________

% Paved Parking Lot Draining to Grass Swales/Ditches __________

% Unpaved Parking Lot Draining to Grass Swales/Ditches __________

Type of Pavement in Parking Lots _________

% Porous Concrete ______ % Porous Asphalt _________

Land Uses

Land Use Type _____________________

% of Land Use in Watershed ____________

Sheet 2 of 2

Structural BMP Information

The purpose of the structural BMP form is to provide general BMP information inherent to all structural BMP types. Structural BMPs include constructed facilities or measures to help protect receiving water quality and control stormwater quantity. Representative practices include structures for storage, infiltration and filtration. Structural BMP information requested includes items such as date of installation, various design parameters, design drawings, and rehabilitation and maintenance frequencies. Structural BMP form data elements and the form are presented in Table
3.13: and Form C, respectively.

Table 3.13: Structural BMP form data elements description

Data Element	Description
BMP Name[2]	The name by which the BMP is referred to locally.
Type of BMP Being Tested[2]	The type of structural BMP being tested at the site. Major categories of structural BMPs include detention basins, retention ponds, wetland channels and swales, wetland basins, hydrodynamic devices, percolation trenchs and dry wells, media filters, grass filter strips, porous pavement and infiltration basins.
What date was the BMP facility put into service?[2]	Month, day and 4-digit year (e.g., 04/05/1998) when BMP became operational. If the exact day is unknown, use the first day of the month.
How many separate inflow points does the facility have? [2]	Number of separate inflow points. For example, a wet pond may receive flow from two (2) storm sewers and one (1) natural drainage, for a total of three (3) separate inflow points.
Is the BMP designed to bypass or overflow when full?[2]	Identifies 'Bypass" or "Overflow" when full..
Describe the type and frequency of maintenance, if any	Type of frequency and maintenance. Practices include: Tree/Shrub/Invasive Vegetation Control, Mowing, Algae Reduction, Sediment Removal/Dredging, Litter/Debris Control, Erosion Control/Bank Stability, Inlet Cleaning, Outlet Cleaning, Media Replacement/Regeneration, Pump Cleaning/Repair, Valve Cleaning/Repair, Pipe Cleaning/Repair, General Maintenance, Odor Control, Mosquito Control, Vector Control.
What was the last date that the facility was rehabilitated, if any?	Month, day and 4-digit year (e.g., 04/05/1998) of most recent rehabilitation. If the exact day is unknown, use the first day of the month.
Describe the type of rehabilitation, if any	Description of rehabilitation activities such as structural modification or major repair.
Describe the type and design of each BMP outlet[2]	Outlet configuration and design information.
BMP Drawing [2]	Drawings of the BMP in plan, profile and layout view.

[2] – National Stormwater BMP Database requirement for all Structural BMPs

Form C

STRUCTURAL BMP INFORMATION

BMP Name ______________________ **Type of BMP Being Tested** ________________

Date Facility Placed in Service ________ **Number of Inflow Points** __________

BMP Designed to Bypass or Overflow __________

Maintenance Type and Frequency

Last Rehabilitation Date ________

Type of Rehabilitation

Description, Types, and Designs of Outlets

BMP Layout Drawing

Non-Structural BMP Information

The purpose of the non-structural BMP form is to provide general BMP information inherent to all non-structural BMP types. A non-structural BMP can generally be described as a preventative action to protect receiving water quality that does not require construction. Nonstructural BMPs rely predominantly on behavioral changes in order to be effective. Major categories of non-structural BMPs include education, recycling, maintenance practices and source controls, as described below.

- Educational BMPs: Include efforts to inform city employees, the public, and businesses about the importance of using practices that protect stormwater from improper use, storage, and disposal of pollutants, toxics, household products, etc. The ultimate goal of educational BMPs is to cause behavioral changes.

- Recycling BMPs: Include measures such as collecting and recycling automotive products, household toxics, leaves, landscaping wastes, etc.

- Maintenance practices: Include measures such as catch basin cleaning, parking lot sweeping, road and street pavement repair, road salting and sanding, roadside ditch cleaning and restoration, street sweeping, etc.

- Source controls: Include preventing rainfall from contacting pollutant-laden surfaces and preventing pollutant-laden runoff from leaving locations such as automobile maintenance, salvage and service stations; commercial, restaurant and retail sites; construction sites; farming and agricultural sites; industrial sites, etc.

The Non-structural BMP form data reports narrative/descriptive information on the type and extent of the BMP being practiced, as well as cost data. The non-structural BMP form and the form fields are described in Table 3.14: and Form D, respectively.

Table 3.14: Non-structural BMP form data elements description

Data Element	Description
Non-structural BMP Type[3]	Categories of non-structural BMPs, such as education, recycling, maintenance practices and source controls.
BMP Name for the subject non-structural BMP[3]	BMP Name for the subject non-structural BMP (e.g., Erosion and Sediment Control Pamphlets).
Date Test Began[3]	Date (month, day and 4-digit year) that the BMP test was begun (e.g., 01/01/1998).
Educational BMP[3] "measurements"	Measure of eductational BMP effectiveness/progress. Examples include: the number of brochures distributed per resident and employee in watershed per year, number of radio ads, percent of stormwater inlets in watershed stenciled, etc.

(Table continued on the following page)

Data Element	Description
Recycling BMP "measurements" [3]	Measure of recycling BMP effectiveness/progress. Could include gallons of used oil collected per resident in the watershed; pounds of household toxics collected per resident in the watershed; tons of landscaping waste per resident collected, etc.
Maintenance BMP "measurements" [3]	Measure of maintenance BMP effectiveness/progress. Could include percent of stormwater catch basins cleaned once each year, twice each year, etc.; tons of materials removed per average inlet each year; lane miles of street swept each year and tons of material removed per lane mile each year; etc.
Source Control "measurements" [3]	Measure of source control BMP effectiveness/progress. Could include percent of industrial storage area in watershed that is covered; etc.
Cost Information	
Initial Costs	Initial costs, including the time and measures necessary to design and implement a program.
Annual Costs	Year-to-year costs once the initial program has been developed.

[3] – National Stormwater BMP Database requirement for all Non-Structural BMPs

Form D

NON-STRUCTURAL BMP INFORMATION

BMP Name ____________________

Type of BMP Being Tested ____________________

Date Test Began __________

Description of Quantity or Measure of BMP

Cost Information

Initial Costs ______________

Annual Costs ______________

Detention Basin Design Data

The primary purpose of the detention basin design data form is to provide structural BMP information specific to detention basins. Detention basins are designed to collect stormwater runoff and completely empty sometime after the end of the runoff event. Detention basins used for water quality purposes differ from flood control basins only by their outlet structures. Detention basin design characteristics are extremely important for comparing their performance under various hydrological and environmental conditions. The detention basin form and the form data elements are presented respectively in Form E and Table 3.15.

Table 3.15: Detention basin design form data elements list

Data Element	Description
Water Quality Detention Volume[4]	The volume of storm runoff that is captured and slowly drained over a period of time (e.g., 12 to 48 hours).
Water Quality Detention Surface Area When Full[4]	The area of the water surface in the detention basin at full water quality detention volume.
Water Quality Detention Basin Length[4]	Length of the water quality detention basin, measured as the distance between inflow and outflow. If there is more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Detention Basin Bottom Area[4]	Area of the bottom of the entire detention basin, not including the side slopes but including the bottom stage area.
Brim-full Volume Emptying Time[4]	Emptying time (in hours) of the water quality detention volume.
Half Brim-full Volume Emptying Time[4]	Emptying time (in hours) of the lower half of the water quality detention volume.
Bottom Stage Volume, If Any[4]	The volume of the lower “bottom stage” portion (if applicable) of the detention basin.
Bottom Stage Surface Area, If Any[4]	The surface area of the lower “bottom stage” portion (if applicable) of the detention basin.
Is There a Micro Pool?[4]	“Yes” or “No” indication of micropool.
Forebay Volume[4]	Volume of the forebay portion of the detention basin when filled to the point of overflow into the rest of the basin.
Forebay Surface Area[4]	Surface area of water in the forebay at the level of overflow to the bottom stage.
Describe Vegetation Cover Within Basin[4]	Describe the types of vegetation on the basin sides and floor.
Flood Control Volume, If Any[4]	The flood control detention volume in excess of the water quality detention basin volume (if any).
List Design Flood Return Periods[4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Depth to Seasonal High Water Table, If Known	The minimum depth from the basin bottom to the water table during the monitoring season.
Detention Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.

(Table continued on the following page)

Data Element	Description
Structural Control Devices	The estimated cost of establishing all structural control devices, such as inlet and outlet structures, trash racks and energy dissipaters, including cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land or the cost of acquiring the land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the detention basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the detention basin.

[4] – National Stormwater BMP Database requirement for all Non-Structural BMPs

Form E

DETENTION BASIN DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Water Quality Detention Volume ______________

Water Quality Detention Surface Area When Full ______________

Water Quality Detention Basin Length ______________

Detention Basin Bottom Area ______________

Brim-full Volume Emptying Time ________ Half Brim-full Volume Emptying Time ________

Bottom Stage Volume, If Any ______________ Is there a micro pool? ☐

Bottom Stage Surface Area, If Any ______________

Forebay Volume ______________ Forebay Surface Area ______________

Vegetation Cover Within Basin

Flood Control Volume, If Any ______________ Design Flood Return Periods

Depth to Water Table ______________

Detention Basin Construction Cost Estimates

Year of Cost Estimate __________

Construction Costs:

Excavation __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Land Costs and Value __________

Rehabilitative Costs:

Average Annual Sediment Removal __________

Average Annual Revegetation __________

Retention Pond Design Data

The retention pond design data form reports BMP specific information for retention ponds. Retention ponds are also commonly known as "wet ponds" because they have a permanent pool of water, unlike detention basins, which dry out between storms. The permanent pool of water is replaced in part, or in total, by stormwater during a storm event. The design is such that any available surcharge capture volume is released over time. Retention of stormwater in the permanent pool over time can provide biochemical treatment. A dry weather base flow, pond liner and/or high groundwater table are required to maintain the permanent pool. The retention pond form and the form data elements descriptions are shown in Form F and Table 3.16:

Table 3.16: Retention pond design form data elements list

Data Element	Description
Volume of permanent pool[4]	Volume of the permanent pool of water.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool.
Permanent Pool Length[4]	Length of the permanent pool of water, measured along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Littoral Zone Surface Area[4]	Surface area of the littoral zone. The littoral zone refers to the area above the level of the permanent pool that is periodically and temporarily covered by captured storm runoff.
Littoral Zone Plant Species List	List plant species (by Latin name, if known), percent of cover and densities in the littoral zone.
Water Quality Surcharge Detention Volume When Full[4]	Water quality detention volume above permanent pool, when full.
Water Quality Surcharge Surface Area When Full[4]	The surface area of water quality detention volume above the permanent pool, if applicable.
Water Quality Surcharge Basin Length[4]	Length of the water quality detention volume, measured along the axis between the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the retention pond water quality surcharge detention volume to be released to the permanent pool level.
Half Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the lower half of the retention pond water quality surcharge detention volume to be released to the permanent pool.
Forebay Volume[4]	Volume of the forebay portion of the retention basin when it is filled to the point of overflow into the lower part of the basin.
Forebay Surface Area[4]	Surface area of water in the forebay when it is filled to the point of overflow into the lower part of the basin.
Describe Vegetation Cover Within Basin[4]	Describe the types of vegetation (provide Latin names, if known) on the basin sides and floor.
Flood Control Volume, If Any[4]	The flood control detention volume in excess of the retention basin volume (if any).
List Design Flood Return Periods (in years)[4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).

(Table continued on the following page)

Data Element	Description
Retention Pond Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Materials Costs	The estimated cost of materials used in constructing the retention pond, excluding vegetation costs.
Basin Construction Costs	The estimated cost for construction of the retention pond, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all retention pond control devices, such as inlet and outlet structures, spillways, and culverts. Includes the cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, etc.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the retention pond.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate and/or reseed the retention pond.

[4] – National Stormwater BMP Database requirement for all Retention Ponds

Form F

RETENTION POND DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Volume of Permanent Pool ____________

Permanent Pool Surface Area ____________

Littoral Zone Surface Area ____________

Littoral Zone Plant Species

Permanent Pool Length ____________

Water Quality Surcharge Detention Volume ____________

Water Quality Surcharge Surface Area, When Full ____________

Water Quality Surcharge Basin Length, When Full ____________

Brim-full Emptying Time ________ Half Brim-full Emptying Time ________

Forebay Volume ____________ Forebay Surface Area ____________

Flood Control Volume ____________ Design Flood Return Periods

Retention Pond Construction Cost Estimate

Year of Cost Estimate ________

Construction Costs:

Excavation ________ Structural Materials Cost ________

Basin Construction ________ Structural Control Devices ________

Vegetation and Landscaping ________ Engineering and Overhead ________

Land Costs and Value ________

Rehabilitative Costs:

Average Annual Sediment Removal ________

Average Annual Revegetation ________

Percolation Trench and Dry Well Design Data

The percolation trench and dry well form contains essential design information for percolation trenches and dry wells. Percolation or infiltration trenches can be generally described as trenches or excavations filled with porous media designed to encourage rapid percolation of runoff to the groundwater. A dry well is a drilled well, often drilled through impervious layers to reach lower pervious layers. The percolation trench and dry well form and data elements are presented in Table 3.17: and Form G.

Table 3.17: Percolation trench and dry well design form data elements list

Data Element	Description
Percolation Trench/Well Surface Area[4]	The top surface area of the percolation trench or well.
Percolation Trench/Well Length[4]	The length of the percolation trench, or the diameter of the well.
Percolation Trench/Well Depth[4]	The depth of the trench or the well that is exposed to permeable soils.
Depth to Seasonal High Groundwater Below Bottom of Trench/Well[4]	The minimum depth to the seasonal high groundwater table below the trench or well.
Depth to Impermeable Layer Below Bottom of Trench/Well[4]	The depth to the first impermeable layer below the trench or well.
Depth and Type of Each Soil Layer Adjacent To and Below Trench/Well[4]	The order of stratification (from the surface downward) and the depth of each layer of soils at the BMP site.
Type and Gradation of Granular Materials Used in Trench/Well[4]	Describe the type and depth of granular material used in the trench or well.
Was Geotextile Used Above Granular Trench Fill? [4]	"Yes" or "no" indication of geotextile use above granular fill.
Was Geotextile Used On the Sides of Granular Fill? [4]	"Yes" or "no" indication of geotextile use on sides of granular fill.
Was Geotextile Used On the Bottom of Granular Fill? [4]	"Yes" or "no" indication of geotextile use below granular fill.
Give porosity (in percent) of the granular fill material[4]	The volumetric portion of the granular material that is not occupied by solid matter (expressed as a percent).
Total Storage Pore Volume in Trench[4]	The volume of the available pore space in the granular materials.
Describe Type of Geotextile Used[4]	Describe the types and locations of the geotextile fabrics used in the trench or well, if any. Include the effective pore opening of the fabrics.
Hydraulic Conductivity of Adjacent Soils[4]	The hydraulic conductivity of the soils adjacent to the trench or well infiltration surfaces.
Groundwater Flow Gradient[4]	The flow gradient of groundwater below the infiltration basin (expressed as unit length per unit length, e.g., feet/feet).
Purpose of Trench or Well	Describe the purpose of the percolation trench or well (e.g., water quality treatment, reduction of surface runoff, groundwater recharge, etc.).
Percolation Trench and Dry Well Construction Costs Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Well Drilling	The estimated cost of establishing the well, if this is a dry well.

(Table continued on the following page)

Data Element	Description
Trench Construction Costs	The estimated cost of establishing the trenches, if this is a percolation trench.
Structural Control Devices Costs	The estimated cost of establishing all percolation trench or dry well control devices, such as inlet and outlet structures and culverts. Include the cost of materials and construction.
Structural Materials Costs	The estimated cost of materials used in the percolation trench, such as granular fill and geotextiles.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the retention pond.

[4] – National Stormwater BMP Database requirement for all Percolation Trenches and Dry Wells

Form G

PERCOLATION TRENCH AND DRY WELL DESIGN DATA

Test Site Name ____________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Percolation Trench/Well Surface Area ____________

Percolation Trench/Well Length ____________ Percolation Trench/Well Depth ____________

Depth to Groundwater ____________ Depth to Impermeable Layer ____________

Depth and Type of Each Soil Layer

Type and Gradation of Granular Materials Used

Was geotextile fabric used above granular trench fill? ☐

Was Geotextile Used On the sides of granular fill? ☐

Was Geotextile Used On the Bottom of Granular Fill? ☐

Type of Geotextile Used, if Any

Porosity of Granular Material

Total Storage Volume ____________

Hydraulic Conductivity of Soils ____________

Groundwater Flow Gradient ____________

Purpose of Trench or Well

Percolation Trench and Dry Well Construction Cost Estimates

Construction Costs:

Year of Cost Estimate ____________

Excavation ____________

Well Drilling ____________

Trench Construction ____________

Structural Control Devices ____________

Structural Materials ____________

Engineering and Overhead ____________

Land Costs or Value ____________

Rehabilitative Costs:

Average Annual Sediment Removal ____________

Media Filter Design Data

The media filter design data form contains design information related to the performance of media filters. A Media Filter is a facility that uses some form of granular or membrane filter, with or without a pre-settling basin, to remove a fraction of the constituents found in stormwater. The most typical filter is sand, but other materials, including peat mixed with sand, compost with sand, geotextiles, and absorption pads and beds are commonly used. The media filter form and data elements are presented in Table 3.18 and Form H.

Table 3.18: Media filter design form data elements list

Data Element	Description
Permanent Pool Volume Upstream of Filter Media, If Any[4]	Volume of the permanent pool (if any) if the pool is part of the filter basin installation and not a separate pretreatment retention pond or a detention basin.
Permanent Pool Surface Area of Sedimentation Basin Preceding Filter, If Any[4]	Area of the water surface in the permanent pool (if any).
Permanent Pool Length of Sedimentation Basin Preceding Filter, If Any[4]	Length of the permanent pool (if any) measured as the distance from pool inflow to outflow. If more than one inflow point, use the average length.
Surcharge Detention Volume, Including Volume Above Filter Bed[4]	The design water quality capture volume, including the volume above the filter.
Surcharge Detention Volume Surface Area[4]	The surface area of the design water quality captured runoff including the area above the filter.
Surcharge Detention Volume Length	The length of the design captured runoff volume, including the portion above the filter, measured as the distance along the flow path. If more than one inflow point, use the average length.
Surcharge Detention Volume's Design Drain Time, If Controlled and Known [4]	The design time for complete drawdown (in hours) of the water quality capture volume if the drain time is controlled by a flow regulating device such as an orifice. Leave blank if the drain rate is only a fraction of the filter's flow-through rate.
Surcharge Detention Volume Design Depth[4]	The design depth of water quality capture volume that can be stored above the filter before overflow or runoff bypass occurs.
Media Filter Surface Area[4]	Surface area of the media filter (e.g., the sand bed or geotextile filter) as a whole orthogonal to the flow.
Angle of Sloping or Vertical Filter[4]	Inclination of filter in degrees above the horizontal plane.
Number of Media Layers in Filter[4]	The number of layers of different filter materials in this BMP.
Describe Depth and Type of Each Filter Media Layer[4]	Describe the type of media used in the filter (Example: ASTM C-33 Sand with d_{50}=0.7 mm, 50% ASTM C-33 Sand with d_{50}=0.6 mm and 50% Peat).
Media Filter Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.

(Table continued on the following page)

Data Element	Description
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Basin Construction Costs	The estimated cost for construction of the media filter, including site survey and construction activities.
Filter Construction Costs	The estimated cost of establishing the filter system itself, including filter material and the underdrain system. Include costs of materials and construction.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as inlet devices, trash racks, energy dissipaters, and outlet structures. Include costs of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Sediment Removal and Media Replacement Costs	Estimated average annual cost to remove sediment accumulated in the media filter and replace the filter material.

[4] – National Stormwater BMP Database requirement for all Media Filters

Form H

MEDIA FILTER DESIGN DATA

Test Site Name ______________________________

Watershed Name ______________ BMP Name ______________

Design Information

Permanent Pool Volume Upstream of Media Filter, If Any ________

Permanent Pool's Surface Area ________ Permanent Pool's Length ________

Surcharge Detention Volume, Including Volume Above Filter Bed ________

Surcharge Detention Volume Surface Area, Including Volume Above Filter Bed ________

Surcharge Detention Volume's Length ________

Surcharge Detention Volume's Design Depth ________

Surcharge Detention Volume's Drain Time in Hours ____

Media Filter's Surface Area ________

Angle of sloping or vertical filter media in degrees (0 to 90) ____

Number of Filter Layers ____

Type and Depth (or Thickness) of Each Filter Media Layer

Media Filter Construction Cost Estimates

Year of Cost Estimate ______

Construction Costs:

Excavation ________ Basin Construction ________

Filter Construction ________ Structural Control Devices ________

Engineering and Overhead ________ Land Costs and Value ________

Rehabilitative Costs:

Average Annual Sediment Removal and Media Filter Replacement Costs ________

Grass Filter Strip Design Data

The grass filter strip form provides design information specific to grass filter strips. Grass filter strips, sometimes called buffer strips, are vegetated areas designed to accept sheet flow provided by flow spreaders which accept flow from an upstream drainage area. Vegetation may take the form of grasses, meadows, forests, etc. The primary mechanisms for pollutant removal are filtration, infiltration, and settling. The grass filter strip form and data elements are shown in Table 3.19 and Form I.

Table 3.19: Grass filter strip form data elements list

Data Element	Description
Grass Strip Length[4]	Length of the grass strip in the direction of the flow path.
Grass Strip Slope[4]	The slope of the strip along the flow path expressed as unit length per unit length (e.g., feet/feet).
Flow Depth during 2-Year Storm[4]	The design depth of flow over the strip during the 2-year storm peak flow.
2-Year Peak Flow Velocity[4]	The design flow velocity over the strip during the 2-year peak flow.
Describe Grass Species and Densities[4]	List of grass species and their densities.
Is Strip Irrigated?[4]	"Yes" or "no" indication of irrigation.
Estimated Manning's n During 2-Year Flow	The estimated Manning's roughness factor, n, during the 2-year flow event.
Depth to Groundwater or Impermeable Layer	Depth to the seasonal high groundwater table and/or the impermeable layer, whichever is shallower.
Measured Saturated Infiltration Rate, if Known	Rate of infiltration into the filter strip under saturated soil conditions.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Grass Filter Strip Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as slotted curbing or other flow spreading devices, and outflow collection and conveyance systems. Include costs of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated on the grass filter strip.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate and/or reseed the grass filter strip.

[4] – National Stormwater BMP Database requirement for all Grass Filter Strips

Form I

GRASS FILTER STRIP DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ BMP Name ____________________

Design Information

Grass Strip's Length __________ Longitudinal Slope ________

Flow Depth during 2-Year Storm __________ 2-Year Peak Flow Velocity __________

Grass Species and Densities

Is Strip Irrigated? ☐

Manning's n During 2-year Flow ________

Depth to Groundwater __________

Saturated Infiltration Rate __________

Soil Group ______

Percolation Trench and Dry Well Construction Cost Estimates

Year of Cost Estimate ______

Construction Costs:

Excavation __________ Structural Control Devices __________

Vegetation and Landscaping __________ Engineering and Overhead __________

Land Costs or Value __________

Rehabilitative Costs:

Average Annual Sediment Removal Costs __________

Average Annual Revegetation Costs __________

Wetland Channel and Swale Design Data

The purpose of the wetland channel and swale design form is to consistently collect and report wetland channel and swale information. A wetland channel is a channel designed to flow very slowly, probably less than two feet per second at the two-year flood peak flow rate. It has, or is designed to develop, dense wetland vegetation on its bottom. A swale is a shallow grass-lined channel designed for shallow flow near the source of storm runoff. The wetland channel and swale form and data elements are provided in Table 3.20 and Form J.

Table 3.20: Wetland channel and swale form data elements list

Data Element	Description
Average Longitudinal Inflow Spacing	The average longitudinal spacing between all separate stormwater inflow points.
Length of Channel/Swale[4]	The length of the wetland channel or swale, from the stormwater inflow to outflow point.
Longitudinal Slope of Channel/Swale[4]	The average longitudinal slope (in unit length per unit drop, e.g., feet per feet or meter per meter) of the wetland channel or swale, as measured between grade control structures.
Bottom Width of Channel/Swale[4]	The average width of the nearly flat bottom of the channel or swale between its side slopes.
Side Slope of Channel/Swale[4]	The average (in vertical unit length per horizontal unit length) of the channel or swale's side slopes.
2-Yr Flow Design Depth in Channel/Swale[4]	The average depth of water in the channel or swale during the two-year flood peak flow.
2-Yr Peak Design Flow Velocity[4]	The flow velocity in the channel or swale during the two-year flood peak flow.
2-Yr Manning's n	The Manning's roughness factor, n, for the 2-year peak flow.
Type of Plant Species in Wetland Zone or Swale[4]	List the plant species, percent of cover and densities.
Maximum Design Flow Capacity Return Period of Swale	The flood return period that the channel has been designed to convey within its banks in addition to the water quality design event. (Example: 2-year and 10-year flood).
Depth to High Groundwater or Impermeable Layer	The minimum depth to the water table during the high water table season, or to the first impermeable layer.
Groundwater Hydraulic Conductivity	The hydraulic conductivity of the groundwater below the channel or swale.
Wetland Channel and Swale Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Control Devices Costs	The estimated cost of establishing all wetland channel or swale control devices, such as inlet and outlet devices, trash racks, etc. Include the cost of materials and construction.

(Table continued on the following page)

Data Element	Description
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the swale/wetland channel.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the swale/wetland channel.

[4] – National Stormwater BMP Database requirement for all Wetland Channels/Swales

Form J

WETLAND CHANNEL AND SWALE DESIGN DATA

Test Site Name ______________________________

Watershed Name ______________ BMP Name ______________

Design Information

Length of Channel/Swale ________ Bottom Width of Channel/Swale ________

Side Slope of Channel/Swale ______ Longitudinal Slope of Channel/Swale ______

Average Longitudinal Inflow Spacing ______

2-Year Flow Design Depth in Channel/Swale ______

2-Year Peak Design Flow Velocity ______ 2-Year Manning's n ______

Depth to High Groundwater ______ Groundwater Hydraulic Conductivity ______

Plant Species in Wetland Zone/Swale

Design Flow Return Periods

Wetland Channel and Swale Construction Cost Estimates

Year of Cost Estimate ____

Construction Costs:

Excavation Costs ______ Control Devices ______

Vegetation ______ Engineering and Overhead ______

Land ______

Rehabilitative Costs:

Sediment Removal ______

Revegetation ______

Porous Pavement Design Data

The porous pavement form provides design information particular to porous pavement BMPs. There are two forms of porous pavement: modular block, which is made porous through its structure, and poured-in-place concrete or asphalt which is porous due to the mix of the materials. Modular block porous pavement consists of perforated concrete slab units underlain with gravel. The surface perforations are filled with coarse sand or sandy turf. It is used in low traffic areas to accommodate vehicles while facilitating stormwater runoff at the source. It should be placed in a concrete grid that restricts horizontal movement of infiltrated water through the underlying gravels. Poured-in-place porous concrete or asphalt is generally placed over a substantial layer of granular base. The pavement is similar to conventional materials, except for the elimination of sand and fines from the mix. If infiltration to groundwater is not desired, a liner may be used below the porous media along with a perforated pipe and a flow regulator to slowly drain the water stored in the media over a 6 to 12 hour period. The porous pavement design form and data elements are given in Table 3.21 and Form K.

Table 3.21: Porous pavement form data elements

Data Element	Description
Porous Pavement Surface Area[4]	Surface area of the porous pavement.
Depth to Seasonal High Groundwater[4]	The minimum depth to the seasonal water table below the porous pavement.
Depth to Impermeable Layer[4]	The depth to the first impermeable layer below the BMP, if known.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Infiltration Rate[4]	Rate of infiltration for site soils under saturated conditions.
Type of Granular or Other Materials Used in or Below Pavement[4]	Describe the type and depth of each granular material layer under the porous pavement, if any. Include each layer of geotextile fabric used as though it was a granular layer.
Porosity of Granular Materials, as a Percent[4]	Porosity measures the volumetric portion of the filter material that is not occupied by solids. If the layer is geotextile fabric, give the effective pore size.
Is Grass Growing in Modular Pores?	“Yes” or “No” indication of grass growing in modular pores.
If Yes, is Grass Healthy?	“Yes” or “No” indication of grass health, if applicable.
Describe Depth of Each Soil Layer Below Pavement, If Known	The order of stratification (from the surface downward) and the depth of each layer of soils below the porous pavement, to a depth of at least ten feet (3.05 meters).
Total Storage Volume Above Pavement, If Any[4]	The volume of water stored in depressions or as a result of attenuation (if any) above the porous pavement surface.
Estimated Drain Time (hrs) of Storage Volume Above Pavement, If Any[4]	The emptying time of the storage volume above the pavement.
Total Storage Volume Under Pavement, If Any[4]	The net available volume of the pore spaces in the granular materials under the porous pavement, if any.
Estimated Drain Time of Storage Volume Under Pavement, If Any[4]	The total emptying time (in hours) for the storage detention volume under the pavement.

(Table continued on the following page)

Data Element	Description
Groundwater Hydraulic Conductivity	The hydraulic conductivity of the groundwater underlying the BMP.
Groundwater Flow Gradient	The flow gradient (in unit length per unit length, e.g. feet/feet) of groundwater below the infiltration basin.
Does Porous Pavement Have Underdrains?[4]	"Yes" or "No" indication of underdrains for the porous pavement.
Describe Purpose of Porous Pavement	Describe the purpose(s) of the porous pavement (examples: water quality treatment, reduction in peak surface runoff rate and volume, groundwater recharge, etc.)
Porous Pavement Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural and Piping Costs	The estimated cost of establishing the structural and piping features of the BMP, including modular blocks, retaining concrete, sub-base material, and inlay material. Include costs of materials and construction.
Granular Fill Costs	The estimated cost of establishing the granular fill for the BMP, including sand or gravel inlay materials, filter fabric, and perforated underdrain (if any). Include costs of materials and construction.
Paving Costs	If poured-in-place porous concrete or asphalt paving was used, this is the estimated cost of establishing the paving. Include costs of materials and construction.
Curb and Gutter Costs	The estimated cost of establishing curbs and gutters for the BMP. Include costs of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Vegetation Replacement and Granular Media Replacement and Maintenance Costs	Estimated average annual cost to revegetate void spaces in modular block pavement. If poured-in-place porous pavement, report estimated average annual cost to wash, vacuum, pressure wash, patch, gutter clean, etc. at a frequency that ensures the continued function of the BMP.

[4] – National Stormwater BMP Database requirement for all Porous Pavement

Form K

POROUS PAVEMENT DESIGN DATA

Test Site Name ______________________________

Watershed Name ______________ BMP Name ______________

Design Information

Porous Pavement Surface Area __________ Depth to Groundwater __________

Depth to Impermeable Layer __________ NRCS Hydrologic Soil Group ______

Infiltration Rate __________

Type of Granular or Soil Materials Used in or Below Pavement

Porosity of Granular or Soil Materials

Is grass growing in modular pores? ______ If yes, is grass healthy? ______

Total Storage Volume Above Pavement, If Any __________

Estimated Drain Time of Storage Volume Above Pavement, If Any ________

Total Storage Volume in the Granular Media Below Pavement __________

Estimated Drain Time of Porous Media Volume ________

Groundwater Hydraulic Conductivity __________

Groundwater Flow Gradient ______

Does porous pavement have underdrains? ______

Depth of Each Soil Layer Below Pavement

Purpose of Basin Above Pavement

Porous Pavement Construction Cost Estimates

Construction Costs: Year of Cost Estimate ________

Excavation __________ Granular Fill __________ Paving __________

Structural and Piping __________ Curb and Gutter __________

Land Costs and Value __________ Engineering and Overhead __________

Rehabilitative Costs:

Average Annual Vegetation Replacement and Granular Media Replacement Costs ________

Infiltration Basin Design Data

The infiltration basin form reports important design information for infiltration basins. An infiltration basin is a basin that can capture a given stormwater runoff volume and infiltrate it into the ground, transferring this volume from surface flow to groundwater flow. The infiltration basin form and data elements are listed in Table 3.22 and Form L.

Table 3.22: Infiltration basin form data elements list

Data Element	Description
Capture Volume of Basin[4]	The design runoff capture volume of the basin.
Surface Area of Capture Volume, When Full[4]	The area of the water surface in the infiltration basin, when full.
Infiltrating Surface Area[4]	The plan area of the surface used to infiltrate the water quality volume.
Basin Length	Length of the infiltration basin, measured as the distance between inflow and outflow.
Depth to Seasonal High Groundwater Below Infiltrating Surface[4]	Depth to the seasonal high groundwater table.
Depth to Impermeable Layer Below Infiltrating Surface[4]	Depth to the impermeable layer, if any.
NRCS Hydrologic Soil Group	The Natural Resource Conservation Service Hydrologic Soil Group (e.g., A, B, C, or D) comprising the infiltrating surface.
Depth and Type of Each Layer of Soil	The order of stratification (from the surface downward) and the depth of each layer of soils at the infiltration basin site, to a depth of at least ten feet (3.05 meters).
Field Measured Infiltration Rate	The saturated soil infiltration rate, based on soil surveys, infiltrometer measurements or observed draw down of a new basin.
List Plant Species on Infiltrating Surface[4]	List the plant species (by Latin names, if known) and densities of cover on the bottom of the infiltration basin.
Describe Granular Material on Infiltrating Surface, If Any[4]	Describe the granular material and its depth and porosity (if any).
Hydraulic Conductivity of Underlying Soils	The hydraulic conductivity of the soils underlying the infiltration surface.
Groundwater Flow Gradient	The flow gradient (in unit length per unit length, e.g. feet/feet) of groundwater below the infiltration basin.
Flood Control Volume Above Water Quality Detention Volume	The volume of the flood control detention volume above the infiltration basin volume.
List All Design Flood Control Return Periods	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Describe Purpose of Basin	Describe the purpose of the infiltration basin (e.g., surface water quality only, groundwater recharge, etc.).
Infiltration Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.

(Table continued on the following page)

Data Element	Description
Structural Materials Costs	The estimated cost of materials used in constructing the infiltration basin, excluding vegetative cover.
Basin Construction Costs	The estimated cost for construction of the infiltration basin, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all BMP control devices, such as inlet devices, trash racks, energy dissipators, and outlet structures. Include costs of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the infiltration basin, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative/ Maintenance Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the infiltration basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the infiltration basin.

[4] – National Stormwater BMP Database requirement for all Infiltration Basins

Form L

INFILTRATION BASIN DESIGN DATA

Test Site Name ______________________________

Watershed Name ______________ BMP Name ______________

Design Information

Capture Volume of Basin ______________ Basin Length ______________

Surface Area of Capture Volume When Full ______________

Infiltrating Surface Area ______________

Depth to Groundwater ______________ Depth to Impermeable Layer ______________

Soil Group ______________

Depth and Type of Each Soil Layer Below Basin

Infiltration Rate ______________

Flow Gradient ______________

Hydraulic Conductivity of Underlying Soils ______________

Plant Species on Infiltrating Surface

Granular Material on Infiltrating Surface

Design Flood Control Return Periods

Purpose of Basin

Flood Control Volume above Water Quality Detention Volume: ______________

Infiltration Basin Construction Cost Estimates

Construction Costs:

Year of Cost Estimate ______________

Excavation ______________

Basin Construction ______________

Structural Materials Cost ______________

Vegetation and Landscaping ______________

Structural Control Devices ______________

Land Costs and Value ______________

Engineering and Overhead ______________

Rehabilitative Costs:

Average Annual Sediment Removal ______________

Average Annual Revegetation ______________

Hydrodynamic Device Design Data

The hydrodynamic device form provides important design criteria specific to hydrodynamic devices. The hydrodynamic device BMP category includes BMPs such as oil-water separators, sand interceptors, swirl-type concentrators, sedimentation vaults, and other prefabricated and package-type treatment devices. The hydrodynamic device form and data elements are provided in Table 3.23 and Form M.

Table 3.23: Hydrodynamic device form data elements

Data Element	Description
Volume of Permanent Pool[4]	Volume of the permanent pool (dead pool) of water.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool (dead pool).
Permanent Pool Length[4]	Length of the permanent pool of water, measured as the distance between inlet and outlet. If more than one inlet location, use the average distance between the inlet location and the outlet location.
Water Quality Surcharge Detention Volume When Full[4]	The surcharge detention volume above the permanent pool volume (device active storage volume).
Inlet Chamber Volume, If Any[4]	Volume of the inlet chamber portion of the hydrodynamic device when it is filled to the point of overflow into the lower (next) part of the device.
Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the hydrodynamic device water quality surcharge detention volume to be released from the outlet discharge.
Half Brim-full Emptying Time For Surcharge[4]	Time (in hours) required for the lower half of the hydrodynamic device water quality surcharge detention volume to be discharged from the outlet.
Comments.	This field can be used for comments and other miscellaneous information such as model type and related manufacturer's specifications for design.
Hydrodynamic Device Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which cost estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring, and backfilling.
Structural Materials Costs	The estimated cost of materials such as gravel, pavement and vegetation necessary for the installation of the hydrodynamic device. These costs should include installation costs but exclude the cost of the device itself.
Device Construction Costs	The estimated cost for supply, construction, and installation of the hydrodynamic device, including site survey and construction activities.
Structural Control Devices Costs	The estimated cost of establishing all hydrodynamic device control devices, such as inlet and outlet structures (manholes), spillways, pipelines and culverts. Include the cost of materials and construction.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove oils, sediments, and trash accumulated in the hydrodynamic device.

[4] – National Stormwater BMP Database requirement for all Hydrodynamic Devices

Form M

HYDRODYNAMIC DEVICE DESIGN DATA

Test Site Name ______________________________

Watershed Name ________________ BMP Name ________________

Design Information

Volume of Permanent Pool ____________

Permanent Pool Surface Area ____________ Permanent Pool Length ____________

Water Quality Surcharge Detention Volume When Full ____________

Brim-full Emptying Time for Surcharge Detention Volume ________

Half Brim-full Emptying Time for Surcharge Detention Volume ________

Forebay Volume ____________

Comments

Hydrodynamic Device Construction Cost Estimates

Year of Cost Estimate ________

Construction Costs:

Excavation ________ Structural Materials Cost ________

Basin Construction ________ Structural Control Devices ________

Engineering and Overhead ________ Land Costs and Value ________

Rehabilitative Costs:

Average Annual Sediment Removal ________

Wetland Basin Design Data

The wetlands basin form provides important design information specific to wetland basins. A wetland basin is a BMP similar to a retention pond (with a permanent pool of water) with more than 50% of its surface covered by emergent wetland vegetation, or similar to a detention basin (no significant permanent pool of water) with most of its bottom covered with wetland vegetation. The wetland basin data form and data elements list are shown in Table 3.24 and Form N.

Table 3.24: Wetland basin form data elements list

Data Element	Description
Volume of permanent pool[4]	Volume of the permanent pool of water, if any.
Permanent Pool Surface Area[4]	Area of the water surface in the permanent pool, if any.
Permanent Pool Length[4]	Length of the permanent pool of water, measured at the water surface along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Water Quality Surcharge Detention Volume When Full[4]	The water quality surcharge detention volume above the permanent volume (when full).
Water Quality Surcharge Surface Area When Full[4]	The surface area of any supplementary water quality detention volume above the permanent pool, if applicable.
Water Quality Surcharge Basin Length [4]	Length of the water quality detention volume, measured at the water surface along the axis of the inflow and outflow. If more that one inflow point, use the average distance between the inflow points and the outflow weighted by the tributary impervious area.
Brim-full Emptying Time For Surcharge [4]	Time (in hours) required for the wetland basins water quality surcharge detention volume to be released to the permanent pool.
Half Brim-full Emptying Time For Surcharge [4]	Time (in hours) required for the lower half of the water quality surcharge detention volume to be released to the permanent pool.
Forebay Volume [4]	Volume of the forebay portion of the wetland basin when it is filled to the point of overflow into the rest of the basin.
Forebay Surface Area [4]	Surface area of water in the forebay when it is filled to the point of overflow into the rest of the basin.
Describe Vegetation Cover Within Basin [4]	Describe the types of vegetation on the basin sides and floor.
Flood Control Volume, If Any [4]	The volume of the flood control detention volume above the wetland basin volume.
Design Flood Return Periods [4]	List the flood return period (in years) for which the flood control volume is designed (e.g., 25-year).
Wetland Surface Area [4]	Surface area of the wetland basin, including all pond areas and meadow wetland areas. Use permanent pool surface area if no other wetland area exists adjacent to the pool.

(Table continued on the following page)

Data Element	Description
Percent of Wetland Pond with 12 inches (0.3 m) Depth [4]	Percent of the wetland basin's surface area typically having 12 inches (0.3 m) or less water depth.
Percent of Wetland Pond with 12 - 24" (0.3 – 0.6 m) Depth [4]	Percent of the wetland basin's surface area typically having 12 to 24 inches (0.3 - 0.6 m) water depth.
Percent of Wetland Pond with 24 - 48" (0.6 – 1.3 m) Depth [4]	Percent of the wetland basin's surface area typically having 24 to 48 inches (0.6 - 1.3 m) water depth.
Percent of Wetland Pond with > 48" (> 1.3 m) Depth	Percent of the wetland basin's surface area typically having greater than 48 inches (> 1.3 m) water depth.
Percent of wetland basin's area that is meadow wetland [4]	Percent of the wetland basin that is meadow area, that is, area without standing water.
List All Known Plant Species in the Wetland [4]	Type and percent cover of the wetland basin by each wetland species, and densities.
Wetland Basin Construction Cost Estimates	
Year of Cost Estimate	Four-digit year (e.g., 1998) for which the above estimates were made.
Construction Costs:	
Excavation Costs	The estimated cost of all excavation-related activities, including stripping, drilling and blasting, trenching and shoring.
Structural Materials Costs	The estimated cost of materials used in the wetland basin, such as imported topsoil or fill.
Basin Construction Costs	The estimated cost of establishing the wetland basin itself, not including vegetation costs.
Structural Control Devices Costs	The estimated cost of establishing all wetland basin control devices, such as inlet and outlet devices, trash racks, etc. Include the cost of materials and construction.
Vegetation and Landscaping Costs	The estimated cost of establishing vegetation for the BMP, including acquiring landscape materials, establishing vegetation, and establishing the irrigation infrastructure, if any.
Engineering and Overhead Costs	The estimated engineering and associated overhead costs, including site, structural, and landscape design and engineering expenses.
Land Costs or Values	The estimated value of the land dedicated to this BMP or the cost of acquiring this land.
Rehabilitative Costs:	
Average Annual Sediment Removal Costs	Estimated average annual cost to remove sediment accumulated in the wetland basin.
Average Annual Revegetation Costs	Estimated average annual cost to revegetate the sides and floor of the wetland basin.

[4] – National Stormwater BMP Database requirement for all Wetland Basins

Form N

WETLAND BASIN DESIGN DATA

Test Site Name ______________________________

Watershed Name ____________________ **BMP Name** ____________________

Design Information

Volume of Permanent Pool ______________

Permanent Pool Surface Area ______________

Permanent Pool Length ______________

Water Quality Surcharge Detention Volume ______________

Water Quality Surcharge Surface Area, ______________

Water Quality Surcharge Basin Length, When Full ______________

Brim-full Emptying Time ________ **Half Brim-full Emptying Time** ________

Forebay Volume ______________ **Forebay Surface Area** ______________

Flood Control Volume ______________ **Design Flood Return Periods** [ ]

Wetland Surface Area ______________

% of Pond 12" (0.3m) Deep Depth ______ **% of Pond with 12" - 24" (0.3-0.6m) Depth** ______

% of Pond with 24" to 48" (0.6-1.3 m) Depth ______ **% of Pond with >48" (1.3m) Depth** ______

% of Wetland Basin Area Without Standing Water ______

Plant Species in the Wetland [ ]

Wetland Basin Construction Cost Estimates

Year of Cost Estimate __________

Construction Costs:

Excavation __________ **Structural Materials** __________

Basin Construction __________ **Structural Control Devices** __________

Vegetation and Landscaping __________ **Engineering and Overhead** __________

Sheet 1 of 2

WETLAND BASIN DESIGN DATA

Land Costs and Value ____________

Rehabilitative Costs:

Average Annual Sediment Removal ____________

Average Annual Revegetation ____________

Sheet 2 of 2

Monitoring Station Information

Monitoring station information is requested for both structural and non-structural BMPs in a test site. The monitoring station information form contains information on monitoring station locations, instrumentation, and monitoring costs. More than one instrument may be present in a monitoring station. For example, a monitoring station may contain a flow gauge and a water quality sampler. A single form should be filled out for each individual monitoring station at the site. The monitoring station form and data elements list are provided in Table 3.25 and Form O.

Table 3.25: Monitoring station form data elements

Data Element	Description
Monitoring Station Information	
Monitoring Station Name[1]	User-defined name for subject monitoring station.
Identify Upstream BMP[1]	BMP upstream of the monitoring point (if any).
Identify Relationship to Upstream BMP[1]	Identify Relationship to Upstream BMP. These may include inflow, outflow, bypass, intermediate or not applicable.
Identify Downstream BMP[1]	BMP downstream of the monitoring point (if any).
Identify Relationship to Downstream BMP[1]	Identify Relationship to Downstream BMP. These may include inflow, outflow, bypass, intermediate or not applicable.
Site Monitoring Instrumentation	
Select monitoring station where instrument is located[1]	A monitoring station that contains the instrument must be selected or defined before entering data on specific instruments.
What date was the instrument installed?	Provide the date (month, day and 4-digit year) the instrument was installed (e.g., 6/1/1998).
What type of instrument is in place?	The instrument type at the monitoring station. These may include a Bubble Gauge, Digital Recorder, Graphic Recorder, Land Line Telemetered, Radio Telemetered, Satellite Relayed, ADHAS, Crest Stage Indicator, Tide Gauge, Deflection Meter, Stilling Well, CR Type Recorder, Weighing Rain Gauge, Tipping Bucket Rain Gauge, Acoustic Velocity Meter, or Electromagnetic Flow Meter, Pressure Transducer, Unknown or Other.
What type of monitoring is conducted?	The type of data collected by the instrument based on U.S. Geological Survey (USGS) code. Data types may include: Tide, Water Flow/Stage Continuous, Water Flow/Stage Intermittent, Water Quality Continuous, Water Quality Grab, Precipitation Continuous, Precipitation Intermittent, Evaporation Continuous, Evaporation Intermittent, Wind Velocity Continuous, Wind Velocity Intermittent, Tide Stage Continuous, Tide Stage Intermittent, Water Quality Probe Continuous, Water Quality Probe Intermittent, Unknown, or Other.
What type of control structure is in place, if any?	Type of control structure in place at the monitoring station (i.e. 90-degree V-notched weir, etc.).
Additional Comments	May be necessary to explain special features associated with the instrument or other information deemed important to the user.
Site Monitoring Costs	
Number of years in which monitoring was conducted	The number of years over which the monitoring station was in operation

(Table continued on the following page)

Data Element	Description
Comments	May be needed to clarify unusual monitoring costs or other details as deemed appropriate by the user.
Fixed Monitoring Station Costs	Those costs associated with fixed monitoring instrumentation installed for long-term use. For example, a shed may be constructed to house the instrumentation. Year of cost basis, equipment, maintenance, sampling and laboratory costs are requested for fixed monitoring stations.
Temporary Monitoring Station Costs	Costs associated with temporary monitoring instruments not intended for long-term use. Year of cost basis, equipment, sampling and laboratory costs are requested for temporary monitoring stations.
Year of Cost Basis	Year that the monitoring activities were conducted or equipment purchased.
Equipment Costs	Costs of sampling and flow gauging equipment (rental or purchase) and installation in U.S. currency.
Maintenance Costs	Annual maintenance costs for equipment in U.S. currency.
Sampling Costs	Annual costs of sampling in U.S. currency.
Laboratory Costs	Annual costs of sample analysis by a laboratory.

[1] – National Stormwater BMP Database requirement for all BMPs

Form O

MONITORING STATION INFORMATION

Site Name

BMP Name ______________________

Monitoring Station Information

Monitoring Station Name ______________________

Upstream BMP Name ______________ Relationship to Upstream BMP ____________

Downstream BMP ______________ Relationship to Downstream BMP ____________

Site Monitoring Instrumentation

Date of Installation ________

Instrument Type ______________ Data Type ______________

Type of Control Structure ______________________

Additional Comments

Site Monitoring Costs

Number of Years Monitoring Conducted ______

Year of Cost Basis (Fixed Station) ________

Equipment Costs ________ Sampling Costs ________

Maintenance Costs ________ Laboratory Cost ________

Year of Cost Basis (Temporary Station) ________

Equipment Costs ________ Sampling Costs ________

Laboratory Cost ________

Comments

Precipitation Data

The precipitation form contains important precipitation data, which can be used for evaluating the performance of BMPs under various conditions. Precipitation information requested includes data such as time and date that the event began and ended, total depth and one-hour peak precipitation rate. The precipitation data form and data elements list are provided in Table 3.26 and Form P.

Table 3.26: Precipitation Form Data Elements

Data Element	Description
Event ID	User provided name or identifier for the precipitation event.
Select Monitoring Station for Event[1]	Monitoring station name where the precipitation event was monitored.
Start Date	Calendar date (month, day and 4-digit year) that storm started (e.g., 01/01/1998).
Start Time	Time that the storm started, e.g., 21:00. If only storm duration is available, record 00:00 for start time and enter the storm duration for end time.
End Date	Calendar date (month, day and 4-digit year) that storm ended (e.g., 01/01/1998). Use six hours as the separation criteria to define a new storm.
End Time	Time that the storm ended, e.g., 13:21. If only storm duration is available, record 00:00 for start time and enter the storm duration for end time.
Total Storm Precipitation	Amount of precipitation that occurred during the storm. For example, a total of 4 inches of rain fell during a 12-hour storm.
Peak One Hour Precipitation Rate	The most intense one-hour of rainfall for the storm. For storms with less than one-hour duration, divide the storm rainfall depth by one hour.

[1] – National Stormwater BMP Database requirement for all BMPs

Form P

WATER QUALITY INFORMATION

BMP Test Site

Watershed

Monitoring Station ____________________

Station Type __________________________________

Sample Type __________________________________ Number of Samples, if Composite ____

QA/QC Description ____

Comments

Sample ID	Sample Date	Sample Time	Related Flow Event	STORET Parameter	Value	Qualifier	Analysis Method

Flow Data

The flow data form provides on-site stormwater runoff information. Accurate flow data coupled with water quality information can be used to estimate removal efficiencies for BMPs, providing a relative measure of a BMP's ability to remove certain pollutants. The flow data form contains information on the date and time of the beginning and end of the flow event and total flow volumes and peak flow rates for runoff and baseflow. Each flow event should have a related precipitation event recorded on the precipitation form. The flow form and data elements list are provided in Table 3.27 and Form Q.

Table 3.27: Flow form data elements

Data Element	Description
Monitoring Station[1]	Provide monitoring station where flow event was monitored.
Select the type of flow[1]	The type of flow: base flow or storm runoff.
If storm runoff, select the related precipitation event, if available[1]	The start-date of the precipitation event associated with the current flow event.
Flow Start Date[1]	Date (month, day and 4-digit year) that the measurement began being taken (e.g., 01/01/1998).
Flow Start Time	Time at beginning of measurement event, e.g., 23:30. If only flow duration is provided, enter 00:00 for start time and enter the flow duration for end time.
Flow End Date	Date (month, day and 4-digit year) that the measurement event ended (e.g., 01/01/1998). The end of runoff event can be defined as that point in time when the recession limb of the hydrograph is <2% of the peak or is within 10% of the pre-storm base flow, whichever is greater.
Flow End Time	Time at the end of the measurement event, e.g., 01:30. The end of runoff event can be defined as that point in time when the recession limb of the hydrograph is <2% of the peak or is within 10% of the pre-storm base flow, whichever is greater.
Total Storm Flow Volume into or from BMP[1]	Total Runoff Volume minus the Bypass Volume.
Peak Storm Flow Rate into or from BMP	Greatest rate of storm flow into or from the BMP.
Total Bypass Volume, if any[1]	Total Runoff Volume minus the Runoff Volume Influent to the BMP.
Peak Bypass Flow Rate, if any	Peak rate of flow measured for flows bypassing the BMP.
Dry Weather Base Flow Rate[1]	Flow rate during dry-weather conditions. Base flow is collected during non-wet weather conditions.

[1] – National Stormwater BMP Database requirement for all BMPs

Form Q

FLOW INFORMATION

BMP Name

Watershed Name ______________________________

Monitoring Station Name ________________________

Flow Start Date	Flow Start Time	Type of Flow: Runoff or Base Flow	Related Precipitation Event	Flow End Date	Flow End Time	Total Flow Volume	Peak Flow Rate	Total Bypass	Peak Bypass Flow Rate	Dry Weather Base Flow Rate

Water Quality Data

The water quality sampling event form provides the general information for a water quality sampling event such as date, time, location, and QA/QC measures used for a study. Provided water quality information must have associated flow and precipitation information recorded on the precipitation and flow forms. The water quality data form and data elements list are provided in Table 3.28 and Form R.

Table 3.28: Water quality form data elements

Data Element	Description
Sample ID	User provided name or identifier for the water quality sample.
Select Monitoring Station Where Data Collected[1]	Monitoring station name where the data was collected.
Related Flow Event[1]	Flow event associated with the water quality sampling event.
Date Water Quality Sample Collected[1]	Date that the water quality sample began being collected.
Time Water Quality Sample Collected	Time that the water quality sample began being collected.
What medium does the instrument monitor? [1]	Groundwater, Surface Runoff/Flow, Soil, Dry Atmospheric Fallout, Wet Atmospheric Fallout, Pond/Lake Water, Accumulated Bottom Sediment, Biological, or Other.
What type of samples are collected?[1]	The type of samples that the instrument collects, including: Flow Weighted Composite EMCs (Event Mean Concentrations), Time Weighted Composite EMCs, Unweighted (mixed) Composite EMCs, or Grab Sample.
Provide the Number of Samples, If Composite	The number of samples collected or mixed (if composite).
Describe Quality Assurance/Quality Control Measures in Place for the Sampling Event	Describe the types of Quality Assurance/Quality Control (QA/QC) measures in place for both laboratories and field activities.
Provide Additional Comments, If Needed	Discuss special circumstances associated with the sampling event.
Water Quality Parameter (STORET)[1]	The STORET name for the U.S. Environmental Protection Agency's STORET water quality database for streams and other waterbodies throughout the United States.
Value[1]	Value of the measured constituent should be provided. If the value is below detection limits, provide the reported detection limit with a "U" qualifier in the qualifier field and place a minus sign in front of the value.
Unit[1]	Unit of the measured constituent should be provided.
Qualifier[1]	Numerical STORET qualifier associated with a data point.
Analysis Method	Analysis Method should be provided for the constituent. For example EPA 8270 or Standard Method 513.

[1] – National Stormwater BMP Database requirement for all BMPs

Form R

WATER QUALITY INFORMATION

BMP Test Site

Watershed

Monitoring Station ____________________

Station Type ____________________

Sample Type ____________________ **Number of Samples, if Composite** ____

QA/QC Description ____________________

Comments

Sample Date	Sample Time	Related Flow Event	STORET Parameter	Value	Qualifier	Analysis Method

3.4.3.3 On-line Information

Forms and field descriptions can be printed from the world-wide-web at www.bmpdatabase.org. Each set of forms is subcategorized into its subsequent BMP type. Each folder contains all of the necessary forms and information needed for monitoring and reporting for a particular BMP type. BMP categories include:

• Non-Structural BMPs. • Detention Basins. • Retention Ponds. • Percolation Trenches and Dry Wells. • Media Filters. • Grass Filter Strips.	• Wetland Channels and Swales. • Porous Pavement. • Infiltration Basins. • Hydrodynamic Devices. • Wetland Basins.

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INDEX

A

Accuracy, 52, 61, 62, 64, 65, 82, 92, 93, 94, 100, 106, 110, 120, 126, 129, 135, 136, 141, 144, 1
Achievable efficiency, 32, 34, 35, 37
Agriculture, 155, 159
Analysis,
  of variance, 26, 41, 70, 72, 74, 145
  sample, 119, 125
  standards violations, 11
Analytical, 12, 13, 45, 46, 48, 76, 77, 79, 80, 81, 82, 121, 123, 125, 128, 129, 137, 142, 143, 144, 145, 146, 209
ASCE, 33, 48, 77, 137, 139, 147, 208, 1
Assumptions, 23, 24, 26, 29, 31
Atmospheric deposition, 63

B

Bias, 81, 109, 112, 126, 140
BMP
  effectiveness, 12, 40, 45, 52, 68, 96, 156, 166, 167
  efficiency, 2, 4, 8, 12, 14, 15, 16, 17, 18, 21, 32, 33, 34, 40, 61, 71
  monitoring, 2, 4, 5, 6, 8, 18, 21, 37, 43, 46, 47, 48, 49, 52, 53, 55, 58, 61, 63, 70, 72, 77, 80, 83, 102, 111, 115, 122, 123, 124, 127, 132, 147, 156
  non-structural, 149, 166
  structural, 149, 161, 164, 166, 167, 170, 207
  systems, 44
  types, 13, 33, 164, 166

C

Calibration, 107, 118, 141
Central tendency, 41
Chi-square, 41
Clean Water Act, 4, 11
Climate, 16, 65, 148
Coefficient of variation, 22, 70, 71, 75, 76, 145
Completeness, 129, 137
Compliance, 6, 49, 51
Concentrations, 17, 18, 205, 211
Construction, 7, 100, 155, 159, 166, 170, 173, 176, 179, 181, 183, 187, 190, 192, 195
Cost, 6, 100, 167, 169, 173, 175, 178, 181, 183, 187, 189, 192, 195, 199
CZARA, 4, 5

D

Data,
  water quality, 22, 58, 69, 130, 149, 205
Data Logger, 83, 84, 85, 88
Data management, 45, 48
Data Quality Objectives, 129, 209
Design flow, 181
Detention Basin, 150, 169, 207
Dry weather flow, 18

E

Effectiveness, 6, 10, 209, 211, 212
Efficiency, 13, 15, 18, 20, 21, 24, 25, 28, 29, 30, 32, 33, 34, 35, 37, 38, 39
Efficiency Ratio (ER), 20, 21, 24, 31, 32, 33, 34, 35, 38, 39, 41
Effluent, 18, 20, 33, 34, 35, 36, 40, 211
EPA, 4, 5, 7, 11, 12, 22, 31, 48, 49, 50, 65, 66, 68, 70, 71, 74, 79, 81, 82, 113, 117, 128, 134, 135, 136, 137, 139, 144, 145, 147, 156, 159, 205, 208, 209, 211, 1
Erosion, 164, 166
Error, 28, 29, 126, 130, 212, 2, 5, 7
Evaluation, 2, 17, 37, 41, 51, 52, 67, 78, 122, 144, 145
Event mean concentration, 16, 17, 18, 21, 22, 23, 24, 36, 70, 72

F

FHWA, 77, 118, 119, 120, 209, 210
Field blanks, 133, 135
Field duplicate samples, 135

Field operations, 134
Filter, 150, 151, 178, 179, 181, 207
Flow Measurement, 90, 96, 99, 102, 208, 210, 212
Flow meter, 141

G

Geology, 64
Grass filter strip,181
Great Lakes, 64

H

Habitat, 6
Human Health, 50
Hydrodynamic device, 192
Hypothesis testing, 72, 145, 147

I

Implementation, 6, 139, 209
Infiltration Basin, 150, 151, 189, 190, 207
Inflow, 183
In-situ, 119, 121, 123
Irreducible concentration, 33

K

Kolmogorov-Smirnov, 41

L

Lakes, 64
Load, 10, 11, 18, 31

M

Management, 2, 3, 10, 15, 16, 18, 48, 65, 66, 137, 138, 146, 147, 208, 209, 212
Mean concentration, 21
Methods
  Effluent Probability, 18, 20, 34, 40
  Reference Watershed, 43
  tracer dilution, 95
Model
  Non-Linear, 20, 40
Models, 20, 40, 87
Monitoring, 4, 5, 8, 9, 10, 11, 12, 14, 24, 43, 45, 46, 47, 49, 51, 53, 55, 56, 57, 59, 60, 61, 62, 68, 76, 83, 92, 102, 109, 114, 124, 139, 141, 146, 147, 148, 149, 157, 198, 199, 201, 203, 205, 208, 209, 210, 211, 212, 213
Monitoring station, 59, 60, 61, 62, 146, 198, 201, 205

N

National Stormwater BMP Database, 2, 147, 148, 149, 150, 155, 156, 157, 161, 164, 167, 170, 173, 176, 179, 181, 184, 187, 190, 192, 195, 199, 201, 203, 205
Nonpoint, 4, 114, 208, 209, 211
NURP, 12, 13, 77

O

Overland flow sampler, 119

P

Percent removal, 39
Pesticides, 17, 79
Ponds, 150, 173, 207, 210
Porous Pavement, 150, 152, 186, 187, 207

Q

Quality assurance and quality control, 129, 130, 131, 134, 135, 136, 137, 143, 144, 205
Quality assurance project plan, 211

R

Range, 99, 128, 157
Regression, 20, 21, 25, 27, 32
Regression of loads (ROL), 20, 21
Retention Pond, 150, 152, 172, 173, 207

S

Safety, 6, 131
Sample, 111, 113, 125, 132, 135, 136, 139, 146, 149, 205

composite, 112
grab, 111
Sampling, 13, 17, 58, 63, 77, 82, 96, 114, 115, 124, 125, 132, 149, 199, 205, 208, 211
automatic, 90, 102
manual, 90, 102, 124, 125
methods, 13, 77
sediment, 63
Sampling Methods, 132, 211
Sensor
ultrasonic depth, 102, 104
Sensors
electromagnetic, 107, 110
Soils, 189
Stage-flow relationships, 98
Statistic
mean, 11, 17, 18, 20, 21, 29, 157, 205
variability, 70
Storm event, 114
Stormwater quality, 7, 8, 51, 69, 145
Stream, 65, 211
Summation of loads, 21
Surface Water, 49

T

Test, 45, 147, 148, 149, 156, 157, 166, 208
Toxicity, 6, 16
Training, 134, 139
TSS, 16, 17, 24, 25, 27, 28, 29, 32, 33, 34, 35, 38, 43, 64, 79, 80, 82

V

Variability, 70
VOC, 112, 115, 117

W

Water Quality, 11, 36, 41, 49, 50, 51, 64, 138, 141, 152, 154, 172, 205
Wetland, ix, 150, 153, 154, 183, 184, 194, 195, 207
Wetland Basin, 150, 154, 194, 195, 207

APPENDIX A
ERROR ANALYSIS

Estimating flow in a pipe or open channel is generally accomplished by measuring two or more variables and relating them with an equation to calculate the flow. The continuity equation relates flow to area and velocity:

$$Q = A \times v \tag{A.1}$$

where,

A: Area
v: Velocity

For a rectangular channel, the cross-sectional area can be calculated as the water depth multiplied by the width of the channel.

$$A = H \times w \tag{A.2}$$

where,

H: Depth
W: Width

Velocity can be directly measured with a mechanical current meter or Doppler technology. Estimating flow in the rectangular channel requires three measured variables; each will have an error associated with it:

$$Q = H \times w \times v \tag{A.3}$$

For depth and width measurements, the accuracy will usually be expressed as absolute error governed by the tolerance of the measuring device (i.e. measured depth $\pm$ X cm). For velocity, the error in measurement will most likely be a relative error expressed as a percent of the measured value (i.e. measured velocity $\pm$ X %). The total error in the calculated flow measurement will include all of the errors associated with the individual measurements as illustrated in the following example:

Equipment tolerances provided by manufacturers generally are based on laboratory data under ideal conditions (e.g. steady state, laminar flow), which may not be representative of installed conditions. A recent USGS study compared several flow monitoring devices designed specifically for stormwater application, and found the error in the observed measurements ranged from 12 to 28 percent.

The actual error is most likely somewhat less than the maximum error and mathematical formulas have been described by Taylor (1997), which describe how error propagates when variables (with associated errors) are combined.

If variables x_i (for I=1 to n) are measurements with small but known uncertainties δx_i and are used to calculate some quantity q, then δx_i cause uncertainty in q as follows.

If q is a function of one variable, $q(x_1)$, then

$$dq = \left|\frac{dq}{dx_1}\right| dx_1 \tag{A.4}$$

If q is the sum and/or difference of x_is then

$$dq = \left[\sum_{i=1}^{n} (dx_i)^2\right]^{1/2} \quad \text{(for independent random errors)} \tag{A.5}$$

Estimates of δq from Equation A.2 are always less than or equal to:

$$dq = \sum dx_i$$

where x_i are measured with small uncertainties δx_i.

If q is the product and quotient of x_is then

$$dq = \left[\sum_{i=1}^{n} \left(\frac{dx_i}{x_i}\right)^2\right]^{1/2} \quad \text{(for independent random errors)} \tag{A.6}$$

Estimates of δq from Equation A.6 are always less than or equal to:

$$dq = \sum \frac{dx_i}{|x_i|} \tag{A.7}$$

This approach can be directly applied to the analysis of error propagation. Examples for applying this method to flow measurement follow.

Relative Error in Flow Versus Relative Error in Head

Errors in flow measurements are most often caused by field conditions that are inconsistent with the conditions under which rating curves for flow devices were calibrated. However, even under ideal conditions, errors in flow measurement can be significant. This section discusses calculations for estimating the theoretical error associated with flow measurement equipment under ideal circumstances. It can be seen that errors, particularly in low flow measurements, can be quite large.

Equations relating the head (H) measured in a primary device to discharge (Q) (i.e., Rating Equations) fall into four general forms:

1) $Q = aH^{d}$
2) $Q = a(H + c)^{d}$
3) $Q = a(bH + c)^{d}$
4) $Q = a + b_1 H + b_2 H^{2} + b_3 H^{3} + \cdots + b_n H^{n}$

The first rating equation is a straight forward application of error propagation for a power function. This equation is

$$dQ = Q\left(d\,\frac{dH}{H} \right) \tag{A.8}$$

Flow and head can only be positive values and the power for Rating Equation 1 is always positive (i.e., flow increases proportionally to head, not decreases), thus the absolute value sign is omitted in the above equation. The relative error in flow equals the relative error in head multiplied by the exponent d.

Rating Equations 2, 3, and 4 require an equation relating the error in flow to the derivative of the flow equation and the error in the measured head, which is:

$$dQ = \left| \frac{dQ}{dH} \right| dH \tag{A.9}$$

Before applying this equation, the derivatives of Rating Equations 2, 3, and 4 are taken with respect to H.

For Rating Equation 2:

$$\frac{dQ}{dH} = ad(H + c)^{d-1} \tag{A.10}$$

For Rating Equation 3:

$$\frac{dQ}{dH} = abd(bH + c)^{d-1} \tag{A.11}$$

For Rating Equation 4:

$$\frac{dQ}{dH} = b_1 + 2b_2 H^{1} + 3b_3 H^{2} + \cdots + nb_n H^{n-1} \tag{A.12}$$

Prior to applying the equation to the derivatives of Rating Equations 2, 3, and 4 the equation is modified by dividing each side of the Equation by the flow (Q). This yields an equation for the relative error in the flow on the left hand side.

$$\frac{dQ}{Q} = \left|\frac{dQ}{dH}\right| \frac{dH}{Q} \tag{A.13}$$

Substituting flow Rating Equation 2 for Q and the derivative of Rating Equation 2 for dQ/dH into the right hand side of the above equation, yields:

$$\frac{dQ}{Q} = ad(H+c)^{d-1} \frac{dH}{a(H+c)^{d}} \tag{A.14}$$

which reduces to:

$$\frac{dQ}{Q} = \frac{d}{\left(1+\frac{c}{H}\right)} \frac{dH}{H} \tag{A.15}$$

Equation A.11 relates the relative error in the flow to the relative error in the head.

A similar analysis for Rating Equation 3 yields:

$$\frac{dQ}{Q} = \frac{d}{\left(1+\frac{c}{bH}\right)} \frac{dH}{H} \tag{A.16}$$

Determining an equation for the relative error for Rating Equation 4 is more cumbersome, but is calculated the same way:

$$\frac{dQ}{Q} = b_1 + 2b_2H^1 + 3b_3H^2 + \cdots + nb_nH^{n-1} \frac{dH}{a + b_1H + b_2H^2 + b_3H^3 + \cdots + b_nH^n} \tag{A.17}$$

Rearranging yields:

$$\frac{dQ}{Q} = \frac{b_1 + 2b_2H^2 + 3b_3H^3 + \cdots + nb_nH^n}{a + b_1H + b_2H^2 + b_3H^3 + \cdots + b_nH^n} \frac{dH}{H} \tag{A.18}$$

Equation A.4, A.11, A.12, and A.14 relate the relative error in flow to the relative error in head for four common equations describing flow through a primary device. While the equations can be unwieldy, it is a relatively simple exercise to enter them into a spreadsheet program to estimate the error in flow based on estimated error in head and other variables. Most primary devices have a relatively simple flow equation that is sufficiently accurate throughout most of the flow range for the device, which allows for the use of an error equation related to one of the Rating Equations.

The equations relating the relative error in the estimate of flow to the relative error in the measurement of head can also be expressed in terms of absolute errors by multiplying each side of the equations by Q. For example the flow Equation 3 becomes:

$$Q \times \frac{dQ}{Q} = \frac{d}{\left(1 + \frac{c}{bH}\right)} \frac{dH}{H} \times a(bH + c)^d = abd(bH + c)^{d-1} dH \qquad \text{(A.19)}$$

An Example of Error Analysis for a BMP

The following example illustrates how estimates of error propagation can be applied to flow measurements. This example assumes a stormwater BMP has two separate sources of inflow and one outflow. The flow measurement devices and errors are listed in Table 1.

Table A.1: Example of inputs for estimation of errors in flow measurement devices

Station	**Variable**	**Equipment**	**Measured Value or formula**	**Accuracy**
Inlet 1	Width	Tape Measure	3 meters	$\pm$ 0.025 meters
	Depth	Pressure Transducer	1.2 meters	$\pm$ 0.007 meters
	Velocity	Doppler	0.071 meters/sec	$\pm$ 4 %
Inlet 2	Depth	Bubbler	0.12 meters	$\pm$ 0.001 meters
		0.457 m (1.5') Palmer-Bowlus Flume	Q (L/s) = $1076.4(H + 0.005715)^{1.8977}$	$\pm$ 3 %
Outlet	Depth	Pressure Transducer	0.70 meters	$\pm$ 0.007 meters
		45^{o} V notch weir	Q (L/s) = $571.4H^{2.5}$	$\pm$ 6 %

For Inlet 1, the flow calculation is:

$$Q_{inlet-1} = (3)\, m \times (1.2)\, m \times (0.071)\ m/s$$
$$Q_{inlet-1} = 0.2556\, m^3/s$$

The error associated with this measurement can be calculated using the equation for error of products and quotients (i.e., Equation A.6):

Assuming that the errors are independent and randomly distributed, the relative error in q equals:

$$\frac{dq}{q} = \sqrt{\left(\frac{dw}{w}\right)^2 + \left(\frac{dH}{H}\right)^2 + \left(\frac{dv}{v}\right)^2} = 0.0413$$

$$\frac{dq}{q} = \sqrt{\left(\frac{.025}{3}\right)^2 + \left(\frac{0.007}{1.2}\right)^2 + (0.04)^2}$$

$$dq = 0.2556\ m^3/s \times 0.0413 = 0.011\ m^3/s$$

So that:

$$Q_{inlet-1} = 0.2556 \pm 0.011\ m^3/s$$

For the Palmer-Bowlus Flume installed in **Inlet 2**, the equation that describes flow (L/s) as function of water depth is:

$$Q_{inlet-2} = 1076.4 \times (H + 0.005715)^{1.8977}$$

Therefore:

$$Q_{inlet-2} = 1076.4 \times (0.12 + 0.005715)^{1.8977}$$

$$Q_{inlet-2} = 21.032 L/s = 0.0210\ m^3/s$$

The error associated with flow measurement above is proportional to the precision of the transducer used to measure the water depth (i.e., $\pm$ 0.007 meters) and the error intrinsic to the primary device (a relative error of 3%). Rating Equation 1 is used for this case; Equation A.8 can be used to determine the magnitude of relative error in the flow measurement as:

$$\frac{dQ}{Q} = \frac{d}{\left(1 + \frac{c}{H}\right)} \frac{dH}{H}$$

$$\frac{dQ}{Q} = \frac{1.8977}{\left(1 + \frac{0.005715}{0.12\ m}\right)} \frac{0.007\ m}{0.12\ m} = 0.11$$

$$dQ = 0.021 m^3/s \times 0.11 = 0.00231\ m^3/s$$

Relative error for the flume itself also has to be included. Since the error is a function of one variable, it can be calculated using Equation A.4:

$$dq = \left|\frac{dq}{dx}\right| dx = 0.03 \times 0.021\ m^3/s = 0.00063\ m^3/s$$

The total error is therefore the sum of errors associated with the measuring device (Equation A.5).

$$dq_{inlet-2(total)} = \sqrt{0.0023^2 + 0.00063^2} = 0.0024\ m^3/s$$

$$Q_{inlet-2} = 0.0210 \pm 0.0024\, m^3/s$$

For the **Outlet weir**, the flow can be calculated using the following equation:

$$Q = 571.4 \times H^{2.5}$$

$$Q = 571.4 \times 0.70^{2.5} = 234.25 L/s = 0.234\ m^3/s$$

This is also a power function (Rating Equation 1) and the error can be calculated similarly to the equation for the flume:

$$dQ = |2.5| \frac{0.007}{0.70} 0.234\, m^3/s = 0.059\, m^3/s$$

The error associated with the weir itself is a single variable as was the flume:

$$dq = 0.06 \times 0.234 m^3/s = 0.014\, m^3/s$$

The total error is the sum of the errors associated with the measuring device and is calculated as follows:

$$dq_{Outlet(total)} = \sqrt{0.059^2 + 0.014^2} = 0.061\, m^3/s$$

$$Q_{outlet} = 0.234 \pm 0.061\, m^3/s$$

Results of this error analysis are provided below in Table A.2.

Table A.2: Summary of examples demonstrating the propagation of errors in flow measurement

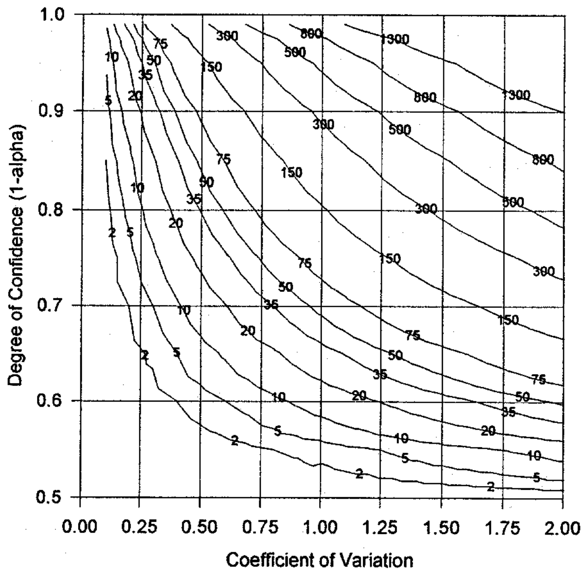
	Flow (m^3/sec)	Total Error (m^3/sec)	Total Relative Error (m^3/sec)
Inlet-1	0.255	± 0.011	4%
Inlet-2	0.021	± 0.0024	11%
Outlet	0.234	± 0.061	26%

APPENDIX B

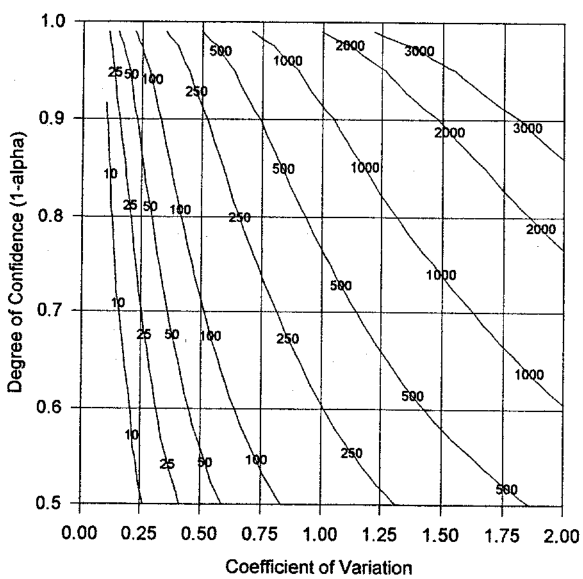
NUMBER OF SAMPLES REQUIRED FOR VARIOUS POWERS, CONFIDENCE INTERVALS, AND PERCENT DIFFERENCES

The figures in this Appendix are from: R. Pitt and K. Parmer. *Quality Assurance Project Plan (QAPP) for EPA Sponsored Study on Control of Stormwater Toxicants*. Department of Civil and Environmental Engineering, University of Alabama at Birmingham. 1995.

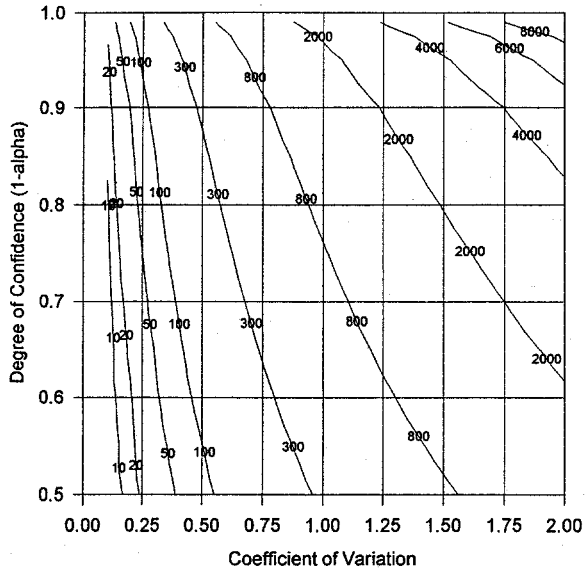
Number of Sample Pairs Needed
(Power = 0.5 Difference = 10%)



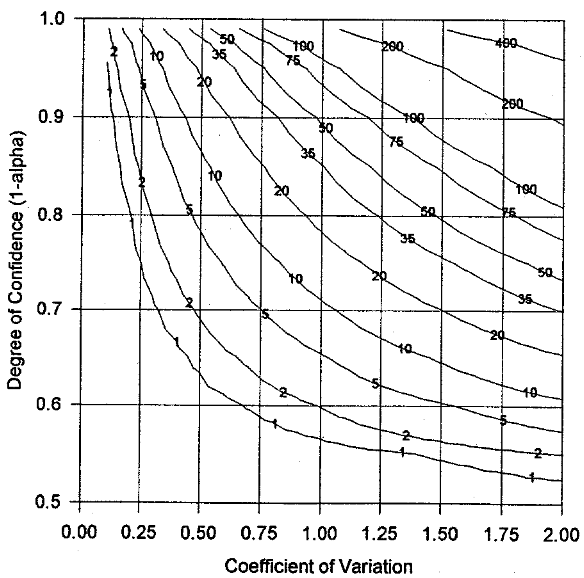
Number of Sample Pairs Needed
(Power = 0.8 Difference = 10%)

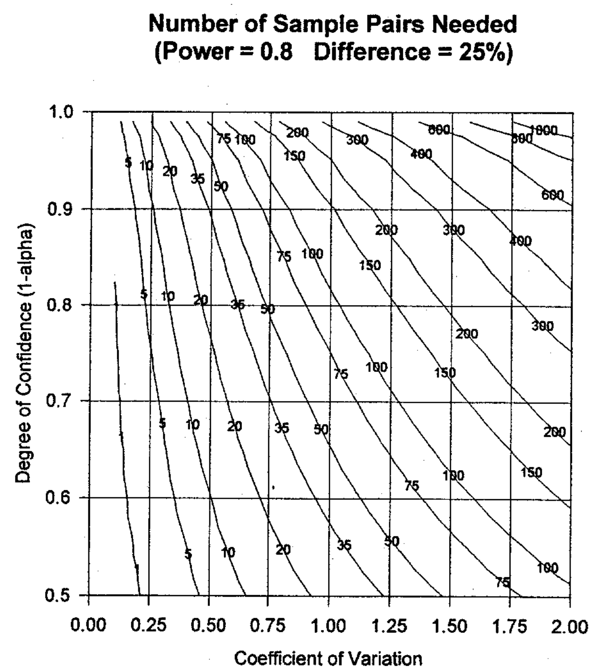


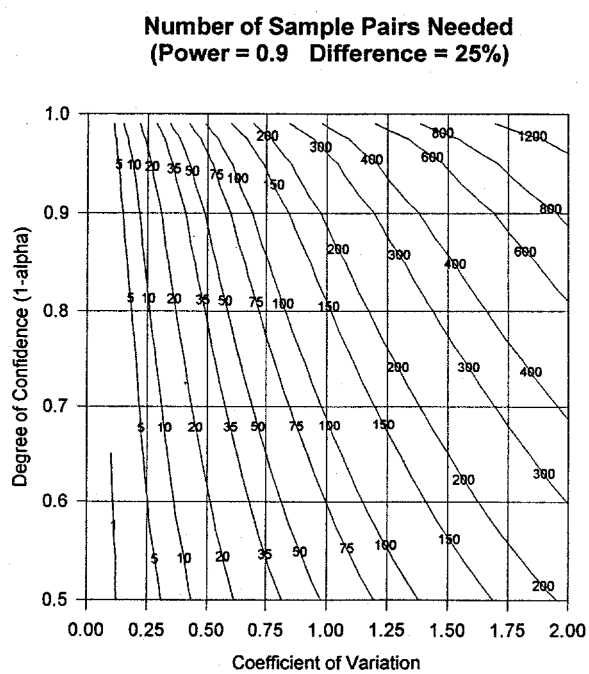
Number of Sample Pairs Needed
(Power = 0.9 Difference = 10%)



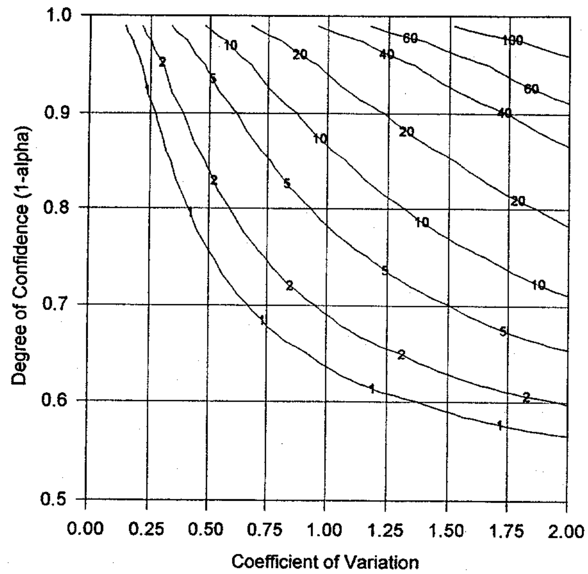
Number of Sample Pairs Needed
(Power = 0.5 Difference = 25%)



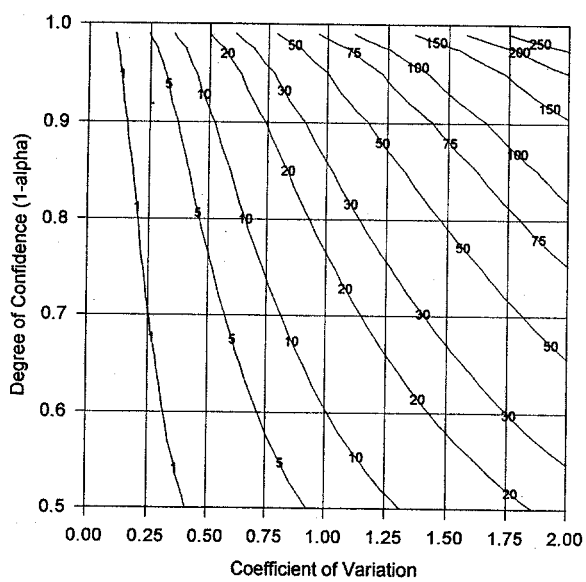

Number of Sample Pairs Needed
(Power = 0.8 Difference = 25%)
Degree of Confidence (1-alpha)
Coefficient of Variation

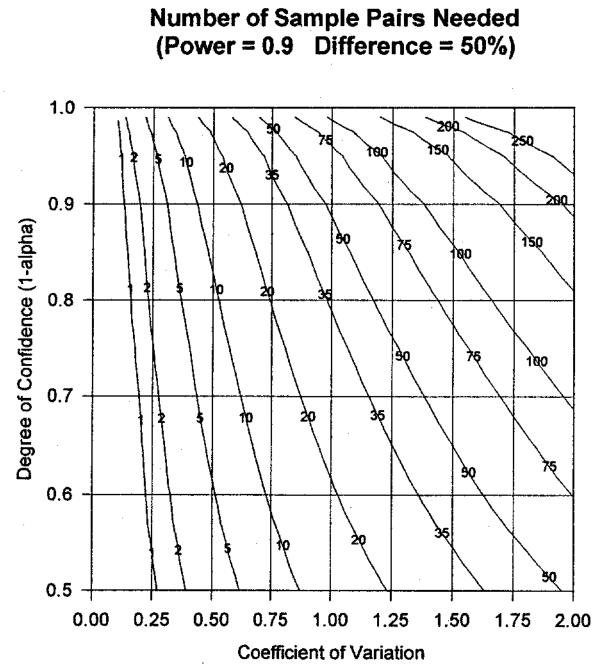

Number of Sample Pairs Needed
(Power = 0.9 Difference = 25%)
Degree of Confidence (1-alpha)
Coefficient of Variation

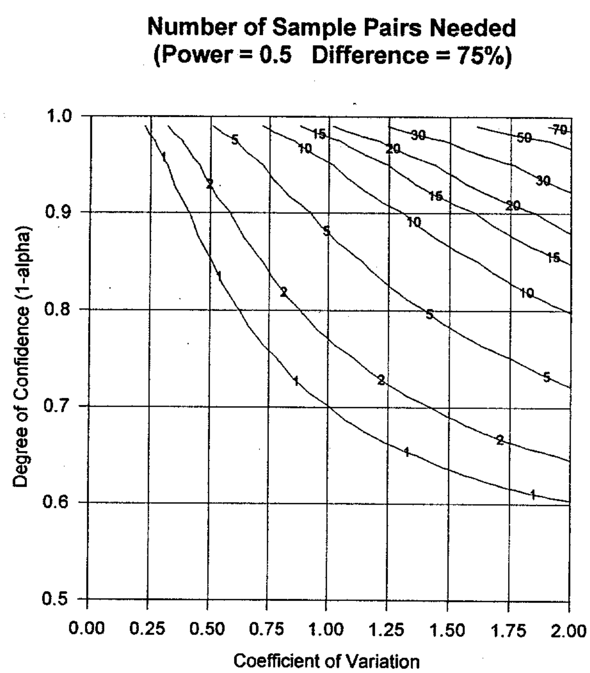
Number of Sample Pairs Needed
(Power = 0.5 Difference = 50%)



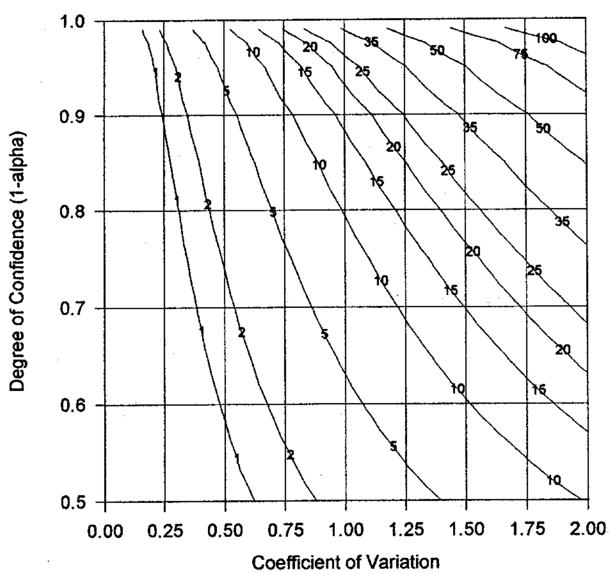
Number of Sample Pairs Needed
(Power = 0.8 Difference = 50%)



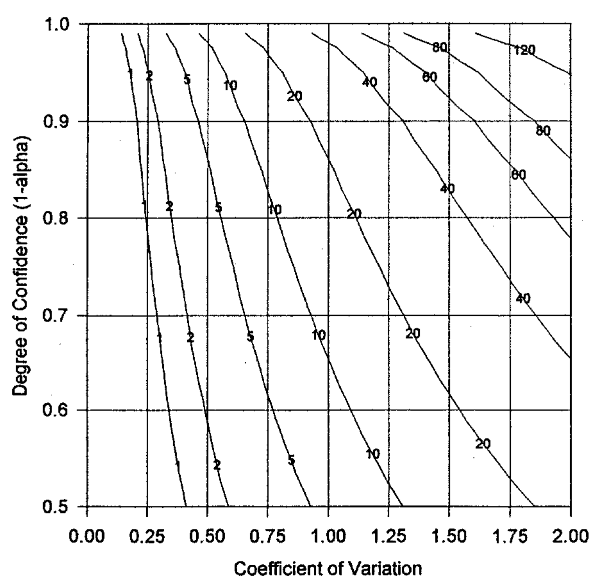

Number of Sample Pairs Needed
(Power = 0.9 Difference = 50%)
Degree of Confidence (1-alpha)
Coefficient of Variation
1.0
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00


Number of Sample Pairs Needed
(Power = 0.5 Difference = 75%)
Degree of Confidence (1-alpha)
Coefficient of Variation
1.0
0.9
0.8
0.7
0.6
0.5
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

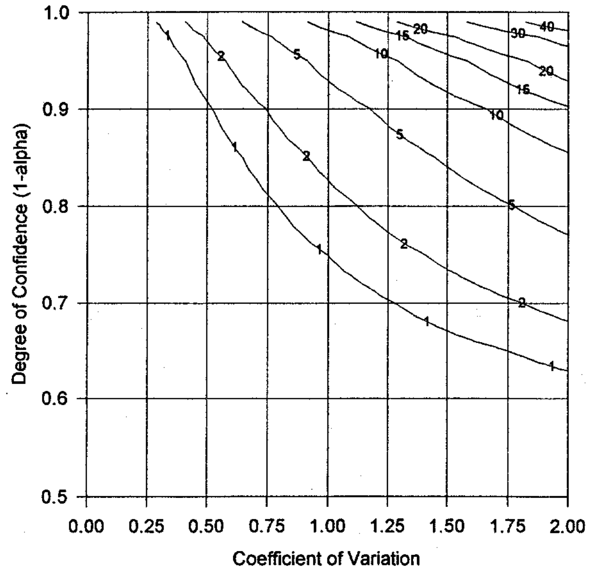
Number of Sample Pairs Needed
(Power = 0.8 Difference = 75%)



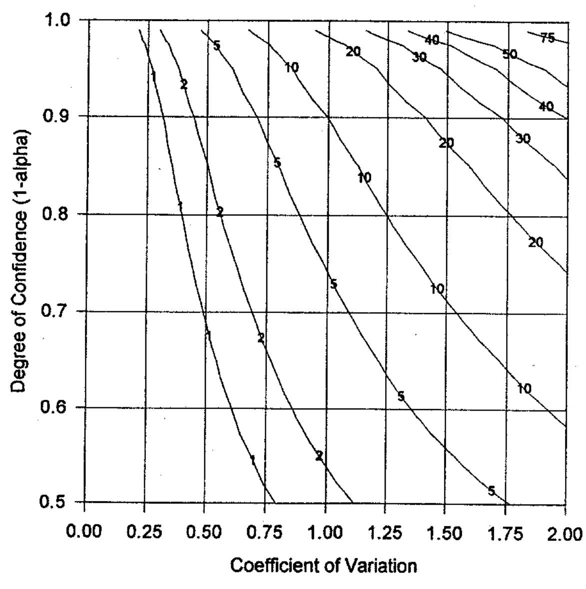
Number of Sample Pairs Needed
(Power = 0.9 Difference = 75%)



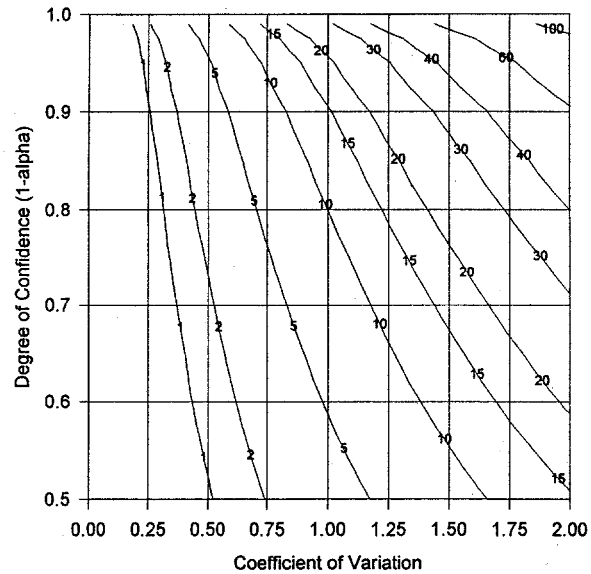
Number of Sample Pairs Needed
(Power = 0.5 Difference = 95%)



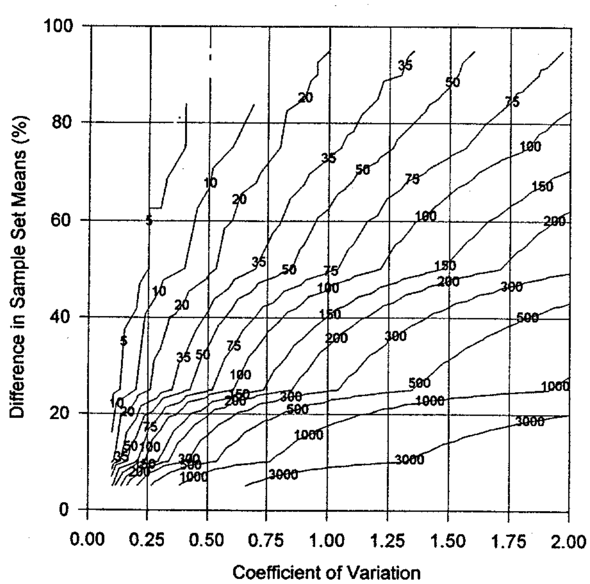
Number of Sample Pairs Needed
(Power = 0.8 Difference = 95%)

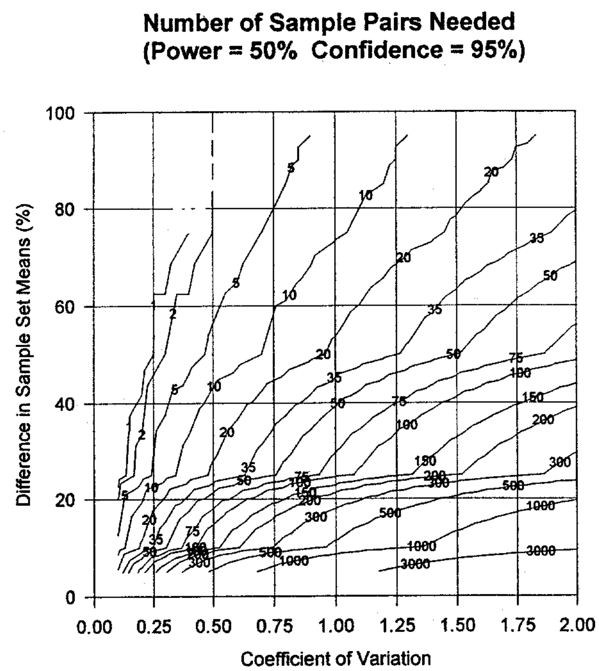


Number of Sample Pairs Needed
(Power = 0.9   Difference = 95%)



Number of Sample Pairs Needed
(Power = 90% Confidence = 95%)




Number of Sample Pairs Needed
(Power = 50% Confidence = 95%)
Difference in Sample Set Means (%)
Coefficient of Variation
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
0
20
40
60
80
100

APPENDIX C

DERIVATION OF THE NUMBER OF SAMPLES REQUIRED TO MEASURE A STATISTICAL DIFFERENCE IN POPULATION MEANS

Define: $COV = \sigma / \overline{C}$

$$\%\ \text{removal} = \left(\overline{C}_{in} - \overline{C}_{out}\right) \big/ \overline{C}_{in}$$

Setting the lower boundary of the influent confidence interval to the upper boundary of the effluent confidence interval gives:

$$\overline{C}_{in} - Z_{a/2} \frac{s_{in}}{\sqrt{n}} = \overline{C}_{out} + Z_{a/2} \frac{s_{out}}{\sqrt{n}}$$

The COV is substituted for the σ in the above equation. While the σ of a BMP effluent is almost certainly less than the σ of the BMP influent, the assumption that $COV_{in} = COV_{out}$ is a more reasonable one. In most instances the COV of the BMP effluent would be less than the influent. Ample data are available for estimating the COV for influent flows to stormwater BMPs, such as the ASCE database; this is not the case for effluent flows. It is also assumed that n is the same for the influent and effluent ($n_{in} = n_{out}$). These assumptions simplify the equation.

Substituting $\sigma_{in} = COV \times \overline{C}_{in}$ and $\sigma_{out} = COV \times \overline{C}_{out}$, where $COV_{in} = COV_{out}$ yield:

$$\overline{C}_{in} - Z_{a/2} \frac{COV \times \overline{C}_{in}}{\sqrt{n}} = \overline{C}_{out} + Z_{a/2} \frac{COV \times \overline{C}_{out}}{\sqrt{n}}$$

rearranging:

$$\overline{C}_{in} - \overline{C}_{out} = COV \times Z_{a/2} \left(\frac{\overline{C}_{in} + \overline{C}_{out}}{\sqrt{n}} \right)$$

Substituting for $\overline{C}_{out} = \overline{C}_{in} - \overline{C}_{in}(\%removal)$ gives:

$$\overline{C}_{in} \times \%removal = COV \times Z_{a/2} \left(\frac{2 \times \overline{C}_{in} - \%removal \times \overline{C}_{in}}{\sqrt{n}} \right)$$

Dividing both sides by $\overline{C}_{in}$ and solving for n yields:

$$n = \left[\frac{Z_{a/2} \times COV \times (2 - \%removal)}{\%removal} \right]^2$$

The above approach considers the number of samples required for a power of 50%. For an arbitrary power the equation becomes:

$$n = \left[\frac{\left(Z_{a/2} + Z_{b/2} \right) \times COV \times \left(2 - \%removal \right)}{\%removal} \right]^2$$

where,

$Z_{\beta/2}$: false negative rate (1-β is the power. If used, a value of β of 0.2 is common, but it is frequently ignored, corresponding to a β of 0.5.)

APPENDIX D
RELATIONSHIPS OF LOG-NORMAL DISTRIBUTIONS

Table D.1

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