Draft Quality Assurance Project Plan

Bioretention Hydrologic Performance Study
Grant Number _____

Date: November 3, 2015

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1.0 Title Page, Table of Contents, and Distribution List

Quality Assurance Project Plan

Bioretention Hydrologic Performance Study

November 3, 2015

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Table of Contents

Page

1.0 Title Page, Table of Contents, and Distribution List 1

2.0 Abstract 6

3.0 Background 7
3.1 Study area and surroundings 7
3.1.1 Logistical problems 7
3.1.2 History of study area 8
3.1.3 Contaminants of concern 8
3.1.4 Results of previous studies 8
3.1.5 Regulatory criteria or standards 9

4.0 Project Description 9
4.1 Project goals 10
4.2 Project objectives 10
4.3 Information needed and sources 10
4.4 Target population 10
4.5 Study boundaries 11
4.6 Tasks required 11
4.7 Practical constraints 11
4.8 Systematic planning process 11

5.0 Organization and Schedule 12
5.1 Key individuals and their responsibilities 12
5.2 Special training and certifications 12
5.3 Organization chart 13
5.4 Project schedule 13
5.5 Limitations on schedule 13
5.6 Budget and funding 13

6.0 Quality Objectives 13
6.1 Decision Quality Objectives (DQOs) 13
6.2 Measurement Quality Objectives 13
6.2.1 Targets for Precision, Bias, and Sensitivity 13
6.2.2 Targets for Comparability, Representativeness, and Completeness 14

7.0 Sampling Process Design (Experimental Design) 16
7.1 Study Design 16
7.2 Maps or diagram 19
7.3 Assumptions underlying design 19
7.4 Relation to objectives and site characteristics 19
7.5 Characteristics of existing data 19

8.0 Sampling Procedures 19
8.1 Field measurement and field sampling SOPs 19
8.2 Containers, preservation methods, holding times 23
8.3 Invasive species evaluation 24

8.4 Equipment decontamination 24
8.5 Sample ID 24
8.6 Chain-of-custody, if required.....24
8.7 Field log requirements 24
8.8 Other activities 24

9.0 Measurement Methods.....25
9.1 Field procedures table/field analysis table.....25
9.2 Lab Procedures Table. This includes:.....25
9.2.1 Analyte.....25
9.2.2 Matrix.....25
9.2.3 Number of samples 25
9.2.4 Expected range of results 25
9.2.5 Analytical method.....25
9.2.6 Sensitivity/Method Detection Limit (MDL).....25
9.3 Sample preparation method(s) 26
9.4 Special method requirements.....26
9.5 Lab(s) accredited for method(s).....26

10.0 Quality Control (QC) Procedures 26
10.1 Table of field and lab QC required 26
10.2 Corrective action processes.....26

11.0 Data Management Procedures 26
11.1 Data recording/reporting requirements.....26
11.2 Lab data package requirements.....27
11.3 Electronic transfer requirements 27
11.4 Acceptance criteria for existing data.....27
11.5 EIM/STORET data upload procedures.....27

12.0 Audits and Reports.....27
12.1 Number, frequency, type, and schedule of audits.....27
12.2 Responsible personnel 28
12.3 Frequency and distribution of report.....28
12.4 Responsibility for reports.....28

13.0 Data Verification.....28
13.1 Field data verification, requirements, and responsibilities 28
13.2 Lab data verification 28
13.3 Validation requirements, if necessary.....28

14.0 Data Quality (Usability) Assessment.....28
14.1 Process for determining whether project objectives have been met 29
14.2 Data analysis and presentation methods 29
14.3 Treatment of non-detects 29
14.4 Sampling design evaluation 29
14.5 Documentation of assessment.....29

15.0 References.....30

16.0 Figures.....30

17.0 Tables 30
Table 1 Measurement Quality Objectives 31
Table 2 Sample Containers, Preservation and Holding Times 31
Table 3 Measurement Methods (Laboratory) 32
Table 4 QC Samples, Types and Frequency 32

18.0 Appendices 33
Appendix A. Title 33

Appendix B -- Glossary, Acronyms, and Abbreviations 34
Quality Assurance Glossary 34
Glossary – General Terms 39
Acronyms and Abbreviations 42
Units of Measurement 43

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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. The expected large increase in the use of bioretention facilities in the Puget Sound region resulting from requirements of the NPDES municipal permit suggests actual facility performances should be assessed to ensure that new bioretention facilities constructed under the Stormwater Management Manual for Western Washington (SWMMWW; WDOE 2014) can be built to attain desired performance and what, if any, changes are needed in the modeling and design 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 would then be compared with the hydrologic design model predictions developed for 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 be applicable not only directly to the SWMMWW modeling and design process, but also for site-specific conditions that can inform local permittee jurisdictions' design and maintenance of bioretention facilities. If appropriate, the final report will include recommendations for improvements to the Western Washington Hydrology Model (WWHM) bioretention modeling algorithms to better and more accurately represent observed actual field conditions. Additionally, the final report will provide a qualitative analysis on the larger set of facilities that were assessed for monitoring in the study.

3.0 Background

As part of the Regional Stormwater Monitoring Program (RSMP) that is funding this current project, a literature review and summary of Low Impact Development Performance was conducted, 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 cells from throughout the Puget Sound regions. All seventy units were evaluated in the field, and using 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 from the experience of highly experienced monitoring practitioners on the project team. These include aptitude in constructing customized retrofit devises to focus flows for more accurate measurement, and 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 the SWMMWW (WDOE 2014). The manual provides minimum requirements for new and retrofitted stormwater management systems that relies 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 pollutant or other water constituents will be conducted as part of the current study.

3.1.4 Results of previous studies

The hydrologic impacts of stormwater runoff on receiving waters has been well documented for almost three decades. The response for improved control of these impacts is largely centered in the use of the SWMMWW (WDOE 2014). The manual provides minimum requirements for new and retrofitted stormwater management systems that relies 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.

3.1.5 Regulatory criteria or standards

Regulatory standards for performance of bioretention facilities lie in the minimum requirements of the SWMMWW (2012 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 #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% Q2 and 50% Q2.

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% Q2 and Q50.

Not all bioretention facilities are required to be designed to meet all three minimum requirements. If LID facilities performance standards are not required, then MR #5 can be ignored. If the water quality treatment is being provided by another type of stormwater facility (e.g., sand filter) then MR #6 can be ignored. And if the bioretention discharge is directly to an-Ecology specified large body of water then MR #7 is not required. 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 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, as well as opportunity cost for 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 with greater expected accuracy and resulting benefits.

4.1 Project goals

The project goal is to compare actual hydrologic performance of constructed bioretention facilities with the expected modeled performance from the original site engineering design. Modeled results using original design data will be compared with the modeled performance calibrated to field results and actual rainfall during the site monitoring. 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.

4.2 Project objectives

The project objectives are to install 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. Rain gages will also be installed 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 calibration of the design model to 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 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 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, and construction monitoring reports.

4.4 Target population

The target population is constructed bioretention facilities in the Puget Sound basin.

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. Conduct data management and quality control for data collected.
5. Obtain design drawings, as-built conditions, technical information reports, construction monitoring records, and modeling parameters used in each facility design model.
6. 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.

4.8 Systematic planning process

No systematic planning process is required.

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 WDOE, 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 Organization chart

No organization chart is needed.

5.4 Project schedule

Because of the wet season requirement needed to obtain sufficient hydrologic data, the schedule revolves around the period October through May. Subsurface water and surface water level data should be collected continuously and simultaneously with storm event monitoring.

5.5 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, and the availability of storm events in a given wet season.

5.6 Budget and funding

Proposed scope task and budget levels for Phase II monitoring and reporting are provided in the following table. Funding is from the Regional Stormwater Monitoring Program.

6.0 Quality Objectives

6.1 Decision Quality Objectives (DQOs)

No decision quality objectives are required for this project.

6.2 Measurement Quality Objectives

Measurement quality objectives are largely related to completeness and verification of rainfall and flow data for up to five events at each of the facilities monitored, and groundwater level data.

6.2.1 Targets for Precision, Bias, and Sensitivity

6.2.1.1 Precision

Level of precision for the instantaneous stage measurements for flow, ponding, and subsurface water elevations are expected to be 2 mm or less. Translation of the stage measurements for inflows and outflows to flow rate will result in flow rates within 5 percent of the flow rate. Precision for rainfall data is also to be within 5 percent of the rainfall.

Bioretention Hydrologic Performance Study

5.6 Budget and Funding

Detailed scope of work and budget	B'ham PM	B'ham Finan. Mngt	P.I. Consultant PM	Modeling Consultant Modeler	Stormwater Monitoring Consultant Lead	Field 1	Field 2	City of Bellingham Monitoring Lead	Geotechnical Assessment Lead	Field 1/GIS	Plant Community Assessment/Download 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 for local staff to implement/ provide tel. support			8		16	16	4		4				
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
Phase II ODCs			$0.00 $1,515.20	$0.00			$87,737.39	$0.00		$16,667.40		$436.00	Total
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	$405,294

Subsurface exploration, geotechnical laboratory and infiltration testing is used in the study 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.

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, accuracy of stem density and percent cover will be within 5 percent.

6.2.1.2 Bias

Flow during each storm flow event, and pond and ground water levels, will be measured with only one instrument 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.

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.

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 measurement of inflows and outflows from each facility. This is the primary basis of the evaluation of the hydrologic performance of bioretention facilities (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 using design drawings, to best assure the sites chosen were accessible and suitable for accurate flow monitoring for comparison to other similar monitoring projects.

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 calibration, 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 Figure 1 for distribution of proposed facilities.
- Storm flow monitoring will be conducted to collect five storm event flows at each of the facilities.
- Ground water and pond stages will be monitored continuously during at least three 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 calibrate the Western Washington Hydrologic Model (WWHM) for each of the ten facilities, the degree of data collected will affect the calibration results. Data collection goals include:

- Inflow and outflow measurements from a minimum of five storm events ranging in size is recommended for the completeness needed for calibration of the model.
- 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 3 months during the wet season to provide additional model calibration 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 Western Washington Hydrology Model (WWHM) and use of the model as described below.

Modeling Approach

The project objective is to compare actual hydrologic performance of constructed bioretention facilities with the expected modeled performance from the original site engineering design. Modeled results from the original design data will be compared with the long term modeled performance as calibrated to the field results found during the site monitoring.

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 changes in computational techniques or parameter input values. With a range of facilities the comparisons will test the strengths and weaknesses of the modeling approach 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 recommendations on what changes are needed in the design and modeling of bioretention facilities to improve their hydrologic performance. 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 Ecology in improving and updating their stormwater LID regulations.

As described above, the hydrologic monitoring in Phase II will be used to quantify hydrologic performance of the Phase II bioretention sites selected for monitoring. 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 #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% Q2 and 50% Q2.
- 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% Q2 and Q50.

Not all bioretention facilities are required to be designed to meet all three minimum requirements. If the LID performance standard is not required, then MR #5 can be ignored. If the water quality treatment is being provided by another type of stormwater facility (e.g., sand filter) then MR #6 can be ignored. And if the bioretention discharge is directly to an-Ecology specified large body of water then MR #7 is not required.

This assessment of the performance in terms of the three minimum requirements 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 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 Phase II bioretention facility the following modeling-related evaluation procedures will be followed.

1. The contributing drainage area described in the technical information report (TIR) will be compared with the contributing drainage area observed at the site. No attempt will be made to actually conduct field measurements of the drainage area except by the apparent contributing area as measured by inflow volumes. The relative pervious and impervious areas draining to the site will be compared to the original model input.
2. The physical dimensions of the bioretention facility will be measured in the field and compared to the original model input.
3. The physical outlet structure configuration and dimensions of the bioretention facility will be measured in the field and compared to the original model input. 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. 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.
8. Any and all discrepancies between the above collected data and the model data will be noted.
9. 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 requirement(s) described above.
10. 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.

7.1.1 Field measurements

Field measurements to be collected include:

- Inflow and outflow flow measurements during targeted 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 Figure 1. All the field sampling described is to be carried out within each facility only.

7.1.3 Parameters to be determined

The model to be used in this study is the Western Washington Hydrology Model, version 2012. The bioretention modeling module will be used with assignment of parameters in the model based either on the original design, or calibrated to the new field collected data using parameter values assigned by the best professional judgement of the modeler.

The parameters to be determined as part of 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 Figure 1.

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.

7.4 Relation to objectives and site characteristics

The project objective is to obtain observations on the actual hydrologic performance of bioretention facilties to provide feedback on the design process for these facilities. The study design supports the project objectives by directly monitoring hydrologic performance in a large numerber of constructed facilities, and using the modeling tool used in the design of bioretention facilities.

7.5 Characteristics of existing data

Existing data on the hydrologic performance of constructed bioretention facilities is lacking in the Puget Sound region. This study will provide a cross section of hydrologic bioretention performance, from which improvements on future facilities will be made.

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

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.

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 Thelmar-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 Thelmar 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 Thelmars 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 calibrate a runoff model based on rainfall. This calibrated model will then estimate inflow into the bioretention facility based on the measured rainfall for an event.

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 Thelmar 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.

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 storm water inflow and precipitation. This data will be compared to staff gauge water level data within the facility.

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.

Site Maintenance
All monitoring sites will be visited at least once 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. 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 Thelmar weir, pipe, and collection sheet (for curb cuts) will be inspected, cleaned and the weir will be leveled if needed.
- Each transducer 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.

Geotechnical Engineering and Hydrogeologic Data Collection

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.

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.

Measure Infiltration Rates

Infiltration rates will be measured in 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's Technical Advisory Committee. 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 (WDOE 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.

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 units that only have woody vegetation (shrubs and trees), the number of stems will be counted within the unit (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 units 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 identify 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

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

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 Equipment decontamination

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

8.5 Sample ID

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

8.6 Chain-of-custody, if required

Not applicable for water samples. No water sampling for pollutant or other water constituents will be conducted as part of the current study. Chain-of-custody protocols for soil samples collected will follow conventional protocols used by the geotechnical consultant and soils lab.

8.7 Field log requirements

Field logs containing all the following information will be maintained for all field 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

8.8 Other activities

No other sampling activities are anticipated.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

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

9.2 Lab Procedures Table. This includes:

9.2.1 Analyte

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

9.2.2 Matrix

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

9.2.3 Number of samples

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

9.2.4 Expected range of results

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

9.2.5 Analytical method

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

9.2.6 Sensitivity/Method Detection Limit (MDL)

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

9.3 Sample preparation method(s)

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

9.4 Special method requirements

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

9.5 Lab(s) accredited for method(s)

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

10.0 Quality Control (QC) Procedures

10.1 Table of field and lab QC required

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

10.2 Corrective action processes

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

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

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

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

11.3 Electronic transfer requirements

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

11.4 Acceptance criteria for existing data

No existing sample data is required for completion of the project.

11.5 EIM/STORET data upload procedures

Tabular results of all data will be provided to Ecology in EIM format.

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

No audits will be conducted.

12.2 Responsible personnel

No audits will be conducted.

12.3 Frequency and distribution of report

Project status reports will be provided monthly 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.

12.4 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

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

13.3 Validation requirements, if necessary

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

14.0 Data Quality (Usability) Assessment

Upon completion of the data verification the project data manager (PDM) 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 PDM

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 calibration; and for the minimum three 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 results using original design data will be compared with the modeled performance calibrated to field results and actual rainfall during the site monitoring. 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

Taylor, W.J. and Cardno TEC Inc. 2013. White paper for stormwater management program effectiveness literature review. Low impact development techniques. Prepared for Association of Washington Cities and Washington State Department of ecology.

WDOE. 2014. Stormwater Management Manual for Western Washington. As amended in December, 2014. Publication number 21-10-030. Olympia, WA.

16.0 Figures

Figure 1. Bioretention Sites Selected.

17.0 Tables

No tables needed.

18.0 Appendices

No appendices needed.

Table 1 Measurement Quality Objectives

Laboratory Analyses of Water Samples*

Parameter	Verification Standards (LCS,CRM,CCV)	Duplicate Samples	Matrix Spikes	Matrix Spike-Duplicates	Surrogate Standards	Lowest Concentrations of Interest
	% Recovery Limits	Relative Percent Difference (RPD)	% Recovery Limits	Relative Percent Difference (RPD)	% Recovery Limits	Units of Concentration

Table 2 Sample Containers, Preservation and Holding Times

Parameter	Matrix	Minimum Quantity Required	Container	Preservative	Holding Time

Table 3 Measurement Methods (Laboratory)

Analyte	Sample Matrix	Samples [Number/ Arrival Date]	Expected Range of Results	Reporting Limit	Sample Prep Method	Analytical (Instrumental) Method

Table 4 QC Samples, Types and Frequency

Parameter	Field		Laboratory			
	Blanks	Replicates	Check Standards	Method Blanks	Analytical Duplicates	Matrix Spikes

18.0 Appendices

Appendix A. Title

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)

Analyte - An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e. g. fecal coliform, Klebsiella, etc. (Kammin, 2010)

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)

Blank - A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process. (USGS, 1998)

Calibration - The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured. (Ecology, 2004)

Check standard - A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards, but should be referred to by their actual designator. (i. e. CRM, LCS, etc.) (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)

Control chart - A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system. (Kammin, 2010; Ecology 2004)

Control limits - Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean. (Kammin, 2010)

Data Integrity- A qualitative DQI that evaluates the extent to which a dataset contains data that is misrepresented, falsified, or deliberately misleading. (Kammin, 2010)

Data Quality Indicators (DQI) - Data Quality Indicators (DQIs) are commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity. (USEPA, 2006)

Data Quality Objectives (DQO) - Data Quality Objectives are qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. (USEPA, 2006)

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)

Duplicate samples - two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis. (USEPA, 1997)

Field blank - A blank used to obtain information on contamination introduced during sample collection, storage, and transport. (Ecology, 2004)

Initial Calibration Verification Standard (ICV) - A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples. (Kammin, 2010)

Laboratory Control Sample (LCS) - A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. (USEPA, 1997)

Matrix spike - A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects. (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)

Measurement result - A value obtained by performing the procedure described in a method. (Ecology, 2004)

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 blank - A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples. (Ecology, 2004; Kammin, 2010)

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)

Percent Relative Standard Deviation (%RSD) - A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin, 2010)

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)

Relative Percent Difference (RPD) - RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

Replicate samples - two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled. (USGS, 1998)

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)

Sample (statistical) – A finite part or subset of a statistical population. (USEPA, 1997)

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)

Spiked blank - A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method. (USEPA, 1997)

Spiked sample - A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency. (USEPA, 1997)

Split Sample – The term split sample denotes when a discrete sample is further subdivided into portions, usually duplicates. (Kammin, 2010)

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

Surrogate – For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis. (Kammin, 2010)

Systematic planning - A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning. (USEPA, 2006)

References

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Glossary – General Terms

Ambient: Background or away from point sources of contamination.

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Eutrophic: Nutrient rich and high in productivity resulting from human activities such as fertilizer runoff and leaky septic systems.

Fecal coliform: That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities. This includes, but is not limited to, atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination is considered a nonpoint source. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act is a nonpoint source.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

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

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

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or is likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Reach: A specific portion or segment of a stream.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Any fish that belong to the family *Salmonidae*. Any species of salmon, trout, or char is considered a salmonid. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

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).

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Synoptic survey: Data collected simultaneously or over a short period of time.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Total suspended solids (TSS): Portion of solids retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standard, and are not expected to improve within the next two years.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a waterbody and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a waterbody and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

BMP	Best management practices
DOC	Dissolved organic carbon
e.g.	For example
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software
GPS	Global Positioning System
i.e.	In other words
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NPDES	(See Glossary above)
NTR	National Toxics Rule
PBDE	polybrominated diphenyl ethers
PBT	persistent, bioaccumulative, and toxic substance
PCB	polychlorinated biphenyls
QA	Quality assurance
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SRM	Standard reference materials
SWMMWW	Stormwater Management Manual for Western Washington
TMDL	(See Glossary above)
TOC	Total organic carbon
TSS	(See Glossary above)
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resources Inventory Area
WSTMP	Washington State Toxics Monitoring Program
WWTP	Wastewater treatment plant

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