Final Quality Assurance Project Plan

Bioretention Hydrologic Performance Study

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1.0 Title Page, Table of Contents, and Distribution List

Quality Assurance Project Plan

Bioretention Hydrologic Performance Study

February, 2016

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2.0 Abstract

While the storage and infiltration capability of bioretention facilities is generally acknowledged, little data exists to verify the hydrologic performance of these facilities. Use of bioretention is widespread in the Puget Sound region and expected to increase in the region resulting from requirements of the NPDES municipal permits. State and local governments are eager to evaluate and ensure that new bioretention facilities constructed under the Washington State Department of Ecology's (Ecology) Stormwater Management Manual for Western Washington (SWMMWW; Ecology 2014) can be built to attain desired performance. Reasons for observed performance discrepancies will be identified to provide feedback on design, construction, maintenance, and/or modeling of bioretention facilities to attain desired performance.

Meeting expected infiltration and overflow conditions from bioretention facilities ensures downstream flows and groundwater receiving water are protected to the extent planned, and ensures water quality treatment is met for the desired treatment volume of runoff events to both streams and groundwater. Saturation levels and durations resulting from the actual performance in bioretention facilities may also affect survival, composition, and health and maintenance of the facility vegetation, which may, in turn, have further impacts on infiltration performance. Conducting a performance assessment of bioretention facilities as part of the "adaptive management" process is essential to ensuring implementation of effective low impact development (LID) facilities in the Puget Sound region.

The approach of the current research project is to conduct inflow and outflow hydrologic monitoring at ten qualifying bioretention facilities selected throughout the Puget Sound region. Geotechnical and hydrogeologic analyses of bioretention soil mix and native soil, ground water level monitoring, infiltration testing and vegetation monitoring will also be conducted. The flow monitoring and site conditions results will then be compared with the hydrologic design model predictions developed based on the design of the facility. Regional application of the project will come from the selection of facilities for study from a wide range of conditions around the Puget Sound region.

Based on the range of sampled facilities, lessons drawn from the study will inform our understanding of the suitability of these LID BMPs across a range of soil conditions and micro-climates. At the site, we will learn-specific scale, lessons regarding design, construction, maintenance, and modelling of bioretention facilities. The final report will provide a qualitative analysis on the larger set of facilities that were assessed for monitoring in the study. If appropriate, the final report may also include recommendations for improvements to the Western Washington Hydrology Model (WWHM) bioretention modeling algorithms to better and more accurately represent observed actual field conditions. .

3.0 Background

The goal is to implement a regional bioretention infiltration effectiveness study as part of the Regional Stormwater Monitoring Program (RSMP). Funding for this current project comes from the RSMP which is a collection of Western Washington Stormwater Municipal Permittees. Prior lead-up work to this project, funded by Ecology, included a literature review and summary of low impact development performance, which includes a summary of findings on the hydrologic performance of bioretention facilities (Taylor and Cardno TEC, 2013).

Findings from this report state:

"The literature review indicates substantial flow volume reduction and water quality improvements result from the use of LID technologies. Site specific volume reductions on the order of 50 to 90 percent are common for each of these technologies, with bioretention facilities appearing to show the highest degree of volume reduction, followed by permeable pavement and green roof facilities. Peak flow reduction and increased lag times coincidentally result from LID volume reduction. The critical design element to the ultimate volume reduction for any of these facilities is the design storage volume relative to the inflow volumes. Success of LID implementation will then depend on accurate sizing that takes site specific conditions into account."

The report also recommends that the most important effectiveness study to be carried out should be to document "the accuracy of sizing of LID designs for volumetric performance relevant to the Puget Sound region, including local exfiltration conditions unique to the region."

The current study design is intended to conduct performance studies that would indicate the accuracy of constructed bioretention facility performance relative to their design performance expectations for a geographically wide range of locations and conditions.

3.1 Study area and surroundings

Ten bioretention facilities have been recommended for monitoring and analysis compared to their designs. These facilities were selected from a range of approximately 23 projects containing approximately seventy different facilities from throughout the Puget Sound region (see Appendix A for a summary of the site selection process, and the sites selected). All seventy facilities were evaluated in the field, and using supporting design drawings, hydrologic modeling parameters, geotechnical reports, and technical information reports (TIRs) when available. The set of overall bioretention facilities selected represent facilities from Bellingham to Olympia and Issaquah to Poulsbo within the Puget Sound Basin. Corresponding to this geographic range, the selected facilities represent a wide range in surficial geology, rainfall, and contributing drainage areas and intensity of pollutant sources in the contributing areas.

3.1.1 Logistical problems

As with most environmental monitoring, the logistical problems anticipated for the project are related to operation of flow monitoring equipment under adverse weather and flow conditions, and exposure to public access with the threat of vandalism or accident. Typical logistical problems will be retrofitting problematic inflow and outflow hydraulic infrastructure to allow accurate measurement of stage and flow. Setup and downloading of electronic equipment will require access to the equipment immediately before and after predicted large storm events to ensure accurate and complete collection of data. The sites will be located in public areas, predominantly at roadways, parking lots, and driving lanes in public facilities.

Solutions to the logistical challenges will be through the use of innovation and protection of equipment based on the experience of the monitoring practitioners on the project team. This experience includes aptitude in constructing customized retrofit devices to focus flows for more accurate measurement, and the use of protective encasements where feasible. Temporary removal and redeployment may be used in some cases.

3.1.2 History of study area

Population growth and the coincident development of impervious stormwater draining surfaces has been significantly spreading throughout the Puget Sound region since the beginning of European settlement. The hydrologic impacts of stormwater runoff on receiving waters has been well documented for almost three decades. These include principally the increase in peak flows and volumes being discharged to receiving water stream channels resulting in sediment delivery to streams, stream channel incision, reduction in base flows, reduction in instream fish habitat diversity, and reduction in biotic complexity.

The response for improved control of these impacts is largely centered in the use of stormwater permits and the SWMMWW (Ecology 2014). The manual provides minimum requirements for new and redeveloped stormwater management systems that rely heavily on the use of bioretention. Taylor and Cardno TEC (2013) provide an extensive summary of literature findings on the hydrologic performance of bioretention, including some projects monitored in the Puget Sound region.

3.1.3 Contaminants of concern

Not applicable. No water sampling for pollutants or other water constituents will be conducted as part of the current study.

3.1.4 Results of previous studies

Taylor and Cardno TEC (2013) provide an extensive summary of literature findings on the hydrologic performance of bioretention, including some projects monitored in the Puget Sound region. The primary conclusions relevant to bioretention were that:

> "Available volumetric storage (abstraction volume), together with the selected design storm duration - return interval, appears to be the key design element that will determine volumetric reduction performance of individual facilities. Water quality performance will largely follow this volumetric reduction sizing."

And,

> "Knowledge of site specific local subsurface exfiltration rates and groundwater levels, appears to be a key to successful programmatic design of LIDs. Volume reduction in LIDs is largely seen for small to medium storms, but increasingly less so for larger storms."

The subject of this investigation is whether the designed volumetric storage and expected exfiltration conditions are attained in constructed bioretention facilities.

3.1.5 Regulatory criteria or standards

State regulatory standards for performance of bioretention facilities reside in the minimum requirements of the SWMMWW (2014 and previous versions).

The 2012 Ecology stormwater manual includes three minimum requirements for which bioretention facilities can be used, and actual performance of the facilities in meeting these requirements will be assessed. These minimum requirements are:

Minimum Requirement (MR) #5: Low Impact Development (LID) Performance Standard. This is a flow duration standard where developed mitigated flows cannot exceed predevelopment flows for the range of flows between 8% of the 2-year peak flow and 50% of the 2-year peak flow.

Minimum Requirement #6: Water Quality Treatment Performance Standard. This is a volume standard where at least 91% of the total developed mitigated runoff volume must be treated in a water quality treatment facility.

Minimum Requirement #7: Stream Protection Flow Control Performance Standard. This is a flow duration standard where developed mitigated flows cannot exceed predevelopment flows for the range of flows between 50% of the 2-year peak flow and the full 50-year peak flow.

Not all bioretention facilities are required to be designed to meet all three minimum requirements. However, the individual facility's ability to meet all three minimum requirements will be evaluated to quantify the actual performance of each facility monitored and modeled.

4.0 Project Description

The overall value in the use of bioretention (and other LID stormwater facilities) will depend firstly on the accuracy with which constructed facilities meet their hydrologic performance expectations. If facilities do not infiltrate, retain, and release flows sufficiently, receiving waters will not be protected from hydrologic impacts, and contact with bioretention soil mix may not be adequate to provide water quality treatment. If facilities are oversized, the land space may have been inefficiently used, with unnecessary cost spent on the design and construction of the facility or related flood control facilities. There may be opportunity costs as well in the loss of other possible uses.

Evaluation of bioretention hydrologic performance will provide feedback to the SWMMWW modeling design process, and to engineers' design approaches, to help optimize designs for greater expected accuracy and resulting benefits.

4.1 Project goals

The project goal is to compare actual hydrologic performance of constructed bioretention facilities around the Puget Sound under a variety of storm conditions with the modeled performance from the same facility using WWHM2012. Results are anticipated to demonstrate the relative importance of site characteristics, design, construction, maintenance, and modelling variables.

Communication goals for the project are to provide presentations to the SWG and Ecology to elicit feedback on the project. These will be done at important junctures of the progress of the project. A draft report of the project findings will be provided to the SWQ and Ecology for feedback to the final.

4.2 Project objectives

The project objectives are to attain the goals stated above. Specific objectives toward the technical goals include obtaining and installing inflow and outflow monitoring instruments that accurately and precisely measure stage at a primary hydraulic device which can then be translated by a rating curve to flow. Obtaining and installing rain gages will be done to measure actual rainfall in the immediate area of the subject bioretention facility being monitored. Rainfall and flow will be measured continuously during a range of storm events to enable evaluation of the design model using the actual rainfall, runoff, and facility flow-through conditions observed. The change in the model parameters required to accurately reproduce the monitored data will reveal the accuracy of the model parameters used in the original engineering design. The comparison of the hydrologic results to the minimum requirements will also reveal the degree to which the results continued to meet or did not meet the hydrologic criteria of the SWMMWW.

Coincident with collecting flow data and comparing the design model with a model based on actual performance, the secondary objectives are to collect data characterizing the bioretention soil mix, shallow subgrade soils, infiltration rate, ponding depths, subsurface water depths, and vegetation community composition, density, root health, and maintenance activity. These additional data will be used in conjunction with hydrologic performance to support hypotheses regarding the possible mechanisms influencing the hydrologic results.

4.3 Information needed and sources

Information needed for this project include design drawings, as-built conditions, and design model parameters. Supporting information will include any other site assessments used to design the project being monitored, including geotechnical exploration logs and laboratory testing data, infiltration tests, original planting plan, construction monitoring reports, and subsequent maintenance activity. The source for all this information is expected to be from the project owner.

4.4 Target population

The target population is constructed bioretention facilities in the Puget Sound basin that met the SWMMWW design criteria at the time of their construction.

A site selection process for the ten facilities to be monitored was previously conducted, and is summarized in the technical memorandum in Appendix A.

4.5 Study boundaries

Study boundaries are the Puget Sound basin.

4.6 Tasks required

Detailed approaches and procedures for field data collection are provided in Section 8.1, Field Measurement and Field Sampling SOPs. The following tasks are required to enable field measurement and sampling.

Tasks to be conducted in this project include:

1. Specifying and obtaining rain gages, and flow and ground water monitoring equipment for all ten facilities to be monitored.
2. Installing flow and ground water monitoring equipment for all ten facilities to be monitored.
3. Operating and downloading electronic data collected at all ten facilities for the duration of monitoring.
4. Collect soil and plant information
5. Conduct data management and quality control for data collected.
6. Obtain design drawings, as-built conditions, technical information reports, construction monitoring records, and modeling parameters used in each facility design model.
7. Calibrate and run new computer models based on actual field performance data collected.

4.7 Practical constraints

Practical constraints include:

1. Retrofitting of inflow and outflow structures to enable more effective flow monitoring.
2. Travel time delays to the various site locations to maintain site equipment prior to storm events to be monitored.
3. Seasonality constraints may limit monitoring to wet season events.
4. Public exposure of the monitoring equipment may result in damage or vandalism.
5. Subsurface exploration is constrained by below ground utilities (underdrains) and difficulty in advancing hand tools in hand exploration borings.

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

1. William Reilly, Project Municipal Sponsor and Contract Administrator
   City of Bellingham
   Stormwater Manager
   Manage execution of the contract with Ecology, including invoicing and progress reporting.

2. Douglas Beyerlein, P.E., Prime Consultant and Hydrologic Modeling Lead
   Clear Creek Solutions, Inc.
   Provide consultant team management, and team administration with the City of Bellingham. Conduct modeling tasks for the project.

3. William J. Taylor, Principal Investigator and principal author of project reports.
   Taylor Aquatic Science
   Lead design of overall project approach. Write project reports with contributions from team members.

4. Bryan Berkompas, Flow Monitoring and Data Collection Lead
   Cardno GS, Inc.
   Specify approaches and equipment, and conduct installation, maintenance, data collection, and management for all surface flow and rainfall data collection.

5. Jennifer H. Saltonstall, L.G., LHg., Hydrogeologic/ Geotechnical Data Collection and Bioretention Soil Assessment Lead
   Associated Earth Sciences, Inc.
   Specify approaches and equipment, and conduct installation, maintenance, data collection, and management for all well point and ponding data collection.

6. Anne Cline and Chris Wright, Vegetation Monitoring Leads
   Raedeke Associates, Inc.
   Specify approaches and equipment, and conduct field data collection and management for all vegetation monitoring procedures.

5.2 Special training and certifications

No specific certifications are required. All team members have the experience required for their role.

5.3 Project schedule

Because of the wet season requirement needed to obtain sufficient hydrologic data, the schedule revolves around the period October through May, for a maximum duration of five months. Subsurface water and surface water level data will be collected continuously and simultaneously with storm event monitoring. The sampling period may be extended as interest has been expressed by Ecology and the SWG to capture enough storm events to make the findings viable.

5.4 Limitations on schedule

Limitations on schedule will be related largely to completion of contracting to enable starting data collection from the beginning of the wet season, purchase of monitoring instrumentation, and the availability of storm events in a given wet season. In addition, the project monitoring duration is presently funded for five months of monitoring (Table 1). This will be the limit of the project monitoring period. The SWG has expressed interest in conducting a longer duration of monitoring, and has requested cost estimates for additional monitoring, including monitoring during the summer season, and monitoring for a complete year.

5.5 Budget and funding

Proposed scope task and budget levels for Phase II monitoring and reporting are provided in Table 1. Funding is from the Regional Stormwater Monitoring Program which is a cooperative of municipal stormwater permittees, and is administered by Ecology.

6.0 Quality Objectives

6.1 Decision Quality Objectives (DQOs)

DQOs are qualitative and quantitative statements developed using a data quality objective process. This process clarifies study objectives and defines the appropriate types and amounts of data and tolerable levels of potential errors. The DQOs for this project are:

1. Sites selected have known designs and as-built information.

   Existing original designs and as-built conditions will be collected from the project jurisdictions and design engineers. These original design features and dimensions will be compared to existing conditions.

2. The data will be generated according to procedures for field sampling, sample handling, laboratory analysis, and recordkeeping.

   Standard operating procedures for hydrologic measurements (identified also in section 8.1) will be generally followed and documentation recorded. These include, but are not limited to, Ecology (2009, 2012) and manufacturer's manuals for proper use of instrumentation.

3. Data reporting and measurement sensitivities will be established and adequate for stormwater management decisions.

   Hydrologic data sensitivity and precision have been determined and reported by the manufacturers. Error estimates for the rain gages and Thel-mar weirs to be used are reported as 5% or less. Grain size distribution is likewise reported as 5% by the soil laboratory to be used.

4. Creation of site-specific bioretention hydrologic performance models using WWHM2012 with field-measured input.

   The model results will reflect field measurements, input data accuracy, and input model assumptions. If the model results do not accurately reflect the monitoring data results (within 10% outflow volume error for the entire monitoring period) then input data will be reviewed and possible sources of error identified. No calibration of WWHM2012 model parameters or algorithms will be attempted.

Once established, DQOs become the basis for measurement quality objectives (MQOs), which are discussed for both hydrological, precipitation, and soil data under each heading in this section.

6.2 Measurement Quality Objectives

MQOs are the acceptance threshold for data, based on the quality indicators (described below) and are specifically used to address instrument and analytical performance. For this project the MQOs will focus on completeness, sensitivity and accuracy of measuring a wide range of hydrologic conditions in Western Washington.

6.2.1 Targets for Precision, Bias, and Sensitivity

6.2.1.1 Precision and Percent Error

Level of precision, or repeatability, for the instantaneous stage measurements for flow, ponding, and subsurface water elevations are expected to be 2 mm or less based on experience of the hydrologic monitoring field staff. Translation of the stage measurements for inflows and outflows to flow rate will result in flow rates within 3 to 5 percent of the true flow rate as reported by the manufacturers of Thel-mar weirs as percent error (Thel-mar Company 1995) and Harmel et al. (2006).

Precision will be tracked by recording observed depths in the field, replacing the measurement instrument, and recording the repeated observation in the field.

Precision for precipitation is also expected to be highly repeatable, within 1 mm rainfall, and is also reported to be within 5 percent error of the true rainfall, as reported in the product specifications by Hydrological Services (Hydrological Services 2008).

While the inherent percent error of the instruments is stated based on the manufacturers' claims for precision and accuracy, the most important means for maintaining the accuracy of the measurements will be field maintenance of the instrumentation (Harmel et al. 2006). Maintenance of equipment in the field will generally follow Ecology (2009) standard operating procedures for conducting stream hydrology site visits. In addition, site visitation for downloading data from each site will be roughly every two weeks during the five month monitoring period, but site visits will be adapted to be conducted immediately prior to anticipated large storm events as possible within the budget.

Table 1. Bioretention Hydrologic Performance Study

5.6 Budget and Funding

Detailed scope of work and budget

	B'ham	B'ham		P.I.		Modeling		Stormwater				City of Bellingham		Geotechnical Assessment			Plant Community		
				Consultant		Consultant		Monitoring Consultant				Monitoring					Assessment/Download		
	PM	Finan. Mngt		PM		Modeler		Lead	Field 1	Field 2		Lead		Lead	Field 1/GIS		Lead	Field 1	
	$86.25	$49		$120		$125		$150	$95	$95		$61.52		$150	$85		$132	$85	
3.3 Prepare For and Implement Site Monitoring Installation																			
~~3.3.1 Write common QAPP for all sites~~																			
~~3.3.2~~ Install inflow and outflow monitoring stations at ten (10) sites																			
i. organize gear logistics for installation visits								8	12	8				4	4				
ii. conduct installation visits (20 visits)																			
equipment assembly and bench test								24	60	20									
installation visits (10 sites)				40				110	110										
iii. organize installation site documentation				16				2		10									
iv. prepare data downloading training material				8				16	16	4				4					
for local staff to implement/ provide tel. support																			
3.4 Conduct Stage Recording Downloading and Data Management																			
3.4.1 Visit sites to download avg. bi-weekly, 5 months, 8 of the ten sites.								36	180	144		58.5		20					
3.4.2 Organize downloaded data and manage data base (from 10 sites)								6	25			9.75							
3.4.3 Data review and correction								20	100					6	30				
3.4.4 troubleshooting				8				16	16	8				20					
3.4.5 Groundwater data analysis (subsurface flow)														40					
3.5 Gather Additional Site Specific Data from On-site and Engineering Design																			
3.5.1 Characterize shallow subgrade soil and groundwater conditions				4										40	80				
3.5.2 Measure infiltration rates				4										50	100				
3.5.3 Install well points				4										2	20				
3.5.4 Conduct geotechnical laboratory testing														2	10				
3.5.5 As-built dimensions, esp. bottom area to side slope				4													15	0	
3.5.6 Characterize vegetation community				4													85	0	
3.5.7 Conduct data analysis for data collected/ GIS Gint (surface flow/soil)				4				40						40	110		4	16	
3.6 Modeling Comparison between Actual Performance and Design Model																			
3.6.1 Format collected performance data for site comparison				1		80													
3.6.2 Set up design models				4		80													
3.6.3 Compare design model results with actual performance				8		40													
3.6.4 Identify result differences				8		40													
3.6.5 Produce summary comparisons				8		40													
3.7 Project Results Reporting																			
3.7.1 Write draft report	24			120		80		24	40					24	12		24	16	
3.7.2 Write final report	16			40		40		4						4			4		
Phase II Hours	40	0		285		400		306	559	194		68.25		256	366		132	32	
Phase II Labor Costs	$3,450.00	$0.00	$3,450.00	$34,200.00	$34,200.00	$50,000.00	$50,000.00	$45,900.00	$53,105.00	$18,430.00	$117,435.00	$4,198.74	$4,198.74	$38,400.00	$31,110.00	$69,510.00	$17,424.00	$2,720.00	$20,144.00
Phase II ODCs			$0.00		$1,515.20		$0.00				$87,737.39		$0.00			$16,667.40			$436.00
Phase II Total Costs			$3,450.00		$35,715.20		$50,000.00				$205,172.39		$4,198.74			$86,177.40			$20,580.00

Subsurface exploration, geotechnical laboratory and infiltration testing is used to characterize bioretention soil and underlying native subgrade. Variability in bioretention soil exists due to the type and quality of compost and aggregate, the supplier's method of mixing, the method of placement during construction, and post-placement changes due to planting, saturation and natural soil processes that occur as soil ages. Variability in native subgrade materials exists both laterally and vertically due to the nature of sediment erosion and deposition through geologic time. Conditions should be expected to vary between explorations.

Soil analyses will include organic matter content of the bioretention soil mix, soil sieving for grain size distribution. Percent error for these measurements is approximately 5% as reported by the project analytical laboratory, NW Agricultural Consultants. A summary of laboratory reporting methods, sensitivity, and detection limits is presented in Table 2.

Vegetation identification precision will be based on the plant ecologist's knowledge of common plants used in bioretention facilities, or identified in the field with field guides. Stem density and estimates of percent cover will be collected for a minimum of twenty five percent of the bioretention area. Within these sampled areas, percent error of stem density and percent cover is expected to be within 5 percent.

Table 2. Laboratory methods, sensitivity, detection limits, and lab accreditation for soil samples to be collected from each of the ten bioretention facilities to be monitored.

Analyte	Matrix	Number of Samples	Expected Range of Results	Analytical Method	Sample Preparation Method/ Special Methods	Sensitivity/ Detection Limit	Lab/ Accreditation
Organic Matter	Soil	3	Dependent on Soil Type	ASTM D2974	No separate preparation method	A scale meeting the requirements of ASTM D 4753 and a 0.01 g readability	AASHTO, A2LA
Particle Size Analysis of Soils	Soil	3	Dependent on Soil Type	ASTM D422	ASTM D421	A scale sensitive to 0.1 percent of the mass of the sample retained on the No. 10 sieve.	AASHTO, A2LA

6.2.1.2 Bias

Flow during each storm flow event, and pond and ground water levels, will be measured with stage recorders for the inflow, outflow and water surface stages. Drift can occur as a source of bias in the sequence of measurements, and will be evaluated and corrected for during data quality assurance review. Other sources of bias include physical disturbance or debris obstruction of the weirs, or the pond and ground water level stage measurement instruments. Avoidance of bias will be achieved through field checking of the sites' equipment and calibration either on a regular or storm event basis.

For the geotechnical engineering and hydrogeologic data collection, the primary concern for bias relates to number and frequency of soil sample collection. Soil sample frequency will be determined by budget. At a minimum, three samples of bioretention soil and two samples of native subgrade soil will be collected for each facility. One set of samples from each facility will be tested for grain size distribution.

Bias in vegetation stem density and percent cover will be minimized by estimates being conducted by a single ecologist in the field, with plant identification cross checked with other staff ecologists. Twenty five percent of each bioretention facility will be sampled for vegetation parameters.

6.2.1.3 Sensitivity

Flow, ponding and groundwater levels will be detected by electronic instrumentation. The limit to sensitivity of detection is based primarily on whether the instrument is electronically functional at the time. Equipment malfunction will cause either lack of detection at all or large errors due to obstructions in the field. While sensitivity of stage recording devices may be recorded by the instruments at greater than 0.01 feet, the results will be reported to the nearest 0.01 feet.

Soil analyses to be conducted include organic content and gradation for both bioretention soil mix and subsurface soils. Sensitivity for both of these is 0.1%.

6.2.2 Targets for Comparability, Representativeness, and Completeness

6.2.2.1 Comparability

Comparability of results from this project will be from the storm-based measurements at each of the inflows and outflows from each facility. This is the primary basis of the evaluation of the hydrologic performance of bioretention facilities in the scientific literature (Taylor and Cardno, 2013). Flow measurements will utilize calibrated manufactured weirs or similar primary devices for comparability to similar studies.

Numerous candidate sites were evaluated in the field, and by reviewing design drawings, to best assure the sites chosen were accessible and suitable for accurate flow monitoring for comparison to other similar monitoring projects. A summary of this selection process is provided in Appendix A.

The subsurface exploration and geologic/hydrogeologic characterization will be conducted in accordance with methods discussed in "Guidelines for Preparing Engineering Geology Reports in Washington," prepared by: Washington State Geologist Licensing Board, November, 2006.

6.2.2.2 Representativeness

Representativeness of this project site selection is based on geographic distribution of subject facilities, representativeness of storm sizes monitored for model performance evaluation, range and duration of storm event and water surface levels, and direct collection of additional soil and vegetation data from each facility.

- Sites to be monitored are distributed from Bellingham to Olympia north to south, and Issaquah to Poulsbo east to west. See Appendix A for distribution of proposed facilities.
- Storm flow monitoring will be conducted for the duration of five months, with the goal to collect flow data for five storm events at each of the ten facilities.
- Ground water and pond stages will also be monitored continuously during five months of the wet season to provide representativeness of continuity of stages during the wet season.
- Surface infiltration rates will be measured at each of the facilities at least at one location, and soil samples will be collected at three locations within each facility.
- Vegetation will be assessed for during mid to late summer, prior to leaf fall.

6.2.2.3 Completeness

Because the hydrologic data to be collected will be used to evaluate the WWHM bioretention input parameters for each of the ten facilities, the degree of data collected will affect the evaluation analysis. Data collection goals include:

- Inflow and outflow measurements from a minimum of five storm events collected during the five-month monitoring period is recommended for the completeness needed for evaluation of the modeled bioretention results.
- Storm sizes to be monitored should range from approximately 0.25 to at least 1.0 inches over 24 hours.
- Ponding depths and subsurface water elevations will be collected for at least five months during the wet season to provide additional model information along with the inflow and outflow monitoring.
- Infiltration rates and soil samples will be collected from each facility.
- Vegetation composition and density will be collected at each facility.

7.0 Sampling Process Design (Experimental Design)

7.1 Study Design

The project study design is a modeling-based assessment established on field measurements of inflow, outflow, ponding and groundwater levels, bioretention soil infiltration rates, soil composition, and vegetation type, density, and maintenance. The intent is to provide adaptive management feedback to the bioretention design modeling process using the WWHM 2012, (or newer version as agreed upon by the RSMP Coordinator). The intended benefits of the project are to identify apparent constructed bioretention facility conditions that affect the actual hydrologic performance of the facility, and use that information to help improve future bioretention designs.

The project objective is to compare actual hydrologic performance of constructed bioretention facilities with the modeled performance from the same facility. Modeled results from the as-built facility will be compared to monitored performance data. .

The comparison of the model results with the field results will either demonstrate the ability of the model algorithms to accurately represent real-world bioretention facility conditions or will identify limitations in the modeling that may require future changes in computational techniques or parameter input values. With a range of facilities the comparisons will test the strengths and weaknesses of bioretention facility performance over a wide-range of conditions involving local bioretention soil mix composition, surficial geology, infiltration rates, groundwater fluctuation, actual constructed site geometry, and vegetation density, health and maintenance.

The final product will be a set of performance comparisons between the model and observed performance. Key factors such as native soil types, climatic conditions, errors in planning/modeling or model input values that best describe observed differences will be discussed in a final report. In addition, recommendations may be made for changes needed in the design, construction, and maintenance of bioretention facilities to improve their hydrologic performance.

If unable to explain observed differences through construction, maintenance or site characteristics, then a recommendation may be made to the WWHM 2012 model input. The recommendations will include potential parameter value changes (for example, for the engineered soil mix), regulatory modeling changes (for example, use of the KSat Safety Factor), and changes in field measurements techniques (for example, native soil infiltration rates). All of these recommendations will assist state and local governments in improving and updating their stormwater LID regulations.

The assessment of the facilities' performance in terms of the three minimum performance requirements in the SWMMM (see Section 3.1.5) will allow us to quantify how well these facilities are performing (even if they were not specifically designed to meet all three minimum requirements). Any deficiencies noted will not be considered a failure of a specific facility but an indication of what key factors significantly influence the actual performance of the facility. This will assist in focusing on possible future changes to the design standards and/or the performance standards.

For each bioretention facility the evaluation procedures to be followed include:

1. The contributing drainage area described in the technical information report (TIR) will be compared with the contributing drainage area observed at the site. The relative pervious and impervious areas draining to the site will be compared to the original model input. Apparent discrepancies in the contributing area as indicated by volume of inflow will be addressed through re-evaluating the measured rainfall and flow data, and measuring the contributing area through field measurements or satellite imagery provided by google earth.
2. The physical dimensions of the bioretention facility will be measured in the field and used to create the model for comparison.

3. The physical outlet structure configuration and dimensions of the bioretention facility will be measured in the field and used to create the model for comparison. Plan drawings will be used where measurements cannot be made due to access or other issues.
4. A new WWHM2012 model of the drainage area and bioretention site will be constructed based on the information collected in procedures 1-3 above.
5. Monitored rainfall data and runoff inflow data (if available) will be input in the WWHM2012 model. If inflow data are not available then simulated inflow data will be used instead.
6. The WWHM2012 model will be run for the monitoring period to compare simulated model results from the bioretention facility with monitored outflow data.
7. Discrepancies between the above collected data and the model data will be noted.
8. Based on all of the above information, and the results of the actual hydrologic performance of the bioretention facility, individual facility performance of the ten monitored facilities will be described in both qualitative and quantitative terms.
9. The comparison of simulated model results from the bioretention facility with monitored outflow data may result in the need to adjust the model input native infiltration rate or other parameters (for example facility dimensions or contributing area) to more accurately replicate the measured outflow data.
10. The adjusted final WWHM2012 model will be run for the entire standard WWHM2012 simulation period (40-60 years) and the model outflow results will be compared with the Ecology minimum requirements described above.

7.1.1 Field measurements

Field measurements to be collected include:

- Inflow and outflow flow measurements. These data will be collected continuously over a five month period. A range of storm event conditions are sought for the study, with a goal of a minimum of five storm events.
- Precipitation.
- Ponding level and groundwater levels.
- Soil borings and associated observations of bioretention soil, underdrain aggregate, subsurface soil, geology, and groundwater.
- Bioretention soil and subsurface sediment character and thicknesses, depth to ground water and field permeability estimates.
- Soil infiltration rates.
- Vegetation composition and density.

7.1.2 Sampling location and frequency

The location of facilities to be monitored are presented in Appendix A. All the field sampling described is to be carried out within each facility.

7.1.3 Parameters to be determined

The model to be used in this study is the WWHM 2012. The bioretention modeling module will be used with assignment of parameters in the model based on the as-built dimensions, and site conditions.

The parameters to be determined as part of the geotechnical engineering and hydrogeologic data collection include bioretention soil mix organic content and gradation, subsurface soil gradation, geologic unit, shallow ground water conditions, permeability, and fate of infiltrated water. These parameters are used to characterize shallow subgrade soil and ground water conditions, including infiltration rate.

7.2 Maps or diagram

A map of the location of the facilities to be monitored is presented in Appendix A.

7.3 Assumptions underlying design

Assumptions for this study design are that infiltration rate, soil characteristics, groundwater, and vegetation characteristics and maintenance are the primary factors affecting the hydrologic performance of bioretention facilities. We further assume that infiltration rate can be estimated by direct field measurements and compared with infiltration estimates derived from flow monitoring data. A final assumption is that each of the bioretention facilities selected to be monitored will prove to be monitorable and continue to meet the selection process criteria already carried out.

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

8.1.1 Water level and flow data collection

This study will collect water level and/or flow data from several points within each bioretention facility. Flow rates will be measured at any inlet or outlet from the facility. Water level will be measured in shallow groundwater wells as well as within the facilities themselves to determine ponding depths. Some facilities may not include all of these elements and the monitoring system will be adjusted accordingly.

8.1.1.1 Inlet Monitoring

Bioretention facilities in this study have three types of inlets: pipes, curb cuts or modeled inlets. Flow rates in piped inlets will be measured using Thel-mar weir inserts sized to fit the inlet pipes. A pressure transducer will measure water level behind the weir to determine the inlet flow rates. Curb cuts will require some modification as the flow through the cut will likely be too shallow to measure directly under all but the most extreme storm conditions. A plastic or rubber sheet will be used to line the curb cut and funnel the flow into a section of pipe. A pressure transducer and a Thel-mar weir insert at the downstream end of the pipe will be used to measure the inlet flow rate. There are a variety of shapes, sizes and expected flow rates for the curb cut inlets at the selected sites and the sheeting, pipes and Thel-mar weirs will need to be custom sized to each inlet. Additionally a small splash pad may be required at the end of the pipe to prevent erosion from the concentrated flow point. Some inlet flows may be estimated using a model rather than measurement. Some facilities have multiple roof drain inlets and the cost to monitor all of the inlets may prove prohibitive. In such cases one or two inlet monitoring systems may be rotated to each inlet for one or two rainfall events to help adjust a runoff model based on rainfall. This adjusteded model will then estimate inflow into the bioretention facility based on the measured rainfall for an event.

8.1.1.2 Outlet Monitoring

Not all of the bioretention facilities have an outlet but those that do will require outlet monitoring. Every facility in this study with an outlet pipe has an overflow structure with an outlet pipe and a sump below the pipe. Additionally, some facilities have an underdrain pipe that connects to this structure. A Thel-mar weir will be installed in the outlet and a transducer will be installed in a stilling well within the sump of the outlet structure to measure the water depth behind the weir.

8.1.1.3 Groundwater and Ponding Depth Measurements.

Monitoring wells may be installed at the facilities to measure ponding depth and groundwater surface elevations at various depths within the facility. The design of each facility will ultimately determine the number and types of monitoring wells needed at each facility. Three different types of monitoring wells may be required at a given facility. The first type of well would be installed to continuously measure the ponding depth on the surface of the bioretention cell. The ponding depth will be used in the analysis of both infiltration rates of the bioretention soil mix and overflow events at each facility. The second type of well will be installed to measure the groundwater surface level at the base of the bioretention soil mix. Data from the bioretention soil mix monitoring well will be used to track infiltration rates within the bioretention soil mix or aggregate layer (if present). The third type of well would be installed in the shallow native soils underlying the facility to monitor groundwater levels beneath the facility. The data from the wells installed into the native soils will provide information about the influence of shallow ground water conditions (if present) on the infiltration rates into the underlying soils at each facility.

The shallow ground water conditions are an important site variable. One screened well point will be installed in the foot print of the facility within the soil boring hole to obtain depth to ground water level measurements and provide a long-term ground water level monitoring station. Additional well points or wells can potentially be installed around the outside of the facility. The well point(s) will be equipped with a datalogger and then used to obtain information on ground water response to stormwater inflow and precipitation. This data will be compared to staff gauge water level data within the facility.

8.1.1.4 Rain Gauge

Precipitation data is an important part of the modeling and inlet flow verification analysis. Each site will require a nearby or on-sight rain gauge. Where possible an existing municipal rain gauge will be utilized. In order for an existing rain gauge to be applicable to this study it must be located close to the facility, be in the same isohyet as the facility, and it must be regularly maintained and calibrated by the owner. Data from the existing rain gauges will be collected from the municipality that operates the gauge. Sites that do not have a suitable rain gauge nearby will require a rain gauge to be installed as part of the monitoring system. The rain gauges installed as part of this study will be sited at or very near to the facility and will be located in an area that accurately represents the rainfall in the drainage basin of the facility.

8.1.1.5 Site Maintenance

All monitoring sites are budgeted to be visited at twice a month for routine maintenance, calibration and downloading. Some sites may require more frequent visits depending on site conditions such as sediment deposition, animals, security concerns etc. and others less. All study-related monitoring equipment will be operated and maintained per manufacturer recommendations. During each maintenance visit the field crew will:

- Download all monitoring data to a laptop and copied to a USB storage drive in the field as a backup.
- Each Thel-mar weir, pipe, and collection sheet (for curb cuts) will be inspected, cleaned and the weir will be leveled if needed.
- Each stage recording instrument and weirs will be inspected, cleaned and calibrated as necessary. Prior to removing and inspecting each transducer a level measurement will be collected behind the weir or within the well.
- Once the transducer is reinstalled a second level measurement will be collected. These level measurements will serve as the starting and ending points for any data corrections associated with sensor drift or offsets.
- Any study-owned rain gauges will be inspected to ensure that is it clean and level per the manufacturer's specifications.

Upon completion of the maintenance visit all project data will be transferred to the project database on the consultant's server. All field forms will be scanned and saved. Some sites may be maintained by the municipality that owns the facility. In these cases, the municipality will send the electronic data to the consultant for storage on the consultant's server.

8.1.2 Geotechnical Engineering and Hydrogeologic Data Collection

8.1.2.1 Subsurface Exploration

Limited information on subsurface conditions will be obtained from hand auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. One hand boring will be performed in the facility bottom and advanced to a depth of 8 to 10 feet or refusal. A second hand boring will be completed to a depth of 4 feet or refusal. Representative samples will be collected, visually classified in the field, stored in water-tight containers and transported to AESI's offices for additional classification, geotechnical testing and study. A detailed record of the observed bioretention soil, underdrain aggregate (if applicable), subsurface soil, geology and ground water conditions will be made.

The sediments will be described by visual and textural examination using the soil classification in general accordance with ASTM D2488, Standard Recommended Practice for Description of Soils. Hydrogeologic analysis and geologic unit assignment will be conducted to estimated infiltration capacity of the native subgrade sediments. At the conclusion of the excavation, each borehole will be immediately backfilled with the excavated material or completed as a monitoring well and the bioretention soil replaced.

8.1.2.2 Geotechnical Testing

The bioretention soil and native subgrade sediments will be further classified using geotechnical laboratory testing procedures. The bioretention soil will be tested for organic matter content using the Loss on Ignition test method (ASTM D2974) to estimate the percent organic matter, and the burned material will then be sieved in accordance with ASTM D422 test procedures.
The native subgrade sediments will be sieved in accordance with ASTM D422 test procedures. Hydrometer analyses will only be conducted if the native material is composed of greater than 15 percent (by weight) silt/clay.

8.1.2.3 Measure Infiltration Rates

Infiltration rates will be measured in one of two ways:

1. If adequate water supply is available and the facility footprint is relatively small, infiltration rates will be measured by full-scale testing (maintaining a constant level of water across the facility at a constant flow rate, and accurately measuring the wetted pool); or
2. When full-scale testing is not practical, infiltration rates will be measured using the Pilot Infiltration Test (PIT). The PIT is not a standard test but rather a practical field procedure recommended by Ecology. A PIT will be performed in the footprint of each bioretention facility per the guidelines for a Small- Scale Test as described in the SWMMWW (Ecology 2014).

For some facilities with underdrains, the measured infiltration rate from the above described testing will be the rate of the bioretention soil, not the underlying native subgrade. The underdrain, if present, will be observed for discharge. The field measurements will be compared to the native subgrade infiltration rate estimated based on grain size distribution methods that account for natural compaction, observations of water level response to testing in the wellpoint, and from a review of prior relevant data for the facility, if available.

8.1.3 Vegetation monitoring

Bioretention facility plant composition and density will be measured for selected monitoring sites in one of three possible approaches depending on site conditions. Only the bottom (area subject to inundation) of the bioretention cell will be sampled for vegetation.

1. For bioretention facilities that only have woody vegetation (shrubs and trees), the number of stems will be counted within the facility (density). A woody plant is considered and inventoried as a single individual, regardless of the number and size of stems emerging from a common root system. A woody sapling/tree with a single stem is also considered and inventoried as a single individual. However, a woody sapling/tree with multiple stems may be considered and inventoried as multiple individuals if the stems split below 50cm in height (along the stem). In addition to a count of the number of stems within the facility, an estimation of the percent cover of the woody vegetation within the study area will be made. The genus and species of the woody plants will be recorded as well as the wetland indicator status of the species observed.

2. For bioretention facilities with only herbaceous plant species, a quadrat along pre-determined points along a transect line(s) will be used to measure density. A 25 cm x 25 cm quadrat will be used to record the percentage of herbaceous vegetation versus the percentage of bare ground that covers each quadrat. Species will be identified to genus and species and note made of the wetland indicator status of the observed species. At a minimum 25% of the unit will be sampled.

3. For bioretention units with woody and herbaceous species, both sampling methods will be used. Stem density will be counted for the woody species and quadrats will be used to estimate density of herbaceous vegetation.

4. For maintenance activity, the owning jurisdiction or private parties will be contacted to define and document the regular routine activities and schedule of maintenance for each facility.

Summary presentation and discussion of results will be used to provide qualitative inference on the possible role of vegetation and maintenance on the hydrologic performance at each of the monitored facilities.
Comparisons will be made to the observed composition of the vegetation community and the originally designed plant community where planting plans exist. Composition of the plant community can be used to infer the duration and frequency of inundation within the bioretention facility to further understand the hydrologic performance of the system.

8.2 Containers, preservation methods, holding times

Soil samples will be the only sample matrix collected for delivery to a laboratory for analysis. Soil samples will be collected with hand tools (shovels) and placed in one gallon zip locked plastic bags. No preservation, cooling, or holding time is applicable for these samples.

8.3 Invasive species evaluation

Equipment used in flow monitoring will be visually evaluated for debris and cleaned as needed between uses at different sample sites.

8.4 Sample ID

Subsurface explorations will be identified with GPS coordinates. Soil samples will be labeled with an exploration identification number, date, and the depth below ground surface.

8.5 Chain-of-custody, if required

Chain-of-custody protocols for soil samples collected will follow protocols used by the geotechnical consultant and soils lab. These procedures include using a chain-of-custody form documenting the delivery and disposition of the samples as they are delivered from the field collection team to the laboratory staff.

8.6 Field log requirements

Field logs containing all the following information will be maintained for all field visits, and will otherwise generally follow Ecology 2009 standard operating procedure for conducting stream hydrology site visits.

- Name and location of project
- Field personnel
- Sequence of events
- Any changes or deviations from the QAPP
- Environmental conditions
- Date, time, location, ID, and description of each sample
- Field instrument calibration procedures
- Field measurement results
- Unusual circumstances that might affect interpretation of results

8.7 Other activities

No other sampling activities are anticipated.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

Field procedures for flow monitoring are described in Section 8.1, Water level and flow data collection, and 8.6 field log requirements above. These procedures will generally be followed for routine maintenance of flow over weirs, calibration of stage measurement instrumentation for weirs and well points, and downloading of data.

It is recognized that these field procedures for maintaining the equipment for accurate measurements are the most important elements to obtaining precise measurements.

Similarly, soils sampling, infiltration rates measurements, and related observation procedures in the field will follow the ASTM and Ecology (2014) procedures identified in section 8.2 above.

9.2 Lab Procedures

The only laboratory procedures will be for soils samples. Soils lab procedures for organic matter and organic matter content will use the Loss on Ignition test method (ASTM D2974) to estimate the percent organic matter, and the burned material will then be sieved in accordance with ASTM D422 test procedures. Details of the laboratory procedures are provided in Table 2.

The native subgrade sediments will be sieved in accordance with ASTM D422 test procedures. Hydrometer analyses for particle size analysis will only be conducted if the native material is composed of greater than 15 percent (by weight) silt/clay.

10.0 Quality Control (QC) Procedures

10.1 Field and lab QC required

Soil samples quality control measures will include comparison of laboratory results with the visual manual classification as described above in Section 8.1. Apparent inconsistencies in these analyses may warrant reanalysis of archived soil samples.

For infiltration testing quality, estimated permeability (infiltration rate) from the grain size testing will compare with the field infiltration test results for consistency. If observed subsurface water levels suggest much different infiltration rates than measured, the groundwater and flow data will be reviewed to attempt to resolve any discrepancies due to water level data inaccuracy.

10.2 Corrective action processes

Corrective actions will generally be required to respond to either (1) physical failure of the precipitation and stage recording instrumentation or weirs (e.g. due to damage, vandalism, obstructions, etc.), or (2) apparently erroneous data has been collected (e.g. data gaps in data collection, bias due to drift, etc.).

Corrective actions to correct physical failures of the monitoring equipment will be implemented through inspection of monitoring equipment prior to anticipated storm events (as possible within the budget allotment and with assistance of local municipalities). If physical failures of equipment are identified prior to or during storm events, simple actions to correct the issue will be taken immediately (e.g. removing debris or reinstallation). Reinstallation of monitoring equipment will otherwise be conducted when best feasible either during or between storm events.

Identification of erroneous data will not occur until data is downloaded from each site (semi-monthly). Correction of erroneous data will be conducted through the data review and correction process (see Section 11.1).

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

11.1.1. Data management and verification

All project related data will be stored on the consultant server and backed up offsite on a daily basis. All flow, rainfall, and groundwater data will be reviewed within a week of the site maintenance visits to identify potential problems and address them to minimize data gaps or errors.

All project related flow and rainfall data will be verified using the following steps.

- Data will be reviewed for gaps and determine if the gaps can be filled with estimated or alternate data. For example, if the facility rain gauge is offline a nearby rain gauge might be used to fill in the gap. The process for filling in each gap will be documented
- Anomalies or spikes will be identified. Examples of anomalies are sudden changes in level, heavy rainfall with no measured inflow, data flatlines, etc. The process for addressing each anomaly will be documented.
- All data will be cross checked against field forms and calibration records. Sensors may need to be adjusted for drift or offset and the flow rates recalculated.
- Data may also be compared across rainfall events. Are expected yields/patterns across events consistent? Do rainfall and inlet flow rates coincide?

11.2 Lab data package requirements

Soil samples analysis results will be reported in accordance with the ASTM geotechnical testing protocols. Lab data package requirements for the soil sample analyses include the weight retained on sieves, and the quality control steps of calibration and washing of the sieves prior to analysis was completed.

11.3 Electronic transfer requirements

Laboratory data results for soil analyses are delivered as a portable document format (.pdf) file, and stored as electronic files locally on the geotechnical consultant's server.

11.4 Acceptance criteria for existing data

Existing data to be used in the project include record drawings (as-builts) for each facility, existing hydrologic model, engineering design, and infiltration tests as described above in section 4.3. These data will be used as presented, unless method or results inconsistencies are apparent, as judged by the individual discipline leads. Otherwise no other existing sample data (such as rainfall or flow data) is required for completion of the project.

11.5 Data presentation procedures

Field data results and WWHM Model output will be delivered in tables and graphically in the final report for the project. Electronic copies of raw data files will also be provided to Ecology.

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

The Bellingham PM will be conducting audits during the project, with a monthly frequency during the five months of active monitoring and for any subsequent data processing. The auditing process will be in regard to the active field and data processing QC steps already detailed in Sections 8.1 and 11.1 above.

12.2 Frequency and distribution of report

Project status reports will be provided to the City of Bellingham during the course of the study. A single draft report will be prepared for review by the City of Bellingham and Department of Ecology. Comments obtained for the draft report will be addressed and changes made to produce a final report. The final report will be available from the RMSP Coordinator at Ecology.

12.3 Responsibility for reports

The final report will be co-authored by William J. Taylor and Douglas Beyerlein, with contributions from the other team co-authors.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

All data generated will also be reviewed by other in-house staff associated with each discipline than those collecting the data (i.e. flow monitoring, geotechnical, hydrologic modeling, and vegetation).

13.2 Lab data verification

Laboratory soil data will be verified through review of the data results and laboratory quality control process by the project geotechnical engineer for completeness and reasonableness of results (based on the engineer's visual knowledge of the samples).

13.3 Validation requirements, if necessary

Not applicable to this study.

14.0 Data Quality (Usability) Assessment

Upon completion of the data verification the project data manager will make a final determination of the data usability. If the data meets the Data Quality Objectives (DQO) stated in this QAPP then the data will be deemed useable for meeting the study objectives. The project data manager will look at qualified data and evaluate its impact to the overall DQO. If data are rejected a determination must be made of whether the quantity and quality of the valid data are sufficient to meet the study objectives. Thorough documentation will be made of any decision to reject data as it may require additional effort to replace the intended data. Usable data is acceptable for all study related analysis.

14.1 Process for determining whether project objectives have been met

Data objectives will be met for the proposed data to be collected based on completeness and data quality of the data sets desired. These include the storm event samples (5 storms minimum), and data reviewed and corrected where needed for use in evaluation of the bioretention facility's performance; and for the minimum five month range of continuous data for pool and ground water stage data. Completeness and data quality for soil samples and vegetation characterization for each bioretention unit as described above will be required for all ten units monitored.

14.2 Data analysis and presentation methods

The results of the modeling and data collection will be presented in a methods, results, and discussion sections of the final report. Data will be presented in tabular and graphical form, and summary descriptive statistics provided. Modeling results will be presented through projected flow duration curves of the calibrated model results, as well as identification of whether the modeled results meet the minimum requirements of the SWMMWW.

Results of the study will be discussed through apparent field conditions (soil density and composition, subsurface infiltration conditions, vegetation conditions and maintenance) contributing to the end results, and referenced against peer reviewed literature.

14.3 Treatment of non-detects

Not applicable. No water sampling for pollutant or other water constituents will be conducted as part of the current study.

14.4 Sampling design evaluation

Recommendations for any perceived needed change in the study design will be provided as data is collected and reported in the monthly progress reports.

14.5 Documentation of assessment

Hydrologic performance of 10 bioretention facilities in the Puget Sound basin will be monitored during storm events and compared to the predicted modeled results for each facility. Using this comparison, and drawing from additional site data such as local bioretention soil mix composition, surficial geology, infiltration rates, groundwater fluctuation, actual constructed site geometry, and vegetation density, health, and maintenance, working hypotheses will be proposed for factors leading to the hydrologic performance observed. These working hypotheses will be supported by published literature on bioretention hydrologic performance.

15.0 References

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16.0 Appendices

Appendix A. Bioretention Hydrologic Performance Study Site Selection Process and List of Selected sites Technical Memo – Deliverables 2.2 and 2.3 Combined

Taylor Aquatic Science and Policy

Technical Memo

To:	Bill Reilly, City of Bellingham Brandy Lubliner, WDOE
From:	William J. Taylor, Taylor Aquatic Science and Policy Douglas Beyerlein, Clear Creek Solutions, Inc.
Date:	October 23, 2015
Re:	Bioretention Hydrologic Performance (BHP) Study Site Selection Process and List of Selected Sites Technical Memo – Deliverables 2.2 and 2.3 Combined

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This memo provides a summary of the site selection process and results of the site evaluations combined into one memo. As the selection process and recommended sites for selection are closely intertwined, it make sense to combine these into one product.

Background

Phase I of the BHP study involved contacting Puget Sound Basin jurisdictions to identify "candidate" bioretention facilities to be recommended for an overall list of facilities for evaluation and possible selection of a set of ten facilities for performance monitoring. The selected sites would then be monitored for inflow and outlflowing stormwater flows during Phase II. Additional site data would also be collected for groundwater and ponding levels, bioretention soil mix composition and infiltration rate, subsurface soil conditions, and vegetation composition and density as supporting information to evaluate the site performances.

Outreach to Jurisdictions, and Candidate Sites Identified and Evaluated in the Field

Jurisdictions selected for contact for nomination of potential sites came from three different sources:

1. Jurisdictions indicating interest in the BHP study during the proposal phase of the Regional Stormwater Monitoring Program (RSMP)

2. Jurisdictions identified through the Ecology Water Quality Grant program as having funded construction of a bioretention facility as part of their grant funded project, and

3. Jurisdictions that contacted the consultant team as a result of group emails from the Stormwater Work Group, the APWA Stormwater Managers Committee, and from the NPDES Stormwater Permit Coordinators forum.

Approximately twenty jurisdictions were contacted through direct telephone contact with stormwater managers or related engineers and water quality specialists to discuss the BHP study, and their thoughts on possible candidate sites within their jurisdiction.

From these twenty jurisdictions, twenty-eight facilities were recommended for possible site evaluation. Site design plans (including planting plans), technical information reports (TIRs) and modeling information was gathered for most of these facilities. Twenty-four facilities were then visited in the field for final evaluation.

Because most of the sites contained multiple cells, each with their own conditions, the site visits for these twenty-three facilities resulted in evaluation of approximately seventy individual cells.

Attachment 1 provides a list of the final bioretention facilities assessed in the field, their location, and the jurisdiction contact for the project. Figure 1 provides a map of the distribution of these sites throughout the Puget Sound Basin.

<u>Site Field Evaluation</u>

After receipt of design drawings, TIRs, and hydrologic modeling results, each consultant discipline leader evaluated their background material before assessing each site in the field. Information then assessed in the field related to each of the main disciplines for selection of the sites:

- Accessibility of inflow and outflow locations for flow monitoring feasibility
- Contributing drainage area
- Qualitative soil media composition and soil probe depths
- Plant community composition, relative density, and apparent maintenance activity

<u>Site Selection Criteria</u>

A long list of site selection criteria was prepared to help evaluate candidate sites. These criteria identified factors that could affect the feasibility of monitoring, site logistics, or later assessment of the results of Phase II. This site selection criteria checklist was previously prepared and delivered to the City and Ecology.

While the criteria checklist provides an almost exhaustive list of items that could be considered in the site selection, the final realistic considerations were limited to those items identified as “fatal flaws” for selection. Once these factors were addressed, understandably, the accessibility of flow monitoring to attain accurate hydrologic results was almost exclusively the deciding factor. The remaining criteria checklist items were nonetheless useful as a checklist reminder of factors affecting site performance and additional data collection needs.

Separate from the criteria checklist, there was a need in both the selection of candidate sites, and sites finally recommended for monitoring, to be geographically well distributed in the Puget Sound Basin to provide a wide surficial geological, meteorological, and jurisdictional representation.

Compilation of Site Information and Recommended Sites for Monitoring

Attachment 2 provides spreadsheets of information on each site used to evaluate the site conditions and existing information for selection. The spreadsheet provides additional information to that listed in the Criteria Checklist compiled by each of the consultant team discipline leads. The spreadsheets cover the disciplines of monitoring access, geotechnical conditions, hydrologic modeling background and vegetation conditions.

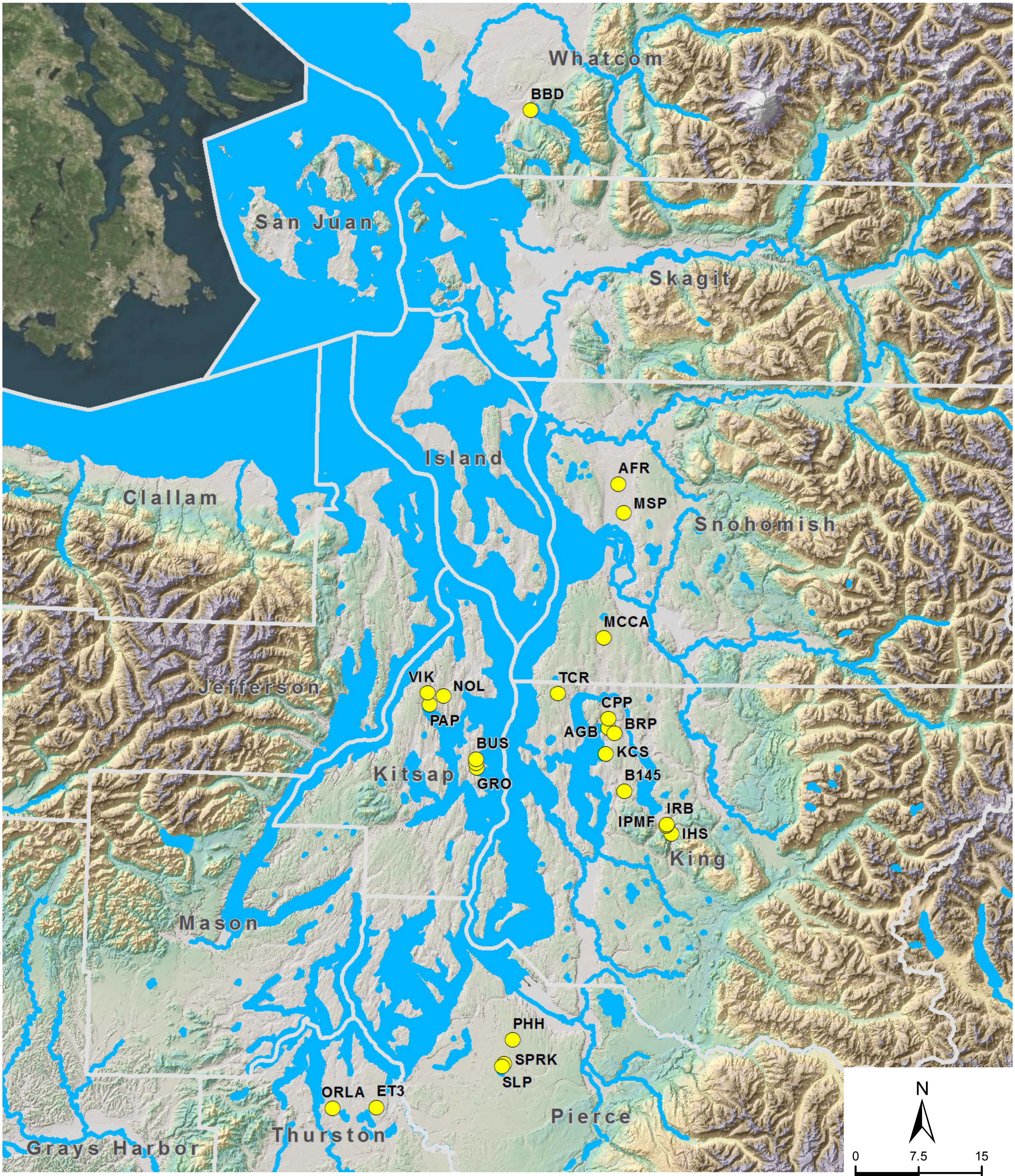
With this spreadsheet, the sites highlighted in yellow are recommended for monitoring, with a total of 10 sites highlighted.

Figure 2 provides a map of these ten sites recommended for monitoring.

Seasonal Schedule for Monitoring

Phase II of the project is intended for conducting the flow monitoring, and ground water and surface water pooling level data collection. While the flow data collection can be storm event targeted data, the ground water and pooling water levels are best collected on a continuous basis during the course of a substantial portion of the wet season to help use the continuity of these data to help reveal the infiltration patterns of the facilities, and to reflect those patterns in the model calibration process. As a result, initiation of these data collection early enough in the wet season is important for the overall quality of the model results. The storm event data collection also needs to be started early enough in the wet season to attain collection of at least storm events of a range of sizes. Of course the uncertainty of the wet weather conditions will affect the data collection, but starting data collection by some time in January would be the latest effective time to start.

If you have any questions, please call Bill Taylor or Doug Beyerlein.



REFERENCE:

NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION.

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associated earth sciences incorporated

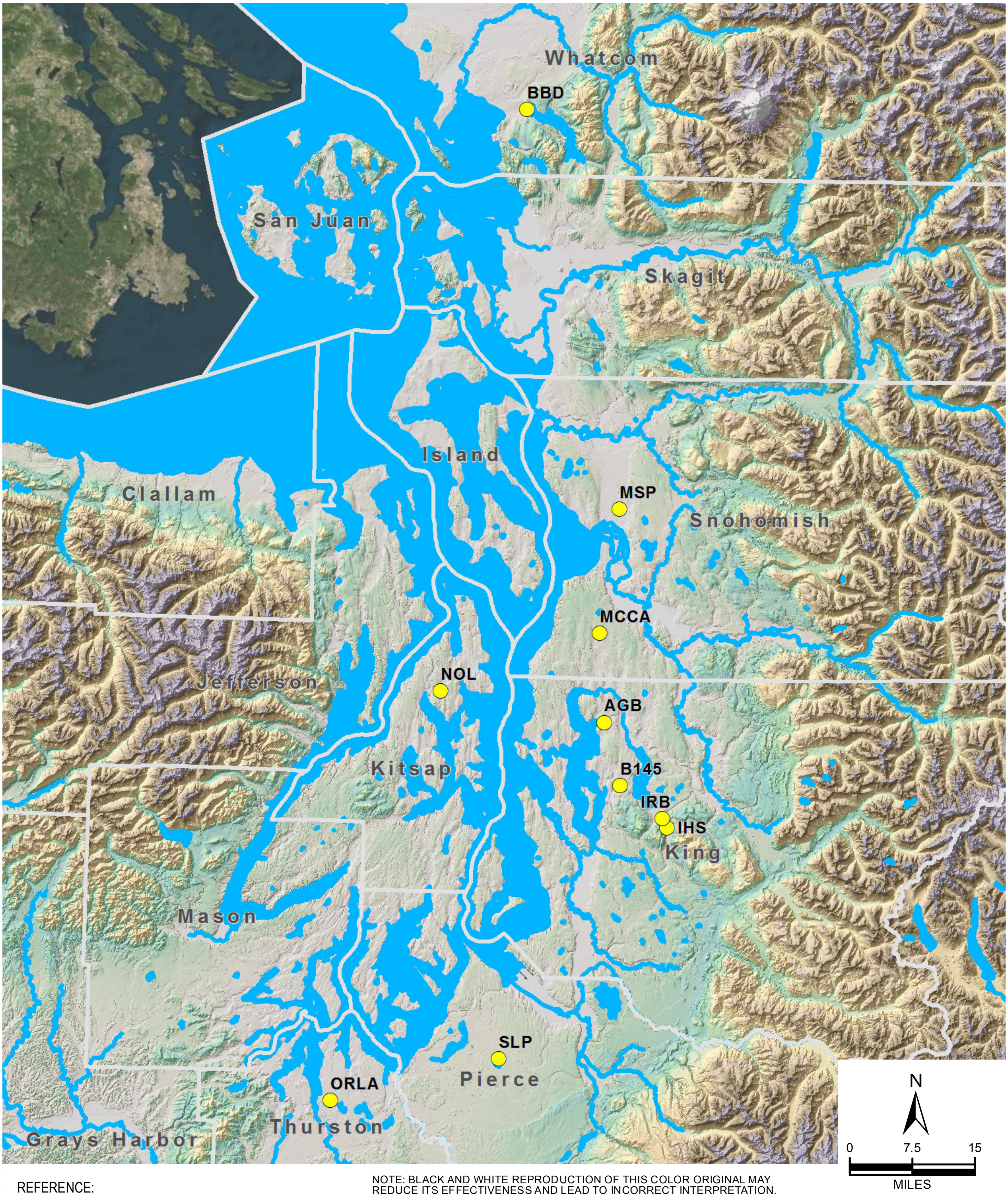
BIORETENTION SITES ASSESSED

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

FIGURE 1

DATE 10/15

PROJ. NO. KH150387A



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associated earth sciences incorporated

BIORETENTION SITES SELECTED

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

FIGURE 2

DATE 10/15

PROJ. NO. KH150387A

Attachment 1. List of candidate bioretention monitoring sites visited and assessed for selection as a site to be monitored during Phase II of the BHP study. Sites highlighted in yellow are selected for monitoring in Phase II.

Jurisdiction	Project Name	Location	Contact Name	Contact Phone
Bainbridge Island	Bainbridge Isl. High School	Bus Barn NE1/4 SE1/4 S22, T25N R2E	Melva Hill	206-780-3724
Bainbridge Island	Bainbridge Isl. High School	200 Building 9330 NE High School Rd.	Melva Hill	206-780-3724
Bainbridge Island	Grow Community	280 Madison Avenue N.	Melva Hill	206-780-3724
Bellevue	145th Place SE	145th Place SE & SE 22nd Street	Rick Watson	425-452-4896
Bellingham	Bloedell Donovan Park	2214 Electric Avenue	Bill Reilly	360-778-7955
Kirkland	AG Bell	11212 NE 112th St	Kelli Jones	425-587-3855
Kirkland	Benjamin Ryan Short Plat-Lot 1	10220 124th Avenue NE	Kelli Jones	425-587-3855
Kirkland	Cedar Park	112th Avenue NE	Kelli Jones	425-587-3855
Kirkland	Kirkland Children's School	5311 108th Avenue NE	Kelli Jones	425-587-3855
Issaquah	Rainier Blvd. LID Phase II	Rainier Boulevard and NW Holly Street	Kerry Ritland	425-837-3410
Issaquah	Park Maintenance Facility	525 1st Avenue NW	Kerry Ritland	425-837-3410
Issaquah	Issaquah High School	700 2nd Avenue SE	Kerry Ritland	425-837-3410
Marysville	Art Investments Res. Devel.	51st Ave NE & 83rd Street NE	Brooke Ensor	360-363-8288
Marysville	Armed Forces Reserve Center	13613 40th Avenue NE	Brooke Ensor	360-363-8288
Mill Creek	MC Community Association Bldg	15524 Country Club Dr.	Mary Ann Heine	425-316-3344
Olympia	ORLA School	12th Avenue SE & Boulevard Rd SE	Jake Lund	360-753-8152
Pierce County	Spanaway Lake Park	14905 Bresemann Blvd S.	Dawn Anderson	253-798-4671
Pierce County	Woods at Golden gibbon	104th and Golden Gibbon	Dawn Anderson	253-798-4671
Poulsbo	Anderson Parkway	Anderson Pkwy & NE Lincoln Rd	Anja Hart	360-394-9753
Poulsbo	Noll Roundabout	Lincoln Rd & Noll Rd	Anja Hart	360-394-9753
Poulsbo	Viking Ave	between SR 305 & New Finn Hill Rd	Anja Hart	360-394-9753
Shoreline	N Fork Thornton Creek	multiple sites	Uki Dele	206-801-2451
Thurston County	Evergreen Terrace III	9th Ave & Torrey	Steve Johnson	360-867-2332

Site Information for Monitoring Assessment

BHP Phase I
Site Selection Monitoring

Yellow = 1st Choice

					Ability to monitor Inflow				Location of nearby rain gauge		Number of inlets and outlets (fewer better)			Type of inlets and outlets (piped or weir preferred)		Underdrain	Hydraulic head available	Near other sites		Availability of current or previous monitoring data at site? Y/N	Stability of inlet and outlet control	Site security for installation of monitoring equipment?		
	AESI KMZ Label	Jurisdiction	Site	Arbitrary Site numbering (in order visited)	Can inflow be easily monitored; 1 = Yes; 0 = No	Can inflow be monitored with simple modifications; 1 = Yes; 0 = No or Not applicable	Accessibility (especially for outflow to monitor (see above) Y/N	Owner staff available to initiate monitoring equipment? Y/N	Rain gauge location very representative of site rainfall? Y/N	Owner staff available to conduct good maintenance/data? Y/N	One primary inlet? Y/N	Multiple inlets? 1-10	Can temp. retrofit for calibration monitoring then remove? Y/N	Piped, weir, or sheet flow?	Can be temporarily retrofitted for calibration monitoring	is underdrain accessible for monitoring	Range is head space for access - can counter sink? 1-10	Inproved efficiency by nearness to other sites? 1-10	Owner staff available for multiple site support? Y/N	Quality of data? 1-10	Hard structures better than soft (grass channel). 1-10	Good/poor site security? 1-10	Monitoring Comments	Comments
1	BRP	Kirkland	Ben Ryan Short Plat (3 cells)	1	1	0	Y	?	?	?	Y	1	Y	Piped in and out	Y	NA	limited, inlet is right at cell bottom, likely submerges	?	?	NA	1	1	4" inlet would need 6" stub for thelmar. Inlet is right on cell floor so likely inundates, good in that one thelmar for inlet, 1 for outlet	underconstruction; upper RG in till, middle in wx till, lower filled with BSM
2	AGB	Kirkland	Alex.Graham Bell Elem. School (2 cells)	2	1	0	Y	?	N	NA	N	5 in #3, 4 in #4	Y	piped in and out	Y	Y	Y	2 cells on same property	?	NA	1	1	6" roof inlets, 6" underdrain, 8" outlets, no sheet flow, would need to use roof runoff for inflow or else monitor multiple inlets	good access, need geotech
3	CPP	Kirkland	Cedar Park Short Plat (several cells)	3	0	1	No outflow	N	?	?	Y	1	Y	curb cut	Y	NA	good head space, edge of curb cut is 3" above cell bottom and 3" below street level	?	N	NA	1	exposed but quiet cul de sac	Only curb cuts, small drainage areas, would need separate transducer to know if cell was full and bypassing	good access, heavily maintained; compacted by foot traffic
4	KCS	Kirkland	Kirkland Children's School (1 cell)	4	1	0	Y	?	?	?	N	2 inlets 4" roof and 8" pipe	Y	piped	Y	NA	OK, inlets are above cell floor	?	?	NA	1	good, behind fence and hidden in brush	4" roof drain need 6" stub, two 8 " thelmars, access only during school hours	poor access
5	B145	Bellevue	145th Bellevue (3 cells)	5	1	0	Y	N	?	?	Y-for RG1 and RG2	1	Y	piped	Y	NA	Y inlet pipes high enough above cell botttom	N	?	need to look	1	pretty exposed, could hide some but would need to harden installation	RG1 and RG2 good with single inlet and single outlet, RG3 has multiple inlets, exisitng float switch installed in RG2 and 3 to record overflows?	good access, check for mon data; need AMEC geotech report
6	GRO	Bainbridge	Grow Community (several cells)	6	0	0	Y	?	?	?	N	11 curb cuts	N	sheet	Y	Y	Y	?	?	NA	riprap cuts	exposed out of the way	too many curb cuts, erosion on inlets, missing outlet control structure at time of visit	Unk geotech
7	BHS	Bainbridge	High School (several cells)	7	?	1-need to clear brush	Y	?	?	?	Y	1-2 area, footing or roof drains	Y	piped	Y	Y	? Couldn't fin inlet pipes	N	N	?	1	exposed on school property	couldn't find inlets, need sheet C-302 to more thoroughly review upper cells.	Geotech report not provided
8	BUS	Bainbridge	Bus Barn (2 cells)	8	0	0	Y	?	?	?	N	yes very convoluted		both and	maybe	Y	Y	?	?	NA	mix of grass and pipe	1	very complicated, couldn't find some pipes. Not a good site unless last resort	Unk geotech
9	NOL	Poulsbo	Noll Roundabout (1 cell)	9	1	0	Y	?	?	?	Y	1	Y	Piped	Y	Y	Y	N	?	?	1	5-exposed but could hide somewhat	inlet and outlet both 12" and close enough to share single datalogger.	Unk geotech
10	VIK	Poulsbo	Viking Ave (several linked cells)	10	0	0	Y	?	?	?	N	1 pipe, long sheet flow stretch	N	pipe and sheet	sheet=no	Y	Y	?	?	?	1	poor but could maybe hide stuff in brush	long sheet flow stretch, single outlet pipe. 1 inlet pipe too. Too much sheet flow and multiple cells chained together by single underdrain pipe	Non-standard BSM; geotech rpt did not address infiltration;
11	PAP	Poulsbo	Anderson Pkwy (Lined)	11	NOT APPLICABLE																			Shallow gw at 6-8' bgs, tidally influenced; geotech rpt did not address infiltration;
12	TCR	Shoreline	Thornton Creek Retrofit (several cells)	12	0	0-would require interception pipe and spreader	Y	N	?	?	N	sheet	N	sheet through gravel	N	Y	Y	Y	?	?	N	poor	only sheet flow through gravel shoulders, would require installation of interception and spreader pipes=look elsewhere	17 bioretention cells; used Ecology '05 manual grain size to est infiltration rate
13	SLP	Pierce County	Spanaway Lake Park (9 cells)	13	0	1	Y for Cell J, NA for cell I	Y	Y	?	2 for J, 1 for I	2 for J, 1 for I	Y	curb cuts	Y	NA	Y	Y if doing both sites	?	NA	3-some spall could rerode	poor	puplic park-could only temporarily install equipment for targeted events. Use tarp to funnel water to 6 or 8 inche thelmar	Spanaway Lake level expression of water table
14	PHH	Pierce County	Habitat for Humanity (several cells)	14	0	1	Y	N	?	?	Y	1	Y	piped roof drain	Y	NA	Y	?	?	NA	1	poor	no outlet, small roof drains only, would need to retrofit drain from4" to 6" for thelmar. No cover but in neighborhood	Standing water present in nearby excvation; looks like glacial till exposed
15	ORLA	Olympia	ORLA (several cells)	15	1	0	Y-could hide it well	?	?	?	N	4 roof drains	Y	Piped	Y	Y	Y	N	?	?	1	outlet very secure, inlet less so	could monitor each inlet a few times to dial in roof drainage/rainfall, outlet is easy, underdrain is lower to promote infiltration	bioretention -> gravel trenches-> infiltration trenches -> pond
16	ET3	Olympia	Evergreen Terrace Phase 3 (several cells)	16	0	0	no outflow just lots of curb cuts and not a good site																	no drainage or geotech report
17	IRB	Issaquah	Ranier Blvd LID Phase II (4 cells)	17	0	1	Y	?	?	?	N	2 curb cuts	Y	curb cut in piped out	Y	NA	Y	?	?	NA	1	poor	would need to tarp and pipe both curb cuts, could secure monitoring box ot sidewall and put themlar in outlet, NE facitlity only	based on MW's; proximity to Issaquah Ck; field rates lower than average for some
18	IPMF	Issaquah	Parks Maintenance FacilityRetrofit (1 cell)	18	0	0	Y	?	?	?	N	4 pipes and many curb cuts	N	pipe and sheet	N	NA	Y	?	?	?	loose sheet flow areas with erosion	good	too many inlets	expect shallow gw; likely lateral flow issues
19	IHS	Issaquah	Issaquah High School Cell #24 (24 cells)	19	1	0	Y	N	?	N	N	2	Y	piped	Y	Y	Y	?	N	NA	Y	good	easy to hide in dense brush	AESI currently monitors surface water level and shallow ground water level
20	AFR	Marysville	AFRC	20	1	0	Y	?	?	?	N	3	Y	piped in, ditch out	Maybe	NA	Y	?	?	?	inlet yes, outlet no	poor	would need to install weir or flume in outlet ditch or tarp and pipe	
21	MSP	Marysville	Residential	21	1	0	Y	?	?	?	Y	1	Y	pipe	Y	No overflow	Y	?	?	?	1	ok, could hide behind fence	1 inlet pipe, overflow sturcture goes into 3 underdrain pipes.	
22	MCCA	Mill Creek	Mill Creek Community Association (MCCA)	22	0	1	NA	?	?	?	N	2-maybe 1 inlet and one out	Y	piped	Y	NA	Y	N	?	NA	1	marginal, quiet area	1 4 in roof drain, another pipe tied to parking lot, not sure if it is inlet or outlet	
23	BBD	Bellingham	Bloedel Donovan Park	23	0	1	Y	Y	Y	Y	N	2	Y	curb cut, pipe out	Y	NA	Y	N	Y	some data exists, not sure how much	Y	OK, could hide most in brush or in CB	2 curb cuts in, overflows to 8" pipe out, outlet may have slight backwater issues, City notes that isde overflow also occurs, may need to sandbag	
24	SPRK	Pierce Cty (Park/Span)	Sprinker Parking Lot LID Retrofit	Did not visit per Dawn at Pierce County																				no drainage or geotech report; MGS mdl 30 iph, dtw of 15 ft

Site Information for Geotechnical Assessment

BHP Phase I
Site Selection | Geotech
Yellow = 1st Choice

	AESI KMZ Label	Jurisdiction	Site	Geotech	CF	Geology	Explorations	Inf Test Type	Hydrogeo	BSM rate < Native iph	Estimated Construction	Site Visit Date	Comments
1	BRP	Kirkland	Ben Ryan Short Plat (3 cells)	Geo-resources	4.76 or 0.21	Till	TP/HA	EPA FH	B1	NO	Aug-15	8/27/15	underconstruction; upper RG in till, middle in wx till, lower filled with BSM
2	AGB	Kirkland	Alex.Graham Bell Elem. School (2 cells)	Unk	NA	Till	Unk	None	B2	NO	2013	8/27/15	good access, need geotech
3	CPP	Kirkland	Cedar Park Short Plat (several cells)	Earth Consultg	Yes	Rec. OW	TP/HA	Unk	AX	YES	2010	8/27/15	good access, heavily maintained; compacted by foot traffic
4	KCS	Kirkland	Kirkland Children's School (1 cell)	Terra		Adv. OW	TP/HA	EPA FH	CX	YES	Sep-13	8/27/15	poor access
5	B145	Bellevue	145th Bellevue (3 cells)	Herrera and AMEC	None	unk (likely thin Till over Qva)	TP	PIT (3'x3')	CX	NO	2012?	8/27/15	good access, check for mon data; need AMEC geotech report
6	GRO	Bainbridge	Grow Community (several cells)	Unk		Likely Till	Unk	Unk	B2 like	Unk		9/1/15	Unk geotech
7	BHS	Bainbridge	High School (several cells)	Krazan (rpt missing)	NA	Till	Unk	None	B2	NO		9/1/15	Geotech report not provided
8	BUS	Bainbridge	Bus Barn (2 cells)	Unk		unk - Till likely	Unk	Unk	B2 like	Unk		9/1/15	Unk geotech
9	NOL	Poulsbo	Noll Roundabout (1 cell)	Unk	None	unk - Till likely	Unk	None (D10 est)	B2	NO		9/1/15	Unk geotech
10	VIK	Poulsbo	Viking Ave (several linked cells)	Krazan (foundations only)	None	unk - Till likely	B	None (D10 est)	B2	NO		9/1/15	Non-standard BSM; geotech rpt did not address infiltration;
11	PAP	Poulsbo	Anderson Pkwy (Lined)	Landau (for seawall)	Unk	Unk - Fill likely	B	None (D10 est)	E	NO		9/1/15	Shallow gw at 6-8' bgs, tidally influenced; geotech rpt did not address infiltration;
12	TCR	Shoreline	Thornton Creek Retrofit (several cells)	HWA	yes, varies	Sandy Till to Qva	B	None (D10 est)	BX/CX	NO		(BT and BB only)	17 bioretention cells; used Ecology '05 manual grain size to est infiltration rate
13	SLP	Pierce County	Spanaway Lake Park (9 cells)	None	2 to 4	Rec. OW Steilacoom	Unk	None	AX	NO		9/9/2015	Spanaway Lake level expression of water table
14	PHH	Pierce County	Habitat for Humanity (several cells)	Unk	Unk	unk - Till likely	Unk	Unk	B2 like	Unk		9/9/2015	Standing water present in nearby excvation; looks like glacial till exposed
15	ORLA	Olympia	ORLA (several cells)	ICI	Yes	Rec. OW Sand	TP/B	None (D10 est)	A2	YES	2014?	9/9/2015	bioretention -> gravel trenches-> infiltration trenches -> pond
16	ET3	Olympia	Evergreen Terrace Phase 3 (several cells)	Unk		Rec. OW Sand	Unk	Unk	AX	Unk	Approved June 2010	9/9/2015	no drainage or geotech report
17	IRB	Issaquah	Ranier Blvd LID Phase II (4 cells)	GeoDesign	0.18	Recent Alluvium	B/HA	EPA FH	D1	NO	Est. Sum 2014	9/16/2015	based on MW's; proximity to Issaquah Ck; field rates lower than average for some
18	IPMF	Issaquah	Parks Maintenance FacilityRetrofit (1 cell)	South Fork Geosciences	0.25	Recent Alluvium	TP	Small Scale PIT	D1	NO	Est. Sum 2014	9/16/2015	expect shallow gw; likely lateral flow issues
19	IHS	Issaquah	Issaquah High School Cell #24 (24 cells)	AESI		Outwash	TP	PIT	A1	NO	Summer 2010	9/16/2015	AESI currently monitors surface water level and shallow ground water level
20	AFR	Marysville	AFRC	AESI		Rec. OW Sand	TP/B	PIT	A1			BT, BK, CW 9/18/2015	
21	MSP	Marysville	Residential									BT, BK, CW 9/18/2015	
22	MCCA	Mill Creek	Mill Creek Community Association (MCCA)										
23	BBD	Bellingham	Bloedel Donovan Park										
24	SPRK	Pierce Cty (Park/ Span)	Sprinker Parking Lot LID Retrofit	Unk		Rec. OW Steilacoom	Unk	Unk	A2	YES	Stamped Oct'10	Did not visit	no drainage or geotech report; MGS mdl 30 iph, dtw of 15 ft

Site Information for Modeling Assessment

BHP Phase I
Site Selection
Yellow = 1st Choice

Modeling

	AESI KMZ Label	Jurisdiction	Site	Design Manual	Model	Underdrains	Liner	Overflow	BSM Rate	BSM b	BSM n	Subgrade Design Rate	TIR Civil	Comments
1	BRP	Kirkland	Ben Ryan Short Plat (3 cells)	KC'09	MGS Fld v.4.12	No	No	Yes	2	1	40	RG#1, 0.21 and RG#2-#3, 0.42	Larson and Assoc.	underconstruction; upper RG in till, middle in wx till, lower filled with BSM
2	AGB	Kirkland	Alex.Graham Bell Elem. School (2 cells)	KC'09	MGS Fld v.4.12	Yes	No	Yes	1	1.5	30	0	CPL	good access, need geotech
3	CPP	Kirkland	Cedar Park Short Plat (several cells)	KC'98	KCRTS	No	No	No	1	1	?	1 iph	Blueline Group	good access, heavily maintained; compacted by foot traffic
4	KCS	Kirkland	Kirkland Children's School (1 cell)	KC'09	MGS Fld	No	No	Yes	1	1.5	40	2	CPH	poor access
5	B145	Bellevue	145th Bellevue (3 cells)	COB'10 (Ecology'05)	WWHM3 Pro	No	No	Yes	2.5	2	40	RG#3 1.3 iph; rate used for RGs, no CF	Herrera (RK)	good access, check for mon data; need AMEC geotech report
6	GRO	Bainbridge	Grow Community (several cells)			Yes	No	Yes	1	1.5 to 2		unk?	Browne Wheeler	Unk geotech
7	BHS	Bainbridge	High School (several cells)	Ecology '05	MGS Fld 3.1	Yes	No	Yes	1	1.5		Nil	CPL	Geotech report not provided
8	BUS	Bainbridge	Bus Barn (2 cells)			Yes	No	Yes						Unk geotech
9	NOL	Poulsbo	Noll Roundabout (1 cell)	WSDOT '08; Ecology '05	WWHM3 Pro	Yes	No	Yes	2	1.5	40	0.5	Parametrix	Unk geotech
10	VIK	Poulsbo	Viking Ave (several linked cells)	WSDOT '08; Ecology '05	WWHM3 Pro	Yes	No	Yes	2	2	40	0.5	Parametrix	Non-standard BSM; geotech rpt did not address infiltration;
11	PAP	Poulsbo	Anderson Pkwy (Lined)	Ecology '05, '12	WWHM	Yes	YES	Yes				initial 2 iph in '09; 2012 plan set shows pvc liner	Parametrix	Shallow gw at 6-8' bgs, tidally influenced; geotech rpt did not address infiltration;
12	TCR	Shoreline	Thornton Creek Retrofit (several cells)	Ecology '05	MGS Fld v.4.29								Perteet	17 bioretention cells; used Ecology '05 manual grain size to est infiltration rate
13	SLP	Pierce County	Spanaway Lake Park (9 cells)		WWHM	No	No		1.5 to 3	2		set equal to BSM;	Pierce County	Spanaway Lake level expression of water table
14	PHH	Pierce County	Habitat for Humanity (several cells)	Unk	Unk	Not seen in field	Unk	Unk	Unk	Unk	Unk	Unk	Unk	Standing water present in nearby excvation; looks like glacial till exposed
15	ORLA	Olympia	ORLA (several cells)	City of Olympia '09	WWHM v4	No	No	Yes	1.5	1.5		varies	LPD	bioretention -> gravel trenches-> infiltration trenches -> pond
16	ET3	Olympia	Evergreen Terrace Phase 3 (several cells)		Unk	No	No	No	Unk	1.5	Unk	Unk	Unk	no drainage or geotech report
17	IRB	Issaquah	Ranier Blvd LID Phase II (4 cells)	City of Issaquah '11 (KC'09)	WWHM v4 and KCRTS Flow Control	No but geotech rec'd	No	Unk - check	Unk	1.5	Unk	field rate of 2.8 iph x 0.18 = 0.5 iph	KPG	based on MW's; proximity to Issaquah Ck; field rates lower than average for some
18	IPMF	Issaquah	Parks Maintenance FacilityRetrofit (1 cell)	City of Issaquah '11 (KC'09)	WWHM v3	No	No	Yes	Unk	1.5	Unk	average rate of 5.7 iph x 0.25 = 1.425 iph	City of Issaquah	expect shallow gw; likely lateral flow issues
19	IHS	Issaquah	Issaquah High School Cell #24 (24 cells)	City of Issaquah '11 (KC'09)		No	No	No	1.5	1.5	40	greater than BSM	CPL	AESI currently monitors surface water level and shallow ground water level
20	AFR	Marysville	AFRC	Ecology '05		No	No							
21	MSP	Marysville	Residential											
22	MCCA	Mill Creek	Mill Creek Community Association (MCCA)		WWHM3	No	No	???		1	40		Harmsen & Associates	
23	BBD	Bellingham	Bloedel Donovan Park											
24	SPRK	Pierce Cty (Park/ Span)	Sprinker Parking Lot LID Retrofit		MGS Fld	No	No	No	Unk	2.5	Unk	30	Unk	no drainage or geotech report; MGS mdl 30 iph, dtw of 15 ft

Site Information for Vegetation Assessment

BHP Phase I
Site Selection
Yellow = 1st Choice

Vegetation

	AESI KMZ Label	Jurisdiction	Site	Planting Plan	Herbaceous (H) or Woody (W) Vegetation or Both	Percent Cover	Comments
1	BRP	Kirkland	Ben Ryan Short Plat (3 cells)	No	Zone 1- H		underconstruction; upper RG in till, middle in wx till, lower filled with BSM
2	AGB	Kirkland	Alex.Graham Bell Elem. School (2 cells)	Yes	Back Cell -W Front cell W, H	Back Cell -90-95% Front cell 75%	good access, need geotech
3	CPP	Kirkland	Cedar Park Short Plat (several cells)	Yes	1st Cell in Series-W	50%	good access, heavily maintained; compacted by foot traffic
4	KCS	Kirkland	Kirkland Children's School (1 cell)	No	Zone 1- H Zone 2- W	90%	poor access
5	B145	Bellevue	145th Bellevue (3 cells)	Yes	Cell #1 -H (Zone 1) Cell #2- H (Zone 1) Cell #3- H (Zone 1)	Cell #1 -70% Cell #2-65% Cell #3- 90%	good access, check for mon data; need AMEC geotech report
6	GRO	Bainbridge	Grow Community (several cells)	Yes	W	50%	Unk geotech
7	BHS	Bainbridge	High School (several cells)	No	Circular Cell-W, H Entry Cell- W Lower & Upper Cells Courtyard- Zone 1-H Front Cell- W, H	Circular Cell- 70 % Entry Cell- 80 % Lower & Lower Cells Courtyard- 80% Front Cell- 90%	Geotech report not provided
8	BUS	Bainbridge	Bus Barn (2 cells)	No	Cell Adj to Road- H Cell # 2- W, H	Cell Adj to Road- 80% Cell #2- 60%	Unk geotech
9	NOL	Poulsbo	Noll Roundabout (1 cell)	No	W, H	70%	Unk geotech
10	VIK	Poulsbo	Viking Ave (several linked cells)	Yes	W	80%	Non-standard BSM; geotech rpt did not address infiltration;
11	PAP	Poulsbo	Anderson Pkwy (Lined)		NA (lined)		Shallow gw at 6-8' bgs, tidally influenced; geotech rpt did not address infiltration;
12	TCR	Shoreline	Thornton Creek Retrofit (several cells)		Did not Visit		17 bioretention cells; used Ecology '05 manual grain size to est infiltration rate
13	SLP	Pierce County	Spanaway Lake Park (9 cells)	Yes	Cell J- W Cell I- W, H	Cell J- 60% Cell I- 90 %	Spanaway Lake level expression of water table
14	PHH	Pierce County	Habitat for Humanity (several cells)	No	H	50-70%	Standing water present in nearby excvation; looks like glacial till exposed
15	ORLA	Olympia	ORLA (several cells)	No	Basin 1B- H Basin 2B- H Side yard Cells- H	Basin 1B- 60 % Basin 2B- 70 % Side yard Cells- 100%	bioretention -> gravel trenches-> infiltration trenches -> pond
16	ET3	Olympia	Evergreen Terrace Phase 3 (several cells)	No	H	(mowed lawn g	no drainage or geotech report
17	IRB	Issaquah	Ranier Blvd LID Phase II (4 cells)	Yes	SW Corner Cell- H SE Corner Cell-H	SW Corner Cell- 50% SE Corner Cell- 70%	based on MW's; proximity to Issaquah Ck; field rates lower than average for some
18	IPMF	Issaquah	Parks Maintenance FacilityRetrofit (1 cell)	Yes	H	50%	expect shallow gw; likely lateral flow issues
19	IHS	Issaquah	Issaquah High School Cell #24 (24 cells)	No	Maint. Area Cell- W	int. Area Cell- 9	AESI currently monitors surface water level and shallow ground water level
20	AFR	Marysville	AFRC	No	H	80%	
21	MSP	Marysville	Residential	No	H	90%	
22	MCCA	Mill Creek	Mill Creek Community Association (MCCA)	No	East Cell- H West Cell- H	East Cell- 70% West Cell- 80%	
23	BBD	Bellingham	Bloedel Donovan Park	No	Boat Launch Cell- W Entry Cell-W	Boat Launch Cell- 75% Entry Cell-85%	
24	SPRK	Pierce Cty (Park/ Span)	Sprinker Parking Lot LID Retrofit				no drainage or geotech report; MGS mdl 30 iph, dtw of 15 ft

Acronyms Used in Attachment Spreadsheets

KC: King County
TIR: Techical Information Report
COB: City of Bellevue
b: soil thickness in feet
n: soil porosity in percent
CF: correction factor, when applied to field infiltration rate
Rec. OW: recessional outwash
Adv. OW: advance outwash
EPA FH: Environmental Protection Agency Falling Head
TP/HA: test pits/hand augers
B: exploration boring

Hydrogeo Category
AX: recessional outwash, no underdrain, ground water depth unknown
A1: recessional outwash, no underdrain, ground water within 10 feet
A2: recessional outwash, no underdrain, ground water greater than10 feet
BX: glacial till, unknown underdrain configuration
B1: glacial till, no underdrain
B2: glacial till, underdrained
CX: advance outwash, no underdrain, ground water depth unknown
C1: advance outwash, no underdrain, ground water within 10 feet
C2: advance outwash, no underdrain, ground water greater than10 feet
DX: recent alluvium, no underdrain, ground water depth unknown
D1: recent alluvium, no underdrain, ground water within 10 feet
D2: recent alluvium, no underdrain, ground water greater than10 feet
E: other

Appendix B. Glossary, Acronyms, and Abbreviations

Appendix B - Glossary, Acronyms, and Abbreviations

Quality Assurance Glossary

Accreditation - A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

Accuracy - the degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms precision and bias be used to convey the information associated with the term accuracy. (USGS, 1998)

Bias - The difference between the population mean and the true value. Bias usually describes a systematic difference reproducible over time, and is characteristic of both the measurement system, and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI). (Kammin, 2010; Ecology, 2004)

Comparability - The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator. (USEPA, 1997)

Completeness - The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator. (USEPA, 1997)

Continuing Calibration Verification Standard (CCV) - A QC sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run (Kammin, 2010).

Dataset - A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010).

Data validation - An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment, and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability and integrity, as these criteria relate to the usability of the dataset. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation
- Use of third-party assessors
- Dataset is complex
- Use of EPA Functional Guidelines or equivalent for review

Examples of data types commonly validated would be:

- Gas Chromatography (GC)
- Gas Chromatography-Mass Spectrometry (GC-MS)
- Inductively Coupled Plasma (ICP)

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier, data is usable for intended purposes
- J (or a J variant), data is estimated, may be usable, may be biased high or low
- REJ, data is rejected, cannot be used for intended purposes (Kammin, 2010; Ecology, 2004)

Data verification - Examination of a dataset for errors or omissions, and assessment of the Data Quality Indicators related to that dataset for compliance with acceptance criteria (MQO's).
Verification is a detailed quality review of a dataset. (Ecology, 2004)

Detection limit (limit of detection) - The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

Measurement Quality Objectives (MQOs) - Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness. (USEPA, 2006)

Method - A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed. (EPA, 1997)

Method Detection Limit (MDL) - This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

Parameter - A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all "parameters" (Kammin, 2010; Ecology, 2004)

Population - The hypothetical set of all possible observations of the type being investigated. (Ecology, 2004)

Precision - The extent of random variability among replicate measurements of the same property; a data quality indicator. (USGS, 1998)

Quality Assurance (QA) - A set of activities designed to establish and document the reliability and usability of measurement data. (Kammin, 2010)

Quality Assurance Project Plan (QAPP) - A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

Quality Control (QC) - The routine application of measurement and statistical procedures to assess the accuracy of measurement data. (Ecology, 2004)

Representativeness - The degree to which a sample reflects the population from which it is taken; a data quality indicator. (USGS, 1998)

Sample (field) – A portion of a population (environmental entity) that is measured and assumed to represent the entire population. (USGS, 1998)

Sensitivity - In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit. (Ecology, 2004)

Standard Operating Procedure (SOP) – A document which describes in detail a reproducible and repeatable organized activity. (Kammin, 2010)

References

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. http://www.ecy.wa.gov/biblio/0403030.html

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Kammin, 2010. Definition developed or extensively edited by William Kammin, 2010.

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. http://ma.water.usgs.gov/fhwa/products/ofr98-636.pdf

Glossary – General Terms

Parameter: A physical chemical or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Streamflow: Discharge of water in a surface stream (river or creek).

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this

report.

Ecology	Washington State Department of Ecology
et al.	And others
MQO	Measurement quality objective
NPDES	(See Glossary above)
QA	Quality assurance
RM	River mile
SOP	Standard operating procedures
SWMMWW	Stormwater Management Manual for Western
Washington	

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow.
dw	dry weight
ft	feet
g	gram, a unit of mass
kcfs	1000 cubic feet per second
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters.
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	milligram
mgd	million gallons per day
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mg/L/hr	milligrams per liter per hour
mL	milliliters
mm	millimeter
mmol	millimole or one-thousandth of a mole. A mole is an S1 unit of matter.
ng/g	nanograms per gram (parts per billion)
ng/Kg	nanograms per kilogram (parts per trillion)
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity units pg/g
picograms per gram (parts per trillion)	

pg/L	picograms per liter (parts per quadrillion)
psu	practical salinity units
s.u.	standard units
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)
ug/L	micrograms per liter (parts per billion)
um	micrometer
uM	micromolar (a chemistry unit)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity
ww	wet weight