QUALITY ASSURANCE PROJECT PLAN

BIORETENTION MEDIA BLENDS TO IMPROVE STORMWATER TREATMENT: FINAL PHASE OF STUDY TO DEVELOP RECOMMENDATIONS FOR NEW SPECIFICATIONS

Prepared for
King County

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA

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BIORETENTION MEDIA BLENDS TO IMPROVE STORMWATER TREATMENT: FINAL PHASE OF STUDY TO DEVELOP RECOMMENDATIONS FOR NEW SPECIFICATIONS

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TITLE AND APPROVAL SHEET

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1. INTRODUCTION

The current Washington State, Phase I and Phase 2 municipal National Pollutant Discharge Elimination System stormwater permits (NPDES stormwater permits), effective January 1, 2017, require the use of low impact development (LID) practices where feasible as the first option for managing stormwater. Phase 1 and 2 Permittees must require On-site Stormwater Management (LID) best management practices (BMPs) as outlined in Minimum Requirements #5, #6, and #7 of the NPDES stormwater permits.

Bioretention is the most widely applicable and flexible BMP in the suite of LID practices for flow control and runoff treatment. Bioretention systems may include under-drains, especially in areas with soils that are less suitable for infiltration. In these cases, a portion of the treated runoff is discharged back into the stormwater conveyance system and into local receiving water bodies. The current Washington State Department of Ecology (Ecology) specification for bioretention soil media (BSM) in western Washington (Ecology 2014) is a mixture of 60 percent sand and 40 percent compost (60/40 BSM). While the 60/40 BSM can provide reliable water quality treatment for some contaminants (e.g., solids removal, zinc [Zn], hydrocarbons, and possibly bacteria), regional and national research indicate that nitrogen (N), phosphorus (P), and copper (Cu) are often exported from BSM containing compost (Herrera 2015a, 2015b, 2016; Mullane et al. 2015; Hatt, Fletcher, and Deletic 2009).

The use of bioretention with underdrains will increase dramatically with the new NPDES stormwater permit requirement for on-site stormwater management. As a result, the export of contaminants to receiving waters from the currently specified BSM will be an increasing concern.

The Bioretention Media Blends to Improve Stormwater Treatment: Final Phase of Study to Develop New Specifications (BSM Phase 2 Study) described herein is the final phase of BSM research beginning in 2014 that focused on testing media components for N, P, and Cu leaching and blends for pollutant capture, hydraulic conductivity and plant growth. King County is the funding recipient and Herrera Environmental Consultants (Herrera) is the technical lead.

The overall goal of the BSM Phase 2 Study is to develop new recommendations for a BSM that protects beneficial uses of receiving waters and achieves the following objectives in order of priority: 1) meets basic treatment (Ecology's treatment objectives for TSS); 2) meets enhanced treatment (Ecology's treatment objectives for dissolved Cu and Zn); 3) meets Ecology's treatment objective for phosphorus; and 4) is affordable, sustainable, and available.

This Quality Assurance Project Plan (QAPP) identifies method quality objectives (MQOs), summarizes the experimental design, and describes the experimental procedures for the BSM Phase 2 Study. The QAPP was prepared in accordance with Ecology's *Guidelines for Preparing Quality Assurance Project Plans* (Ecology 2004), and describes specific procedures for sample

collection, processing, and analysis to ensure that resulting data are scientifically and legally defensible. This document is organized as follows:

1. Introduction
2. Background
3. Project Description
4. Organization and Schedule
5. Quality Objectives
6. Experimental Design
7. Measurement Procedures
8. Measurement Procedures
9. Quality Control
10. Data Management Procedures
11. Audits and Reports
12. Data Verification and Validation
13. Data Quality Assessment
14. References

2. BACKGROUND

This section provides a description of the BSM Phase 2 Study and briefly summarizes the results of previous laboratory testing and field monitoring.

2.1. TECHNOLOGY DESCRIPTION

Bioretention facilities are shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions that receive stormwater from small contributing areas. The hydrology of these systems is designed to more closely mimic natural forested conditions where healthy soil and vegetation promote the infiltration, storage, filtration, and slow release of stormwater flows. Within the low impact development approach, bioretention areas are designed as small-scale, dispersed systems that are integrated into the site as a landscape amenity (see Figure 1).

Figure 1. Bioretention Installation Located in West Seattle.

2.2. RESULTS OF PREVIOUS STUDIES

Bioretention using compost-based BSM can provide good water quality treatment for some contaminants (e.g., sediment, Zn, hydrocarbons, and likely bacteria); however, regional and national research indicate that bioretention with these types of BSM export N, P and Cu (Mullane et al. 2015; Chahal, Shi, and Flury 2016). Various materials including mineral aggregates, and natural and engineered amendments may be sources of N, P, and Cu (Herrera 2015a, 2016), but compost contributes most of these contaminants (Herrera 2015a, 2016; Hatt, Fletcher and Deletic 2009). Export of N, P, and Cu is of particular concern for bioretention installations with under-drains that discharge to receiving waters and bioretention installations with or without under-drains located close to shallow groundwater wells for drinking water supplies or in proximity to phosphorus and nitrogen sensitive receiving waters.

A 2015 report prepared by Herrera in partnership with Kitsap County entitled *Analysis of Bioretention Soil Media for Improved Nitrogen, Phosphorus, and Copper Retention* focused on the selection and leaching potential of BSM components as well as pollutant export and capture characteristics of new BSM blends for high performance water quality treatment (Herrera 2015a). Findings from that research suggest that some of the new BSM blends significantly reduce the export of N, P, and Cu compared to the currently prescribed 60/40 BSM. The Kitsap County sponsored study was limited in scope and did not include the following critical components for recommending new BSM and developing an associated specification:

- Chemical (with the exception of leaching tests) or physical characterization of the BSM components.
- Hydraulic analysis (e.g., manipulation of particle size distribution to control permeability).
- Plant growth tests using plants typical to bioretention systems.
- Selection of appropriate metrics to describe the BSM components and blends in a specification.
- Information on how well these new blends protect targeted aquatic organisms (biological effectiveness).

A second Kitsap County study (Bioretention Media Component Analysis to Improve Runoff Treatment or BSM Phase 1 Study) was completed June 2017 to: 1) test and select additional BSM components for inclusion in new BSM blends; and 2) test the plant-growing capability of these new blends. Findings from the Phase 1 study demonstrated that all the selected BSMs grow plants; however, compost-based BSMs supported more vigorous plant growth than those without compost. Two BSM approaches showed promise for improved water quality treatment and vigorous plant growth. These included a sand and compost BSM with a polishing layer beneath to capture contaminants from the BSM above; and a sand, coconut coir, and high-carbon wood ash blend (high-performance media) with a 2-inch mulch layer placed on top of

the BSM. While the initial BSM study completed in 2015 with Kitsap County focused on water quality treatment of the BSM, no water quality treatment analyses were performed in the Phase 1 study.

The BSM Phase 2 Study builds on the initial Kitsap County and other studies and will evaluate the best performing BSMs for pollutant flushing, pollutant capture, and ability to protect aquatic organisms as well as develop metrics to specify these new media blends.

3. PROJECT DESCRIPTION

The overall goal of the BSM Phase 2 Study is to develop new recommendations for a BSM that protects beneficial uses of receiving waters and achieves the following specific goals in order of priority: 1) meets basic treatment (Ecology's treatment objectives for TSS); 2) meets enhanced treatment (Ecology's treatment objectives for dissolved Cu and Zn); 3) meets Ecology's treatment objective for total phosphorus; and 4) is affordable, sustainable, and available.

To achieve these goals, the following objectives will be met:

- Confirm that project study design meets project partner and Ecology's needs for recommending new BSM specifications required by the NPDES stormwater permit.
- Determine the export potential and pollutant capture capability of the new BSM blends and select the optimum blend(s).
- Evaluate the ability of the BSM blends to reduce or eliminate toxicity in aquatic animals exposed to urban stormwater runoff.
- Determine potential for BSM pollutant saturation and breakthrough.
- Determine metrics and numeric ranges for the new recommended BSM that can be consistently replicated in western and eastern Washington.
- Determine component and blend costs; identify any local sources of BSM components and whether these sources can supply volumes needed for BSM projects.

The study will be conducted at the laboratory scale and begin with testing individual BSM components for contaminant leaching potential. Components with low leaching potential will be mixed into primary BSM and polishing layer blends. The primary BSM will be designed as a physical and chemical filter. Some treatments will include a polishing layer, placed under the primary BSM, designed as a chemically active filter to enhance capture of dissolved contaminants. BSM blends will then be dosed with stormwater to evaluate the ability to capture pollutants. Aquatic organisms will be exposed to BSM effluent to evaluate the ability to protect those organisms. See Sections 6 and 7 below for a detailed description of the experimental design and sampling procedures.

4. ORGANIZATION AND SCHEDULE

The project is funded through Stormwater Action Monitoring (SAM) as part of the Effective Studies Component (S8.C). Ecology administers SAM project funding for the Stormwater Work Group (SWG). King County is the funding recipient and manager. Herrera is the technical lead and will design and conduct the BSM evaluation in cooperation with project partners. Exact Scientific Services, Specialty Analytical, and Western Washington University (WWU) Institute for Watershed Studies will provide analytical laboratory services for the water quality analyses. Project organization and key personnel for this study are identified in Table 1.

Table 1. Project Organization and Key Personnel.

Title	Name	Affiliation
Client Project Manager	Jenée Colton	King County
Ecology Project Manager	Brandi Lubliner	WA Dept of Ecology
Herrera Principal-in-Charge	John Lenth	Herrera
Herrera Project Manager	Curtis Hinman	Herrera
WSU Aquatic Toxicology Lead	Jenifer McIntyre	Washington State University
Exact Scientific Services Laboratory Project Manager	Fiona Bestwick	Exact Scientific Services
WWU Laboratory Lead and Test Site Contact	Joan Pickens	Western Washington University
Specialty Analytical Project Manager	Zaiga LaCasa	Specialty Analytical
Herrera Water Quality Data Quality Assurance Lead	Gina Catarra	Herrera
Herrera Data Management Lead	Meghan Mullen	Herrera
Herrera Field Sampling Support	TBD	Herrera

Project partners include King County, Kitsap County, City of Seattle, City of Redmond, Thurston County, City of Tacoma, City of Portland, Washington State University (WSU), WWU, and Ecology. The project partners together form the Bioretention Work Group (BWG).

4.1. RESPONSIBILITIES

Responsibilities for key personnel assigned to the BSM Phase 2 Study are as follows:

Client Project Manager – Jenée Colton

Jenée Colton will oversee project progress and review and comment on the technical work and deliverables. She will be the primary point of contact for King County.

Ecology Quality Assurance Coordinator – Brandi Lubliner

Brandi Lubliner will provide Ecology approval of the QAPP as well as oversee project progress and review and comment on the technical work and deliverables. She will be the primary point of contact for Ecology and the SWG.

Herrera Principal-in-Charge – John Lenth

John Lenth will provide senior quality assurance review of technical work and deliverables throughout all phases of the project.

Herrera Project Manager and Technical Lead – Curtis Hinman

Curtis Hinman will direct all technical work and analysis in the lab with the column array and coordinate analyses with labs and Dr. Jenifer McIntyre at WSU. He will also draft and finalize all project deliverables.

Washington State University (WSU) Aquatic Toxicology Lead – Dr. Jenifer McIntyre

Dr. Jenifer McIntyre will direct all technical work and analysis for the toxicological analyses through WSU, and coordinate water sample collection and transportation with Curtis Hinman.

Exact Scientific Services Laboratory Project Manager – Fiona Bestwick

Fiona Bestwick will track samples and results in the laboratory, provide properly cleaned sample bottles with appropriate preservatives, evaluate laboratory compliance with this QAPP and laboratory quality assurance plan, report discrepancies to the Herrera Project Manager, and transmit laboratory results to the Herrera Project Manager.

WWU Laboratory Lead and Test Site Contact – Joan Pickens

Joan Pickens will assist Herrera with coordinating students to support sampling for the BSM study at WWU. She will also manage the water quality analysis performed at WWU Institute for Watershed Studies laboratory.

Specialty Analytical Project Manager – Zaiga LaCasa

Zaiga LaCasa will track samples and results in the laboratory, evaluate laboratory compliance with this QAPP and laboratory quality assurance plan, report discrepancies to the Herrera Project Manager, and transmit laboratory results to the Herrera Project Manager.

Herrera Water Quality Data Quality Assurance Lead – Gina Catarra

Gina Catarra will independently review water quality data entry (laboratory reports compared to electronic files) and will review quality assurance worksheets to determine appropriate response actions to any quality assurance issues.

Herrera Data Management – Meghan Mullen

Meghan Mullen will manage data and conduct statistical analyses with the technical team.

Herrera Field Sampling Support – TBD

The field technician will set up column arrays; assist with equipment maintenance; collect flow and water quality data; perform quality assurance audits, including preliminary review of laboratory data; document sample collection procedures and quality assurance/quality control measures; and maintain field records. They will also coordinate WWU students to conduct BSM experiments in the laboratory columns.

Bioretention Work Group – Project Partners (see above)

The BWG will review all deliverables, provide input, and guide the development and implementation of the goals, objectives, and experimental design.

4.2. SCHEDULE

The estimated project schedule for the BSM Phase 2 Study is outlined in Table 2.

Table 2. Project Milestones.

Project Milestone	Date Completed
Draft QAPP for project partner review	August 8, 2018
Final QAPP	November 8, 2018
Select, blend and place BSM components	October 1, 2018
Complete flushing analysis of BSM blends	November 30, 2018
Complete dosing analysis of BSM blends	March 29, 2019
Complete draft report	May 31, 2019
Complete final report with BSM recommendations	July 31, 2019

5. METHOD QUALITY OBJECTIVES

The goal of this QAPP is to ensure that data collected through this study are scientifically accurate and legally defensible. To meet this goal, the collected data will be evaluated using the following quality assurance indicators:

- **Precision:** A measure of the variability in the results of replicate measurements due to random error.
- **Bias:** The systematic or persistent distortion of a measurement process which causes errors in one direction (i.e., the expected measurement is different from the true value).
- **Representativeness:** The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency, and sampling methods.
- **Completeness:** The amount of data obtained from the measurement system.
- **Comparability:** The ability to compare data from the current project to data from other similar projects, regulatory requirements, and historical data.

Method Quality Objectives are performance or acceptance criteria established for each of these quality assurance indicators. The specific MQOs that have been identified for this project are described below and summarized in Table 3.

5.1. PRECISION

Precision will be assessed based on the relative percent difference (RPD) of duplicate samples and calculated using the following equation:

$$RPD = \frac{(C_1 - C_2) \times 100\%}{(C_1 + C_2)/2}$$

where: RPD = relative percent difference

C1 = larger of two values

C_2 = smaller of two values

Method Quality Objectives for the laboratory duplicate RPD are identified in Table 3 for each parameter. The relative percent difference will be less than or equal to the indicated percentages for values greater than 5 times the reporting limit and ±2 times the reporting limit for values less than or equal to 5 times the reporting limit.

Table 3. Method Quality Objectives for Water Quality Data.							
Parameter	**Reporting Limit**	**Units**	**Method Blank**	**Equipment Blank**	**Control Standard Recovery**	**Matrix Spike Recovery**	**Laboratory Duplicate RPD[a]**
Total suspended solids	1.0	mg/L	<RL	<2 x RL	80–120%	NA	≤10% or ±2 x RL
pH	NA	std. units	<RL	NA	NA	NA	≤10% or ±2 x RL
Dissolved organic carbon	1.5	mg/L	<RL	<2 x RL	90–110%	75–125%	≤20% or ± 2 x RL
Nitrate-nitrite	0.1	mg/L	<50% RL	<2 x RL	90–110%	90–110%	≤20% or ±2 x RL
Total phosphorus	0.008	mg/L	<RL	<2 x RL	90–110%	75–125%	≤20% or ±2 x RL
Ortho-phosphorus	0.004	mg/L	<RL	<2 x RL	90–110%	75–125%	≤20% or ±2 x RL
Cadmium, dissolved	0.1	µg/L	<RL	<2 x RL	90–110%	70–130%	≤20% or ±2 x RL
Cadmium, total							
Copper, dissolved	0.1	µg/L	<RL	<2 x RL	90–110%	70–130%	≤20% or ±2 x RL
Copper, total							
Lead, dissolved	0.1	µg/L	<RL	<2 x RL	90–110%	70–130%	≤20% or ±2 x RL
Lead, total							
Zinc, dissolved	1.0	µg/L	<RL	<2 x RL	90–110%	70–130%	≤20% or ±2 x RL
Zinc, total	2.5	µg/L	<RL	<2 x RL	90–110%	70–130%	≤20% or ±2 x RL
TPH (diesel)	0.25	mg/L	<RL	≤ 2 x RL	50–150%	50–150%	≤50% or ±2 × RL
TPH (motor oil)	0.5	mg/L	<RL	≤ 2 x RL	50–150%	50–150%	≤50% or ±2 × RL
PAH	0.01	µg/L	<RL	≤ 2 x RL	30–160%	30–160%	≤30% or ±2 × RL
Fecal Coliform bacteria	1	CFU/100 mL	<RL	NA	NA	NA	≤35% or ±2 x RL

[a] The relative percent difference will be less than or equal to the indicated percentage for values greater than 5 times the reporting limit, and ±2 times the reporting limit for values less than or equal to 5 times the reporting limit.

Note that each treatment is replicated, thereby providing field duplication as part of the study design.

CFU/100 mL = colony forming units per 100 milliliter.

mg/L = milligrams per liter.

µg/L = micrograms per liter.

TPH = total petroleum hydrocarbons.

PAH = polycyclic aromatic hydrocarbons.

std. units = standard units.

RL = reporting limit (note that RL and quantification limit will be used interchangeably in lab reports).

RPD = relative percent difference.

NA = not applicable.

pH = negative log of the hydrogen ion (proton) molar concentration.

5.2. BIAS

Bias will be assessed based on analyses of method blanks, matrix spikes, and control standards. Method blank values will not exceed the reporting limit. Percent recovery will be used for matrix spikes and control standards. The percent recovery of matrix spikes will be calculated using the following equation:

$$\%R = \frac{(S - U) \times 100\%}{C_{sa}}$$

where: %R = percent recovery

S = measured concentration in spike sample

U = measured concentration in un-spiked sample

C_{sa} = actual concentration of spike added

If the analyte is not detected in the un-spiked sample, then a value of zero will be used in the equation.

Percent recovery for control standards will be calculated using the following equation:

$$\%R = \frac{(M) \times 100\%}{T}$$

where: %R = percent recovery

M = measured value

T = true value

Method Quality Objectives for the percent recovery of matrix spikes and laboratory controls are identified in Table 3 for each parameter.

5.3. REPRESENTATIVENESS

Flushing and dosing experiments will be conducted in 8–inch-diameter columns. A maximum of eight BSM blends will be selected consisting of various proportions of selected BSM components. The treatment will be replicated a minimum of three times. Flushing and dosing experiments will be based on typical bioretention surface area to contributing area ratios. Flushing and dosing volumes will be based on the Ecology water quality treatment design storm (see Experimental Design below).

5.4. COMPLETENESS

A minimum of 95 percent of the samples submitted to the laboratory will be judged valid. An equipment checklist and chain-of-custody forms will be used to prevent loss of data resulting from missing containers, inoperable delivery and collection apparatus or sample delivery. Sample packaging for shipping and transfer will minimize risk of sample loss from container breakage.

5.5. COMPARABILITY

Standard sampling procedures, analytical methods, units of measurement, and reporting limits will be applied to meet the goal of data comparability. The results will be tabulated in standard spreadsheets to facilitate analysis and comparison with comparable bioretention and filter media studies. Experimental and analytical methods for the project are duplicated from Phase 1, and other previous studies where possible, to maximize comparability of data.

6. EXPERIMENTAL DESIGN

This section of the QAPP provides information on the study design, including overall approach and phases of the study, description of the column array, water delivery, and water sampling.

6.1. STUDY APPROACH BY TASK

Overall the study approach is designed to optimize the BSM for TSS, P, Cu and Zn capture. Note that achieving Ecology's basic, phosphorus, and enhanced treatment is the focus of this study; however, other contaminants of concern will also be evaluated including dissolved organic carbon (DOC), nitrate-nitrite, cadmium (Cd), Lead (Pb), diesel and motor oil fractions of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and fecal coliform bacteria. These additional parameters will be assessed to confirm adequate treatment of other common stormwater contaminants of concern. There are seven primary tasks to the study:

1. Review potential bioretention BSM components based on pollutant capture capability, cost, availability, and sustainability. Select individual BSM components from survey and project partner input.

2. Conduct Synthetic Precipitation Leaching Protocol Method 1312 (SPLP) to determine N, P, and Cu leaching potential of the BSM components. Select the components that minimize leaching potential, provide adequate hydraulic conductivity and support plants. Note that results from the BSM Phase 1 and this study will be used to make these determinations.

3. Combine components at various ratios, place in columns, flush the BSM blends with deionized water, and assess the effluent for TSS, pH, DOC, nitrate-nitrite, TP, orthophosphorus (ortho-P), Cd, Cu, Pb, Zn, fecal coliform bacteria (bacteria samples will be collected at the first and last flush only), PAH, and TPH. Hydraulic conductivity of the media blends will also be assessed during the flushing experiments. See Table 6 in Section 6.1.4 for a complete list of contaminants.

4. Dose the BSM blends with natural stormwater and assess the effluent for TSS, pH, DOC, nitrate-nitrite, TP, ortho-P, Cd, Cu, Pb, Zn, fecal coliform bacteria, PAH, and TPH. See Table 6 for a complete list of contaminants.

5. Conduct toxicological tests to determine how well the BSM blends protect aquatic organisms.

6. Select the best performing BSM blends (maximum of two) and conduct breakthrough analysis to determine how long the blends will remain effective for capturing contaminants.

7. Determine metrics and numeric ranges (specification) for the best performing BSM.

The following qualitative criteria will guide the selection of BSM components and blends:

- **Leaching:** BSM components that leach the minimum amount of N, P, and Cu will be considered first for testing in the BSM blends.
- **Pollutant retention:** BSM blends estimated to meet or exceed Ecology's basic and enhanced treatment from previous BSM studies will be considered optimal.
- **Hydraulic performance:** BSM blends that have a saturated hydraulic conductivity (Ksat) greater than 20 inches/hour (51 cm/hour) will be considered optimal. No maximum Ksat will be targeted.
- **Sustainability:** includes availability, transportation requirements, manufacturing and/or extraction processes.
- **Cost:** Cost will be considered along with the above criteria to attain the best balance of cost to optimum performance.

6.1.1. BSM Component Selection

A survey of available scientific and practical information on BSM components will be conducted and a summary provided to the BWG. In selecting BSM components, the BWG will consider practical factors such as availability, sustainability, and cost as well as research from the previous two Kitsap studies. A broad range of components will be considered and included in the survey.

The BSM components will be organized into a matrix with three categories: 1) bulk aggregate (e.g., sands), and 2) bulk organic materials (e.g., coconut coir) that comprise most of the BSM blends; and 3) amendments that provide specific pollutant capture and/or hydraulic characteristics and comprise less of the total volume.

6.1.2. Media Component Leaching Tests

The leaching potential for N, P, and Cu for selected BSM components will be assessed using SPLP Method 1312. The analysis will be performed at Analytical Resources Inc. (ARI), an Ecology-certified laboratory. The SPLP analysis will be conducted for total nitrogen, nitrate-nitrite, TP, ortho-P, and dissolved Cu using two procedures:

- **Metals:** weak acid (H2SO4/HNO3) extraction using a pH recommended for western United States.
- **Nutrients:** deionized water extraction.

Suppliers will be identified for the BSM components selected from the survey process described in Section 6.1.1. Samples of the selected BSM components will then be collected from suppliers and, where possible, samples will be collected by Herrera staff from multiple locations in material stockpiles and composited for analysis.

Bulk mineral, bulk organic, and amendments will be selected from the SPLP analysis using the following criteria: Cu ≤10 µg/L; nitrate-nitrite ≤0.5 mg/L; and TP ≤0.5 mg/L. If none of the components initially selected meet these criteria, additional components will be considered for SPLP analysis. If none of the components initially or subsequently selected meet these criteria, then components with the lowest concentrations will be selected and polishing layers with chemically active materials (e.g., activated alumina) will be considered to reduce effluent concentrations from the BSM blends.

One SPLP analysis will be conducted per BSM component; accordingly, no statistical analysis will be performed on the leaching results.

6.1.3. Combine Components and Flush BSM

Media components meeting criteria in Section 6.1.2 from the SPLP analysis will be combined into BSM blends, placed in polyvinyl chloride (PVC) columns, and flushed with deionized water at the WWU Institute of Environmental Toxicology (see Figure 2 for a column array schematic). The flushing experiments will be conducted not to replicate actual stormwater conditions, but rather as a conservative test to determine if any contaminants flush from the media blends when exposed to water with very low concentrations of contaminants.

The BSM depth will be 18 inches (45.7 cm) and a 12-inch (30.5 cm) polishing or drainage layer will be placed under the BSM to provide a final filter before discharge through the under-drain pipe. The columns will be 8 inches (20.3 cm) in diameter and 36 inches (91.4 cm) tall. A maximum of eight treatments will be selected. Each treatment will be replicated three times (24 columns maximum). Table 4 provides preliminary recommendations for BSM and polishing layer blends.

The proportions of BSM components in each blend will be selected for the appropriate gradation and density to minimize migration of fine fractions and organic material and prevent excessively high or low hydraulic conductivity and desired pollutant capture. The minimum target for hydraulic conductivity is 20 inches (51 cm)/hour. No maximum hydraulic conductivity will be targeted. Coefficient of Uniformity, Guidelines for Filter Media in Biofiltration Systems (FAWB 2009), and best professional judgment will be used to estimate proper gradation.

Flushing experiment hydraulic load will be based on typical bioretention facility surface area to contributing area ratios (see below). The facility surface area will be 20/1 or 5 percent of the contributing area and the contributing area effectiveness will be 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to facility area).

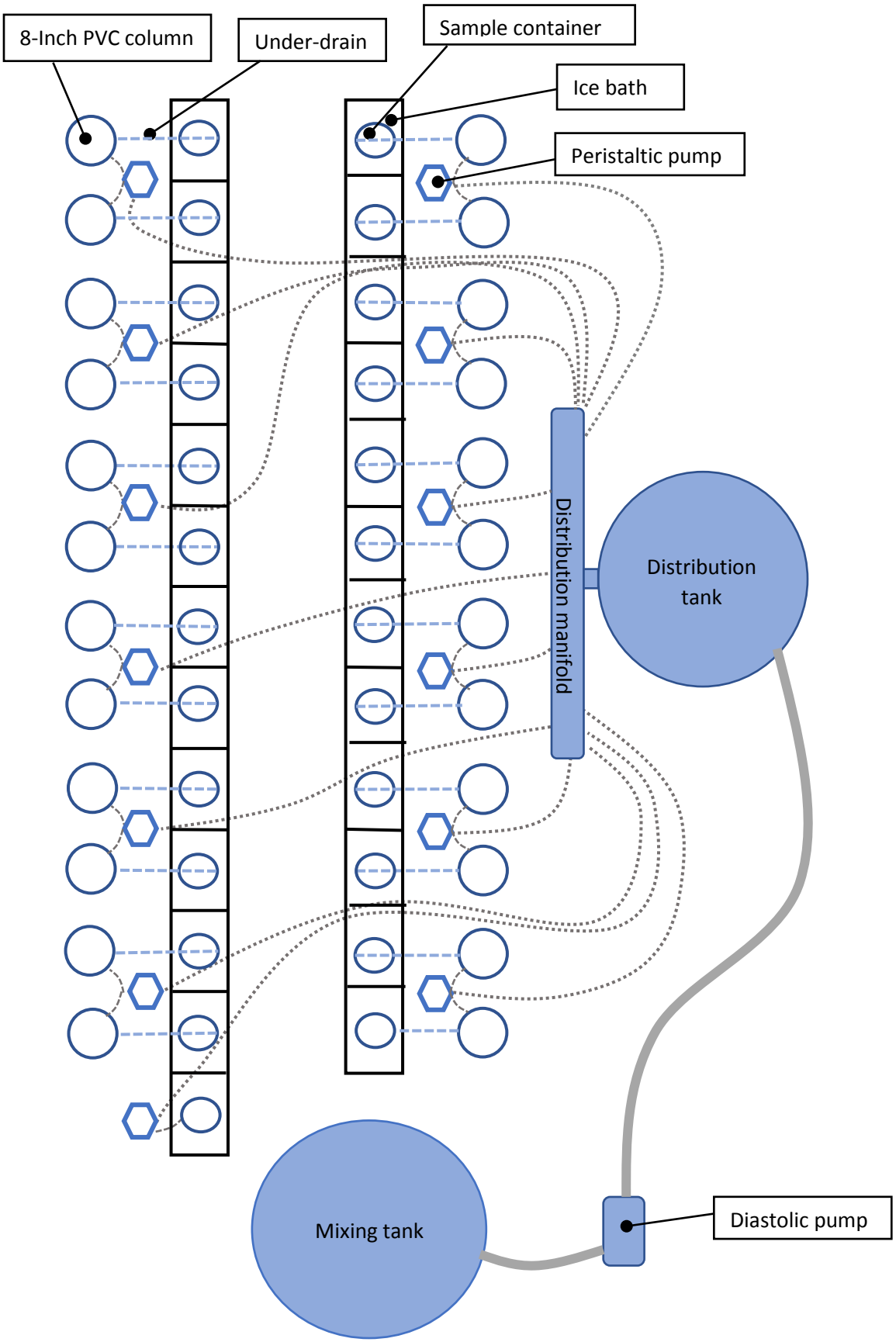

Figure 2. Schematic of the Water Delivery, Column, and Collection Array.

Table 4. Preliminary Recommendations for Bioretention Soil Media (BSM) Components and Blends.

BSM Blend Number	BSM Blend Abbreviations	Primary BSM Blend	Polishing Layer	Justification	Notes
1	60/40	60% ecology sand/40%compost	none	Current Ecology specification for comparison to other treatments. **Sand**: Use current BSM sand specification.	
2	60/40/aafep-layer	60% ecology sand/40%compost	90% state sand/7% coarse activated alumina/3% iron aggregate	Current Ecology specification with polishing layer to assess performance compared to 60/40 without polishing layer and other high-performance treatments. **Sand**: Use current BSM sand specification.	
3	70vs/20cp/10ash/compmulch	70% volcanic sand/20% coco coir/ 10% high carbon wood ash/ 2-inch compost mulch	None	BSM Phase 1 Study suggests that this blend with compost mulch grows plants as well as the 60/40 BSM; however, no water quality treatment performance was evaluated in that study. **Sand**: volcanic sand has tested well in previous studies and represents the finer gradation material for this study.	Blend attempts to meet all plant growing and treatment performance needs, at lower cost/cubic meter.
4	70vs/20cp/10ash/compmulch/ aafep-layer	70% volcanic sand/20% coco coir/ 10% high carbon wood ash/ 2-inch compost mulch	90% state sand/7% coarse activated alumina/3% iron aggregate	BSM Phase 1 Study suggests that this blend with compost mulch grows plants as well as the 60/40 BSM; however, no water quality treatment performance was evaluated in that study. This blend adds the polishing layer to ensure higher treatment performance if primary BSM does not capture all contaminants from compost mulch. **Sand**: volcanic sand has tested well in previous studies and represents the finer gradation material for this study.	Blend attempts to meet all plant growing and treatment performance needs, but at a higher cost/cubic meter.
5	70vs/20cp/10ash	70% volcanic sand/ 20% coco coir/ 10% high carbon wood ash	None	Volcanic sand combined with best performing materials from initial high-performance BSM study with Kitsap Co (Herrera 2015). **Sand**: volcanic sand has tested well in previous studies and represents the finer, high flow gradation material for this study.	
6	70ss/20cp/10ash	70% state sand/20% coco coir/ 10% high carbon wood ash	None	State sand combined with best performing materials from initial high-performance BSM study with Kitsap Co (Herrera 2015). **Sand**: state sand has tested well in previous studies and represents the coarser, high flow gradation material for this study.	
7	70ls/20cp/10ash	70% lava sand/20% coco coir/ 10% high carbon wood ash	None	Lava sand combined with best performing materials from initial high-performance BSM study with Kitsap Co (Herrera 2015). **Sand**: Lava sand is more porous with a rougher surface and may provide better TSS capture.	Examines lava sand for improved TSS capture, but with no orifice control.
8	70ls/20cp/10ash/orifice	70% lava sand/20% coco coir/ 10% high carbon wood ash (orifice control)	None	Lava sand combined with best performing materials from initial high-performance BSM study with Kitsap Co (Herrera 2015). **Sand**: Lava sand is more porous with a rougher surface and may provide better TSS capture.	Examines lava sand for improved TSS capture with orifice control.

Treatment comparisons:

- Treatments 1 and 2: compare 60/40 BSM with and without polishing layer.
- Treatment 3 and 4: compare different BSM blends below compost mulch (compost mulch provides improved plant growth).
- Treatments 5 and 6: evaluate treatment performance of high Ksat vs higher Ksat BSM blends.
- Treatments 7 and 8: same high Ksat BSM blends with orifice vs no orifice control.

Activated alumina: Actiguard F 14-18 mesh.

Coco coir: Botanicare Cocogro.

Compost: medium compost supplied by Cedar Grove meeting Washington Administration Code 173-350-220.

Iron aggregate: Connelly-GPM ETI CC-1004.

High carbon wood ash: Biological Carbon PD 100+mesh.

Flushing equivalent precipitation depth will be based on the Ecology water quality treatment design storm. The four flushing experiments will be conducted using two loading rates to provide a conservative test of effluent quality. The first two flushing tests will use the Ecology water quality treatment design storm. The effective precipitation depth will be doubled for the second two flushing tests. See Table 5 for the equivalent precipitation depth and flushing volumes applied. The flushing regime will be as follows:

- **Target depth for first two flushing experiments:** 1.32 inches (3.35 cm) of equivalent precipitation (the 6-month, 24-hour storm for the Seattle area).

- **Per column flushing volume for the first two experiments:** approximately 17.81 liters per sampling event.

  Flushing volume is determined by the following:

  (Column Area x Contributing to Facility Surface Area Ratio x Contributing Area Effectiveness x Bypass)/61.02

  where: Column Area = 50.264 in^2 (324.28 cm^2)

  Contributing to Facility Surface Area Ratio = 20/1

  Contributing Area Effectiveness = 0.9

  Bypass = 0.91

  61.02 = conversion for cubic inches to liters

- **Target depth for the last two flushing experiments:** 2.64 inches (6.70 cm) equivalent precipitation

- **Per column flushing volume for the last two flushing experiments:** approximately 35.62 liters per sampling event.

- **Drain down:** columns will be allowed to drain down for a minimum of 18 hours between flushing experiments.

- **Sampling event duration:** For the first two lower-rate flushing events, 17.81 liters will be delivered with a pump rate set at 6.7 liters per hour for approximately 2.5 hours. For the last two higher-rate flushing events, 26.72 liters will be delivered at a pump rate of 11.0 liters per hour for approximately 3.2 hours.

- **Sample event coverage:** the entire storm volume will be collected and one sub-sample for each analyte will be collected from each column per sampling event.

- **Influent concentrations:** Deionized water will be used for the flushing experiments. Influent concentrations will be below reporting limits for TSS (1.0 mg/L), TP (0.008 mg/L), ortho-P (0.004 mg/L, nitrate-nitrite (0.1 mg/L), dissolved Cu (2.0 µg/L), and dissolved Zn (2.5 µg/L) for deionized water.

Table 5. Flushing Regime.

Flushing Event	Day	Volume Applied (liters/column)	Equivalent Storm Size (inches)	Cumulative Rain (inches)	Percent Water Year (Seattle)
Sample 1	1	17.81	1.32	1.27	4
Flush 2	3	17.81	1.32	2.59	7
Flush 3	5	17.81	1.32	3.91	11
Flush 4	7	17.81	1.32	5.23	15
Flush 5	9	17.81	1.32	6.55	18
Flush 6	11	17.81	1.32	7.87	22
Sample 2	13	17.81	1.32	9.19	26
Flush 8	15	17.81	1.32	10.51	29
Flush 9	17	17.81	1.32	11.83	33
Flush 10	19	17.81	1.32	13.15	37
Flush 11	21	17.81	1.32	14.47	40
Flush 12	23	17.81	1.32	15.79	44
Sample 3	25	35.62	2.64	18.43	51
Flush 14	27	35.62	2.64	21.07	59
Flush 15	29	35.62	2.64	23.71	66
Flush 16	31	35.62	2.64	26.35	73
Flush 17	33	35.62	2.64	28.99	81
Flush 18	35	35.62	2.64	31.63	88
Flush 19	37	35.62	2.64	34.27	95
Sample 4	27	35.62	2.64	36.91	103

Hydraulic conductivity will also be assessed during the flushing experiments (see Section 7.2.1.3 for details). If the measured Ksat values for any BSM blend is below the minimum Ksat target (20.0 inches/hour or 51 cm/hour) during the first three flushing events, that BSM blend will not be tested further.

Effluent from the flushing experiments will be analyzed for contaminants listed in Table 6 below.

6.1.4. Dose BSM Blends

Following flushing, the same BSM blends will be dosed with stormwater obtained from catch basins located near the WWU lab and analyzed to confirm contaminant concentrations are within range stated in Table 6. The first three dosing events will be at lower target concentrations to test the ability of the BSM to attain contaminant reduction objectives at typical stormwater concentrations. For the fourth dosing event, the collected stormwater will be

augmented with reagent grade chemicals to attain the high target concentrations. This dosing experiment will test the ability of the BSM to capture high concentrations. The final dosing event will return to the low target concentrations to assess the ability of the BSM to retain previous contaminant loads and continue to attain reduction objectives at typical stormwater concentrations. All dosing experiments will be conducted at the WWU Institute of Environmental Toxicology (see Table 6 for contaminants analyzed in the effluent and the target concentrations for the influent).

The dosing experiment hydraulic load will be based on typical bioretention facility surface area to contributing area ratios. The facility surface area will be 20/1 or 5 percent of the contributing area and the contributing area effectiveness will be 0.9 (i.e., 90 percent of precipitation depth delivered from contributing area to facility area). See Section 6.1.3 hydraulic load calculation.

Table 6. Selected Analytes and Analyte Concentrations for Dosing Stormwater.

Analyte	Target Concentration (low)	Range (low)	Target Concentration (high)	Range (high)
Total Suspended Solids (TSS)	75 mg/L	50–200 mg/L	200 mg/L	no target
pH	no target	no target	no target	no target
Dissolved Organic Carbon (DOC)	no target	no target	no target	no target
Total Cd	0.3 µg/L	0.3–1.0 µg/L	no target	no target
Dissolved Cd	0.2 µg/L	0.2–1.0 µg/L	no target	no target
Total Cu	20.0 µg/L	10.0–50.0 µg/L	50 µg/L	no target
Dissolved Cu	7.0 µg/L	5.0–20.0 µg/L	20 µg/L	no target
Total Pb	no target	no target	no target	no target
Dissolved Pb	no target	no target	no target	no target
Total Zn	150.0 µg/L	100.0–500.0 µg/L	500 µg/L	no target
Dissolved Zn	50 µg/L	2.0–300.0 µg/L	300 µg/L	no target
Nitrate-nitrite	0.3 mg/L	0.1–1.0 mg/L	no target	no target
Total phosphorus (TP)	0.25 mg/L	0.1–0.5 mg/L	5 mg/L	no target
Ortho-phosphorus (ortho-P)	0.035 mg/L	0.02–0.1 mg/L	2 mg/L	no target
Total Petroleum Hydrocarbons (TPH diesel and motor oil)	no target	no target	no target	no target
Polycyclic Hydrocarbons (PAH)	no target	no target	no target	no target
Fecal coliform bacteria	no target	no target	no target	no target

PAH analytes include: phenanthrene, fluoranthene, chrysene, benzo[K]fluoranthene, and benzo[a]pyrene.

Dosing equivalent precipitation depth will be based on the Ecology water quality treatment design storm. The dosing hydraulic regime will be as follows:

- **Target depth for all dosing experiments:** 2.64 inches equivalent precipitation.
- **Dosing volume for all dosing experiments:** Approximately 35.62 liters per sampling event.

- **Column drain down:** minimum of 18 hours between dosing experiments.
- **Sampling event duration:** For all five dosing events 35.62 liters will be delivered at a pump rate of 11 liters per hour for approximately 3.2 hours.
- **Sample event coverage:** a 22-liter composite sample will be collected by removing the effluent line from the sample bottle every 20 minutes (five times) for 15 minutes and discarding a total of 15 liters.

6.1.5. Breakthrough Analysis

Following the dosing experiments, one or two top-performing BSM will be selected for breakthrough analysis. This experiment will examine sorption mechanisms of various pollutants and the time it takes for the pollutants to break through (no longer captured) by the media column.

Extra BSM from the initial blending will be placed in PVC columns, and dosed with stormwater at the WWU Institute of Environmental Toxicology. Each BSM blend will be replicated three times. The BSM depth will be 18 inches (45.7 cm) and a 12-inch (30.5 cm) polishing or drainage layer will be placed under the BSM to provide a final filter before discharge through the under-drain pipe. The columns will be 4 inches (10.2 cm) diameter and 36 inches (91.4 cm) tall. Effluent samples will be collected in 10 pore volume increments. The pore volume of the BSM is approximately 30 percent. Ten pore volumes are about five, 6-month 24-hour storms.

Approximately 20 samples will be collected and analyzed for ortho-P, nitrate-nitrite, dissolved Cu and dissolved Zn. Collecting 20 samples (1 sample per 10 pore volumes) equates to approximately four Seattle water years for the contributing area determined in Section 6.1.3 and 4-inch (10.2 cm) columns. Breakthrough curves will be constructed from the concentrations measured in the column effluent. Extrapolation of these breakthrough curves will be used to determine approximate useful lifetime of the BSM blend.

6.1.6. Toxicological Analysis

During the five dosing events described in 6.1.4, sub-samples will be collected from the effluent water to test the ability of the eight BSM blends to protect aquatic organisms from contaminants that produce acute toxicity. Tests will be conducted on two model aquatic organisms to efficiently screen BSM blends for biological effectiveness. An early life stage screening test with zebrafish (*Danio rerio*) embryos will be used to assess survival and sublethal toxicity to fish. Sublethal toxicity will include changes in morphometrics associated with exposure to toxic contaminants such as changes in embryo size and development of cardiovascular abnormalities. Daphnia (*Ceriodaphnia dubia*) neonates will be used to test toxicity to aquatic invertebrates.

6.1.7. Determine BSM Metrics and Numeric Ranges

To provide recommendations for a new BSM specification, the appropriate metrics and numeric ranges for those metrics must be determined using data from the above analyses. Metrics for components and blends are necessary for suppliers and designers to identify materials and processes that ensure consistent performance of the BSM. Selecting metrics for BSM specification will follow a two-step process:

1. Select and analyze the BSM components for specific physical and chemical characteristics that will be used for developing a BSM specification. Potential metrics include (a final list will be determined in collaboration with Ecology and the BWG):
    - Synthetic Precipitation Leaching Protocol extraction.
    - Water holding capacity.
    - Cation exchange capacity.
    - Electrical conductivity.
    - P availability test (e.g., Bray test for adsorbed forms of phosphate).
    - Particle size distribution.
2. Select and analyze the BSM blends for specific physical and chemical characteristics that will be used for developing a BSM specification. Potential metrics include (a final list will be determined in collaboration with Ecology and the BWG):
    - Water holding capacity.
    - Cation exchange capacity.
    - Electrical conductivity.
    - Carbon to nitrogen ratio.[1]
    - Organic matter content.[1]
    - Iron/aluminum oxalate ratio.[1]

Note that these are potential metrics. The final determination will be made by the BWG and Ecology. Accordingly, methods will be provided in an addendum to this QAPP once metrics are determined.

[1] These parameters are appropriate only for blends, not individual components.

6.1.8. Supplemental Toxicological and Dosing Experiments

The ability of the BSM to protect aquatic organisms is a critical performance metric and a key technical issue identified in the scope of work for this study that was developed by SWG, Ecology and King County. Recent research by Dr. Jenifer McIntyre suggests that the protective quality of compost-based BSM effluent may diminish after a BSM is dosed with a volume of water equivalent to two typical Seattle water years. Dr. McIntyre has also added neurotoxicity analysis to improve our understanding of stormwater impacts to aquatic organisms. Accordingly, the BWG recommended extending the dosing volume under the existing scope of work from an equivalent of 25 percent of a Seattle water year to two Seattle water years and including the neurotoxicity analysis. However, implementation of this supplemental experimentation is contingent on the availability of additional SAM funding through the SWG and Ecology. In the event this funding becomes available, Appendix A provides a more detailed description of these experiments.

6.2. Experiment Duration

A minimum of four composite samples for all treatments will be collected for the flushing experiments and five composite samples for the dosing experiments over a period of approximately 4 months.

7. SAMPLING PROCEDURES

This section of the QAPP describes laboratory sampling procedures necessary to ensure the quality and representativeness of the collected samples. This section includes information on laboratory safety, flow monitoring, and water quality sampling.

7.1. LABORATORY SAFETY PROCEDURES

Laboratory experiments will be conducted at WWU Institute of Environmental Toxicology and Exact Scientific Services. Personnel will follow safety requirements for WWU and Exact Scientific Services as outlined in their laboratory procedures.

7.2. OBTAIN AND SAMPLE BSM COMPONENTS

Individual BSM components selected from the survey process described in Section 6.1.1 will be collected from producers or suppliers of those materials. For suppliers not located in this region, representatives will be contacted by Herrera staff and samples collected and shipped by the suppliers. For local suppliers with bulk aggregate or organic materials, Herrera staff will collect samples on-site from various representative locations in those material piles and composite into a single sample. Samples will be collected using clean shovels and plastic buckets. All sample containers will be pre-cleaned with Liquinox detergent and finally rinsed with deionized water.

7.3. COLUMN ARRAY SETUP

7.3.1. Large Columns (flushing and dosing)

Twenty-four columns will be located at the WWU Institute of Environmental Toxicology. The PVC columns will be 8 inches (20.3 cm) diameter and 36 inches (91.4 cm) tall and include a 1-inch (2.54 cm) slotted under-drain placed at the bottom of the column. The inside of the column walls will be roughened to minimize preferential flow between the BSM and the column wall.

BSM proportions will be determined by volume. Component volumes will be measured in calibrated containers and the components thoroughly mixed in 10-gallon containers.

The polishing or drainage layer and BSM blends will be placed in each column in 6-inch (15-cm) lifts and compacted with a disc dropped from the same height and for the same number of blows to attain similar compaction across all columns.

Flow into the columns will be mixed and delivered from a mixing tank by an air-actuated diaphragm pump to a distribution tank elevated above the columns. Calibrated peristaltic pumps will deliver water from the distribution tank to the columns. Clean glass beads will be placed on top of the BSM to prevent particle sorting and promote even distribution of influent flow across the BSM surface.

7.3.2. Small Columns (breakthrough analysis)

Following the dosing experiments, one or two top-performing BSM will be selected for breakthrough analysis. Extra BSM from the initial blending (following blending procedures described above in Section 7.3.1) will be placed in PVC columns.

The columns will be 4 inches (10.2 cm) diameter and 36 inches (91.4 cm) tall. Stainless steel screen will be placed over the bottom of the column to retain media and allow drainage. The polishing or drainage layer and BSM blends will be placed in each column in 6-inch (15-cm) lifts and compacted with a disc dropped from the same height and for the same number of blows to attain similar compaction across all columns.

Flow into the columns will be mixed and delivered from a mixing tank by an air-actuated diaphragm pump to a distribution tank elevated above the columns. Calibrated peristaltic pumps will deliver water from the distribution tank to the columns. Clean glass beads will be placed on top of the BSM to prevent particle sorting and promote even distribution of influent flow across the BSM surface.

7.4. Hydraulic Monitoring

This section discusses the water distribution system, calibration of that system and influent and effluent flow measurement.

7.4.1. Influent Flow Volume Monitoring

For the flushing and dosing experiments, influent flow volume will be monitored by applying a known volume to the columns through a peristaltic pump and distribution system. The distribution system will be calibrated by adjusting the flow rate of the peristaltic pumps and collecting the entire volume from each pump for each calibration to confirm delivered volume. Pumps will be adjusted until the desired flow rate is achieved. The variation among distribution lines will be no more 20 percent (±10 percent from the target flow volume).

During the first phase of flushing tests, flow rate to the columns will start low (approximately 6.7 liters/hour) and increase for the second phase of flushing (approximately 11.0 liters/hour). The higher flow rate will also be used for all dosing experiments. All overflow through the column outlets (invert located 6 inches above BSM surface) will be collected and re-delivered to the same column.

7.4.2. Effluent Flow Volume Monitoring

The entire effluent volume will be collected for each flushing and dosing sampling event in a pre-weighed container and the sample and container weighed to determine whole sample volume. The sample weight will be recorded and converted to liters.

7.4.3. Saturated Hydraulic Conductivity

Ksat will be evaluated for each BSM blend after the last flushing event (Table 5). These falling head tests will be conducted using the following procedure:

- At the end of the flushing event and while there is still water ponded on the surface of the BSM, close the under-drain valve.
- Fill the column until there is 6 inches of ponded water.
- Open the valve and record the time of drawdown from the point when the ponding depth is 6 inches to the point when the water is no longer visible on the surface of the BSM to estimate Ksat.

7.5. Water Quality Sampling

This section discusses stormwater collection and lab sampling methods, standardized sampling forms, sample containers and preservation, sample identification and labeling, and chain-of-custody forms.

7.5.1. Influent Water Sampling

BSM blends will be dosed with stormwater obtained from catch basins located near the lab. Before collecting stormwater for dosing the catch-basin water will be sampled and analyzed to confirm contaminant concentrations are within range stated in Table 6. Once concentrations are confirmed stormwater will be pumped from the catch basin to a holding tank, transported to the lab and pumped into a mixing tank. Stormwater will be stirred in the mixing tank by propeller and pumped to a distribution tank.

Thirteen distribution ports will be placed at the bottom of the distribution tank. Twelve ports will distribute flow, by peristaltic pump, to the BSM columns and the thirteenth will discharge directly to a sample bottle and be used to sample influent water quality. Half of the columns will be sampled one day and half the next day. For TSS, pH, nutrients, and metals, influent water will be collected in a 24.6-liter glass containers placed in a tub of ice. The whole sample will be delivered to the laboratory where samples for each analyte will be obtained using a churn splitter. Grab samples will be collected in appropriate sample containers (see Table 7 in Section 8) for TPH, PAH, and bacteria and placed on ice for transportation to the laboratory.

7.5.2. Effluent Water Sampling

For TSS, pH, nutrients, and metals, effluent water from the BSM columns will be collected in 24.6-liter glass containers placed in a tub of ice. All water from the sampling event will be collected and delivered to the laboratory where samples for each analyte will be obtained using a churn splitter. Grab samples will be collected in appropriate sample containers (see Table 7) for TPH, PAH, and bacteria and placed on ice for transportation to the laboratory.

See sections below for Sample Handling, Delivery, and Processing.

7.5.2.1. pH Monitoring

The pH and temperature of each sample will be measured with a calibrated field meter (Thermo Scientific Orion Star A221) within 30 minutes after the conclusion of the dosing period. The pH electrode will be immersed in the sample container and the measurement recorded when the meter indicates a stable reading.

Photos will be taken of representative samples to document effluent visual characteristics.

7.5.3. Sampling Forms

For each experiment, sampling personnel will record the following information on a standardized sampling form before and after sampling:

- Date and time of sample collection, measurement, or observation.
- Name(s) of sampling personnel present.
- All cleaning and preparation procedures.
- Any calibration procedures and findings.
- Sample volume collected in sample bottles.
- Sample pH.
- Duration of experiment (start of inflow to end of effluent volume collection).
- Unusual conditions (e.g., odor, color, turbidity, equipment leaks or spills).
- Modifications of, or unusual, sampling procedures.
- Any miscellaneous factors that might influence samples.

7.5.4. Sample Containers and Preservation

The analytical laboratory will clean the 24.6-liter sample bottles. Spare sample bottles will be available in case of breakage or possible contamination. Sample containers and preparation will follow Code of Federal Regulations [40 CFR 136] guidelines. Refer to Table 7 in Section 8 (Measurement Procedures) for information on recommended sample containers.

7.5.5. Sample Identification and Labeling

All sample containers will be labeled with the following information, using waterproof labels and indelible ink and placed on the dry sample container:

- Column/sample ID.
- Date of sample collection (month/day/year).
- Lab lead/contact name.

7.5.6. Chain-of-Custody

After samples have been obtained and the collection procedures properly documented, a written record of the chain-of-custody of each sample will be completed by sampling and laboratory personnel to ensure that samples have not been tampered with or compromised in any way and to track the requested analysis for the analytical laboratory. Information necessary in the chain-of-custody includes:

- Name(s) of sampling personnel.
- Date and time of sample collection.
- Location of sample collection.
- Printed names, signatures and contact information of sampling personnel and laboratory personnel handling the samples.
- Laboratory analysis requested and control information (e.g., duplicate or spiked samples) and any special instructions (e.g., time sensitive analyses).

Sample custody will be tracked in the laboratory through the entire analytical process, and the signed chain-of-custody forms and analytical results returned to the Herrera project manager. The Herrera monitoring lead will record the date and time of sample deliveries for the project file.

7.5.7. Sample Delivery

Immediately after collection, samples will be delivered to Exact Scientific Services (an Ecology accredited lab) located in Ferndale (approximately 30 minutes from the WWU lab). Samples will be capped to prevent contamination and kept on ice to maintain a temperature of 6 degrees C or less. At Exact Scientific Services, samples will be churn split into clean, prepared bottles. Once split, TP and ortho-P samples will be returned on ice to the WWU Institute for Watershed Studies for analyses. Metals, TSS, pH, DOC, nitrate-nitrite, PAH, TPH, and fecal coliform bacteria will be analyzed at Exact Scientific Services.

7.6. Toxicological Analysis

During the five dosing events, 1-liter sub-samples will be collected from the effluent water to test the ability of the eight BSM blends to protect aquatic organisms from contaminants that produce acute toxicity. Effluent water will be immediately frozen for transportation to WSU Puyallup Research and Extension Center (WSU Puyallup). Tests will be conducted at WSU Puyallup on two model aquatic organisms to efficiently assess BSM blends. An early life stage screening test with zebrafish (*Danio rerio*) embryos will used to assess survival and sublethal toxicity to fish. Sublethal toxicity will include changes in morphometrics associated with exposure to toxic contaminants such as changes in embryo size and development of cardiovascular abnormalities. Daphnia (*Ceriodaphnia dubia*) neonates will be used to test toxicity to aquatic invertebrates. Methods will be similar to protocols developed by the Organization for Economic Cooperation and Development (OECD 236: Fish Embryo Acute Toxicity Test) and U.S. Environmental Protection Agency (EPA-821-R-02-012: Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms). In general, the tests will follow these procedures:

- Tests with zebrafish will use embryos <4 hours post fertilization (hpf) that will be exposed until the embryos are 48 hpf. Exposures will take place in glass-lined, 96-well plates with 32 embryos per treatment.
- *C. dubia* tests will use neonates <24 hours old exposed for 48 hours. Exposures with *C. dubia* will take place in glass petri dishes with 4 replicates of 10 neonates per treatment.
- Both types of tests will include an influent (positive) control sample and a negative (laboratory water) control sample.

8. MEASUREMENT PROCEDURES

Laboratory analytical procedures will follow methods approved by the US Environmental Protection Agency (EPA) (APHA et al. 1992, 1998; US EPA 1983, 1984). These methods provide reporting limits that are below the state and federal regulatory criteria or guidelines and will allow direct comparison of the analytical results with these criteria. Preservation methods, analytical methods, reporting limits, and sample holding times are presented in Table 7.

Samples for parameters requiring filtration (i.e., ortho-P, dissolved Cu, Cd, Pb, and Zn) will be delivered to the laboratory within 4 hours of their collection. Upon their receipt, laboratory personnel will immediately filter and preserve these samples.

Exact Scientific Services and WWU Institute for Watershed Studies (laboratories identified for this project) are certified by Ecology and participate in audits and inter-laboratory studies by Ecology and EPA. These performance and system audits have verified the adequacy of the laboratory's standard operating procedures, which include preventive maintenance and data reduction procedures.

The laboratory will report the analytical results within 30 days of receipt of the samples. The laboratory will provide sample and quality control data in standardized reports suitable for evaluating the project data. The reports will also include a case narrative summarizing any problems encountered in the analyses.

Table 7. Methods and Detection Limits for Water Quality Analyses.							
Analyte	**Analytical Method**	**Method Number[a]**	**Holding Time[b]**	**Sample Container**	**Preservation**	**Reporting Limit**	**Units**
Total suspended solids	Gravimetric	SM 2540 D	7 days	HDPE	Cool, ≤6°C	1.0	mg/L
pH	Meter	EPA 150.2	15 minutes[c]	HDPE	Cool, ≤6°C	NA	std. units
Dissolved Organic Carbon	Combustion	SM5310B	24 hours (filter), 28 days (total)	Amber Glass	Filter, Cool, ≤6°C; H2SO4 to pH<2	1.5	mg/L
Nitrate-nitrite	Ion Chromatography	EPA 300	48 hours	HDPE	Cool, ≤6°C	0.1	mg/L
Total phosphorus	Colorimetric	4500-P J	28 days	HDPE	Digest, Cool, ≤6°C	0.008	mg/L
Ortho-phosphorus	Colorimetric	4500-P G	28 days	HDPE	Filter, Freeze, ≤18°C	0.004	mg/L
Cadmium, dissolved	ICP-MS	EPA 200.8	24 hours, filter 6 months	HDPE	Filter, Cool, ≤6°C; HNO3 to pH<2	0.1	µg/L
Copper, dissolved						0.1	
Zinc, dissolved						1.0	
Lead, dissolved						0.1	
Cadmium, total			6 months		Cool, ≤6°C; HNO3 to pH<2	0.1	
Copper, total						0.1	
Lead, total						0.1	
Zinc, total						2.5	
TPH (diesel)	NWTPH-Dx	NWTPH-Dx	14 days	Amber Glass	Cool, ≤6°C; HCl to pH<2	0.25	mg/L
TPH (motor oil)	NWTPH-Dx	NWTPH-Dx	14 days	Amber Glass	Cool, ≤6°C; HCl to pH<2	0.5	mg/L
PAH	GC/MS	8270D	7 days	Amber Glass	Cool, ≤6°C, 10% CH2Cl2	0.1	µg/L
Bacteria (fecal coliform)	Membrane filtration	SM 9222 D	6 hours (transit) 8 hours (overall)	Corning (sterile)	Cool, ≤6°C	1	CFU/100 mL

[a] SM method numbers are from APHA et al. 1998; EPA method numbers are from US EPA 1983, 1984. The 18th edition of Standard Methods for the Examination of Water and Wastewater (APHA et al. 1992) is the current legally adopted version in the Code of Federal Regulations (CFR). However, the 20th edition provides additional guidance on certain key items. For this reason, the 20th edition is referenced in this table as the best available guidance. An equivalent standard method can be substituted.

[b] Holding time specified in EPA guidance or referenced in Standard Methods for equivalent method.

[c] EPA requires pH reading within 15 min of collection of the last aliquot. This is generally not feasible with composite or flow weighted composite sampling.

TPH = total petroleum hydrocarbons. PAH = polycyclic aromatic hydrocarbons.

9. QUALITY CONTROL

This section includes information on field quality assurance/quality control (QA/QC) and laboratory quality control.

9.1. COLUMN ARRAY AND LAB QUALITY CONTROL

This section summarizes the QA/QC procedures that laboratory personnel will implement to evaluate sample contamination and sampling precision and to maintain and calibrate monitoring equipment.

9.1.1. Equipment Blanks

For the flushing tests, two to three columns will be randomly selected and one to three duplicate influent samples will be collected to determine if the column array distribution system is contaminated. The first duplicate influent sample will be collected at the beginning of the flushing experiments. If the samples meet criteria in Table 3 for equipment blanks, no other duplicate influent samples will be collected. If the samples do not meet the criteria in Table 3, subsequent duplicate influent samples will be collected for the deionized water system before the water enters the distribution system, at the end of the distribution system (discharge point to columns), and the 24.6-liter sample bottles. The volume of deionized water pumped through the influent distribution system for the duplicate influent samples will be similar to the volume of water collected during a sampling event.

Stormwater containing various contaminants will be used for the dosing tests. Given measurements from previous studies, residuals in the mixing and distribution tanks and the distribution lines from previous dosing should not significantly influence concentrations of target contaminants in subsequent dosing. Accordingly, the tanks and distribution lines will not be cleaned between dosing experiments.

9.1.2. Bottle Blanks

One sample bottle blank will be collected at the beginning of the flushing experiments, and one at the beginning and end of the dosing experiments. The bottle blanks will be collected by filling sample bottles with reagent-grade water using a similar volume collected during column experiments. Bottle blanks will be used to assess contaminants contributed from sample bottles.

9.1.3. Equipment Maintenance and Calibration

Maintenance procedures and frequencies are summarized in Table 8. Calibration activities will be documented on standardized field forms.

Table 8. Equipment Maintenance Schedule.		
Item	**Procedure**	**Minimum Frequency**
Distribution tank	Check for debris, flush with deionized water	Before flushing experiments
Distribution lines	Check for debris, flush with deionized water	Before flushing experiments
Peristaltic pumps	Calibrate	Once at beginning of flushing and once at beginning of dosing experiments

9.2. LABORATORY QUALITY CONTROL

This section summarizes the quality control procedures the laboratory will perform and report with the analytical results. Accuracy of the laboratory analyses will be verified using blank analyses, duplicate analyses, laboratory control spikes and matrix spikes in accordance with the EPA methods employed. WWU Institute for Watershed Studies and Exact Scientific Services will be responsible for conducting internal quality control and quality assurance measures in accordance with their own quality assurance plans. The required frequency for quality control procedures and evaluation criteria are summarized in Tables 9 and 10.

Water quality results will first be reviewed at the laboratory for errors or omissions. Laboratory quality control results will be reviewed by the laboratory to verify compliance with acceptance criteria. The laboratory will also validate the results by examining the completeness of the data package to determine whether method procedures and laboratory quality assurance procedures were followed. The review, verification, and validation by the laboratory will be documented in a case narrative that accompanies the analytical results.

Data will be reviewed and validated within 7 days of receiving the results from the laboratory. This review will be performed to ensure that all data are consistent, correct, and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Table 3) will also be examined to determine if MQOs for the project have been met.

Results from these data validation reviews will be summarized in quality assurance worksheets (see example in Appendix B) that are prepared for each sample batch. The Herrera project manager and Herrera quality assurance lead for water quality data will be jointly responsible for identifying and initiating corrective action. Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified with an *R*. Estimated values may be used for evaluation purposes, but rejected values will not be used. The following sections describe in detail the data validation procedures for quality control.

For toxicology testing, average mortality in laboratory control water must be <10 percent for *D. rerio* and <20 percent for *C. dubia*. Exposures not meeting these criteria will be repeated with an additional aliquot of frozen water sample.

Table 9. Anticipated Number of Samples and Associated Quality Assurance Requirements for Flushing and Dosing Experiments.										
Parameter	**Sample Type**	**Sample Events**	**Number of Columns**	**Total Number of Samples**	**Duplicate Influent Samples**	**Method Blanks**	**Control Standard**	**Matrix Spike**	**Lab Duplicates**	**Bottle Blanks**
Total suspended solids	Whole sample composite	9	24	216	3	1/sample event	1/sample event	NA	1/sample event	3
pH	In situ	9	24	216	NA	NA	NA	NA	NA	NA
DOC	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Nitrate-nitrite	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Total phosphorus	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Ortho-phosphorus	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Cadmium, dissolved	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Cadmium, total	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Copper, dissolved	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Copper, total	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Zinc, dissolved	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Zinc, total	Whole sample composite	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
TPH (diesel)	Grab sample	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
TPH (motor oil)	Grab sample	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
PAH	Grab sample	9	24	216	3	1/sample event	1/sample event	1/sample event	2/sample event	3
Bacteria (fecal coliform)	Grab sample	7	24	168	3	1/sample event	1/sample event	1/sample event	2/sample event	3

DOC = dissolved organic carbon.

TPH = total petroleum hydrocarbons.

PAH – polycyclic aromatic hydrocarbons.

Table 10. Anticipated Number of Samples and Associated Quality Assurance Requirements for Breakthrough Analysis.										
Parameter	**Sample Type**	**Sample Events**	**Number of Columns**	**Total Number of Samples**	**Duplicate Influent Samples**	**Method Blanks**	**Control Standard**	**Matrix Spike**	**Lab Duplicates**	**Bottle Blanks**
Nitrate-nitrite	Whole sample composite	20	6	120	1	1/sample event	1/sample event	6	12	3
Ortho-phosphorus	Whole sample composite	20	6	120	1	1/sample event	1/sample event	6	12	3
Copper, dissolved	Whole sample composite	20	6	120	1	1/sample event	1/sample event	6	12	3
Zinc, dissolved	Whole sample composite	20	6	120	1	1/sample event	1/sample event	6	12	3

10. DATA MANAGEMENT PROCEDURES

Exact Scientific laboratory will report the analytical results within 30 days of receipt of the samples. The laboratory will provide sample and quality control data in standardized reports that are suitable for evaluating the project data. These reports will include all quality control results associated with the data. The reports will also include a case narrative summarizing any problems encountered in the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifies.

Laboratory data will be entered into the project database for all subsequent data management and archiving tasks. Herrera's quality assurance lead for water quality data will perform an independent review to ensure that the data were entered without error. Specifically, 10 percent of the sample values will be randomly selected for rechecking and crosschecking with laboratory reports. If errors are detected, they will be corrected, and then an additional 10 percent will be selected for validation. This process will be repeated until no errors are found in the data.

All sample volume and pH data will be entered manually into a project database within 24 hours of sample collection.

Toxicology data will be provided for each event in an Excel file, with a summary document to interpret the data results.

11. AUDITS AND REPORTS

This section provides information on audits and reports that will be part of this monitoring program.

11.1. AUDITS

Audits performed for water quality data will occur within 7 business days of receiving results from the laboratory. This review will be performed to ensure that all data are consistent, correct, and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Table 3) and raw data will also be examined to determine if the MQOs for the project have been met. Results from these audits will be documented in QA worksheets (see Appendix A) that will be prepared for each batch of samples.

In the event that a potential QA issue is identified through these audits, Herrera's data quality assurance lead will review the data to determine if any response actions are required. Response actions in this case might include the collection of additional samples, reanalysis of existing samples if not yet past holding time or advising the laboratory that methodologies or QA/QC procedures need to be improved.

11.2. REPORTS

Herrera will prepare a preliminary and final project report for project partner (including Ecology) review.

12. DATA VERIFICATION AND VALIDATION

Data verification and validation will be performed on the water quality data that are collected through the duration of this project. The specific procedures that will be used to verify and validate each type of data are described in the following sections. Toxicology data will be assessed for control survival as defined in Section 9.2.

12.1. VERIFICATION AND VALIDATION METHODS FOR WATER QUALITY DATA

Data will be reviewed and audited within 7 business days of receiving the results from the laboratory. This review will be performed to ensure that all data are consistent, correct and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Tables 3, 7, 9, and 10) will also be examined to determine if the MQOs for the project have been met. Results from these data validation reviews will be summarized in quality assurance worksheets that are prepared for each sample batch (see Appendix B). Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified *R*. Estimated values may be used for evaluation purposes, while rejected values will not be used. The following sections describe in detail the data validation procedures for these quality control elements:

- Completeness
- Methodology
- Holding times
- Method blanks
- Reporting limits
- Duplicates
- Matrix spikes
- Control standards
- Sample representativeness

12.1.1. Completeness

Completeness will be assessed by comparing valid sample data with this quality assurance project plan and the chain-of-custody records. Completeness will be calculated by dividing the number of valid values by the total number of values. If less than 95 percent of the samples submitted to the laboratory are judged to be valid, then more samples will be collected until at least 95 percent are judged to be valid.

12.1.2. Methodology

Methodologies for analytical procedures will follow US EPA approved methods (APHA et al. 1992, 1998; US EPA 1983, 1984) specified in Table 7. Lab procedures will follow the methodologies described in this QAPP. Any deviations from these methodologies must be documented in an addendum to this QAPP. Deviations that are deemed unacceptable will result in rejected values (*R*) and will be corrected for future analyses.

12.1.3. Holding Times

Holding times for each analytical parameter in this study are summarized in Table 7. Holding time compliance will be assessed by comparing sample collection dates and times to filtration (pre-filtration) and analytical (post-filtration or total) dates and times. Sample collection times will be based on the date and time that the last aliquot was collected, but the sampling date and start time will be recorded as well.

12.1.3.1. Pre-Filtration Holding Times

Samples requiring filtration should be filtered within holding times specified in Table 7. Holding time calculation begins after collection of the last aliquot.

12.1.3.2. Post-Filtration or Total Holding Times

- **For analytes with holding times in excess of 7 days:**
    - Data from samples that exceed the specified maximum post-filtration holding times by less than 48 hours will be considered estimates (*J*). Data from samples that exceed the maximum post-filtration holding times by more than 48 hours will be rejected values (*R*).
- **For analytes with holding times equal to or less than 7 days:**
    - Data from samples that exceed the specified maximum post-filtration holding times by less than 24 hours will be considered estimates (*J*). Data from samples that exceed the maximum post-filtration holding times by more than 24 hours will be rejected values (*R*).

12.1.4. Method Blanks

Method blank values will be compared to the MQOs that have been identified for this project (see Table 3). If an analyte is detected in a method blank at or below the reporting limit, no action will be taken. If blank concentrations are greater than the reporting limit, the associated data will be labeled with a *U* (in essence increasing the reporting limit for the affected

samples), and associated project samples within 5 times the de facto reporting limit will be flagged with a *J* (G. Grepo-Grove, Manchester Laboratory, personal communication, September 4, 2007). In each of these cases, the de facto reporting limit for that analyte will be recorded along with the raw data, equipment will be decontaminated, and samples will be rerun if possible.

12.1.5. Equipment Blanks

Equipment blank concentrations will be compared to the MQOs that have been identified for this project (see Table 3). If concentrations are detected in the equipment blanks that exceed 2 times the reporting limit, then associated sample tubing will be cleaned or replaced and associated samples collected since the previous equipment blank that are within 5 times the new reporting limit will be flagged with a J.

12.1.6. Reporting Limits

Both raw values and reporting limits will be presented in each laboratory report. If the proposed reporting limits are not met by the laboratory, the laboratory will be requested to reanalyze the samples or revise the method, if time permits. Proposed reporting limits for this project are summarized in Table 7.

12.1.7. Duplicates

Duplicate results exceeding the MQOs for this project (see Table 3) will be recorded in the raw data tables, noted in the quality assurance worksheets; and associated values flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values will be rejected (*R*).

12.1.8. Matrix Spikes

Matrix spike results exceeding the MQOs for this project (see Table 3) will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (*J*). However, if the percent recovery exceeds the MQOs and a value is less than the reporting limit, the result will not be flagged as an estimate. Non-detected values will be rejected (*R*) if the percent recovery is less than 30 percent.

12.1.9. Control Standards

Control standard results exceeding the MQOs for this project (see Table 3) will be noted in the quality assurance worksheets, and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values will be rejected (*R*).

13. DATA QUALITY ASSESSMENT

Separate subsections herein describe the procedures that will be used to assess the usability of the data and analyze the data.

13.1. DATA USABILITY ASSESSMENT

The Herrera quality assurance officer will provide an independent review of the water quality QC data from each sampling event using the MQOs that have been identified in this QAPP. The results will be presented in a water quality data quality assessment report (see *Audits and Reports* section). The data quality assessment report will summarize quality control results, identify when data quality objectives were not met, and discuss the resulting limitations (if any) on the use or interpretation of the data. Specific quality assurance information that will be noted in the data quality assessment report includes the following:

- Changes in and deviations from the QAPP.
- Results of performance or system audits.
- Significant quality assurance problems and recommended solutions.
- Data quality assessment results in terms of precision, bias, representativeness, completeness, comparability, and reporting limits.
- Discussion of whether the quality assurance objectives were met, and the resulting impact on decision-making.
- Limitations on use of the measurement data.

13.2. DATA ANALYSIS PROCEDURES

Data analysis will be conducted to document the performance of the BSM blends for pollutant removal efficiencies and relative to treatment goals that are specified in the Technology Assessment Protocol-Ecology guidelines (Ecology 2011) for basic, enhanced, phosphorus, and metals. Separate subsections below describe the specific data analysis procedures that will be applied to meet these objectives.

13.2.1. Evaluation of Treatment Performance

To evaluate the treatment performance of the various BSM blends, the following data compilations and analyses will be generated from the sampling results:

- Sampling event data will be reviewed to determine if goals for representativeness that are specified in the Quality Objectives section of this QAPP were met.
- Statistical comparisons (median values and hypothesis testing) will be performed for each parameter from each flushing and dosing event.
- Pollutant removal efficiency will be calculated for each parameter from each dosing event.

Each of these activities is described in more detail below.

13.2.1.1. Statistical Comparisons of Influent and Effluent Pollutant Concentrations

Statistical analyses will be performed to determine whether there are significant differences in pollutant concentrations between the influent and effluent of each BSM blend across individual sampling events. The specific null hypothesis (H_o) and alternative hypothesis (H_a) for these analyses are as follows:

H_o: Effluent pollutant concentrations are equal to or greater than influent concentrations.

H_a: Effluent concentrations are less than influent concentrations.

Two-factor analysis of variance (ANOVA) tests will be used to compare effluent concentrations across the BSM blends in both the flushing and dosing experiments. These tests will be performed specifically to identify BSM blends with superior performance relative to others in each of these experiments.

For both flushing and dosing experiments, one factor will be the BSM blend's effluent concentration and the other factor will be the sampling event sequence (as noted above, the collected stormwater will be augmented with reagent grade chemicals to attain higher target ortho-P concentrations for the fourth dosing event).

Because an ANOVA test is considered a parametric procedure, there are several underlying assumptions that must be met when this approach is used; most notably, the data must have a normal distribution and each treatment group must have an equal variance. Data distributions from previous BSM research suggest that the distributions from these experiments will be non-normal. Accordingly, the ANOVA tests for all parameters will be performed on the ranks of the data following guidance provide in Helsel and Hirsh (2002). Each test indicates whether there was a significant difference in effluent concentration or percent removal due to one or both

factors, and the interaction of the two. Where a significant difference in effluent concentration is detected due to the BSM blend effluent concentration factor in both the flushing and dosing experiments, follow-up Tukey multiple comparison tests will be performed to determine which specific BSM blends were different relative to the others. Statistical significance in all tests will be assessed based on an alpha (α) level of 0.05.

13.2.1.2. Pollutant Removal Efficiency Calculations

Pursuant to TAPE guidelines, pollutant reduction efficiencies for each BSM blend will be estimated. The reduction (in percent) in pollutant concentration during each individual experiment (ΔC) will be calculated as:

$$\Delta C = 100 \times \frac{\left(C_{in} - C_{eff}\right)}{C_{in}}$$

where: C_{in} = composite influent pollutant concentration

C_{eff} = composite effluent pollutant concentration for each treatment

13.2.2. Statistical Evaluation of Performance Goals

Statistical analyses will be performed to determine whether the collected data demonstrate that the BSM blends meet applicable performance goals specified in the TAPE guidelines (Ecology 2011) for basic, enhanced, and phosphorus treatment (see Table 11). The statistical analysis will involve the computation of bootstrapped confidence intervals around the mean effluent concentration or pollutant removal efficiency. Bootstrapping offers a distribution-free method for computing confidence intervals around a measure of central tendency (Efron and Tibshirani 1993). The generality of bootstrapped confidence intervals means they are well-suited to non-normally distributed data or datasets not numerous enough for a powerful test of normality (Porter et al. 1997).

Bootstrapping consists of drawing *n* elements from the dataset randomly with replacement and equal probabilities of drawing any element. The statistic of interest is then calculated on this synthetic dataset, and the process is repeated for many repetitions. Repetition generates a distribution of possible values for the statistic of interest. Percentiles of this distribution are confidence intervals of the statistic. For example, if the mean is calculated for 1,000 synthetic datasets, after sorting the replications, the result for ranks 25 and 975 are the lower and upper 95 percent confidence intervals, respectively, around the mean.

Table 11. Basic, Enhanced, and Phosphorus Performance Goals for TAPE Monitoring.

Performance Goal	Influent Range	Criteria
Basic Treatment	20–100 mg/L TSS	Effluent goal ≤20 mg/L TSS[a]
	100–200 mg/L TSS	≥80% TSS removal[b]
	>200 mg/L TSS	>80% TSS removal[b]
Enhanced (Dissolved Metals) Treatment	Dissolved copper 0.003–0.2 mg/L	Must meet basic treatment goal and exhibit >30% dissolved copper removal[b]
	Dissolved zinc 0.02–0.3 mg/L	Must meet basic treatment goal and exhibit >60% dissolved zinc removal[b]
Phosphorus Treatment	Total phosphorus 0.1 to 0.5 mg/L	Must meet basic treatment goal and exhibit ≥50% TP removal[b]

Source: Ecology (2011).

[a] The upper 95 percent confidence interval around the mean effluent concentration for the treatment system being evaluated must be lower than this performance goal to meet the performance goal with the required 95 percent confidence.

[b] The lower 95 percent confidence interval around the mean removal efficiency for the treatment system being evaluated must be higher than this performance goal to meet the performance goal with the required 95 percent confidence.

mg/L – milligrams per liter
TSS – total suspended solids
Cu – copper
Zn – zinc
TP – total phosphorus

For basic, enhanced, and phosphorus treatment with goals that are expressed as a minimum removal efficiency (i.e., 80 percent TSS removal, 30 percent dissolved Cu removal, 60 percent dissolved Zn removal, and 50 percent TP removal), bootstrapping will be used to compute the 95 percent confidence interval around the mean removal efficiency for each parameter. The lower 95 percent confidence limit will then be compared to the applicable performance goal. If the lower confidence limit is higher than the treatment goal, it can be concluded that the BSM blend met the performance goal with the required 95 percent confidence.

For the basic treatment with a goal that is expressed as a maximum effluent concentration (i.e., 20 mg/L TSS), bootstrapping will be used to compute the 95 percent confidence interval around the mean effluent concentration. The upper 95 percent confident limit will then be compared to the applicable performance goal. If the upper confidence limit is lower than the treatment goal, it can be concluded that the BSM blend met the performance goal with the required 95 percent confidence.

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APPENDIX A

Supplemental Toxicological and Dosing Experiments

Supplemental Toxicological Experiments

In the scope of work and QAPP for the BSM Phase 2 Study (C1800070), the toxicological endpoints included coarse morphometric features such as growth (embryo length), eye development (eye area), and various cardiovascular abnormalities (edema, heart deformities). A collaboration between WSU's Puyallup Research and Extension Center (Dr. Jenifer McIntyre) and the Vancouver Campus (Dr. Allison Coffin) recently published in Nature (Young et al. 2018) found that fish embryos (zebrafish and coho salmon) exposed to stormwater runoff during development had fewer peripheral sensory neurons than unexposed controls. These surface neurons detect water flow and alert fish to the movement of predators. Importantly, the researchers found that compost-based BSM used to treat more than one season of stormwater runoff may not prevent this neurotoxicity (Young et al. 2018).

If funding is secured through SAM or other sources, the supplemental toxicological analysis would add neurotoxicity as an endpoint to the existing morphological analyses as well as one additional toxicological analysis for a total of six analyses (five are proposed in the existing scope of work).

Supplemental Dosing Experiments

The scope of work and QAPP for the BSM Phase 2 Study indicate eight BSM blends will be flushed with deionized water and then dosed five times with stormwater. Each blend will be replicated three times for a total of 24 columns. This dosing experiment will deliver a water volume to each column representing approximately 33 percent of a typical Seattle water year.

If funding is available, the supplemental dosing experiments would increase the dosing events from five (current scope of work) to 29 events and deliver a water volume to each column representing two Seattle water years for one or two top performing BSM blends. Increasing the dosing from 33 percent of one to two water years allows for additional toxicological analyses necessary to assess the ability of the new BSM to protect aquatic organisms longer-term.

After the first five dosing events, the one or two top performing BSM blends will be selected and those three to six columns would be dosed 25 more times. Four additional effluent samples would be collected approximately every seven doses, and the effluent water from the intermediate dosing events discarded. The effluent samples will be collected and analyzed following the same procedures described in Sections 6 and 7. The toxicological analyses will also follow the same procedures described in Sections 6 and 7 for the first five effluent samples; however, one additional toxicological analysis will be added (see description of Supplemental Toxicological Experiments above). Table A-1 provides details for the extended dosing regime.

Table A-1. Extended Dosing Regime.					
Dosing Event	**Day**	**Volume Applied (liters/column)**	**Equivalent Storm Size (inches)**	**Cumulative Rain (inches)**	**Percent Water Year (Seattle)**
Dose and Sample 1	1 and 2	35.62	2.64	1.26	4
Dose and Sample 2	8 and 9	35.62	2.64	3.90	11
Dose and Sample 3	15 and 16	35.62	2.64	6.54	18
Dose and Sample 4	23 and 24	35.62	2.64	9.18	26
Dose and Sample 5	30 and 31	35.62	2.64	11.82	33
Dose 6	38	35.62	2.64	14.46	40
Dose 7	39	35.62	2.64	17.10	48
Dose 8	40	35.62	2.64	19.74	55
Dose and Sample 6	47	35.62	2.64	22.38	62
Dose 10	54	35.62	2.64	25.02	70
Dose 11	55	35.62	2.64	27.66	77
Dose 12	56	35.62	2.64	30.30	84
Dose 13	63	35.62	2.64	32.94	92
Dose 14	64	35.62	2.64	35.58	99
Dose 15	65	35.62	2.64	38.22	106
Dose and Sample 7	72	35.62	2.64	40.86	114
Dose 17	79	35.62	2.64	43.50	121
Dose 18	80	35.62	2.64	46.14	128
Dose 19	81	35.62	2.64	48.78	136
Dose 20	88	35.62	2.64	51.42	143
Dose 21	89	35.62	2.64	54.06	150
Dose 22	90	35.62	2.64	56.70	158
Dose and Sample 8	97	35.62	2.64	59.34	165
Dose 24	104	35.62	2.64	61.98	172
Dose 25	105	35.62	2.64	64.62	180
Dose 26	106	35.62	2.64	67.26	187
Dose 27	113	35.62	2.64	69.90	194
Dose 28	114	35.62	2.64	72.54	202
Dose and Sample 9	115	35.62	2.64	75.18	209

APPENDIX B

Quality Assurance Worksheets

Data Quality Assurance Worksheet: BSM Phase 2 Study (water)

Columns:			**Entry date**		**Page**	**1**	**of** **1**
Laboratory/Parameters:			**Checked by:**				
Sample Date/Sample ID:			**Sample collection time:**				

Parameter	Completeness/ Methodology	Pre-Filter Holding Time		Total Holding Time		Lab Method Blanks/ Reporting Limit		Surrogate Recovery (% Recovery)		Matrix Spikes (% Recovery)		Lab Duplicates (RPD) **		Field Duplicates (RSDp)***		Rinsate Blanks		Lab Control Standard (% Recovery)		ACTION
		Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	Reported	Goal	
pH	EPA 150.2		15min‡		24hr		NA		NA		NA		NA		≤35%		NA		NA	
Total Suspended Solids	SM 2540D		7dy		7dy		≤1.0 mg/L		NA		NA		≤10%or± 2xRL		≤35%		<2xRL		80-108%	
TP	4500-P J		NA		28dy		≤0.008 mg/L		NA		±25		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Ortho P	4500-P G		15min‡		28dy		≤0.004 mg/L		NA		±25		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Nitrate+nitrite	EPA 300		48HR		48hr		RL≤0.10 mg/L Blanks<50% RL		NA		±10		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals total (Cd)	EPA 200.8		NA		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals diss (Cd)	EPA 200.8		24hr		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals total (Cu)	EPA 200.8		NA		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals diss (Cu)	EPA 200.8		24hr		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals total (Pb)	EPA 200.8		NA		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals diss (Pb)	EPA 200.8		24hr		6mo		≤0.1 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals total (Zn)	EPA 200.8		NA		6mo		≤2.5 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
Metals diss (Zn)	EPA 200.8		24hr		6mo		≤1.0 µg/L		NA		±30		≤20%or± 2xRL		≤35%		≤2xRL		±10	
TPH (diesel)	NWTPH-Dx		NA		14dy		0.25 mg/L		NA		±50		≤50% or ±2 × RL				≤2 x RL		±50	
TPH (motor oil)	NWTPH-Dx		NA		14dy		0.5 mg/L		NA		±50		≤50% or ±2 × RL				≤2 x RL		±50	
PAH	GC/MS		6hr		7dy		0.01 µg/L		NA		30-160		30-160%				≤2 x RL		30-160	
Fecal coliform bacteria	SM 9222D		6hr		8hr		<1 CFU/100mL		NA		NA		≤35%or± 2xRL		≤35%		NA		NA	

****** The relative percent difference (RPD) must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.

******* The pooled relative standard deviation (RSDp) will only be calculated for values that exceed 5 times the RL. Reported values are for the following pooled duplicates:_____

‡ EPA requires field filtering and pH reading within 15 min of collection of the last aliquot. This is generally not feasible with composite or flow weighted composite sampling.