BMP Effectiveness/Efficiency Monitoring
Annotated Bibliography

GeoSyntec Consultants and Oregon State University

Report to:
Oregon Department of Transportation
Project SPR - 335
Water Quality Facility Investigation

Response to Task 1: Literature Search
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Background

The Oregon Department of Transportation (ODOT) has installed several stormwater treatment facilities to improve the quality of runoff discharged from the State's highway network. These facilities include a variety of both above ground and below ground structures, such as vegetated swales, filter strips, detention basins, infiltration ponds, catch basin filters, and various proprietary systems. To complement existing work devoted to providing effectiveness and efficiency information of stormwater best management practices (BMPs) (www.bmpdatabase.org), ODOT is interested in evaluating the performance of the stormwater treatment facilities that are currently employed and identify the ones that are most appropriate for Oregon's highways. Implementation of stormwater BMPs is likely to be expanded by ODOT in the near future in response to the Phase II NPDES requirements. Therefore ODOT would like to know how well their current BMPs perform, their relative cost-effectiveness, and how they compare with other water quality best management practices (BMPs) not currently being used by ODOT.

To ensure the collection and analysis of quality data using scientifically sound techniques, a monitoring approach must be developed that specifically addresses all of the steps necessary to collect, analyze, and report stormwater BMP efficiency and effectiveness data. As Task 1 in developing a monitoring approach, an extensive analysis of the most recent literature relating to performance monitoring of stormwater best management practices (BMPs) was be conducted. This document provides an annotated bibliography summarizing the most current information related to BMP monitoring, as well as a description of the potential value of the information with regards to the development of ODOT's stormwater BMP monitoring protocols.

During the next task of this project, information summarized below will be evaluated to identify what local information is currently available, how it might be expanded, and how it could be used to assess the efficiency or effectiveness of various water quality treatment facilities.

Goal of the Literature Search

The primary goal of the literature search was to obtain monitoring guidance information with a focus on highway runoff, stormwater BMPs, local precedents, and federal and jurisdictional guidance.

Organizations Contacted

During the search, several organizations and agencies were queried with regard to their BMP monitoring activities. While the focus was primarily on the Pacific Northwest, those believed to have pertinent information outside the region were also contacted. The organizations that have been contacted are listed in the table below. Some contacts have not yet responded.

Table 1. Primary Information Sources and Professional Contacts

Organization
Oregon Department of Environmental Quality (ODEQ)
Oregon Association of Clean Water Agencies (ACWA)
Oregon Chapter of the American Public Works Association (APWA)
Oregon Department of Transportation (ODOT)
Portland Bureau of Environmental Services (BES)
Clackamas County
Washington Chapter of the American Public Works Association (APWA) Stormwater Managers Group
Washington Department of Transportation (WSDOT)
Washington Department of Ecology
University of Washington
Clean Water Services
USGS – Portland Office
Bay Area Stormwater Management Agencies Association (BASMAA)
Toronto and Region Conservation Authority (TRCA)
California Department of Transportation (Caltrans)
Florida Department of Environmental Protection (DEP)
University of Louisiana
University of Alabama
Federal Highway Administration (FHWA)
ASCE Urban Water Resources Research Council (UWRRC)
Urban Drainage and Flood Control District
Colorado Department of Transportation
Utah Department of Transportation
Oregon State University Library

Structure of the Information

The following annotated bibliography contains citations of reports and articles that may be useful to the development of a monitoring and assessment protocol for structural stormwater treatment facilities owned and operated by the Oregon Department of Transportation (ODOT). The references cited include guidance documents specifically addressing stormwater and BMP effectiveness monitoring, as well as more general guidance documents relating to water quality or environmental monitoring. Also included are articles summarizing BMP effectiveness studies, either relating generally to highway runoff or specifically to the Pacific Northwest.

This annotated bibliography has been sorted according to the potential usefulness of the cited reference, followed by alphabetical order of the author. The first set of twelve references has the highest potential of being useful for the development of ODOT's monitoring protocol. The next set of 27 references has moderate potential of being useful to ODOT and may provide ancillary information. The last set of references does not include annotated summaries. This set is included to address the possibility of unforeseeable informational needs that may be encountered in subsequent tasks.

All bibliographic data are stored in a Microsoft Access database. The database includes some additional archival information beyond what is extracted in the citations that follow and is available to ODOT upon request.

High Usefulness Potential References

Database Reference 9
Eisenberg, Olivieri & Associates (1996). "Guidance for Monitoring the Effectiveness of Stormwater Treatment Best Management Practices." *Bay Area Stormwater Management Agencies Association (BASMAA).* www.basmaa.org
Annotated Summary
The purpose of this document is to provide guidance and recommendations on monitoring the effectiveness of post-construction BMPs in order to increase the usefulness and transferability of monitoring study results to other locations and programs. The BMPs specifically addressed in this document include oil/sediment separators, sand filters, vegetated swales and filter strips, extended detention basins, constructed wetlands, and wet ponds. The second chapter of the document outlines a general design of a BMP monitoring program including a statement of the objectives, site characterization, study duration, study elements, and a quality assurance plan. The study elements include storm event monitoring, data analysis (from which the recommended pollutant removal efficiency measurement in this document is the efficiency ratio), and data reporting. Flow measurements and sampling procedures are covered in Chapter 3 with the focus on sampling equipment, sample collection methods and storage, field measurements/observations, and sample documentation. Chapter 4 includes a list of recommended parameters for assessing BMP performance. This list includes several parameter categories including solids, nutrients, hardness, oxygen demand, organic carbon, metals, hydrocarbons, pH, temperature, and conductivity. Considerations for specific BMPs are provided in Chapter 5, including BMP-specific parameters, maintenance issues, and pollutant removal characteristics. The final chapter provides example monitoring studies.
Potential Value to ODOT
This document is directly applicable to the development of ODOT's BMP monitoring protocol. The monitoring program design presented in the paper is well organized and easy to understand with a thorough assessment of general monitoring program elements. The recommended data reporting elements are modeled after other documents found in the literature (e.g. Urbonas, 1994, ID# 32). Chapter 3: Flow Measurements and Sampling provides useful information on sampling equipment, sampling location selection, and sample methods and storage. The recommended reporting parameters include the media (water and/or sediment) and the suggested method detection limit that should be achieved. The example studies do not include any results; however the references may be useful sources of BMP performance studies.

Database Reference 45
Ice, George, Liz Dent, Jenny Walsh, Rick Hafele, Dave Wilkinson, Lann Brodziak, Larry Caton, Travis Hunt, Ellen Hammond, and Paul Measeles. (1999). "Oregon Plan for Salmon and Watersheds Water Quality Monitoring Technical Guide Book." *Oregon Watershed Enhancement Board*
[Online Available, April 2002] http://www.oweb.state.or.us/publications/mon_guide99.shtml
Annotated Summary
The monitoring techniques, or "protocols," presented in this guide book describe the steps used for obtaining specific, field-based water quality data. This guidebook is a verification tool that can be used to refine the public's understanding and diagnosis of watershed and water quality conditions. The initial chapters provide background information, monitoring strategies and ways to develop a monitoring plan. Also explained in these chapters are criteria for selecting monitoring sites, data quality guidelines, and methods to store and analyze water quality data. References and contacts are provided in each chapter to obtain more detailed or up-to-date information. The subsequent chapters provide protocols for monitoring stream temperature, dissolved oxygen, pH, conductivity, nitrogen/phosphorus concentration, turbidity, macroinvertebrates, pesticides and toxic chemicals. Each of these protocol chapters is designed to be a stand-alone document that provides basic monitoring techniques for that protocol.
Potential Value to ODOT
In addition to the useful information presented in the main body of the document, Appendix B discusses

the difference in types of monitoring. As mentioned in this appendix, monitoring activities can be broken into 6 broad categories: baseline, trend, implementation, effectiveness, compliance, and validation. Of greatest importance to the ODOT BMP Monitoring project is the effectiveness monitoring. Effectiveness monitoring is used to determine whether a properly implemented control practice (i.e., BMP) performs as expected. Since this document applies specifically to Oregon, its contents should be considered while developing ODOT's BMP monitoring protocol.

Database Reference 27

Shoemaker, Leslie, Mohammed Lahlou, Amy Doll, Patricia Cazenas (2000). “Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring” *FHWA Office of Natural Environment.* FHWA-EP-00-002

Annotated Summary

The purpose of this report is to provide a planning-level review of the applicability and use of new and more traditional BMPs in ultra-urban areas. This report focuses on the unique characteristics specific to ultra-urban settings and provides specific guidance for selecting and siting stormwater management technologies. The information is structured in an informative, user-friendly format, with case studies highlighting examples of BMP monitoring throughout the country and tables illustrating the characteristics of each BMP to facilitate comparison and identification of specific technologies appropriate to a given site. BMP information is provided in fact sheets, which address applicability, effectiveness, siting and design, maintenance, and cost considerations. The report is organized into separate chapters that address ultra-urban considerations, BMP design information tailored to the ultra-urban environment, monitoring program design, and BMP selection. The monitoring program section provides a strategy for developing a monitoring program to determine the performance of highway BMPs. Useful information such as typical highway runoff constituents and concentrations/loads, BMP characterization and design considerations, and a list of possible project resources and constraints are included. In the design phase of the monitoring plan, development data quality objectives are identified and various monitoring design approaches are considered. Additional sections describe data collection protocols that include locating sampling sites and sensor locations, as well as the number of samples necessary to obtain statistically significant data. Database design considerations and various data analysis techniques are also included in the document.

Potential Value to ODOT

Section 3 has fact sheets for various BMPs that could be useful if info on description / design considerations of BMPs is needed. Section 4 of the document contains the most pertinent information with respect to the ODOT monitoring protocol development. Table 25 in this section provides a good summary of the advantages and disadvantages of different sampling techniques. The only shortcoming of this document is that the efficiency ratio is the only approach mentioned as a measure of BMP performance. Two pertinent monitoring case studies are included in Section 5, 1) Modified Delaware Sand Filter BMPs at Alaska Marine Lines, Seattle, Washington and 2) Compost Stormwater Treatment System, Hillsboro, Oregon. Cost information is provided in the fact sheets.

Database Reference 33

Strecker, Eric (1998). “Considerations and Approaches for Monitoring the Effectiveness of Urban BMPs.” *Proceedings in National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicago, IL*

Annotated Summary

The purposes of this paper are to describe some of the problems with typical Best Management Practices (BMP) monitoring and effectiveness reporting and suggest the utilization of consistent stormwater monitoring techniques. This paper overviews some of the problems of previous BMP effectiveness studies from the perspective of comparability between studies. It suggests some of the ways that data could be collected to make them more useful for assessing factors that might have led to the performance levels achieved. This document discusses in detail the recommended water quality constituents to be measured, as well as the system and environmental parameters to report when evaluating the performance of stormwater BMPs. Three methods for estimating pollutant removal efficiency are presented: efficiency ratio (ER), summation of loads (SOL), and regression of loads (ROL). The ROL method is not recommended because it assumes that the treatment efficiency is the same for all storms. The ER method is recommended if the differences between inlet and outlet concentrations are statistically significant. The SOL method is recommended if enough data on storms are collected such that total loads can be adequately assessed.

Potential Value to ODOT

This article will be useful as it suggests constituents to monitor and parameters to report with BMP performance studies. Parameters to report for 7 different types of BMPs are included, as adapted from Urbonas, "Parameters to Report with BMP Monitoring Data" (Ref. ID# 32). Most of the information presented in this article has been reiterated in more recent documents authored or co-authored by Eric Strecker.

Database Reference 55

Strecker, Eric and Marcus Quigley (1999). "Development of Performance Measures: Determining Urban Stormwater BMP Removal Efficiencies." *ASCE/EPA,* [Online Avail.] http://www.asce.org/pdf/task3_1.pdf

Annotated Summary

This technical memorandum provides a good overview of some of the measures of BMP effectiveness, performance, and efficiency where effectiveness is a measure of how well a BMP system meets its goals in relation to all stormwater flows, performance is how well a BMP system meets its goals for stormwater that the BMP is designed to treat, and efficiency is how well a BMP or BMP system removes pollutants. Some of the commonly used efficiency calculation methods include: efficiency ratio, summation of loads, regression of loads, mean concentration, efficiency of individual storm loads, reference watersheds and before/after studies. The authors' proposed efficiency calculation method, the Lognormal Statistical Efficiency (LSE), is an expansion of the most often used method, the efficiency ratio. The LSE is based on the statistical significance in the difference in the pollutant event mean concentrations (EMCs) of the BMP inflows and outflows. Another approach offered by the authors for quantifying BMP efficiency is the relative outflow concentration. Based on a detailed analysis of the National Stormwater Database, it was found that the outflow concentrations are independent of or only partially dependent on inflow concentrations. The memo is concluded with a discussion of a process for selecting parameters used to evaluate the relationship between design and environmental conditions and efficiency.

Potential Value to ODOT

This technical memo should be helpful in determining how to measure the effectiveness or performance of ODOT's stormwater BMPs. The method chosen for calculating efficiency should be consistent with regional as well as national standards. This memo is an addendum to the EPA/ASCE National Database effort; therefore, the use of the LSE or relative effluent quality for efficiency calculation is recommended for ODOT's BMP evaluation.

Database Reference 4

Strecker, Eric, Lynn Mayo, Marcus Quigley, and Jim Howell (2001). "Guidance Manual for Monitoring Highway Runoff Water Quality." *U.S. Department of Transportation Federal Highway Administration* FHWA-EP-01-022

Annotated Summary

This document provides detailed guidance for selecting and using stormwater runoff monitoring equipment for the monitoring of highway runoff. The characteristics of highway runoff and its relative importance to regional stormwater quality are identified, as well as some of the goals and constraints of highway stormwater monitoring. Factors to consider when selecting monitoring equipment for various monitoring goals are presented, including detailed information of the different types of monitoring equipment currently available. The document also includes general guidance on the installation of monitoring equipment and how the equipment should be integrated for an efficient, reliable, and safe monitoring effort. Analytical methods and the QA/QC process are outlined to ensure precise, accurate, and representative sampling of stormwater constituents. Finally, the document stresses the need for a site-specific health and safety plan for all stormwater monitoring efforts. The appendices include data evaluation and statistical hypothesis testing procedures, an example health and safety plan, and example standard operating procedures for field sampling.

Potential Value to ODOT

This document provides highway runoff monitoring guidance at a national level, which can be helpful in developing an ODOT BMP Monitoring Protocol that will enable the collection of data with a higher confidence of transferability. This document provides up-to-date guidance on the development of a highway BMP monitoring program, the selection of monitoring equipment, and implementation of the monitoring program using a QA/QC process. At a minimum, this document would provide a checklist for the development of ODOT's monitoring protocol.

Database Reference 26

Strecker, Eric, Marcus Quigley, Ben Urbonas, Jim Howell, and Todd Hesse (2002). "Urban Stormwater BMP Performance Monitoring: A guidance manual for meeting the National Stormwater BMP Database Requirements." *ASCE/EPA* [Online Available, May 2002] http://www.bmpdatabase.org

Annotated Summary

This document provides extensive guidance on the collection, analysis, and reporting of stormwater quality data with respect to BMP performance estimation. Sections of this manual were developed by the authors concurrently with the Federal Highway Administration's (FHWA) "Guidance Manual For Monitoring Highway Runoff Water Quality." This manual is more general than the FHWA manual in that it is not specific to highway runoff; however, most of the monitoring and evaluation concepts are the same. Following the introductory section, 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 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.

Potential Value to ODOT

This document is the most current example of BMP performance monitoring guidance available. All of the information provided should be of some use to the development of ODOT's monitoring protocol. Meeting the requirements of the National Stormwater BMP Database by using this document as a guide will increase the value of the data obtained in ODOT's monitoring efforts because the data will be transferable on a national level.

Database Reference 32

Urbonas, Ben (1994), "Parameters to Report with BMP Monitoring Data." *Proceedings of the Engineering Foundation Conference on Storm Water Monitoring. August 7-12 Crested Butte, CO* pp. 306-351

Annotated Summary

This paper presents an argument for standardization of the physical, chemical, climatic, geological, biological, and meteorological parameters being reported along with the data acquired by various investigators on the performance of structural Best Management Practices (BMPs) used to enhance stormwater quality. Also, a standard minimum list of such parameters is suggested. Such a list is needed for the meaningful exchange of data from the BMP performance studies being conducted throughout the world. Transferability of performance results and consistency, or lack of it, in the performance of various BMPs has been an ongoing problem. To begin to address this problem, a mutually agreed upon minimum list of reporting parameters can be used to relate the performance of BMPs to some, or all, of these parameters. Over time, such standardization will conserve the resources being expended by various field investigations and may eventually lead to improvements in the selection of, and design of, various BMPs. The table provided at the end of this article is a summary of reportable BMP site parameters for retention ponds, extended detention basins, wetland basins, wetland channels, sand filters, oil/sand traps, and infiltration/percolations type facilities.

Potential Value to ODOT

Most of the information presented in this article has been reiterated in the EPA/ASCE "Urban Stormwater BMP Performance Monitoring" document; however, the development of the recommended parameters is included in more detail in this article. A BMP monitoring protocol should include a list of parameters to be reported for all BMPs as well as specific parameters for different types of BMPs. The recommended list of parameters provided in this article will be a good reference when determining the parameters to be required by ODOT.

Database Reference 56

Woodward-Clyde Consultants (1995). “Stormwater Quality Monitoring Guidance Manual.” *Washington State Department of Ecology*

Annotated Summary

The stormwater quality monitoring guidance manual is an extensive document outlining all of the steps necessary to develop and implement a stormwater monitoring plan. The manual is organized to facilitate use by audiences with diverse objectives and needs. By providing background information on stormwater quality and the challenges associated with stormwater monitoring, followed by step-by-step instructions for developing a stormwater monitoring program in Sections 2 and 3, the user can obtain more specific guidance on designing a monitoring plan to address common stormwater monitoring objectives by reading Sections 4 through 8. Guidance on these more common stormwater monitoring objectives include: estimating pollutant concentration and loads, identifying pollutant sources, detecting trends, evaluating BMP effectiveness, and comparing water quality criteria. Each of these guidance sections are organized into four phases: determining the objectives and scope of the monitoring program, developing the monitoring plan in view of your objectives, implementing the monitoring plan, and evaluating and reporting the results. The appendices provide a monitoring "tool box" designed to assist manual users with various stormwater monitoring concepts and methods.

Potential Value to ODOT

This document, especially Section 7: Evaluation of BMP Effectiveness, should be directly applicable to the development of ODOT's BMP monitoring protocols. Appendices A, B, and C provides some valuable information on sampling, including how to retrofit a stormwater BMP to facilitate a sampling

Database Reference 6

Zeigler, Eric, Brian Laurenson, Armand Ruby, and Jon Ingersoll (2000). “Caltrans Guidance Manual: Stormwater Monitoring Protocols (2nd Edition).” *California Department of Transportation*

Annotated Summary

The primary objective of this guidance manual is to ensure consistency in monitoring methods among Caltrans various monitoring programs and projects and to provide for data comparability and ease of data entry into the Caltrans stormwater database. Procedures for preparing and implementing a stormwater monitoring plan are outlined in two sections of the document. Preparing the monitoring plan includes developing the purpose and objectives of the monitoring effort, selecting a representative site, choosing a sampling suite of constituents, selecting the monitoring methods and equipment, and preparing a sampling and analysis plan. Implementing the plan includes installing and maintaining the monitoring equipment, training the monitoring personnel, preparing and orchestrating monitoring personnel and sampling events, collecting quality assured and quality controlled samples, analyzing the samples in the laboratory, and evaluating and reporting the data. The appendices include advantages and disadvantages of various monitoring approaches, descriptions and characteristics of analytical constituents, methods of obtaining unbiased flow-proportional water quality samples, preparation of a health and safety plan, sample bottle and equipment cleaning procedures, weather tracking, and Caltrans data reporting protocols.

Potential Value to ODOT
This document is an excellent example of a monitoring protocol for a highway stormwater monitoring program. Useful information on developing and implementing a monitoring plan is provided. However, methods on how to quantify and evaluate BMP performance are somewhat limited. A thorough discussion of how to select monitoring methods and equipment, including equipment installation and the QA/QC procedure for data collection and analysis is included. Overall, this document is a good reference and starting point for development of ODOT's stormwater BMP monitoring protocol.

Database Reference 63
Washington Department of Ecology (2002). "Stormwater Treatment Facility Performance Evaluation Guidance Document (DRAFT – Do Not Cite)." *Washington Department of Ecology*
Annotated Summary
The purpose of the guidance document is to establish a testing protocol and process for evaluating and reporting on the performance and appropriate use of stormwater treatment technologies by characterizing pollutant removal effectiveness in terms of ecology-specified treatment goals. The protocol is intended to be used to evaluate emerging as well as public domain stormwater treatment technologies. Before the onset of a stormwater BMP effectiveness monitoring program, a quality assurance project plan should be prepared in accordance to the protocol. Vendors or manufacturers of emerging technologies must submit a QAPP to the DOE for approval. The document outlines the storm event criteria and required sampling procedures, including the methods to use and the parameters to report. Well defined method quality objectives and a thorough data quality assessment are stressed as being absolutely necessary in any stormwater treatment technology evaluation. Appendix A of the protocol includes four alternative methods for calculating efficiency, and it is recommended that all applicable efficiencies be calculated. Appendix B provides factors other than treatment performance that can be used to evaluate various technologies, including the relevant treatment mechanisms, appropriate applications, design criteria, construction considerations, costs, operation and maintenance, and reliability. Other items included in the appendices include recommended analytical methods and sample letters and forms. Statistical considerations by Dr. Robert Pitt are included in the final appendix.

Potential Value to ODOT
This document provides criteria and recommendations that are applicable to the Pacific Northwest. The recommended sample size, storm characteristics, and monitoring parameters may be useful in development of ODOT's monitoring protocol. Some of the recommended treatment calculation methods presented in Appendix A agree with other guidance documents; however, the recommended approach from the ASCE/EPA BMP Database Project is neglected. The statistical considerations discussed in Appendix I provide valuable information on the statistical significance of water quality data.

Database Reference 64
Breault, Robert F. and Gregory E. Granato (2000). "A Synopsis of Technical Issues of Concern for Monitoring Trace Elements in Highway and Urban Runoff." *U.S. Geological Survey in cooperation with Federal Highway Administration.* Open-file report 00-422
Annotated Summary
Monitoring of highway and urban runoff differs substantially from monitoring natural runoff due to the physical, hydraulic, and chemical differences between the two systems; however, much of the available information on the behavior of trace elements is derived from studies of natural systems. The lack of valid, current, and scientifically defensible urban and highway runoff data has led several transportation agencies to begin studying and characterizing the quality of runoff from these sources. The objectives of

this synopsis are to examine the technical issues associated with the monitoring of the trace-element chemistry of highway and urban runoff, to discuss trace element monitoring artifacts, and to discuss matrices of potential use for monitoring trace elements. The focus of the report is on the sampling of trace elements in runoff on the pavement, in drainage structures, in structural BMPs, at discharges to receiving waters, and in other matrices potentially affecting trace elements measured in runoff and receiving waters. One of the primary issues discussed in the article is data validity due to sample contamination, collection technique, processing, preservation, and analytical procedures. An analysis of clean monitoring techniques, spatial and temporal variability, highway stormwater monitoring logistics, and the QA/QC process is provided. Also included are technical concerns of whole water sampling, such as total versus total recoverable constituents and method detection limits, dissolved phase sampling, such as filtration practices and analyte preservation, and suspended sediment sampling, such as representative collection techniques and contamination problems. Technical issues with bottom sediment sampling and biological tissue sampling are also discussed. The document concludes with an assessment of highway runoff contaminant sources and data-quality issues for regional or national synthesis.

Potential Value to ODOT

This document provides technical issues to consider when monitoring highway runoff. Several items that must be reported with monitoring study results to be scientifically defensible including examples of how the omission of these items reduces the comparability of data are discussed in the document. Specific guidance or recommendations on monitoring techniques are not provided. Instead the document provides discussion and examples of how various techniques affect results. Overall, this document is an excellent resource for preparing and conducting highway runoff monitoring.

Medium Usefulness Potential References

Database Reference 8

Bachhuber, James, Steven Corsi, and Roger Bannerman (2002). “ETV Verification Protocol Stormwater Source Area Treatment Technologies, Draft 4.1.’ *U.S. EPA Environmental Technology Verification Program.* www.epa.gov/etv

Annotated Summary

This document establishes requirements and guidelines for verifying the performance of stormwater treatment technologies under the Wet Weather Flow Technologies Pilot of the U.S. EPA Environmental Technology Verification Program. The protocol applies to pre-engineered, commercially-available, proprietary technologies that are used to treat stormwater runoff from urbanized areas. Verification testing conducted in accordance with the protocol will objectively measure the performance of a stormwater treatment technology in relation to the claims made by the manufacturer by monitoring loads and concentrations of water quality constituents entering and exiting the treatment device in question. Performance verification is based on three phases: planning, verification testing, and data assessment and reporting. The planning phase involves establishing and documenting the procedures to be followed during the verification of a specific technology, including identifying a field-testing organization and personnel responsible for performance and oversight of the testing. The testing phase involves establishing the required test conditions, conducting the required tests, and collecting the relevant data. The data assessment and reporting phase includes the data preparation and analysis procedure, the format the data should be reported, and the items to be included in a Verification Report and a Verification Statement.

Potential Value to ODOT

This document is similar to the "Protocol for the Acceptance of Unapproved Stormwater Treatment Technologies for Use in the Puget Sound Watershed" in that it provides a protocol for evaluating "innovative" stormwater treatment technologies. The methods used to determine performance are similar, however this document specifically stresses the importance of using event mean concentrations (EMCs) in determining the efficiency ratio and load reduction ratio. As with the other protocol, confidence intervals are not mentioned. More information on sampling and data analysis is provided; however, the document does not distinguish between different types of testing scenarios (i.e., field/laboratory study, real/simulated storm, etc.).

Database Reference 10

Barrett, M.E., M.V. Keblin, P.M. Walsh, and J.F. Malina Jr. (1997). “Evaluation of the Performance of Permanent Runoff Controls: Summary and Conclusions.” *Center for Research in Water Resources* CRWR Online Report 97-3. [Online Available, April 2002] http://www.ce.utexas.edu/centers/crwr/reports/online.html

Annotated Summary

This study was designed to help the Texas Department of Transportation (TxDOT) to identify the types of runoff control systems that are most applicable for highways in Texas. The study investigated the capability of vegetative controls (grassed swales and vegetated buffer strips) and sedimentation/filtration systems for treating stormwater runoff. A grassed swale was constructed in an outdoor channel to investigate the impacts of swale length, water depth, and season of the year on removal efficiency. Results indicate that swale length and water depth affect the removal of constituents by swales. The actual detention times were much greater than designed (4-10 days compared to 24-48 hours). The additional detention time did not provide substantial improvement in particulate removal and caused untreated runoff to bypass the facility. However, nutrient removal was greater than expected.

Potential Value to ODOT

This is a good summary of BMP performance statistics (results, no actual data) for two swales treating highway runoff. There was no information on monitoring protocols, but some useful info on swale design considerations in the conclusion & recommendations section. Despite the intensive monitoring effort, there was no information indicating that a protocol was being followed. Also, the percent removal calculation was not adequately described, so the transferability of the data is questionable without further research. Overall the document provides some good recommendations and conclusions for highway medians, roadside swales, and offline

Database Reference 50

Water Quality Monitoring (1996). Bartram, Jamie and Richard Ballace, eds., *United Nations Environmental Programme and World Health Organization*

Annotated Summary

This book provides guidance on the development and implementation of a water quality monitoring plan using state-of-the-practice methodologies. The book is well organized and simplistic in its presentation of information. The basic elements of a general water quality monitoring program are outlined from the statement of objectives to the reporting and analysis of the data collected. General information on the importance of water quality and some of the sources of primary pollutants causing impairment in surface and groundwaters today is presented, followed by information on designing a monitoring program and the resources necessary for its implementation. Fieldwork associated with the collection and transport of water samples, including the field testing of various water quality parameters is provided in substantial detail. Nearly 100 pages are dedicated to the physical and chemical analysis of water samples, however laboratory procedures requiring delicate or sophisticated equipment were omitted in this section for simplicity; some of the more advanced analyses of water quality constituents are presented in a separate chapter. Analytical quality assurance techniques and reasons why they should be employed are outlined. Four chapters are dedicated to microbiological analyses, biological monitoring, and hydrological and sediment measurements, followed by the use and reporting of monitoring data.

Potential Value to ODOT

Chapters 3 & 4 of this book, which include monitoring program design and necessary resources, will probably be the most useful in the development of the ODOT BMP monitoring protocols. It may be good to cross reference some of the information presented in the other chapters, particularly the sampling and analysis methods presented in the book compared to methods proposed by more regional

Database Reference 54

CalCert (2001). "Stormwater Best Management Practice Demonstration Tier II Protocol for Interstate Reciprocity." *States of California, Massachusetts, New Jersey, Pennsylvania, and Virginia*
[Online Available, April 2002] http://www.calepa.ca.gov/CalCert/documents/Stormwater.pdf

Annotated Summary

This demonstration protocol is intended to provide a uniform method for demonstrating stormwater technologies and developing test quality assurance (QA) plans for certification or verification of performance claims. The States of California, Massachusetts, New Jersey, Pennsylvania, and Virginia are endorsing partners in this demonstration protocol and have agreed, among other things, to accept performance tests and data, and acknowledge the approval results of a partner's review of a technology demonstration, as appropriate, in order to reduce subsequent review and approval time. The Protocol primarily deals with the demonstration of BMPs that are designed for one or more of the following: 1) directing and distributing flows; 2) reducing erosive velocities; and 3) removing contaminants such as suspended or dissolved pollutants from collected stormwater through physical and chemical processes such as settling, media-filtering, ion-exchange, carbon adsorption, and precipitation. The two primary sections of this document include the preparation of a Test QA Plan for validation screening and the required contents of the Test Plan. When preparing a Test Plan for the Validation Screening, a proponent of a Stormwater BMP Technology Demonstration should completely describe technology specifications, performance claims, and the procedures for a stormwater BMP field test. Technology specifications include a detailed description of the physical, chemical, and biological processes, operation and maintenance requirements, process flow diagrams and algorithms, equipment and drawings and specification, existing test plans, performance data, certifications, and a description of process inputs and outputs. A Test QA Plan should include standardized test methods and procedures for stormwater BMP data collection and analysis.

Potential Value to ODOT

This document provides a protocol for determining the effectiveness of "innovative" stormwater BMPs for the purposes of evaluating performance claims. This document is similar to the "Protocol for the Acceptance of Unapproved Stormwater Treatment Technologies for Use in the Puget Sound Watershed" (ref. ID#7). However, this protocol is endorsed by 5 states instead of being state specific. Following a protocol such as this will enhance interstate reciprocity of data, which could lead to more efficient implementation of stormwater NPDES programs across the nation.

Database Reference 52

California State University Sacramento (2002). "CSUS OWP Storm Water Program." *CSU Sacramento Office of Water.* http://stormwater.water-programs.com/

Annotated Summary

The goal of the OWP Storm Water Program is to determine appropriate methods for addressing storm water with an emphasis on measuring best management practice effectiveness, characterizing runoff, developing new storm water treatment technologies, determining which technologies meet the definition of maximum extent practicable, and creating and disseminating new storm water management tools via the world wide web. The website provides useful information on stormwater issues in California, as well as tools for planning and designing stormwater BMPs. Information on Caltrans' current BMP monitoring sites can be searched and linked using an interactive map with access to water quality data. Caltrans' statewide stormwater BMP database can be accessed and water quality data throughout the state can be downloaded in Microsoft Excel format.

Potential Value to ODOT

The Caltrans Monitoring sites web page provides an excellent example of how highway stormwater BMP monitoring sites and data can be organized and presented. The design of the stormwater monitoring database allows for efficient uploading and downloading of water quality data throughout the state and can be used as a model for ODOT's water quality monitoring data handling and presentation.

Database Reference 57

Church, Peter E. and Paul J. Friesz (1993). "Effectiveness of Highway Drainage Systems in Preventing Road-Salt Contamination of Groundwater - Preliminary Findings." *Transportation Research Record* 1420 pp. 56-64

Annotated Summary

An effectiveness study of four highway drainage designs at preventing the contamination of groundwater by road salt was conducted by the Water Resources Division of the USGS in cooperation with the Massachusetts Highway Department and FHWA. The four highway drainage systems varied in cost and design, with the least expensive design (Site A) contributing the largest fraction of runoff being infiltrated (~100%) and the most expensive design (Site D) contributing the smallest fraction of runoff being infiltrated (~0%). Site A is an open drainage design where runoff collected in catch basins on the road surface is discharged locally. Sites B is a closed drainage design where runoff collected in catch basins is conveyed by a trunkline drainage pipe beneath the center median to a sedimentation basin prior to discharge to a surface channel. For Sites C & D, a 5-cm bituminous concrete layer approximately 1-m below the highway shoulder was used to convey runoff to the collection systems, which was either treated in a sedimentation basin prior to discharge (Site C) or discharged directly to the Cape Cod Channel (Site D). Highway runoff and groundwater samples were collected and concentrations of dissolved sodium, calcium, and chloride were measured to determine the amount of road salt entering the groundwater at each site. Since chloride is more easily transported to groundwaters than sodium and calcium, estimates of chloride loads (based on runoff volumes and concentrations) were used to compare results at the four sites. The results show that the most controlled runoff system (Site D) produced groundwater chloride loads that were approximately 20% of the loads produced from the least controlled system (Site A). These are preliminary findings and do not necessarily represent the relative effectiveness of the highway drainage systems. However, the study does produce results that should be applicable to the transport of other conservative chemical constituents in highway runoff.

Potential Value to ODOT

The findings of this study may be useful to ODOT in assessing the impacts of highway de-icing and anti-icing chemicals to groundwater resources, as well as other conservative pollutants in highway runoff. The methodology used to evaluate the relative effectiveness of different highway drainage systems in preventing groundwater contamination may be used as a reference in ODOT's monitoring.

Database Reference 61

Collins, Kathleen and Madonna Narvaez (1996). "EPA Region 10 Guidance For WQBELs: Below Analytical Detection/Quantitation Level." *EPA Region 10.* [Online Available, May 2002] http://yosemite.epa.gov/r10/water.NSF/95537302e2c56cea8825688200708c9a/bf1fec41015d81938825687900595624/$FILE/Wqbel.pdf

Annotated Summary

The guidance covers the issue of reporting NPDES compliance monitoring data where water quality-based effluent limitations (WQBELs) are set below the method detection limit (MDL). Often values below the detection limit are reported as "zero". However, there is a serious loss of information when doing so. To address this issue, MDLs should be incorporated into the NPDES permit to ensure the laboratory is using the most sensitive analytical test method available. If the analytical results are less than the MDL, then the permittee should report "less than MDL" instead of "zero". The USEPA Region 10 recommends incorporating a mass loading limit in addition to the concentration limit, limits for internal waste streams, and/or sediment toxicity and bioaccumulation studies into NPDES permits with WQBELs below the analytical detection level. When conducting reasonable calculations and water-quality-based effluent limitations, all data reported above the published MDL should be used, and data below the MDL should be used as "zero" in calculations. If a laboratory used by a permittee is unable to meet the specified MDLs, the permittee must distinguish between poor laboratory technique and matrix interferences by following the guidelines and procedures set forth in 40 CFR 136. If matrix interferences are found to be the cause, the permit may be reopened and the MDLs modified accordingly.

Potential Value to ODOT

This guidance document provides information on issues encountered with method detection limits. DOT monitoring efforts should comply with these recommended guidelines. However, other methods for dealing with values below the MDLs for statistical evaluations may be necessary. For example, if the distribution of a water quality parameter is known, such as the lognormal distribution, values below the MDL can be reported at their respective plotting positions using a maximum likelihood estimator (MLE).

Database Reference 12

Dierkes, C. and W.F. Geiger (1999). "Pollution Retention Capabilities of Roadside Soils." *Water Science and Technology* Volume 39, No. 2, pp. 201-208

Annotated Summary

The primary objective of the study was to estimate the impact of pollutants on groundwater and soil by infiltration of highway runoff over 5 greened embankments in Germany. Pollutants were measured in roadside soils, surface water, and seepage water (lysimeter effluent). Generally, concentrations of pollutants in roadside soils depended on the age of embankments and traffic density. Highest concentrations were found in the upper 5 cm of the soil and within a distance of up to two meters from the street. Concentrations of most pollutants decreased rapidly with depth and distance. Zinc and lead were found at the highest concentrations in soils. The buffering capacity of the soils remained high due to the high organic content. Leaching of metals from the soils was limited. Lead and cadmium could not be detected in lysimeter effluent. Zinc and copper were found in concentrations that did not exceed European and German drinking water quality limits. Cadmium and zinc were found to have the highest mobility, and 80% of the cadmium was present as dissolved species.

Potential Value to ODOT

This document demonstrates a strategy for evaluating the pollutant adsorption and dissolution characteristics of highway runoff to determine the threat to groundwater resources as a result of infiltration practices. The comparison of runoff quality and lysimeter effluent demonstrates that heavy metals are retained in the roadside soils. Some of the factors influencing retention capabilities include traffic density and embankment age, probably due to a decrease in soil adsorption sites. This type of monitoring effort, if standardized in a monitoring protocol, could be useful in evaluating the performance of ODOT's infiltration BMPs.

Database Reference 15

Dressing, Steven A., Jon Harcum, Michael Barbour, Mohammed Lahlou, Sam Stribling, Esther Peters, Sam Pett, George Townsend, and Marti Martin (1997). "Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls." *U.S. EPA,* EPA 841-B-96-004

Annotated Summary

This monitoring guidance addresses the design of water quality monitoring programs to assess both impacts from nonpoint source pollution and the effectiveness of control practices and management measures. There are diverse opinions regarding the most effective way to design a monitoring program. Since each situation is different and may need a unique monitoring approach, this guidance presents the theory and information needed to design monitoring programs tailored to particular situations. The document begins with an overview of the nonpoint source problem in the U.S. by defining NPS pollution and its adverse effects on natural resources. A monitoring plan development methodology is presented next, which includes identification of objectives, data analysis and presentation plans, variable selection, program design, and implementation considerations. The next section discusses biological monitoring of aquatic communities; specifically, habitat assessment, various biological assessment approaches, reference sites and conditions, rapid bioassessment protocols, sampling considerations, biomonitoring program design, monitoring trends in biological monitoring, and an overview of some state programs. The data analysis section (Section 4), gives detailed information on statistical procedures for analyzing data, such as hypothesis testing, data characterization, regression techniques, multivariate analysis, and time series evaluation (to name a few). The final section (Section 5) outlines the necessary field, laboratory, data analysis, and reporting elements of a sound quality assurance and quality control program. The appendices include a review of available monitoring guidelines (however stormwater monitoring guidelines were not included in the list), data sources, example monitoring programs, and statistical tables. Portions of Section 5 should be useful for developing monitoring protocols.

Potential Value to ODOT

This manual provides organized and thorough guidance in preparing a monitoring plan for determining the effectiveness of nonpoint source (NPS) controls. NPS controls include non-structural stormwater BMPs, so not all of the information presented will be directly applicable to the development of ODOT's monitoring protocol. The extensive chapter on data analysis (Chapter 4) will likely be a good reference when developing a similar section in the ODOT protocol.

Database Reference 16

EvTEC; David Evans and Associates (2000). "EvTEC Evaluation Plan for Ultra-Urban Stormwater Technologies." *Washington State Department of Transportation*

Annotated Summary

This study includes a detailed evaluation of the ultra-urban stormwater treatment technology by a panel of stormwater professionals. The four objectives of the evaluation include verifying the performance claimed by the vendor, evaluating the technology as a Best Management Practice for treating urban stormwater, evaluating the technology in a treatment train with other BMPs, and evaluating the operation and maintenance costs, safety, and other operational issues. The test facility was located in the City of Seattle in the SR 5 right-of-way. The drainage area consisted of 22.7 acres of pavement and 8.9 acres of roadside landscaping. Catch basins provide the only treatment for the drainage area and consist of 15 Type 1 catch basins and 53 Type 2 catch basins. Baseline water quality and flow data were collected during the 1999/2000 wet season. Vendors installed stand-alone, off-the-shelf units sized for the expected flows. A monitoring plan was developed and the tasks required to implement the plan were outlined to determine the pollutant removal efficiency of the catch basin inserts.

Potential Value to ODOT

The document provides a succinct monitoring plan for evaluating the performance of the catch basin inserts. The main topics covered in the plan include the sampling strategy, number of samples to collect, storm event criteria, rainfall and runoff measurement methods, sampling procedures, site operations, data management, and data evaluation and reporting. A follow-up report containing the results of this evaluation may be of more use than this document, however the monitoring plan just described and the protocols in the references should be of some use for developing protocols for the ODOT document.

Database Reference 19

Hathhorn, Wade and David Yonge (1996). "The Assessment of Groundwater Pollution Potential Resulting From Stormwater Infiltration BMPs." *Washington Department of Transportation,* WA-RD 389.1

Annotated Summary

This study was conducted to assess the potential for degrading the quality of underlying groundwater resources as they relate to trace heavy metal concentrations associated with the infiltration of highway stormwater runoff. The primary objective was to examine the environmental performance of a typical infiltration basin under the framework of the possible presence of facilitated heavy metal-normal organic matter (NOM) transport mechanisms. The goal was to establish revised guidelines (if necessary) for the design of an environmentally compliant infiltration facility. The project was divided into two phases. The first phase examined the controlled transport behavior of a single metal constituent (lead) with a laboratory-scale column to investigate the metal and NOM interactions. The second phase was a field-scale experiment focusing on the transport characteristics of several metals (lead, cadmium, zinc, and copper).

Based on these studies, when siting infiltration BMPs organic content of the soil, the cation exchange capacity, the silt and clay content, depth to groundwater, and background metals concentrations must be considered. Recommendations to the WSDOT for the design of infiltration basins (not including already accepted design and maintenance practices) include: avoiding soils with concentrations in excess of 20 ug/g lead, 20 ug/g copper, 1 ug/g cadmium, and 50 ug/g zinc; soil organic carbon should be between 0.3 and 1.5% (by weight) to a depth of at least 1 meter; the maximum silt and clay contents should be 20% and 10%, respectively; and the minimum depth to an underlying unconfined aquifer

Potential Value to ODOT

Infiltration BMPs are often assumed to be 100% effective at removing pollutants. However as this study suggests, there are other factors to consider when evaluating the effectiveness of infiltration-type BMPs. The ability of soils to retain pollutants is necessary to ensure groundwater resources are not impacted. It is important to be able to determine the pollutant retention capacity of soils and the geochemistry involved to maintain pollutant immobility. For the ODOT monitoring protocol, soil sampling and/or groundwater sampling may be necessary to determine the effectiveness of infiltration BMPs.

Database Reference 14

Legret, Michel and Valerie Colandini (1999). "Effects of a Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals." *Water Science and Technology,* Volume 29, No. 2, pp. 111-117

Annotated Summary

The paper reports a study conducted in Reze, France to compare the pollutant loading of runoff waters collected at the outlet of a porous pavement with reservoir structure to the runoff from a nearby catchment drained by a conventional separate sewer system. The porous pavement, as well as the materials below the pavement was analyzed to determine the accumulation zones of heavy metals (zinc, copper, lead, and cadmium). The drainage areas contributing flows to the porous pavement and the nearby catchment are residential areas. During a 4-year water quality survey (1991-1994) both catchments were simultaneously sampled for 11 rain events. The results of the study showed appreciably lower concentrations of pollutants for the porous pavement, except for copper, which showed negligible differences. On average, the percent difference in pollutant loadings of porous pavement and the reference catchment were 59%, 84%, 77%, and 73% for suspended sediment, total lead, total cadmium, and total zinc, respectively. Within the reservoir structure, three different vertical samples were taken: the clogging particles on the pavement surface, the crushed material below the porous pavement, and the sediment particles accumulated on the geotextile. The results of the study indicated that a large fraction of the total metals, especially lead, were retained in the clogging particles. A mass balance evaluation of the metals sampled revealed that 89% of the lead is retained in the clogging material with 11% infiltrating into the soils and negligible quantities discharged in the effluent. For copper, 41% was retained, 57% was infiltrated, and 2% was discharged in the effluent. For cadmium, 12% was retained, 85% was infiltrated, and 3% was discharged in the effluent. For zinc, 36% was retained, 62% was infiltrated, and 2% was discharged in the effluent.

Potential Value to ODOT

This article summarizes a performance study of porous pavement using a reference watershed to estimate removal efficiency. The data analysis revealed that some metals (particularly Pb) are more prone to be removed with the sediment particles, while other metals (particularly Cd) were more prone to infiltrate as dissolved constituents. Overall, this study provides an example of a method of determining the effectiveness of porous pavement as a stormwater BMP.

Database Reference 59

Loftis, Jim C., Graham B. McBride, and Julian Ellis (1991). "Considerations of Scale in Water Quality Monitoring and Data Analysis." *AWRA Water Resources Bulletin, V*ol. 27, No. 2

Annotated Summary

During water quality monitoring efforts, temporal and spatial scale assumptions are often made without much thought even though these types of assumptions may affect both sampling design and data analysis. As an example, the authors examine the affect of scale on estimating average conditions and the evaluation of trends. The issue of scale stems from the characteristics of data, or more specifically whether the data are statistically independent or serially correlated. Serial correlation (or autocorrelation) refers to the dependence of individual observations that are spaced closely in time or in space. Based on the definition of autocorrelation, as the spacing between successive observations decreases, the correlation tends to increase, and so does the confidence interval. Therefore, there is a limit on how well closely spaced data can describe long-term averages (e.g., annual average). On the other hand, if the goal were to determine the average value over a specified interval (i.e., day, week, month), serial correlation of successive observations would yield a better estimate (smaller variance) of the mean over that period than statistically independent observations. The issue of scale is also important in the analysis of trends. More often than not, the temporal or spatial scale chosen is over the period of record for which data are available. This may or may not be appropriate for any particular management objective. If short-term trends are of greater interest than long-term trends (e.g., diurnal fluctuations of dissolved oxygen), sufficient data must be available over the interval of interest to determine if any given change is statistically significant. If too few data are available over the interval of interest, a trend may mistakenly be overlooked. In conclusion, an explicit consideration of scale in monitoring system design and data analysis is very important for producing meaningful statistical information.

Potential Value to ODOT

The arguments provided in this article are directly applicable to the development of a stormwater monitoring and analysis plan. Event mean concentrations (EMCs) are used to describe the influent and effluent conditions of a BMP due to the inherent serial correlation of observations taken from a single event. When attempting to compile BMP effectiveness or efficiency data, it is important to consider spatial and temporal scales because data taken from one geographical region or during a particular time frame may be serially correlated. The article provides a case study to demonstrate the concepts

Database Reference 7

Minton, Gary R., Paul Bucich, Mark Blosser, Bill Leif, Jim Lenhart, Joseph Simmler, and Steven True (1999). "Protocol for the Acceptance of Unapproved Stormwater Treatment Technologies for Use in the

Puget Sound Watershed." *Municipal Research and Services Center*
http://www.mrsc.org/environment/water/water-s/apwa/protocol.htm

Annotated Summary

The protocol has four parts: 1) the "performance criteria" used to compare currently unapproved treatment technologies to approved treatment technologies, 2) the types of data to use in the evaluation and the collection methods, 3) factors in addition to performance that should be considered, and 4) the content of the report provided to the local jurisdiction by either a development engineer or a manufacturer who is seeking approval of a technology. The basic premise of this protocol is that an unapproved technology must perform equally well or better at treating the target pollutants as the currently accepted treatment technologies (e.g., wet ponds, grass swales). The document provides lines of comparative performance based on accepted BMP removal efficiencies from data in the Pacific Northwest. These lines are performance thresholds to evaluate the acceptability of proposed technologies. Only total suspended solids, total phosphorus, and total zinc are used as performance indicators. Three sets of protocols with advantages and disadvantages of each are provided in the document: for field studies with real storms, for field studies with artificial storms, and for laboratory studies with simulated stormwater. Specific requirements, such as the number of sites to be evaluated, the number of storms that should be sampled, which pollutants should be analyzed, etc., are outlined for each protocol. Three different measures of efficiency are outlined, all of which are expressed as percentages: removal in each storm based on arithmetic mean of influent and effluent concentrations, aggregate removal of all the storms sampled weighted by the flow of each storm (arithmetic means), and aggregate removal of all storms based on the geometric mean influent and effluent concentrations. The document concludes with the required contents of an applicant's performance report.

Potential Value to ODOT

This document provides useful information on how to evaluate different types of performance studies. It may be useful to compare the performance criteria and efficiency calculation methods with other protocols. Reporting removal efficiency as a single value does not adequately describe the true removal efficiency of a BMP. Confidence intervals or inter-quartile ranges should be reported with any removal estimate. Overall, the document lacks sufficient detail to be stand-alone. However, it is a good example of a regional protocol for evaluating structural BMP performance.

Database Reference 53

Newberry, George P. and David B. Yonge (1996). "Retardation of Heavy Metals in Stormwater Runoff by Highway Grass Strips." *Washington Department of Transportation,* WA-RD 404.1; NTIS PB96-192133

Annotated Summary

This document presents an effectiveness study of a full-scale grass strip model that allowed control of the slope and simulated stormwater flow rate and contaminant concentrations. Sediment, lead, cadmium, copper, and zinc were studied to determine the effectiveness of retention in the 1.2 m wide (perpendicular to flow path) and 3 m long vegetated filter strip. Research activities included determining the hydraulic residence time for various slope and flow combinations, as well as retention times and fate of the metals with regard to spatial location. Metals concentrations were based on observed median concentrations of highway runoff at selected sites in the State of Washington and typical values reported in the literature. Distribution of metals between the solid and liquid phase were estimated by developing single solute adsorption isotherms. The sampling structures consisted of a sub-surface sampling well and a surface sampling cup at 15 locations throughout the test plot. The results of the study were that most of the metals (and sediment) were retained within the upper 1 m of the grass strip and 0.4 inches of depth. A mass balance approach to determining the metal retention found that 84% of zinc, 93% of lead, and >99% of cadmium and copper were retained in the grass strip.

Potential Value to ODOT

This regional study provides experimental effectiveness information of a highway grass strip. The sampling methods utilized may be applicable to field studies depending on specific site characteristics. The thoroughness of the analysis demonstrates many of the factors to consider when determining pollutant removal effectiveness of a vegetated filter strip, such as slope, fate and transport, soil compaction, vegetation density, etc. Overall, this study provides practical information on the how to conduct a performance study and some of the limitations involved.

Database Reference 58

Oregon Department of Environmental Quality (2000). "Oregon Department of Transportation Permit Evaluation Report and Fact Sheet for NPDES Permit for MS4." *Water Quality Program* http://www.deq.state.or.us/wq/wqpermit/odotpermiteval.pdf

Annotated Summary

The evaluation report summarizes the proposed permit action to renew and expand the NPDES permit for the Oregon Department of Transportation (ODOT) as an individual applicant, to regulate and allow the discharge of stormwater runoff from the State highway system and ODOT maintenance yards. ODOT has previously been a co-permittee on six MS4 permits with other jurisdictions operating large and medium sized municipal separate storm sewer systems. The proposed permit will require ODOT to inventory major outfalls (and their receiving water bodies) within urban growth boundaries (UGBs) of municipalities with populations of 10,000 or greater across the State, and any area designated by DEQ as making significant contributions to water pollution. Major outfalls as defined by the USEPA are pipes 36" in diameter or greater or discharges from drainage areas of 50 acres or more, or discharges from industrial land from pipes 12" in diameter or greater or from drainage areas of 2 acres or more. Previous outfall monitoring studies conducted in a portion of the approximate 1,000 miles of State highways within the UGBs in Oregon, found that the water quality constituents of most concern are cadmium, copper, lead, silver, zinc, bacteria, polyaromatic hydrocarbons, total petroleum hydrocarbons, pH, total suspended solids, sediment, and biochemical oxygen demand. Other requirements of the proposed permit include taking an inventory and making a map of road segments that are served by BMPs for stormwater management.

Potential Value to ODOT

This document summarizes some of the requirements that ODOT will have to meet in order to comply with their NPDES permit(s). This evaluation report, although somewhat out-dated, refers to some useful information that may be available from DEQ and ODOT for development of the monitoring protocol. Of particular interest is the inventory and map of road segments that are served by ODOT's stormwater BMPs throughout the state. A copy of the most recent NPDES permit may also be of some use.

Database Reference 24

Oregon Department of Environmental Quality (1998). "DEQ Laboratory: Field Sampling Reference Guide." *Oregon DEQ* http://www.deq.state.or.us/lab/qa/techdocs.htm

Annotated Summary

The goal of this guide is to provide Regional and Program staff with information they need to make knowledgeable and efficient use of the resources available from the Laboratory Division. The document provides valuable information of how to collect reliable water, air, and biotic field samples to be submitted to the DEQ laboratory. Outlined in the document are information contacts, safety considerations, procedures for environmental investigations and compliance inspections, sampling and analysis plan development, the quality assurance process, sample collection techniques, and submitting samples and requesting analysis. The guide includes the chemical analysis methods available at the laboratory as well as some of the significant differences and specifications of alternative methods. The document does not include much detail on sampling procedures. However a reference is provided to find more information, and the appendices include provide specific information on sampling for volatile organics, dissolved oxygen, and a field filtration procedure. Also included in the appendices is a procedure for legal sample chain-of-custody, a description of matrix and surrogate spikes, and tables providing valuable sampling information such as the type of container, the minimum quantity, type of preservative, and the maximum holding time for various chemical and biological constituents.

Potential Value to ODOT

This document will be useful in determining the methods that should be used to collect water quality samples and measure analytical constituents. Valuable information on the relationship between the sampling team and the laboratory can be obtained from this document. If ODOT chooses to use the DEQ laboratory for water quality analysis, this sampling guide must be adhered to.

Database Reference 13

Sansalone, John (1999). "In-Situ Performance of a Passive Treatment System for Metal Source Control." *Water Science and Technology,* Volume 39, No. 2, pp. 193-200

Annotated Summary

An experimental site located on I-75 in Cincinnati, Ohio was set up to determine the performance of a roadside treatment and conveyance system, more specifically, a partial exfiltration trench (PET). A PET is a trench filled with a porous media with the primary function of filtering and adsorbing pollutants. Some of the water flowing through the trench is conveyed to an underdrain system connected to the storm sewer or surface drainage, while some of the flow is exfiltrated to surrounding soils (hence the name). Average daily traffic of 140,000 passenger cars and 15,000 commercial vehicles with annual snow and rainfall of 420 and 1020 mm, respectively, occurs at the site. The roadside PET receives runoff from a 15 X 20 m area of asphalt pavement. The PET was 30 cm wide, with a porous media of oxide-coated sand (density 2.75 g/cc and porosity of 0.37) and covered by 10-cm of porous pavement. Surrounding soils at the site are glacial tills, classified as clayey soils. Influent flows and concentrations were approximated with the runoff from an adjacent, 15 X 20 m area of the roadway. Effluent was taken directly from the underdrain system. Influent and effluent flows and concentrations were taken for 1 year. Flow-weighted samples from the influent and effluent were taken during four storm events. Dissolved and particulate-bound concentrations for zinc, cadmium, copper, and lead were measured. Average dissolved fractions of zinc, cadmium, and copper dominated the total influent concentrations with dissolved fractions equaling 90%, 77%, and 61%, respectively. Lead was primarily particulate-bound with an average dissolved influent fraction of 24%. Effluent concentrations were not reported in the article. However, percent removals indicate that mass removal efficiencies generally exceeded 80% for both dissolved and particulate fractions. The amount of flow exfiltrated to the surrounding soils was generally between 10 and 30%.

Potential Value to ODOT

The partial exfiltration trench (PET) technology is useful when space is a limiting factor and/or surrounding soils do not have the transmissivity for complete infiltration of the runoff. This study is an example of a performance evaluation using a reference drainage area. The hydrology of the study area is very different than in Oregon; however, clayey soils are not atypical of Oregon soils, so the results of this study may be comparable to similar studies of ODOT BMPs if conducted.

Database Reference 20

Strecker, Eric, Marcus Quigley, and Ben Urbonas (2000). "Determining Urban Stormwater BMP Effectiveness." *Proceedings of the National Conference on Tools for Urban Water Resources Management and Protection, Chicago IL,* EPA/625/R-00/001

Annotated Summary

This paper overviews some of the problems of past BMP effectiveness studies from the perspective of comparability and transferability of data. It suggests some of the ways that data should be collected to make them more useful for assessing factors (such as settling characteristics of inflow solids and physical features of the BMP) that might lead to the performance level achieved. It briefly presents the database that has been developed by this project, which not only served as a tool for storing data from existing studies, but as a tool for entering and storing data collected form future studies. Discussed are considerations that affect data transferability, such as sampling and analysis techniques, effectiveness estimations, statistical testing, etc. It overviews the efforts to establish and analyze the database for existing studies and overviews proposed analyses for the future, when more studies that have followed the protocols are available. The database has specifically pointed out the need for additional BMP performance studies, as the current data are very sparse in terms of studies that have recorded enough information to be useful in assessing BMP type performance.

Potential Value to ODOT
This document provides recommended parameters for assessing BMP performance, data analysis and reporting guidelines, and strong arguments for statistical characterization of inflow and outflow concentrations when determining pollutant removal effectiveness. Overall this document provides a brief assessment of the some of the inconsistencies in BMP performance studies and recommendations to overcome these inconsistencies in future efforts.

Database Reference 23
U.S. EPA Office of Research and Development (1994). "Guidance for the Data Quality Objectives Process." *U.S. EPA,* EPA 600/R-96/055; NTIS PB2000-104368
http://www.epa.gov/clariton/clhtml/pubtitle.html

Annotated Summary
The DQO Process is a strategic planning approach based on the Scientific Method that is used to prepare for a data collection activity. It provides a systematic procedure for defining the criteria that a data collection design should satisfy, including when to collect samples, where to collect samples, the tolerable level of decision errors for the study, and how many samples to collect. The seven steps of the DQO Process include: 1. State the problem, 2. Identify the decision, 3. Identify inputs to the decision, 4. Define the study boundaries, 5. Develop a decision rule, 6. Specify limits on decision errors, and 7. Optimize the design for obtaining data. This process can be iterated for an increased level of evaluation effort. The document is organized with a chapter dedicated to each of the DQO Process steps. Appendix A includes some of the important quality assurance (QA) management steps that should occur after the completion of the DQO process. Appendix B presents a DQO case study of a cadmium-contaminated fly ash waste data collection project. Appendix C provides a derivation of the sample size formula for the case when the standard deviation of a population is known and unknown.

Potential Value to ODOT
This document may be helpful in the design of ODOT's monitoring protocols. The DQO process is not specific to stormwater monitoring, or even water quality monitoring, so the methodology is very general. However, by following the DQO process, monitoring efforts will be in conjunction with the EPA's environmental data acquisition methodology. The sample size estimation rational and formula provided in the document should be included in the ODOT protocol.

Database Reference 31
U.S. EPA Office of Research and Development (1996). "Guidance for Data Quality Assessment." *U.S. EPA,* EPA 600-R-96-084,http://www.epa.gov/clariton/clhtml/pubtitle.html

Annotated Summary
Data Quality Assessment (DQA) is the scientific and statistical evaluation of data to determine if data obtained from environmental data operations are of the right type, quality, and quantity to support their intended use. This guidance demonstrates how to use DQA in evaluating environmental data sets and illustrates how to apply some graphical and statistical tools for performing DQA. This document summarizes the final phase assessment of an environmental data collection project. The five steps involved in the DQA process include: 1) Review the Data Quality Objectives (DQOs) and Sampling Design, 2) Conduct a Preliminary Data Review, 3) Select the Statistical Test, 4) Verify the Assumptions of the Statistical Test, 5) Draw Conclusions from the Data. These steps are often followed iteratively until the DQOs are met. Several statistical and data validation methods are presented in the document.

Potential Value to ODOT
This document provides useful information on the statistical analysis of data using scientifically accepted techniques. These techniques should be referenced in the ODOT monitoring protocol. Again, to be in conjunction with the EPA's environmental monitoring protocol, the procedure outlined in this document should be considered.

Database Reference 30

U.S. EPA Office of Research and Development (1998). "EPA Guidance for Quality Assurance Project Plans." *U.S. EPA,* EPA 600-R-98-018 http://www.epa.gov/clariton/clhtml/pubtitle.html

Annotated Summary

This document presents detailed guidance on how to develop a Quality Assurance Project Plan (QAPP) for environmental data operations. The QAPP is the critical planning document for any environmental data collection operation because it specifies how quality assurance (QA) and quality control (QC) activities will be implemented during the life cycle of a program, project, or task. Every environmental data collection project should be divided into three phases: planning, implementation, and assessment. The QAPP links these three project phases. The planning phase involves the development of Data Quality Objectives (DQOs) where the recipients of the data (i.e., decision makers) outline their expectations and requirements of the type and quality of data that are to be obtained. In the QAPP these requirements are translated into measurement performance specifications and QA/QC procedures for the data suppliers to provide the information needed to satisfy the data user's needs. The QAPP will ensure that project goals and responsibilities are clearly stated, that all participants understand them, and that they are clearly and thoroughly documented. During the implementation phase, the QAPP ensures that appropriate methods for sampling, analysis, data handling, and QC are employed and are verified with assessment and oversight. During the assessment phase, the QAPP ensures that the individual data elements conform to the specified criteria (i.e., data validation, analysis, and reporting), thus enabling reconciliation of the project's objectives.

Potential Value to ODOT

As with the "Guidance for the Data Quality Objectives Process" (Ref ID#23), by following the recommended procedure for developing a QAPP, monitoring efforts will be in conformance with the EPA's environmental monitoring protocol. Section B2 on sample handling and chain-of-custody procedures are probably the most useful sections of the reference for the ODOT project; however, the concepts presented throughout the document should be considered when developing monitoring protocols.

Database Reference 28

U.S. EPA Office of Water (1992). "NPDES Storm Water Sampling Guidance Document." *U.S. EPA,* EPA 833-B-92-001

Annotated Summary

This document focuses on the technical aspects of stormwater sampling with regard to the NPDES permitting process. Chapter 2 includes background information on the NPDES program such as a summary of permit application requirements, who must sample, when and where to sample, and staffing considerations. Chapter 3 describes some of the fundamentals of sampling, such as types of sampling, obtaining flow data, handling samples, and sending them to the laboratory for analysis. This chapter provides detailed information on measuring flow rates and collecting water quality samples. Analytical considerations are presented in Chapter 4, including the stormwater pollutants that must be analyzed under the regulations. Regulatory flexibility with respect to stormwater sampling and health and safety considerations are included in Chapters 5 and 6, respectively.

Potential Value to ODOT

Highway runoff that enters municipal storm sewer systems may be subject to the requirements of municipal NPDES permits; therefore, this document, despite the fact that it is nearly 10 years old, may be directly pertinent to ODOT's BMP performance evaluations. Portions of Chapter 4 should be useful for development of monitoring protocols. The municipal stormwater pollutants that must be analyzed according to this chapter may apply to highway runoff if connected to a municipal storm sewer system.

Database Reference 40

US Army Corps of Engineers (2001). "Requirements for the Preparation of Sampling and Analysis Plans."

Department of the Army, EM-200-1-3, http://www.usace.army.mil/inet/usace-docs/

Annotated Summary

This manual provides guidance for the preparation of project-specific sampling and analysis plans (SAP) for the collection of environmental data. In addition, default sampling and analytical protocols are included, which may be used verbatim or modified based upon project-specific data quality objectives (DQOs). The goal of this manual is to promote consistency in the generation and execution of sampling and analysis plans and thus to help generate chemical data of known quality for its intended purpose. Four chapters, ten appendices and a glossary are included in the manual. Chapter 1 includes an introduction and statement of the manual's purpose. Chapter 2 presents guidelines for use of the manual. Chapter 3 discusses format and content requirements of the Field Sampling Plan and the Quality Assurance Project Plan. Chapter 4 lists guidelines for developing sampling and analysis protocols when the protocols in Appendices C, D, E, F, G, H, and I are not appropriate.

Potential Value to ODOT

This document should be helpful in developing a sampling and analysis plan for the ODOT BMP Evaluation. At a minimum, the document provides a checklist of items to include in the final ODOT BMP Monitoring and Assessment Plan. Sampling protocols in Chapter 4 and the appendices (e.g. C) should be useful for developing ODOT protocols.

Database Reference 36

Wood, Tamara (2001). "Herbicide Use in the Management of Roadside Vegetation, Western Oregon, 1999-2000: Effects on the Water Quality of Nearby Streams." *USGS* Water-Resources Investigations Report 01-4065

Annotated Summary

The purpose of this study was to assess whether the use of herbicides in integrated vegetation management (IVM) programs could be a significant contributor to the loads of herbicides carried by streams in Oregon. The study site was in the Willamette Valley near Colton, Oregon where Highway 211 crosses over Bull Creek. The fieldwork was divided into two phases to examine the transport of herbicides from the road shoulders under both controlled and natural rainfall conditions. During the controlled phase (spring of 1999), 0.3-inch per hour rainfall events were simulated and runoff collected 1 day, 1 week, and 2 weeks after the application of a herbicide compound typical of ODOT application rates and concentrations. The simulated rainfall was applied long enough to collect between 13 and 15 liters of runoff (between 0.5 and 1.9 hours). The event-mean concentration in the runoff of each of the herbicides (diuron, glyphosate, bromacil, and sulfometuron-methyl) declined by about 1.5 orders of magnitude from the first day after application to the second week after application. The results of the simulated rainfall experiments suggested that a heavy rainstorm occurring soon after herbicide application could generate concentrations in the runoff leaving the roads shoulder of nearly 1 mg/L glyphosate and diuron, and concentrations on the order of a few hundred ug/L of sulfometuron-methyl. Bromacil was not measured in this phase. During the second phase (winter 1999-2000), concentrations were measured in the runoff occurring from natural rain events after a single herbicide application. Five rainfall events were chosen for the sampling. Runoff directly from the shoulder remained in the 1-10 ug/L range for diuron for all event sampled with concentrations decreasing with time.

Potential Value to ODOT

The results of this study probably will not be useful for development of the ODOT monitoring protocol. However, the results could be used as a comparison to future ODOT monitoring efforts if the same type of analytical methods are used. The results of this study suggested that ODOT's integrated vegetation management plan has not significantly contributed to the herbicide pollution observed in Bull Creek. However, since the test plots did not have a history of vegetation management there is no way to determine long-term effects of herbicide application from this study. Overall, this study provides a good example of how to monitor the effectiveness of roadside soils at retaining pollutants, more specifically herbicides.

Database Reference 47

Woodward-Clyde Consultants (1991). "Field Manual for the City of Portland Outfall Investigation Program." *City of Portland*

Annotated Summary

This manual was created to provide a systematic procedure for conducting the field screening requirements described in the EPA storm water rule of November 16, 1990. This manual is designed to achieve the following objectives: 1) provide step by step procedures for the investigation of all major outfalls discharging from the City of Portland and (co-applicants) storm sewer system, 2) provide criteria of when and where to collect water quality sample for laboratory analysis, 3) provide guidance on laboratory sample collection, preservation, analysis and completion of chain-of-custody forms, and 4) provide guidance for safety of field personnel. The manual is provides detailed field investigation procedures according to three different scenarios: when water is flowing, when water is present but not flowing, and when the outfall is dry. Each of these procedures provides field personnel with steps to be taken during any particular scenario. Methods for field reporting and data handling, as well as health and safety guidelines for field personnel, are included.

Potential Value to ODOT

This manual provides useful field procedure guidelines for sampling of storm sewer outfall water. BMPs are not focused on in the document; however, storm sewer outfall sampling would likely have similar characteristics to the sampling of some of inflows and outflows to ODOT's stormwater BMPs. Because this is a field manual it lacks detailed information regarding the sampling techniques and data analysis. It could be useful in developing a field manual for ODOT monitoring efforts.

Database Reference 17

Yu, Shaw and Monika Stopinski (2001)."Testing of Ultra-Urban Stormwater Best Management Practices." *Virginia Department of Transportation,* FHWA/VRTC 01-R7

Annotated Summary

This study monitored the field performance of four ultra-urban BMPs: three oil and grit separators (Isoilater, Stormceptor, and Vortechs Stormwater Treatment System) and a bioretention area. Flow-weighted stormwater samples and first flush samples were analyzed to calculate the removal efficiency for each constituent monitored. Sediment sampling was also performed to determine the accumulated sediment composition in the drainage system. Because the Vortechs systems was installed improperly, its removal efficiency results in this study are not reliable. Therefore, the system could not be fully evaluated. The Isoilater performed closest to the manufacturer's claims for TSS removal efficiency; however, the units used at the two study sites were oversized for the flow rates provided. The drainage area for Stormceptor study site was very close to (slightly less than) the design drainage area, but the TSS removal efficiency was nearly 30% less than the manufacturer claimed. The bioretention area provided high TSS removal efficiencies during low flows, but resuspension of sediment occurred during larger events. Minimal establishment of vegetation had occurred at the site prior to the onset of the study. The bioretention area was the most cost-effective BMP monitored in the study due to the high installation and maintenance costs of proprietary BMPs.

Potential Value to ODOT

The results of the study are site specific, and the performance of the BMPs was affected by varying factors. However, the study demonstrates a DOT's effort at assessing the performance of proprietary BMPs in comparison to known treatment technologies. Some of the significant recommendations when evaluating the cost-effective ultra-urban technologies include: estimated maintenance costs should include sediment disposal since sediment pollutant concentrations may reach bio-hazardous levels; document the sediment depth measurements and the cleanout information to help determine overall efficiency and longevity of the BMP; and frequently monitor ultra-urban BMPs that are installed in new development areas during construction for pollutant buildup.

Additional References

The following references are believed to be of limited use to the development of ODOT's stormwater BMP monitoring protocol. They are listed here as to provide additional sources of information to accommodate changes to the project's objectives or unforeseeable informational needs. Summaries have been omitted in this set of annotated bibliographies; however, they are available in the references database if needed.

Database Reference 44
Apfelbeck, Randy and Marti Martin (1995). "Montana DEQ - Water Quality Assurance Project Plan." *Montana Department of Environmental Quality,* http://www.deq.state.mt.us/ppa/mdm/SOP/sop.asp

Database Reference 35
Brown, Thomas, William Burd, James Lewis, and George Chang (1994). "Methods and Procedures in Stormwater Data Collection." *Proceedings of the Engineering Foundation Conference on Storm Water Monitoring. August 7-12, Crested Butte, CO*

Database Reference 25
Conrad, John and E.R. Burch (2001). "Highway Runoff Manual." *Washington State Department of Transportation,* http://www.wsdot.wa.gov/hq/library/default.htm

Database Reference 22
Driscoll, Eugene, Dominic DiToro, David Gaboury, and Philip Shelley (1986). "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality." *U.S. EPA,* EPA 440/5-87-001

Database Reference 49
Dunn, Chris, Scott Brown, Kenneth Young, Stuart Stein, and Mark Mistichelli (1995). "Current Water Quality Best Management Practices Design Guidance." *Transportation Research Record* 1483

Database Reference 60
Field, Richard and Thomas P. O'Conner (1996). "Assessment of Vortex Solids Separators for the Control and Treatment of Wet-Weather Flow." *USEPA,* EPA/832-B-96-006; NTIS PB97-141550

Database Reference 21
Galli, John (1992). "Analysis of Urban BMP Performance and Longevity." *Prince George's County Department of Environmental Resources Watershed Protection Branch* 92711

Database Reference 37
Hayes, B.D., T.F. Marhaba, N.W. Agnoli, and D.M. Lackey (1996) "Evaluation of Highway Runoff Pollution Control Devices." *New Jersey Department of Transportation* 96-007-7620

Database Reference 62
Hoenicke, Rainer and Terry Cooke (1995). "Monitoring Protocol Standardization Project." *Bay Area Stormwater Management Agencies Association (BASMAA).* www.basmaa.org

Database Reference 41
Horner, Rich (1992) "Boeing Customer Service Training Center Stormwater Quality Monitoring and Assessment Program. " *Sverdrup Corporation*

Database Reference 42
Hufnagel, Carol, Lou Regenmortor, Tom Quasebarth, and Tom Pedersen (1996). "Rouge River National Wet Weather Demonstration Project Field Sampling Plan: 1996 Baseline Water Quality Sampling." *Wayne County, Michigan* RPO-WMOG2B-FSP17.00

Database Reference 34
Lee, Fred (2002). "The Right BMPs?: Another Look at Water Quality." *Stormwater: The Journal for Surface Water Professionals,* [Online Available, April 2002] http://www.forester.net/sw_0011_right.html

Database Reference 39
Newton, Bruce, Catherine Pringle, and Ronald Bjorkland (1998). "Stream Visual Assessment Protocol." *USGS Natural Resources Conservation Service* Technical Note 99-1

Database Reference 5
Robben, Joshua and Liz Dent (2002). "Oregon Department of Forestry Best Management Practices Compliance Monitoring Project: Final." *Oregon Department of Forestry* [Online Available, April 2002] http://www.odf.state.or.us/FP/fpmp/Projects/BMPCMP/BMPFinal.doc

Database Reference 48
Schaftlein, Shari (1995). "Washington State's Stormwater Management Program." *Transportation Research Record* 1523

Database Reference 29
Thrush, Cindy and Dana B. DeLeon (1993). "Automatic Stormwater Sampling Made Easy." *The Water Environment Federation*

Database Reference 46
Washington Department of Ecology (2001). "Volume V - Runoff Treatment BMPs in Stormwater Management Manual for Western Washington." *Washington Department of Ecology* 99-15 [Online Available, April 2002] http://www.ecy.wa.gov/programs/wq/stormwater/index.html

Database Reference 11
Watt, Edgar W. and Jiri Marsalek (1994) "Comprehensive Stormwater Pond Monitoring." *Water Science and Technology* Volume 29, Issue 1-2, pp. 337-345

Database Reference 43
Wilde, F.D. and D.B. Radtke (1998). "Field measurements in National Field Manual for the Collection of Water Quality Data Chapter A6." *USGS Water Resources* TWRI Book 9 [Online Available, April 2002] http://water.usgs.gov/owq/FieldManual/

Database Reference 18
Yu, Shaw, Robert Kaighn, and Shih-Long Liao (1994). "Testing of Best Management Practices for Controlling Highway Runoff, Phase II." *Virginia Department of Transportation,* FHWA/VTRC 94-R21; NTIS PB95-225611