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# Scientific Framework for Stormwater Monitoring by the Washington State Department of Transportation

Open-File Report 2009–1236

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
U.S. Geological Survey

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## Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| mile (mi) | 1.609 | kilometer (km) |
| acre | 0.004047 | square kilometer ($km^2$) |
| liter (L) | 0.2642 | gallon (gal) |

## Abbreviations and Acronyms

| | |
|---|---|
| AADT | annual average daily traffic |
| BMP | Best Management Plan |
| CRM | certified reference material |
| CFR | Code of Federal Regulations |
| $EC_{50}$ | half maximal effective concentration |
| Ecology | Washington State Department of Ecology |
| EMC | event mean concentration |
| GIS | geographic information system |
| MS4 | municipal separate storm sewer |
| NFM | USGS National Field Manual |
| NPDES | National Pollutant Discharge Elimination System |
| PAH | polycyclic aromatic hydrocarbon |
| QA | quality assurance |
| QAPP | Quality Assurance Project Plan |
| QC | quality control |
| SOP | standard operating procedure |
| SRM | standard reference material |
| TAPE | Technology Assessment Protocol-Ecology |
| TI/RE | toxicity identification/reduction evaluation |
| TMDL | Total Maximum Daily Load |
| USGS | U.S. Geological Survey |
| USEPA | U.S. Environmental Protection Agency |
| WSDOT | Washington State Department of Transportation |

# Scientific Framework for Stormwater Monitoring by Washington State Department of Transportation

By R.W. Sheibley, V.J. Kelly, and R.J. Wagner

## Abstract

The Washington State Department of Transportation municipal stormwater monitoring program, in operation for about 8 years, never has received an external, objective assessment. In addition, the Washington State Department of Transportation would like to identify the standard operating procedures and quality assurance protocols that must be adopted so that their monitoring program will meet the requirements of the new National Pollutant Discharge Elimination System municipal stormwater permit. As a result, in March 2009, the Washington State Department of Transportation asked the U.S. Geological Survey to assess their pre-2009 municipal stormwater monitoring program. This report presents guidelines developed for the Washington State Department of Transportation to meet new permit requirements and regional/national stormwater monitoring standards to ensure that adequate processes and procedures are identified to collect high-quality, scientifically defensible municipal stormwater monitoring data. These include: (1) development of coherent vision and cooperation among all elements of the program; (2) a comprehensive approach for site selection; (3) an effective quality assurance program for field, laboratory, and data management; and (4) an adequate database and data management system.

## Introduction

U.S. Environmental Protection Agency (USEPA) regulations require National Pollutant Discharge Elimination System (NPDES) permits, as mandated by the Federal Clean Water Act, for stormwater discharges from municipal separate storm sewer systems (MS4s), industrial activities, construction activities, and sand and gravel activities. The Washington State Department of Transportation (WSDOT) has permits under all these categories; however, their municipal stormwater permit is the focus of this report. Beginning in 1995, the WSDOT municipal stormwater permit was incorporated into NPDES permits issued by the Washington Department of Ecology (Ecology) to three Water Quality Management Areas (Washington State Department of Ecology, 1995a, 1995b, 1995c), which covered most of King, Snohomish, and Pierce Counties, respectively (fig. 1). These permits, referred to as the 1995 permits in this report, were superseded by a separate NPDES permit issued directly to WSDOT in February 2009, referred to as the 2009 permit in this report. The 2009 permit greatly expands the scope of the WSDOT stormwater monitoring program to include sites in Phase I and Phase II designated areas of the State and mandates a more extensive set of requirements for monitoring sites and constituents. Phase I areas describe medium and large MS4s generally serving populations of 100,000 or greater, and Phase II areas include small MS4s located in “urbanized areas” as delineated by the Bureau of the Census (2002). The permit’s Total Maximum Daily Loads (TMDL)-related requirements include additional monitoring obligations.

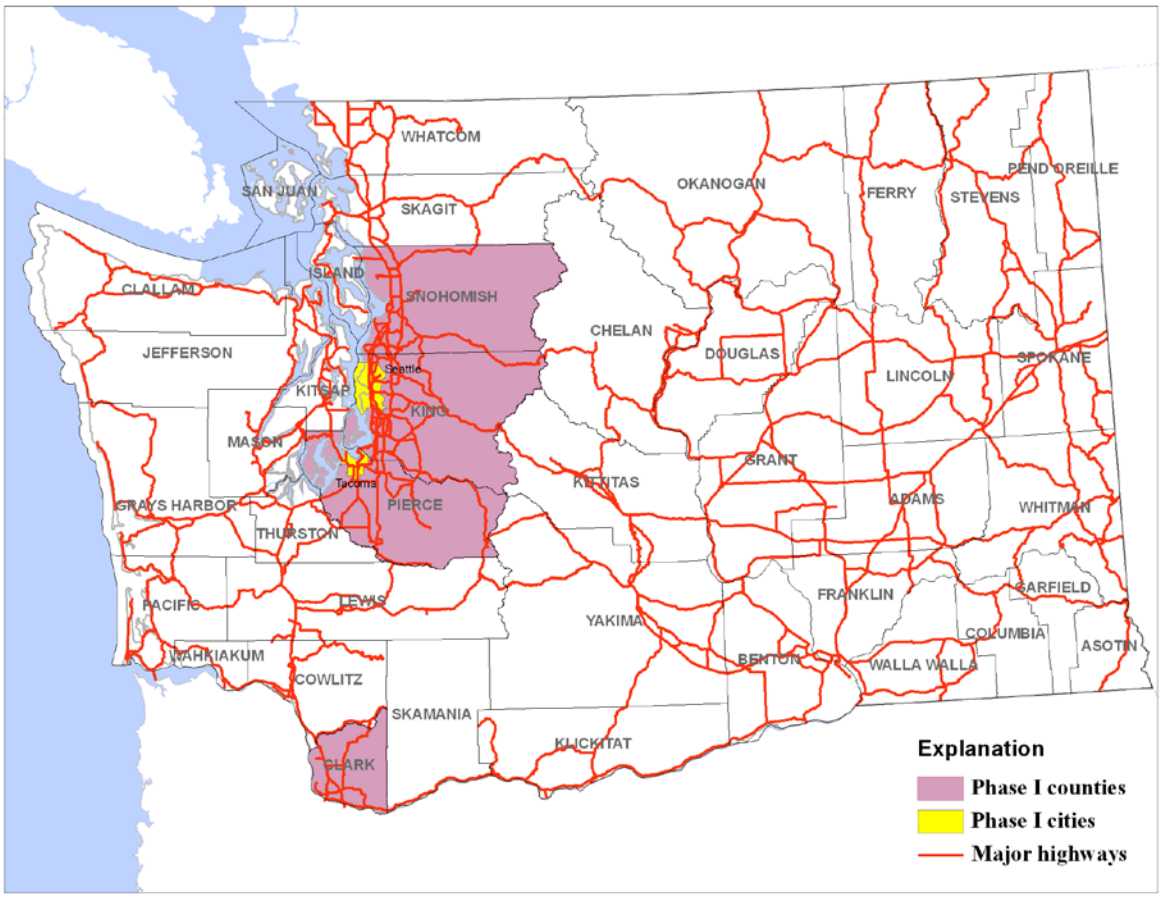


Figure 1. Map showing the Phase I municipal stormwater permit areas in Washington.

Coincident with the issuance of the 2009 permit, an internal review of the WSDOT stormwater monitoring program (WSDOT Stormwater and Watersheds Program staff, written commun., 2009) identified several areas of concern related to the implementation of the stormwater monitoring program under the 1995 permits, referred to as the pre-2009 monitoring program in this report. In response to this internal review and the expanded scope of monitoring under the 2009 permit, WSDOT asked the U.S. Geological Survey (USGS) to review their pre-2009 stormwater monitoring program. The question of particular interest was whether or not monitoring processes and procedures that evolved under the 1995 permits were sufficient and, if so, will they continue to be sufficient based on the expanded specifications of the 2009 permit. This report provides the results of the USGS review and is primarily focused on describing the scientific framework and specific programmatic components that will be necessary for a successful WSDOT stormwater monitoring program that meets the new 2009 permit requirements.

## Purpose and Scope

The purpose of this study is to evaluate the pre-2009 WSDOT stormwater monitoring program and to provide guidelines that will enable WSDOT to (1) meet the requirements of the new permit issued in February 2009, (2) meet regional/national stormwater monitoring standards, and (3) ensure that adequate processes and procedures are established to collect high-quality scientifically defensible stormwater monitoring data. The evaluation began with the review of the 1995 permits (Washington State Department of Ecology, 1995a, 1995b, 1995c) and recent 2009 permit (Washington State Department of Ecology, 2009) to understand the original and current range of the WSDOT stormwater program requirements. Because no stormwater monitoring was active at the time of this review, the scope of this analysis was limited to:

- Review of the most recent (2007–08) WSDOT stormwater monitoring Quality Assurance Project Plans (QAPPs),
- Site visits to previous monitoring locations,
- Interviews with various past and present personnel from WSDOT and their consultants who have been in charge of stormwater monitoring programs for several years.

Additionally, all available and relevant guidance documents provided by the USEPA and Ecology were examined. Finally, stormwater monitoring programs by selected NPDES Phase I municipal stormwater permittees were evaluated to identify specific elements of a successful stormwater monitoring program so that WSDOT can focus on developing and refining their stormwater program.

## Description of Study Area

Washington State Department of Transportation is responsible for the construction and maintenance of all State highways, ferry terminals, rest areas, and park-and-ride lots in the State of Washington. This infrastructure includes more than 7,000 centerline miles of roads and covers approximately 41,000 acres (Washington State Department of Transportation, 2008a), most of which is impervious surface. Because impervious surfaces prevent water from soaking into the soil, large volumes of stormwater are generated from WSDOT roads and facilities every year. Without adequate treatment, these stormwater discharges could result in major erosion, flooding, and transport of contaminants to surface waters that could potentially result in violations of Washington State water-quality standards and requirements of their NPDES permit. To manage the discharge of pollutants to meet the mandate established by Ecology, WSDOT is required to control and manage stormwater runoff from its roads and facilities located within Phase I and Phase II areas of the State in order to reduce the discharge of pollutants to the maximum extent practicable. The Phase I areas include Clark, King, Pierce, and Snohomish Counties and the cities of Seattle and Tacoma (fig. 1). The Phase II areas include smaller MS4s.

## Brief History of Washington State Department of Transportation Stormwater Monitoring Program

A brief overview of the history of the WSDOT stormwater monitoring program up to the present time begins with a description of the 1995 permit requirements, which are relatively limited compared to the requirements of the 2009 permit. Understanding the limits of these requirements provides the critical context for assessing the pre-2009 program that was implemented to address them. Finally, a short summary of the results of the WSDOT internal review of the pre-2009 monitoring program identifies the primary issues and concerns that are associated with the implementation of that program.

### Requirements for the 1995 Permit

Monitoring under the 1995 set of municipal stormwater permits was mandated as part of a required stormwater management program to evaluate the effectiveness in reducing pollutants discharged to surface waters, ground waters, and sediments (Washington State Department of Ecology 1995a, 1995b, 1995c). Under the monitoring program, WSDOT was required to evaluate field sites, sampling, and analysis to (1) estimate concentrations and loads from representative areas based on average daily traffic volumes, (2) evaluate the effectiveness of selected Best Management Practices (BMPs), (3) identify specific sources of pollution, and (4) identify the degree to which stormwater discharges are impacting selected receiving waters and sediments. The permits noted that the monitoring program should include a quality-assurance/quality-control plan, but did not require the monitoring plan to be either reviewed or approved by Ecology.

Additional requirements were provided for the monitoring program in the General Conditions section of the permit (Washington State Department of Ecology, 1995a, 1995b, 1995c). This section described general requirements that sampling should be representative of the volume and nature of the monitored discharge, although no further detailed criteria were provided for determining what constitutes a representative stormwater sample. Specific requirements were described only for the length of records retention and what information should be recorded for every sample. Ecology also required that all sampling and analytical methods conform to guidelines published in Title 40 of the Code of Federal Regulations (CFR), part 136 (U.S. Environmental Protection Agency, 2009) and that all monitoring data should be prepared by an accredited laboratory. Finally, flow measurement devices and methods must be consistent with accepted scientific practices, and calibrated in conformance with the manufacturer's recommendations or at a minimum frequency of at least once per year. No mention was made of specific guidelines for site selection or constituents to be measured, of the sampling methodology, or number or frequency of samples necessary for adequate estimation of concentrations and loads. However, at the time guidance on topics such as storm criteria, sample methodology, and sample frequency for municipalities could be found elsewhere (U.S. Environmental Protection Agency, 1992).

### Implementation of the Pre-2009 Stormwater Monitoring Program

Because the requirements of the 1995 permits were not explicit (such as storm criteria, sampling methods, types of samplers), the stormwater monitoring program implemented by WSDOT was developed largely to address the internal priorities of the agency. Consistent with the permit requirement to estimate concentration and loads from representative areas, site selection initially focused on basic highway runoff characterization, and subsequently was augmented to include a range of BMP types to meet the requirement for evaluated BMP effectiveness. For the BMP effectiveness evaluation, flow into

the BMP selected area was considered 'untreated' highway runoff, and flow out of BMP selected area was 'treated' runoff, which allowed calculation of pollutant removal efficiencies. Monitoring required to identify specific sources of pollutants and to identify the degree to which stormwater discharges are impacting selected receiving waters and sediments was not made. Generally, 10 to 12 storm events were sampled at each site every year and storm event criteria were devised from draft guidelines provided by Ecology that were later published as the Technology Assessment Protocol–Ecology (TAPE, Washington State Department of Ecology, 2008a). Although analytical constituents varied from year to year, they generally included a subset of the following measurements: hardness, total suspended solids, phosphorus, metals (dissolved and total concentrations of cadmium, copper, lead, and zinc), petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and coliform bacteria. Data management procedures varied throughout this time, but most recently consisted of maintaining laboratory data in an Excel spreadsheet and discharge data in a Microsoft Access database. The QAPPs were produced throughout the life of the monitoring program, although they sometimes described procedures and study design after the completion of sampling, which may limit appropriate interpretation of the quality of data collected. The QAPPs specified the basic monitoring design; including sample handling, quality control samples, and procedures for data verification and validation. All QAPPs were developed by the consulting firms in charge of the monitoring and were reviewed by the WSDOT project manager. Ecology did not review and provide signatory approval of any the QAPPs for this monitoring.

### Washington State Department of Transportation Internal Review of the Pre-2009 Stormwater Monitoring Program

In February 2009, WSDOT staff reviewed their stormwater monitoring program to assess whether or not past monitoring design and data collected: (1) met procedural guidelines and quality standards in effect at the time of the monitoring, (2) met or meet data practices such as Ecology's TAPE and Credible Data Policy, and (3) are in line with future monitoring requirements under the recently issued WSDOT NPDES municipal stormwater permit. The internal review identified several areas of concern, including, but not limited to the following:

- The absence of independent audit functions in program structure relative to the process of data collection, including field and laboratory work, data quality assessments, data analysis, and reporting;
- Lack of sufficient quality-assurance oversight by WSDOT, especially related to the lack of standard operating procedures (SOPs) for field work, method-quality objectives for laboratory work, and collection of quality-control samples;
- A range of issues related to the QAPPs, including laboratory methods and criteria that did not meet Ecology guidelines; lack of protocols to evaluate whether or not samples are representative of the site, and erroneous site information in finalized QAPPs;
- Lack of an adequate database to store raw and final data, and lack of appropriate tools for data validation and verification; and
- Lack of complete documentation and maintenance of laboratory analysis records, unprocessed flow monitoring information, and equipment calibration and site maintenance information.

As a result of these deficiencies, the review noted the following specific concerns related to the monitoring program:

- Problems with study design and how specific sites were selected for monitoring
- Problems with equipment malfunction
- Problems with quality assurance of sample data due to issues with quality-control sample collection.

## Monitoring Requirements for the 2009 Permit

The new municipal stormwater permit issued in February 2009, includes a comprehensive set of requirements for stormwater monitoring (Washington State Department of Ecology, 2009) and greatly expands on those under the original Phase I municipal stormwater permits. The objectives of the current permit include:

1. Establishing baseline stormwater discharge information from WSDOT highway conveyances, rest areas, maintenance facilities, and ferry terminals.
2. Developing and implementing a monitoring program for BMP effectiveness.

Separate monitoring requirements are presented for baseline monitoring of WSDOT highways; seasonal first flush toxicity testing; baseline monitoring of rest areas, maintenance facilities, and ferry terminals; and effectiveness monitoring for BMPs. Further guidelines on representative sampling, recording results, analytical methods, laboratory accreditation, and flow measurement were provided in the General Conditions section of the permit, which did not differ much from those described in the 1995 permits (Washington State Department of Ecology, 1995a; 1995b; 1995c). Now, WSDOT is required to monitor 19 sites for the new permit rather than just 6 sites they were monitoring previously (Herrera Environmental Consultants, 2008). The scope of the new requirements is briefly described in the following sections. Additional monitoring requirements associated with TMDL obligations also are referenced in the permit but not covered here.

### Baseline Monitoring of Washington State Department of Transportation Highways

Washington State Department of Transportation is required to collect stormwater data to describe discharge quality and quantity from the edge of pavement at five highway sites to determine pollutant loads and to prioritize pollutants of concern. Continuous flow (discharge) records of all storm events are necessary for at least 1 year at all sites to establish a baseline rainfall-runoff relation. The conveyance system and drainage area must be mapped for all sites and the time of concentration (the time required for a drop of water to travel from the most hydrologically remote point in the drainage area to the point of sample collection) must be documented based on rainfall durations for typical seasonal storms. Sites are to be selected to meet the following criteria, based on annual average daily traffic (AADT), where the number designates the number of vehicles per day:

- Two highly urbanized western Washington sites (greater than or equal to ($\geq$) 100,000 AADT)
- One urbanized western Washington site (less than or equal to ($\leq$) 100,000 AADT and $\geq$30,000 AADT)
- One rural western Washington site ($\leq$ 30,000 AADT)
- One urbanized eastern Washington site ($\leq$ 100,000 AADT and $\geq$ 30,000 AADT)

Flow-weighted composite sampling methods must be used, and samples must be analyzed for a comprehensive set of chemical parameters, including metals, polycyclic aromatic hydrocarbons (PAHs), total suspended solids, chlorides, phthalates, herbicides, and nutrients. Specific criteria are required and listed for the location of the sampling sites and number of sample aliquots for each composite sample in order to collect an event mean concentration (EMC). Additionally, grab samples must be collected early in each storm event for a separate constituent list that includes total petroleum hydrocarbons, fecal coliform bacteria, temperature, and observations of visible sheen. Finally, annual sediment samples must be collected from each site using in-line sediment traps, and analyzed for particle size, total organic carbon, metals, PAHs, petroleum hydrocarbon, phenolics, herbicides, phthalates, and total solids.

Detailed criteria for sample collection, including specific requirements for sample timing and frequency are described in the new permit (Washington State Department of Ecology, 2009). A minimum of 11 storm events must be sampled at each site, roughly proportional to the distribution of rainfall between the wet and dry seasons. Samples must be collected during qualifying storms, based on specified conditions of rainfall amount, duration, and antecedent dry period.

All monitoring data must be reported in an Annual Stormwater Monitoring Report, due October 31 of each year of the permit cycle beginning in 2010. These reports are to include (1) detailed information for each sampled storm event (all data, antecedent and precipitation conditions, graphical representation of storm hydrograph with aliquot collection points spatially located throughout, sampled period, total runoff period and runoff volume); (2) continuous flow data for at least 1 year for each site; (3) EMCs from sampled events at each site; and (4) calculated annual and seasonal pollutant loads at each site.

## Seasonal First-Flush Toxicity Testing

Six time- or flow-weighted composite samples must be collected for toxicity screening at least once per monitoring year in August or September to characterize first-flush conditions. Adequate sample volume must be collected for the toxicity test and the chemical analyses (approximately 6–14 liters, Washington State Department of Ecology, 2009, appendix 6). Samples will be collected from three untreated highway runoff monitoring locations and from three BMP discharge locations, according to further criteria specified in the permit. Chemicals analyzed in toxicity samples should include metals, herbicides, total suspended solids, chlorides, hardness, methylene-blue activated substances, PAHs, phthalates, and petroleum hydrocarbons.

Toxicity testing will be made for *Hyalella azteca* (a 1/4-inch-long amphipod common to aquatic systems) as specified in guidance documents listed in the permit (Washington State Department of Ecology, 2009, appendix 6). The half maximal effective concentration ($EC_{50}$) (Washington State Department of Ecology, 2008b) will be calculated for a series of dilutions of the stormwater sample and refers to the concentration when 50 percent of the test population does not survive. Follow-up actions are required whenever the $EC_{50}$ from any valid and non-anomalous test is 100 percent or less stormwater. These actions must include preparation of a study design to refine knowledge of toxicant concentrations in stormwater, including (1) mapping of discharge sites and any installed or planned structural BMPs sites; (2) proposed sampling and analysis; and (3) describing toxicity pathways to receiving waters. If needed, a toxicity identification/reduction evaluation (TI/RE) based on specific guidelines also should be included in the study design.

The Annual Stormwater Monitoring Report shall include a section on toxicity testing, which must report the $EC_{50}$ for each test and include all laboratory documentation and reference toxicant results for test methods, as appropriate. Specific guidelines are presented for submission of test results and calculation of $EC_{50}$.

### Baseline Monitoring of Rest Areas, Maintenance Facilities, and Ferry Terminals

Washington State Department of Transportation is required to monitor stormwater discharge and collect baseline water quality data from the following land uses:

- Two high-use rest areas
- Six maintenance facilities, one in each WSDOT region
- One high-use ferry terminal

A minimum of seven composite samples shall be collected at each site within the first hour of runoff, and each must be comprised of at least five individual time-weighted aliquots collected and composited manually or with automatic composite samplers. Samples should be analyzed for a comprehensive list of constituents that varies between the three major land use types. Detailed criteria are described for sample timing and frequency, and qualifying storm events. Reporting requirements for the Annual Stormwater Monitoring Report are similar to those for baseline monitoring of highways.

### Best Management Practice Effectiveness Monitoring

Washington State Department of Transportation is required to establish a monitoring program to evaluate the effectiveness, operation, and maintenance requirements of stormwater treatment and hydrologic management BMPs. Sites should be selected that have existing BMP facilities constructed in accordance to the WSDOT Highway Runoff Manual (Washington State Department of Transportation, 2008b). If selected sites do not have such existing BMP facilities, then approval of engineering designs and specifications is required from a professional engineer and Ecology before monitoring can begin. At least two treatment BMP facilities and a flow-reduction BMP facility must be monitored, at no less than two sites per facility. Sites should be selected from the following treatment categories:

- Basic treatment
- Enhanced treatment
- Metals/phosphorus treatment
- Oil control

Specific constituents are required to be monitored, depending on the BMP type. Additionally, the accumulated sediment at selected test sites should be sampled for total solids, particle size, petroleum hydrocarbons, phosphorus, and metals. Monitoring is required to continue until statistical goals of 90–95 percent confidence and 75–80 percent power for the estimation of percent removals for each BMP type are met (Washington State Department of Ecology, 2008a). Extensive guidance from Ecology for preparing, implementing, and reporting the results of the BMP evaluation program is specified in the permit. Reporting requirements are to focus on a technical evaluation of each BMP facility monitored once statistical goals are met.

## Review of Pre-2009 Stormwater Monitoring Program

This stormwater-monitoring program was reviewed during the transition period between the 1995 and 2009 permits and during ongoing preparation to meet the new municipal stormwater permit requirements. As a result, no specific 2009 permit requirements had been explicitly incorporated yet into the program and no stormwater monitoring was being performed at any WSDOT stormwater sites in 2009. Because there was no current monitoring to observe, this review focused primarily on evaluation of the most recent QAPPs (Herrera Environmental Consultants, 2007, 2008) that reasonably reflect the most recent stormwater monitoring program in place immediately prior to implementation of the 2009 permit. In addition, field sites were visited by USGS and WSDOT personnel that were monitored previously under the old permit. Although several key staff during implementation of the 1995 permits are no longer employed by WSDOT, further insight was provided by interviews with current WSDOT employees, a former WSDOT project manager, and personnel from consultants for WSDOT who have been involved in the monitoring since 2005. The results of a recent internal WSDOT review also were examined (WSDOT Stormwater and Watersheds Program staff, written commun., 2009). The following three sections of this report evaluate (1) the implementation of the pre-2009 monitoring program and whether or not it was adequate to meet the 1995 permit requirements, (2) an evaluation of the pre-2009 monitoring program within the context of available national and state stormwater monitoring protocols to provide some basis for determining if this program is adequate to move forward to meet regulatory obligations, and (3) a comparison of the pre-2009 program with stormwater monitoring programs by other NPDES Phase I permittees in the State of Washington. This recent internal review supplied an informal benchmark to assess the adequacy of the WSDOT program to meet the 2009 permit requirements.

### Implementation of the Pre-2009 Stormwater Monitoring Program

The pre-2009 stormwater monitoring program effectively met many of the functional requirements of the permit in place at the time, although those requirements were nonspecific and relatively open-ended. However, shortcomings in meeting the old permit's monitoring requirement did occur. For example, the required monitoring was not done to identify specific sources of pollutants and identify the degree to which stormwater discharges are impacting selected receiving waters and sediments. Additionally, a quality-assurance plan often was not completed prior to the commencement of monitoring. The 1995 permit language did not describe some elements of the program that are now considered essential in carrying out stormwater monitoring such as storm criteria, sampling methods, and number of aliquots for a representative sample. At that time, standard procedures for the discipline of stormwater monitoring were relatively undeveloped. Nonetheless, the QAPPs evaluated for this review (Herrera Environmental Consultants, 2007, 2008) describe protocols that were adequate to meet the original objectives and guidelines if properly implemented. As newer and more specific guidance became available from Ecology, these guidelines were incorporated into the QAPPs. For example, criteria for qualifying storm events and collection of representative samples were added to the QAPPs based on new guidance in the TAPE publication described by Ecology (Washington State Department of Ecology, 2008a).

The concerns that were identified in the internal WSDOT review of the pre-2009 monitoring program primarily reflect deficiencies that were recognizable in 2009 given recent developments in protocols and guidelines but not explicitly incorporated into the 1995 permit requirements. An issue to consider from the internal review is the appropriate use of the historical monitoring data. The data from

this program should be placed in the appropriate context whenever they are reported or used for any purpose, and associated quality control (QC) data should be carefully evaluated to help define the quality and usability of data. Failure to collect or carefully evaluate QC data can impact greatly the quality of the stormwater data and the integrity of the stormwater monitoring program. The chemical composition of stormwater discharge is a dynamic entity identified by a number of factors. Many factors were not consistently addressed throughout the duration of the pre-2009 monitoring program, such as changes in analytical procedures, collection of composite samples that did not uniformly cover runoff distribution during storm events, site features such as ambiguous and unaccounted inflows or the potential for unmeasured treatment effects, and a range of other circumstances that can influence contaminant sources and transport. These factors must be considered when interpreting data associated with stormwater monitoring. Although full control of the use of data is not possible within the public domain, WSDOT could provide a comprehensive context for all historical monitoring data that are provided to others to ensure the limitations of the data are correctly understood. Furthermore, detailed evaluation of the quality of historical monitoring data was outside the scope of this review, although such a review would be useful for determining the adequacy of the data to meet specific objectives.

Overall, the technical issues and shortcomings that may be associated with the previous implementation of the WSDOT stormwater monitoring program were primarily the result of insufficient oversight and attention to detail in the original guidance for the program, and a lack of a requirement for site and QAPP review or approval by Ecology. Many of those technical concerns and other issues raised by the internal review of the pre-2009 monitoring program are resolved by the 2009 permit, primarily through the requirement that Ecology must review and approve all stormwater monitoring sites and QAPPs. Issues related to inadvertent sources and/or treatment will be recognized more readily because 1 year of hydrologic data (flow and precipitation) is required at every site under the 2009 permit. Additionally, opportunity to collect ambiguous samples will be minimal because most elements of the stormwater monitoring program (storm event qualification, constituent lists, and sampling frequency) are explicitly prescribed by the 2009 permit. Any inconsistencies in sampling methodologies and analytical methods will be identified by the required Ecology review of all monitoring QAPPs. Finally, WSDOT management must be diligent in overseeing implementation of the Ecology-approved QAPPs.

## Comparison to National and State Stormwater Monitoring Protocols

A survey of national and state protocols for stormwater monitoring was taken to determine if the WSDOT monitoring program procedures and practices were consistent with published stormwater sampling methods at the time they were carried out. In recognition that WSDOT is currently preparing for implementation under their new NPDES municipal stormwater permit, information from applicable national and state protocols presented here are useful guidance for development of the WSDOT stormwater monitoring program. As mentioned earlier in this report, any mention of the pre-2009 WSDOT stormwater monitoring program refers to the information included in the most recent WSDOT QAPP (Herrera Environmental Consultants, 2007, 2008). When referring to the new WSDOT program, discussion is in reference to the monitoring requirements of the 2009 WSDOT municipal stormwater permit (Washington State Department of Ecology, 2009).

### National Stormwater Monitoring Protocols

The USGS contacted employees at the Regional (Region 10) and National offices of the USEPA in order to identify any applicable national sampling protocols for stormwater monitoring. Although older protocols and reports are available (U.S. Environmental Protection Agency, 1992), current national protocols are not available from USEPA. In addition, a query of an internal USEPA NPDES

listserve on the Internet returned no results for commonly used national sampling protocols. However, several guidance documents for stormwater monitoring were identified during these discussions and through independent research that may serve as a substitute for current national monitoring protocols; these should be referenced by WSDOT as they develop their new stormwater monitoring program (U.S. Environmental Protection Agency, 1992; Federal Highway Administration, 2001; U.S. Environmental Protection Agency and American Society of Civil Engineers, 2002; Center for Watershed Protection, 2008). These documents were written in general terms with much of their content addressing stormwater monitoring components such as:

- Selection of sample type (grab or composite) and method (manual or automatic),
- Determination of number of samples to collect,
- Determination of parameters for analysis and analytical methods to be used,
- Selection of storm criteria for representative samples, and
- Selection of sampling equipment.

Although a wealth of information is available on these subjects in the various guidance documents, presentation is general without any explicit recommendations. These general guidelines were adequately satisfied by the procedures utilized by the pre-2009 WSDOT program. Furthermore, much of the information presented in these guidance documents is now superseded by the specific requirements of the new NPDES municipal stormwater permit (Washington State Department of Ecology, 2009). Therefore, as long as the new WSDOT monitoring program complies with the monitoring requirements of the permit issued by Ecology, the WSDOT program should be adequate as a credible monitoring program consistent with national guidelines or protocols. Whether or not WSDOT decides to do their 2009 permit monitoring in-house, a review should be done on information describing the types of sampling equipment available and their advantages and disadvantages as presented in the U.S. Environmental Protection Agency (1992) and Federal Highway Administration (2001) documents.

One common theme within the reviewed national guidance documents is that adequate staffing and resources are imperative to the success of any monitoring program (U.S. Environmental Protection Agency, 1992; Center for Watershed Protection, 2008). In addition, having in-house expertise and training (Center for Watershed Protection, 2008) and long-term personnel in place will ensure program goals and objectives are met. When considering the amount of staff needed for a stormwater program, factors to consider are the number of locations, size of the area to be sampled, distance between locations, type of sampling, sampling techniques to be used, number of samples taken, and the safety of field crews (U.S. Environmental Protection Agency, 1992). If outside consultants are used for WSDOT's stormwater monitoring program, then enough in-house expertise and personnel must be available at WSDOT to oversee and ensure success of the program.

Inherent in stormwater sampling is the potential for a large number of samples to be discarded due to sampling errors, changes in weather conditions, equipment loss or damage, or other problems with quality assurance (Center for Watershed Protection, 2008). In some cases, as much as 50 percent of samples collected are discarded (Center for Watershed Protection, 2008). Therefore, enough resources should be allocated to cover these types of sample losses and to allow for unsuccessful or unproductive sampling attempts.

### Site Selection

The reviewed national guidance documents highlight that one of the most important aspects of a stormwater monitoring program is the selection of representative sites to monitor. Factors to consider when selecting representative monitoring sites include, but are not limited to (U.S. Environmental Protection Agency, 1992; Center for Watershed Protection, 2008):

- Sites should be safe and accessible for field crews, with minimal opportunities for vandalism.
- Site proximity should be considered to ensure efficient sampling of multiple sites during storm events.
- Locations of flow measurements should be selected to avoid depositional areas, backwater conditions, and steep slopes.
- Flow assumptions should be confirmed by visiting sites during wet conditions to identify unaccounted for inflow, outflows, or short-circuiting of flow and to confirm details about contributing areas to runoff.
- Streamflow should be monitored at sites for as much as 1 year to develop rainfall-runoff relations and improve ability to set pacing for flow-weighted composite samples using automated samplers.
- A range of storms should be sampled to determine storm variability.

In addition, the Center for Watershed Protection (2008) recommends reviewing historic precipitation data to determine the types of storms to expect and what is likely to constitute a qualifying runoff event. In summary, the site selection step is extremely important and can take a large amount of time, because only a small proportion of the candidate sites will be adequate for stormwater monitoring (Center for Watershed Protection, 2008). Therefore, one of the first steps in developing a stormwater monitoring program is to screen a suite of potential locations, preferably using a geographic information system (GIS).

### Quality Assurance

The reviewed national guidance documents also highlight that a rigorous quality assurance (QA) program is necessary to verify and validate the quality of stormwater data. To identify and limit the potential for field contamination, a regular schedule for collection of Quality Control (QC) samples, including field blanks, equipment blanks, and travel blanks should be followed. Descriptions of these samples are provided for the reader in the Glossary of this report. In addition, the QA program should establish chain-of-custody procedures for field and laboratory personnel to ensure correct handling of samples. Some examples for the frequency of QC samples that should be collected are:

- Replicate samples collected with at least 5 percent frequency (U.S. Environmental Protection Agency, 1992, Center for Watershed Protection, 2008, Federal Highway Administration, 2001);
- Field blanks be collected at least once annually by each field crew (or as members change) in order to ensure common practices (Federal Highway Administration, 2001); and
- Equipment cleaned following standard procedures between each sample event and an equipment blank should be collected at the beginning of each year to check the adequacy of the cleaning procedures.

In addition to field QC procedures, laboratory QC samples must be included in the QA plan, such as method blanks, laboratory duplicates, spike samples, and certified reference samples. If the laboratory work is contracted out, then an Ecology-approved laboratory should be used and laboratory QA procedures should be reviewed to ensure that data quality objectives and project goals are met. Sample handling, preservation, holding times, and bottle types should conform to those listed in Title 40 of the CFR, part 136 (U. S. Environmental Protection Agency, 2009).

Based on the review of the most recent WSDOT QAPPs (Herrera Environmental Consultants, 2007, 2008) and discussion of recent changes that have been implemented in the WSDOT consultant's QA program, the current elements of the contractor's QA program seem sufficient to meet the requirements of the 2009 permit. However, no corresponding QA plan within WSDOT currently is available to ensure that these procedures will be continued if another entity does the monitoring. Therefore, WSDOT should consider drafting their own QA plan (or work with contractors collaboratively) and define the role of any internal and external audit procedures in order to maintain a consistent level of data quality for their stormwater program. Furthermore, these QA and data audit procedures should be reviewed and revised over time in order to address future changes in the program. Whether stormwater samples are collected in-house or by an external consultant, a designated QA officer within WSDOT should check and confirm that data quality objectives for the program are being met and should identify when corrective actions should be taken. In this way, WSDOT will be able independently to identify potential problems early and provide for inquiry into and resolution of any problems that arise in a timely fashion. The internal QA officer should not be under direct line authority with other personnel involved in the stormwater program to ensure appropriate and independent responses to any issues that may arise.

The 2009 permit requires that flow be measured in order to calculate pollutant loads in runoff, so flow measurements also should be part of the QA plan. Many flow measurements use a primary (weir or flume) and secondary (level logger) flow device. Most primary flow devices come calibrated from the factory, and accuracy is difficult to determine in the field (U.S. Environmental Protection Agency, 1992). The best way to ensure the accuracy of a primary flow device is to install and maintain the device following the manufacturer's specifications (for example, making sure the device is level throughout its use). Secondary flow devices should be calibrated prior to use in the field and before each storm event, if feasible. All flow devices should be chosen for accuracy over the range of flows expected and inspection of equipment in the field must be done to ensure that there are no leaks, flow bypass, backwatering, or possible obstructions (U.S. Environmental Protection Agency, 1992; Federal Highway Administration, 2001), which is especially important for BMP effectiveness studies. Guidance on using flumes to measure discharge is described by Kilpatrick and Schneider (1983).

The USGS maintains very detailed SOPs for water-quality sampling in the USGS National Field Manual (NFM; U.S. Geological Survey, variously dated). Although this manual was not developed specifically for stormwater monitoring, details are provided on equipment selection and cleaning, sample processing, field measurements, and field QC procedures that are universally applicable to any water-quality monitoring program. As WSDOT develops their program and new QAPPs, the NFM should be considered as a guide for topics such as equipment cleaning, collecting field and equipment blanks, splitting samples, and decontamination procedures (Wilde, 2004; Wilde and others, 2004; U.S. Geological Survey, 2006). As an example of how the NFM can be incorporated into the QAPPs for a Phase I NDPES municipal stormwater permit, the reader is referred to the Clark County QAPPs which were recently approved by Ecology (Rod Swanson, Clark County, Washington, written commun., September 2009).

## Washington State Stormwater Monitoring Protocols

The Puget Sound area is in the process of experiencing a major change in their stormwater monitoring programs. A recent report from the Puget Sound Partnership noted that stormwater runoff is a problem affecting the health of the Puget Sound (Puget Sound Partnership, 2009). As a result, several groups have formed in the area to develop a comprehensive monitoring program for the region. As part of this process, a pilot project was started to develop stormwater monitoring SOPs with the goal of providing well-defined procedures to follow for consistency in stormwater data collection in the region. The first SOPs are available to the public at the Ecology website (*http://www.ecy.wa.gov/programs/eap/quality.html*).

The first four SOPs cover automated sampling, collection of grab samples, pollutant load calculations, and in-line (pipes) sediment sampling. A review of these draft SOPs showed that the most recent WSDOT QAPPs (Herrera Environmental Consultants, 2007, 2008) are consistent with the State SOPs for automated and grab sampling. However, the current WSDOT QAPPs do not state how pollutant loads were calculated, and so future pollutant load calculations should follow the Ecology SOP for this activity. Previously, sediment sampling was not a requirement for WSDOT under any of its NPDES municipal stormwater permits; but the new permit requires sediment sampling and WSDOT should follow this SOP for sediment sampling in pipes if the SOPs meet the requirements of WSDOT permits.

## Benchmarking With Other National Pollutant Discharge Elimination System Programs

Benchmarking of the WSDOT stormwater monitoring program was done by evaluating stormwater monitoring programs implemented by other Phase I NPDES permittees (King County and the City of Tacoma) under the 1995 Phase I municipal stormwater permit. Comparison is not possible between the WSDOT program and either of these programs, however, because each agency addressed different elements of monitoring under the 1995 permit. In order to provide further context for the monitoring required by the 2009 permit, King County and the City of Tacoma were the other permittees selected for this process because their reissued NPDES permits were issued in January 2007, 2 years prior to the issuance of the current WSDOT stormwater permit, and their revised monitoring programs are just beginning. Because the requirements for edge of pavement and BMP effectiveness monitoring are similar in many respects, and King County and the City of Tacoma are further along in the development of their monitoring programs to address these requirements, it was assumed that their experience would be instructive for WSDOT in beginning to develop their monitoring program for implementation under the new permit.

The City of Tacoma has been monitoring several of the current stormwater monitoring sites as part of their cooperative work with the USEPA Superfund Program (U.S. Environmental Protection Agency, 1991; City of Tacoma, 2009). Their water-quality section and internal laboratory personnel have gained considerable expertise in stormwater monitoring through the Superfund monitoring and through the routine monitoring of storm drains. Because of these cooperative efforts between the groups, USEPA and the City of Tacoma have developed the necessary communication, trust, and expertise for a successful program. King County has sampled Lake Sammamish and Lake Washington, two of the larger receiving bodies under their jurisdiction, as part of the monitoring requirements of their 1995 permit, and also has sampled limited stormwater from a highway bridge over Lake Washington as part of another project. Through this work, and other water-quality projects, King County also has developed the high levels of communication, trust, and expertise between the sampling crew and their internal laboratory that are necessary for a successful program.

King County and the City of Tacoma have worked with Ecology to select their monitoring sites and complete their QAPPs, and have now begun monitoring flow to gain a better understanding of the rainfall-runoff relation for these sites. The programs emphasized the importance of the iterative learning process that is required and the need to work closely with Ecology throughout the process of site selection and QAPP development. King County and the City of Tacoma also recommend that WSDOT should:

- Seek guidance from other programs in order to incorporate what has already been proven successful into their program.
- Encourage a strong sense of team effort among all monitoring personnel, including those from WSDOT, any contractors, and Ecology. Ecology needs to be especially involved in QAPP development.
- Take particular care in the process of site selection, ensuring that sites are relevant and representative so the data can be extrapolated as widely as possible.
- Research equipment needs thoroughly and purchase only what has been tested and proven reliable rather than relying on the lowest bids.
- Determine rainfall-runoff relation scenarios prior to the initiation of sampling.

It should be noted that WSDOT has a much larger task at hand with the requirements of its recently issued permit relative to other permittees. The permit of WSDOT requires them to monitor 19 sites (14 for characterizing runoff, 4 for BMP effectiveness, and 1 flow reduction BMP), whereas other Phase I permittees only need to monitor 8 sites (3 for characterizing storm runoff, 4 for BMP effectiveness, and 1 flow reduction BMP). An additional challenge is that the geographic scope for WSDOT includes sites in eastern Washington, where personnel have very little experience in collecting stormwater data.

## Components of a Successful Stormwater Monitoring Program for Washington State Department of Transportation

Compared to the 1995 permits, the requirements of the 2009 Phase I municipal stormwater permits in general are more comprehensive in scope. As a result, implementation of stormwater monitoring under the new permit will require a greater commitment of staff and resources from WSDOT than the previous program. The new permit requirements are particularly demanding for WSDOT because of the need to monitor a diverse set of sites in eastern and western Washington, including highways, rest areas, maintenance facilities, and ferry terminals. The 2009 permit includes many details and requirements that are not incorporated in the stormwater monitoring program as presently configured. New monitoring sites and BMPs to be evaluated will have to be selected, reviewed, and approved by Ecology. A number of new program components will have to be developed, including (1) sampling methodologies appropriate for the new objectives (for example, toxicity testing and sediment) and specific suites of constituents (low-level metals and organics); (2) standard operating procedures for field and laboratory work to address these new elements; (3) data management and analysis capabilities consistent with the new sampling and reporting mandates; and (4) a consistent and comprehensive quality assurance program, including field audits and collection and analysis of quality-control data. Some technical support is currently available from Ecology to help meet these requirements and should be utilized as much as possible.

Additional and programmatic elements need to be in place in order for WSDOT to successfully implement and maintain a stormwater monitoring program in the context of the new permit, including:

- Coherent vision and cooperation among all elements of the program,
- Recognition of the high priority of the program by management,
- Cultivation and maintenance of in-house stormwater monitoring expertise,
- Comprehensive approach for site selection,
- Effective QA program for field, laboratory, and data management,
- Standard operating procedures,
- Appropriate system for internal and external review, and
- Adequate database and data management system.

## Vision and Program

Perhaps the most critical component of any successful monitoring program is a coherent vision of the program goals. This vision can be outlined in the QAPPs, or in a separate vision statement. The vision should also define and support effective working relationships among all participants. Stormwater monitoring is complex and difficult, and a team approach with clear roles and responsibilities in critical to build an effective program. It will also help WSDOT to quickly and efficiently address the inevitable problems that will come up. Simple steps, such as regular and frequent status report meetings, including both WSDOT and contractor staff, can facilitate implementing this vision. To be successful, adequate resources are needed to implement the stormwater monitoring program.

Maintaining sufficient personnel to do the necessary work and building staff expertise through adequate training is critical and will require consistent long-term support. If consultants are relied upon for implementing the bulk of the monitoring program, WSDOT personnel should monitor at least one site. Involvement with monitoring will build technical expertise related to stormwater monitoring within the agency and facilitate exchange of ideas with other permittees and consultants. WSDOT should retain a project manager who is experienced in stormwater monitoring and has a solid understanding of collecting, managing, evaluating, and interpreting stormwater data.

## Comprehensive Approach for Site Selection

A comprehensive approach should be taken for site selection. One year of flow (discharge) and precipitation data are required prior to monitoring, so this should be one of the first actions of the program. Ecology should be consulted early during this process and historical and ancillary information on site and flow conditions and storm characteristics should be evaluated and used to guide the process. A thorough site reconnaissance should be made prior to site selection and the site hydrology should be characterized adequately before the final decision to monitor is made. Visits to several potential sites may be required during storms to ensure assumptions on flow and contributing area are correct. Particular attention should be paid to recognize potential sources of inflow from groundwater, dilution from other sources, backwater conditions, and multiple inlets to selected BMP facilities. Close communication with Ecology throughout this process will allow selection of representative monitoring sites.

## Quality Assurance and Control

A thorough QA program is an integral component to any successful monitoring program. All activities of the stormwater program should be incorporated into the QA program, including the development and administration of the QAPPs, all aspects of monitoring and the associated components of quality control, and data management. For the WSDOT stormwater monitoring program, development of an effective QA program begins with the preparation of the QAPPs for each element of the program. If contractors will be responsible for writing the QAPPs, then they should work in close collaboration with WSDOT and rely on technical guidance from Ecology. Reference to the Clark County NPDES QAPPs developed around the USGS NFM may prove useful (U.S. Geological Survey, 2008a, 2008b). Standard operating procedures for sampling with automatic samplers, collection of grab samples and sediment trap samples, and calculation of pollutant loads are being created and posted as they become available from Ecology at the following webpage: *http://www.ecy.wa.gov/programs/eap/quality.html*. Other SOPs that will need to be developed by the program include collection and management of hydrologic data, identification and qualification of storm events for sampling, sample processing and handling, equipment cleaning, collection of quality-control samples, and data verification and validation. Thorough and regular audits of field, laboratory, and data management procedures are another essential element of a meaningful QA program. A qualified QA officer should do these audits, preferably under a separate line of authority from project management, to identify unexpected problems and to ensure that SOPs are being followed. Independent audits of field activity and data management provide a means for ongoing communication and sharing of experience among the personnel involved in the program. Sufficient and ongoing training for field, laboratory, and data analysis components of the program is also a necessary component of the overall QA program.

## Database

An integrated hydrologic and water-quality database that is linked with a GIS is a crucial part of a successful stormwater monitoring program. Data must be stored in a database that is designed for the particular management needs of the data type. For example, hydrologic data require a database that can deal with time-series analysis and tracking of shifts that are occasionally necessary from changes in flow control during storm events. Similarly, chemical data require a database that can handle multiple data flags that show the status of ongoing data review and verification in consultation with the laboratory. Easy linkage between the hydrologic and chemical databases is also necessary so that sample aliquot collection over the storm hydrograph can be plotted and constituent loads can be calculated. These functions cannot be met by simply loading data into a standard worksheet but require investment in appropriate database software and personnel training. Adequate database support and maintenance is a related fundamental element of an effective QA program.

## Summary

Under the National Pollution Discharge Elimination System (NPDES) program, the Washington State Department of Transportation (WSDOT) has been monitoring stormwater runoff from roads and highways, and Best Management Practice (BMP) performance for 8 years without the benefit of an external review of their municipal stormwater monitoring program. An internal review of the WSDOT stormwater monitoring program identified several key programmatic deficiencies, including a lack of independent audit functions and sufficient quality assurance (QA) oversight of the program by WSDOT. In preparation for their new NPDES municipal stormwater permit issued in February 2009, which greatly expands the scope of their monitoring requirements, WSDOT asked the U.S. Geological Survey to review their current program to assess what will be necessary for them to effectively move forward under the new permit. The USGS reviewed the program by evaluating the most recent WSDOT Quality Assurance Project Plans (QAPPs), meeting with current and past employees and consultants involved in WSDOT's stormwater monitoring activities, visiting monitoring field sites, comparing WSDOT protocols to National and State guidelines for stormwater monitoring, and comparing the WSDOT stormwater monitoring program to the NPDES stormwater monitoring programs for the City of Tacoma and King County under the original Phase I NPDES stormwater monitoring permits.

The new permit requires baseline monitoring at five highway sites, each representing a defined level of annual average daily traffic, two rest areas, six maintenance facilities, and one ferry terminal. Flow-weighted composite samples must be collected from a minimum of 7 to 11 qualifying storm events each year and analyzed for a large suite of constituents. Grab samples must be collected at each highway site early in the storm event and annual sediment samples must be collected with inline sediment traps. A second category of sampling is to evaluate the effectiveness of stormwater treatment from two BMP facilities. Monitoring is required to continue until inflow and outflow loads can be determined within defined statistical goals. A final category of sampling is required to measure toxicity during seasonal first-flush storm events from three highway sites and three BMP effluent sites. These samples must include adequate volume for toxicity and chemical analyses.

The monitoring requirements of the old permits lacked guidance in many key points, beyond the stated objectives to estimate concentrations and loads in order to identify pollution sources and to evaluate the effectiveness of BMP facilities. The lack of guidance indicated the undeveloped nature of the discipline of stormwater monitoring at the time of permit development. Nonetheless, QAPPs from the previous WSDOT stormwater monitoring program did an adequate job of addressing the objectives of the old permits, notwithstanding the programmatic issues identified in the internal review. Subsequently, WSDOT should evaluate their data thoroughly in order to address issues brought up in the internal review as the program moves forward.

The expanded scope and monitoring requirements of the new permits will necessitate some major changes within the WSDOT program. Given adequate staffing and resources and by designing a new program around the following elements, WSDOT should be able to succeed in meeting the new permit requirements.

- Coherent vision and cooperation among all elements of the program,
- Recognition of the high priority of the program by management,
- Cultivation and maintenance of in-house stormwater monitoring expertise,
- Comprehensive approach for site selection,
- Effective quality assurance program for field, laboratory, and data management,
- Standard operating procedures,
- Appropriate system for internal and external review, and
- Adequate database and data management system.

Whether the WSDOT stormwater monitoring program will be implemented exclusively by WSDOT personnel or contracted out to consultants, WSDOT personnel should consider the possibility that at least one site be monitored by WSDOT personnel in order to cultivate internal experience within the agency. This experience will assist WSDOT personnel to understand the difficulties of monitoring stormwater and to develop a basis for effective communication with others regarding stormwater sampling techniques, methods, and troubleshooting problems. Internal QA reviews and independent audits of all aspects of the program, including consultant work and laboratory analyses will be necessary. In particular, WSDOT should develop its own standard operating procedures for their components of the program, and work closely with any contractors in order to develop trust and reliability in the collected data. Finally, to meet state requirements WSDOT should immediately begin working closely with Ecology throughout the site and BMP selection and QAPP development process in order to satisfy required timelines.

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## Glossary

Blank Solution–A solution that is free of the analyte(s) of interest. Such a solution would be used to develop specific types of blank samples.
Certified Reference Material (CRM)–A reference material, for which one or more property values are certified by a technically valid procedure, accompanied by or traceable to a certificate or other documentation which is issued by a certifying body.
Chain of Custody–The documentation of all sample transfer procedures in order to emphasize careful documentation of sample collection, labeling, and transfers of all samples sent from the field to the laboratory.
Equipment Blank–A blank solution that is poured or pumped through the same field sampler used for the collection of an environmental sample.
Field Blank–A blank solution that is subjected to all aspects of sample collection, field processing, preservation, transportation, and laboratory handling as an environmental sample
Quality Assurance (QA)–All those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.
Quality Assurance Program–The documented plans for implementing the organizational structure, responsibilities, procedures, processes, and resources to support the assurance of quality in meeting program objectives.
Quality Control (QC)–The operational techniques and the activities used to fulfill requirements of quality.
Reference Material–A material or substance with one or more properties which are sufficiently well established to be used for the assessment of a measurement method or for assigning values to materials.
Replicate Samples–A group of samples, collected in a manner such that the samples are thought to be essentially identical in composition. Replicate is the general case for which duplicate is the special case consisting of two samples.
Standard Operating Procedure (SOP)–A written document which details the method of an operation, analysis, or action whose techniques and procedures are thoroughly prescribed and which is accepted as the method for performing certain routine or repetitive tasks. It may be a standard method or one developed by the user.
Standard Reference Material (SRM)–A certified reference material (CRM) produced by the U.S. National Institute of Science and Technology.
Spike Sample–A sample to which known concentrations of specific analytes have been added in such a manner as to minimize the change in the matrix of the original sample.
Spike Solution–A solution with one or more well established analyte concentrations that is added in known quantities to an environmental sample to form a spiked sample.
Time of concentration–The time required for a drop of water to travel from the most hydrologically remote point in the drainage area to the point of collection.
Travel blank–A blank solution that is put in the same type of bottle used for an environmental sample and kept with the set of sample bottles before and after sample collection.

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Director, Washington Water Science Center
U.S. Geological Survey, 934 Broadway — Suite 300
Tacoma, Washington 98402
http://wa.water.usgs.gov