Quality Assurance Project Plan

Bioretention Hydrologic Performance Study
Phase 3

Date: June 1, 2023

Prepared by:

William J. Taylor
Raedeke Associates, Inc.

Jennifer H. Saltonstall, L.Hg.
Associated Earth Sciences, Inc.

Prepared for:

Jesse Barham
City of Olympia, Washington

Publication Information

Author and Contact Information

William J. Taylor, btaylor@raedeke.com 206-755-3211
Jennifer H. Saltonstall, L.Hg., jsaltonstall@aesgeo.com 425-827-7701

Available online at SAM Effectiveness Studies Website, under LID – BMPs.

https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Stormwater-monitoring/Stormwater-Action-Monitoring/SAM-effectiveness-studies

1.0 Title Page, Table of Contents, and Distribution List

Quality Assurance Project Plan

Bioretention Hydrologic Performance Study Phase 3

June 1, 2023

Approved by:

Signature: ____________________ Date: 6/12/2023
Jesse Barham, City of Olympia

Signature: ____________________ Date: 6/13/2023
Chelsea Morris, SAM Scientist, Washington State Department of Ecology

Signature: ____________________ Date: 06/13/2023
Brandi Lubliner, QA Coordinator, Washington State Department of Ecology

Signature: ____________________ Date: 6/1/2023
William J. Taylor, Raedeke Associates, Inc.
Principal Author/Principal Investigator

Signature: ____________________ Date: 6/1/2023
Jennifer H. Saltonstall, L.Hg., Associated Earth Sciences, Inc.,
Author/Project Manager

Signature: ____________________ Date: 6/1/2023
Annamaria Clark, Raedeke Associates, Co-author

Signature: ____________________ Date: 6/1/2023
Christopher W. Wright, Raedeke Associates, Co-author

Table of Contents

Distribution List

Name: Doug Howie
Title: Stormwater Engineer
Organization: Washington State Department of Ecology
Contact Information: douglas.howie@ecy.wa.gov

Name: Brandi Lubliner
Title: Stormwater Action Monitoring Coordinator
Organization: Washington State Department of Ecology
Contact Information: brandi.lubliner@ecy.wa.gov

Name: Chelsea Morris
Title: Stormwater Action Monitoring Scientist
Organization: Washington State Department of Ecology
Contact Information: chelsea.morris@ecy.wa.gov

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 because of requirements of the National Pollutant Discharge Elimination System (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's) Stormwater Management Manual for Western Washington (SWMMWW; Ecology, 2019) can be built to attain desired performance.

This study is the third of three related studies. The first Bioretention Hydrologic Performance (BHP) Study investigated the performance of 10 bioretention facilities designed using the design approaches in effect prior to the Ecology (2014) manual. The second BHP Study (Phase 2) documented the hydrologic performance of 10 additional bioretention facilities designed using the Western Washington Hydrologic Model (WWHM) version 2012.

This study (BHP Phase 3) will evaluate performance lifespan by evaluating the oldest bioretention facilities in Western Washington. The intent is to conduct a point-in-time checkup on 50 or so older (10 years or older) bioretention facilities, and communicate the long-range bioretention hydrologic performance to a broad base of NPDES jurisdictions. The study will measure infiltration rates and identify site characteristics (e.g., plant community and maintenance activity) that may correspond with well performing or under-performing facilities. It is not a study of hydrologic model parameters, continuous hydrologic performance, or water quality. The findings will inform bioretention facility designs and maintenance standards.

This study is associated with Contract NO. C2300003 between the State of Washington Department of Ecology and City of Olympia.

3.0 Background

The goal of this study is to implement the third in a series of regional bioretention infiltration effectiveness studies as part of the Stormwater Action Monitoring (SAM) program. Funding for this current project comes from the SAM 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) and the results of the BHP Phase 1 and Phase 2 study.

Findings from the Taylor and Cardno TEC (2013) 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."

Within the design sizing of bioretention facilities using WWHM is an anticipation of the reduction in infiltration rate over time depending on the draining basin size. A "safety factor" is applied to the estimated infiltration rate in the WWHM design model which increases the design size of the facility. The safety factor is meant to ensure flow control at the 'end of life' infiltration rate. The infiltration rate of the bioretention media may be greater than this rate for most of the facility's lifespan. The two previous studies measured infiltration rates greater than 12 inches per hour.

This review will help discern whether older bioretention facilities sustain a functional infiltration rate that indicates their continued effectiveness. As part of this review, we will measure and document factors associated with infiltration rate and contributing to long-term performance, such as types of contributing area, and vegetation composition and maintenance activity.

3.1 Study area and surroundings

This study will measure infiltration rate and document plant community composition and maintenance activities from up to 50 bioretention facilities. The bioretention facilities selected will 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.

3.1.1 Logistical problems

Logistical problems include (1) availability of candidate sites; (2) water supply for infiltration testing; and (3) availability of design information.

The identification of candidate sites greater than 10 years in operation depends primarily on communication and participation by stormwater professionals. The approach to locating candidate sites will be through using previously identified sites and owner contacts from Phases 1 and 2, but also through additional direct contact with staff of local stormwater programs and schools to offer facilities within their jurisdiction. The accessibility and cooperation of local jurisdictions' staff could pose a logistical limitation in the final number of candidate sites identified for inclusion in the study.

In contrast to the previous two BHP studies, no meteorological or flow monitoring will be conducted. The only remaining logistical problem to monitoring the infiltration rate of facilities will be the availability and accessibility to deliver water into the facility basin for infiltration measurements. Access for documenting the plant communities is expected to be easily managed with access granted by the facility owner.

Supporting supplemental site information such as original bioretention media composition, native soil infiltration rate measurements, planting plans, maintenance records and contributing drainage area may not be readily available. Access to supporting documentation will also rely on the cooperation of project owners.

3.1.2 History of study area

Population growth and the coincident development of impervious stormwater draining surfaces has spread 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 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 regulatory response for improved control of these impacts is largely centered in the use of stormwater permits and the SWMMWW (Ecology 2019). The manual provides guidance that local municipalities use to set stormwater requirements for new and redeveloped projects. Bioretention is one frequently used best management practice for on-site stormwater management, flow control, and runoff treatment. Taylor and Cardno TEC (2013) provide a 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 a 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 these previous investigations was whether the designed volumetric storage and expected exfiltration conditions are attained in constructed bioretention facilities.

Two previous BHP studies (BHP I and II) funded by the SAM program were conducted during earlier funding cycles. Both studies included measuring continuous rainfall and flow monitoring followed by hydrologic modeling to compare WWHM 2012-modeled and observed performance. The current BHP III project involves only measuring infiltration and plant community composition with no flow measurements or modeling involved.

The BHP I study evaluated the hydrologic performance of bioretention facilities designed with a variety of models. Observed flows and infiltration conditions compared with the modeling results found the sites generally performed well for infiltration, although high infiltration rates were consistent with higher subsurface infiltration and coarser media than under current specifications. Many of the original hydrologic models were improperly set up, also potentially resulting in high infiltration conditions. Many of the sites did not use site-specific hydrogeologic information, which may have also contributed to higher infiltration rates. Vegetation was often planted with hydrophilic herbs that did not survive well in the very dry and exposed bioretention conditions, while shrubs thrived well.

The BHP II study also compared WWHM 2012-modeled results with observed flows and infiltration rates. The WWHM 2012 model built from field measurements of each site adequately represented observations, verifying accuracy of the model's ability to predict performance. However, the design models were often not set up correctly for infiltration rates and safety factors. Top areas (at overflow elevation) for three constructed bioretention facilities (two of which were retrofits) were substantially smaller than indicated in the design report, resulting in less flow control than intended. Low-set overflow elevations in other cases allowed frequent overflows to occur. Field-measured infiltration rates were substantially higher in the field at five facilities, resulting in a greater degree of infiltration than predicted by the model.

Bioretention soil texture was again coarser than Ecology's guidance, resulting in greater infiltration rates than designed. More infiltration appears to occur near inflow locations, potentially affecting vegetation survival and water quality treatment performance in underdrain facilities. Plantings reflected the original planting plans, but unfortunately the many water-loving plants were a mismatch with the well-drained soil conditions of bioretention facilities. Shrubs generally survive better than herbaceous plants.

Fact Sheets of the BHP results for Phases 1 and 2 can be found at the Ecology direct links:

- https://www.ezview.wa.gov/Portals/_1962/Documents/SAM/FS%23012_BioretentionHydrologicPerformanceStudy_Phase1.pdf
- https://www.ezview.wa.gov/Portals/_1962/Documents/SAM/FS%23020-Bioretention-hydrologic_performance-phaseII.pdf

3.1.5 Regulatory criteria or standards

State regulatory standards for stormwater management reside in the minimum requirements of the Municipal stormwater general permits. The nine minimum requirements for new or redeveloped sites are listed in Appendix 1 of the Phase I / Phase II Municipal Stormwater Permits. Bioretention facilities can be used in at least three of the nine minimum requirements:

- 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.

While these minimum requirements will not be directly assessed, measured infiltration rates will describe on-going performance in relation to these goals.

4.0 Project Description

The overall value in the use of bioretention (and other LID stormwater facilities) will depend 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 long-term 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. Assessment of owners' maintenance activities in relation to site performance will help owners plan and implement their maintenance more effectively.

4.1 Project goals

The project goal is to measure infiltration rates of up to 50 bioretention facilities greater than 10 years in operation. With these measurements together with plant composition, maintenance activity, and associated available design information, hypotheses can be drawn about what initial or ongoing conditions have contributed to the current infiltration rates.

Communication goals for the project are to provide presentations to the Stormwater Workgroup (SWG), SAM, 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 SWG, SAM, and Ecology for feedback to the final. Presentations on the findings will be provided to local stormwater managers and engineers to help incorporate the results in future facility design and maintenance.

4.2 Project objectives

Specific project objectives will be to identify a set of candidate facilities greater than 10 years in operation, conduct field measurement of the current infiltration rate of each facility, document the vegetation composition, obtain available site design information, and conduct a survey of each owner's maintenance activities. Using these data, a narrative of possible connections between the original design and ongoing operation will be provided to inform design and maintenance of future facilities. Modification of maintenance activities or reconditioning of the project facilities may also be recommended.

4.3 Information needed and sources

While design information on each facility is not necessary for inclusion as candidate sites, background information will help inform hypotheses on the results of the infiltration tests and plant community composition. Background information for this project includes basis of design documents, design drawings, design parameters, as-built conditions, construction history, performance records, and maintenance methods and schedule.

Information on maintenance activity (gathered through in-person surveys) is a primary goal of the project. Maintenance activity information may be anecdotal, maintenance records, or both.

The source for all this information is expected to be from the project owners.

4.4 Target population

The target population is constructed bioretention facilities in the Puget Sound basin that are greater than 10 years in operation. The basis for selection will not be limited to any design approach as was the case for selection of sites in Phases 1 and 2.

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. Collect soil, infiltration rate, and plant composition information
2. Collect design and maintenance information on each site as available
3. Conduct survey of maintenance crews responsible for site maintenance
4. Conduct data management and quality control for data collected

4.7 Practical constraints

Practical constraints include:

1. Participation of local jurisdiction owners to propose and support access of candidate facilities
2. 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. Jesse Barham, Interim Water Resources Director City of Olympia, Project Municipal Sponsor and Contract Administrator
   Manage execution of the contract, including invoicing and progress reporting.

2. Jennifer H. Saltonstall, L.Hg., Prime Consultant and Hydrogeologic / Geotechnical Data Lead
   Associated Earth Sciences, Inc.
   Provide consultant team management, and team administration with the City of Olympia. Conduct bioretention soil assessment tasks for the project.

3. William J. Taylor, Principal Investigator and Principal Author of Project Reports.
   Raedeke Associates, Inc.
   Lead design of overall project approach. Write project reports with contributions from team members.

4. Annamaria Clark and Christopher W. Wright, Vegetation Monitoring Leads
   Raedeke Associates, Inc.
   Specify approaches and equipment, and conduct field data collection and management for all vegetation monitoring procedures.

5. Doug Beyerlein, P.E., Hydrologic Modeling Lead
   Clear Creek Solutions, Inc.
   Review project reports and provide hydrologic review.

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 the project involves assessment of the vegetation community in the bioretention facilities, the field monitoring will be conducted from approximately April 1 – August 1.

5.5 Limitations on schedule

No limitations within the above time period is expected as the work is not otherwise limited due to season.

5.6 Budget and funding

Funding is from the SAM 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 are selected according to the site selection criteria and are representative of older bioretention facilities in Western Washington.

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

The data will be generated according to procedures for field sampling, sample handling, laboratory analysis, and recordkeeping. Standard operating procedures for infiltration rate measurement and vegetation sampling (detailed in Section 8.1) will follow and documentation recorded.

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 bioretention facility parameters and infiltration rates from a wide range of native soil and hydrologic conditions in Western Washington. A summary of measurement objectives and methods is presented in Table 1.

Field-based infiltration rates are a function of estimated surface and subsurface ponding areas, water depth and flow rate measurements. Particle size distribution and organic matter content sensitivity will be reported by the soil laboratory to be used. The soil will be described by geotechnical professionals. Vegetation community will be identified to species by a trained plant identification specialist. Specimens needing verification will be cross checked with additional staff.

Table 1: Measurement objectives and methods to be implemented.

Measurement Objective	Measurement Method
Soil Properties	Selected laboratory tests (see Table 2) and Visually described per ASTM D-2488
Water Levels	Staff gauges, pressure transducers
Flow Rate	Flow meter
Ponded Area	Hand tapes
Soil Compaction	Geotechnical soils probe
Vegetation	Visual identification by trained plant biologist

6.2.1 Targets for Precision, Bias, and Sensitivity

6.2.1.1 Precision

Subsurface exploration, geotechnical laboratory and infiltration testing is used to characterize bioretention soil and underlying native subgrade. Variability in infiltration rate, soil analyses, and vegetation identification is due to the type and quality of compost and aggregate of the bioretention soil, the supplier's method of mixing the soil, 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. Samples collected from the hand augers will be described per ASTM D-2488 Standard Recommended Practice for Description of Soils (Visual-Manual Procedures).

Infiltration rate testing involves estimates of the ponded surface area, flow rate and volume of pumped water, and depth of water. Flow rate and volume will be measured to the nearest 0.1 gallon per minute (gpm) and gallon. Water depths will be measured in feet to the nearest 0.01 feet. The ponded surface dimensions are typically irregular and will be measured using hand tapes to the nearest 0.1 feet. The ponded area will then be estimated by solving for trapezoidal areas. The accuracy of the resultant area measurement is approximately 5 to 10 percent, and is dependent on the area size, shape irregularity and obstructions (e.g., large vegetation).

The thickness of loose bioretention soil as a qualitative indicator of compaction will be estimated through use of a geotechnical soils T-probe. This qualitative data will be used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth.

This study will analyze organic matter content of the bioretention soil mix and particle size distribution of the bioretention soil mix and subsurface soils. Percent error for organic matter content measurements is approximately 0.5% 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 biologist's trained knowledge and use of existing field guides of common plants of the Pacific Northwest. Stem density and estimates of percent cover will be collected for a minimum of 25% of the bioretention area. Within these sampled areas, the percentage 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 fifty 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 D-2974	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 D-6913	ASTM D-6913	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

For the soil analyses, the primary concern for bias relates to number and frequency of soil sample collection. At a minimum, one sample of bioretention soil from each of three hand-auger borings, and one sample each of native subgrade soil from two of those three hand-auger borings will be collected for each facility and visually characterized. Three samples from each facility will be tested for particle size distribution and percent organic matter, two from the bioretention media and one from the native subgrade, reported individually and in aggregate.

Bias in vegetation stem density and percent cover will be minimized by estimates being conducted by a single plant biologist in the field, with plant identification cross checked with other staff ecologists. A minimum of 25% of the bottom area of each bioretention facility will be sampled for vegetation parameters.

6.2.1.3 Sensitivity

Soil analyses to be conducted include organic content and particle size distribution for both bioretention soil mix and subsurface soils. Sensitivity for both will range from 0.1% to 0.5%.

Electronic flow meters will be used to record both flow rates and total gallons of water applied to the bioretention soil during infiltration testing. Flow meters have a minimum readout total of 0.01 gallons and accuracy can vary up to ±5%. Flow meters record flows as low as 0.3 gpm and as high as 300 gpm. Flow meters will be visually inspected prior to testing and filters will be set in line above the flowmeter to prevent sediment from interfering with the magnetic turbines which record flow. During testing, flow rates will be confirmed by conducting a bucket test using a calibrated container and a digital stopwatch.

Electronic pressure transducers may be used in addition to hand measurements to record the water level ponded at the surface and in below-ground monitoring points. Pressure transducers are sensitive to 0.05% of full scale. Pressure transducers will automatically record and will be compensated with an on-site barometer.

The lowest detectable infiltration rate of 0.02 inches per hour (iph) was calculated based on the precision of the staff gauge (0.01 foot) divided by the maximum duration of the constant-head test (6 hours).

6.2.2 Targets for Comparability, Representativeness, and Completeness

6.2.2.1 Comparability

Comparability of results from this project will be from the infiltration and vegetation measurements at each study site.

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.

Some sites in the present study are expected to be the same sites from the previous two BHP studies. Data collected from these same sites during this study will be comparable to the previous two BHP studies results for infiltration and vegetation as the data and protocols will be the same.

6.2.2.2 Representativeness

Representativeness of this project site selection is based on geographic distribution of subject facilities and qualification of the facility as a bioretention facility following the selection criteria.

- Sites to be monitored are distributed from Bellingham to Olympia north to south, and Issaquah to Poulsbo east to west
- Surface infiltration rates will be measured at each of the facilities, and soil samples will be collected at three locations within each facility
- Vegetation will be assessed during spring to late summer

6.2.2.3 Completeness

Complete data collection goals include:

- Infiltration rates and soil samples will be collected from each facility
- Vegetation composition and density will be collected at each facility
- Maintenance activity surveys will be requested from each facility site owner

7.0 Sampling Process Design (Experimental Design)

7.1 Study Design

This project will measure point-in-time infiltration rates and plant community composition along with historical maintenance activity of up to 50 bioretention facilities each greater than 10 years in operation and distributed around the Puget Sound basin. The purpose of the study is to assess apparent long-term performance of older bioretention facilities. The intended benefits of the project are to improve future bioretention designs and maintenance activity.

7.1.1 Field measurements

Field measurements to be collected include:

- 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 groundwater and field permeability measurements
- Soil infiltration rates
- Vegetation composition and density

7.1.2 Sampling location and frequency

All the field sampling described is to be carried out once within each of the 50 facilities. The individual bioretention sites have not yet been selected.

7.1.3 Field Parameters and laboratory analyses to be determined

The following parameters are used to characterize shallow subgrade soil and groundwater conditions, including infiltration rate:

- bioretention soil mix organic content and particle size distribution
- subsurface soil particle size distribution
- subsurface geologic unit and soil classification
- shallow groundwater depth
- in-situ permeability.

A minimum of 25 percent of each bioretention site will be assessed for plant composition and plants will be identified to species.

7.2 Maps or diagram

The geographic extent of the facility sites to be selected will be generally from in the Puget Sound basin from Bellingham to Olympia and Issaquah to Poulsbo, Washington.

The soil sampling plan includes collecting bioretention media and one hand-auger boring near the inflow and two other soil samples away from the inflow, to maximize hand-auger depth through the bioretention soil, underdrain gravel (if present) and into the underlying native subgrade.

The infiltration test will be generally located in the low area of the cell and the ponding area will depend on the infiltration rate and water source flow capacity. Where possible, the test will flood the facility up to the level of the overflow.

Vegetation sampling will be conducted across the entire planted area, quadrants at specific distances along a transect that may incorporate sample points on side walls, in the center bottom and at points in between. In many, if not most, cases the bioretention units will be small enough to allow identification of all plants within the unit.

7.3 Assumptions underlying design

Assumptions for this study design are that infiltration rate, soil characteristics, groundwater, and vegetation characteristics, and site 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.

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

8.1.1 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 groundwater conditions will be made.

The sediments will be described by visual and textural examination using the soil classification in general accordance with ASTM D-2488, Standard Recommended Practice for Description of Soils. Hydrogeologic analysis and geologic unit assignment will be conducted to estimate 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 for use during the infiltration test and the bioretention soil replaced.

Groundwater and Ponding Depth Measurements.

Ponding depth will be measured with a staff gauge(s). Temporary monitoring wellpoints will be installed to measure subsurface ponding depth and groundwater surface elevations at two depths within the facility during infiltration testing. The design of each facility will ultimately determine the number and types of monitoring wellpoints needed at each facility. Three different types of monitoring points may be required at a given facility. The first type would be installed to measure the ponding depth on the surface of the bioretention cell via a staff gauge. The ponding depth will be used with flow rate to estimate bioretention soil mix infiltration rate. The second type of wellpoint will be installed to measure the subsurface ponding at the base of the bioretention soil mix. Data from the bioretention soil mix monitoring wellpoint will be used to estimate subsurface ponding and infiltration rates within the bioretention soil mix or aggregate layer (if present). The third type of wellpoint would be installed in the shallow native soils underlying the facility to monitor groundwater levels beneath the facility. The data from the wellpoint installed into the native soils will provide information about the influence of shallow groundwater conditions (if present) on the infiltration rates into the underlying soils at each facility. If underdrain cleanouts are present, water levels in the underdrain will also be measured.

The temporary wellpoint(s) may be equipped with a data logger during infiltration rate testing. This data will be compared to staff gauge water level data within the facility.

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 Ash Content and Organic Material test method (ASTM D-2974) to estimate the percent organic matter, and the burned material will then be washed and sieved in accordance with ASTM D-1140 and ASTM D-6913 testing procedures.

The native subgrade sediments will be washed and sieved in accordance with ASTM D-1140 and ASTM D-6913 testing 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 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 2019).

For some facilities with underdrains, the measured infiltration rate will be the rate of the bioretention soil, not the combination of the bioretention soil and underlying native subgrade. The underdrain, if present, will be observed for discharge. The field measurements will be compared to the native subgrade infiltration capacity estimate based on particle 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.

8.1.2 Vegetation Monitoring and Maintenance Activity Survey

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.

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 50 centimeters (cm) in height (along the stem). In addition to a count of the number of stems within the facility, an estimation of the basal area and 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.

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 bottom area will be sampled.

The portion of the facility to be considered for vegetation monitoring will be the relatively flat area as measured from the toe-of-slope for the entire perimeter of the facility. One or more transects will be set lengthwise from the main point of inflow. Enough sample quadrats will then be selected and randomly off-set from the transect center line(s) to equal at least 25% of the study area. The number of transects for each facility will be determined based on the need to establish an adequate number of sample quadrats to represent 25% of the facility.

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

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 will be used to infer the duration and frequency of inundation within the bioretention facility to further describe 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 (4-inch-diameter hand-operated soil auger) 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

No characterization of invasive species will be conducted.

8.4 Equipment decontamination

Care will be taken to minimize the transport of seed and vegetative material from one site to another. Boots will be washed between sites, quadrats and tapes will be wiped off to prevent seed and vegetation transport between sites.

8.5 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.

8.6 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.

8.7 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

8.8 Other activities

No other sampling activities are anticipated.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

Soil sampling, infiltration rates measurements, and related observation procedures in the field will follow the ASTM and Ecology (2019) 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 Ash Content and Organic Material test method (ASTM D-2974) to estimate the percent organic matter, and the burned material will then be washed and sieved in accordance with ASTM D-1140 and ASTM D-6913 testing procedures. Details of the laboratory procedures are provided in Table 1.

The native subgrade sediments will be washed and sieved in accordance with ASTM D-1140 and ASTM D-6913 testing procedures. Hydrometer analyses for particle size analysis will only be conducted if the native material is composed of greater than 15% (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 particle 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 field and soil data will be reviewed to attempt to resolve any discrepancies.

10.2 Corrective action processes

Corrective actions will generally be limited to issues encountered during the site infiltration tests (e.g., lack of sufficient water to complete the test). These will be addressed by field staff after consultation with the hydrogeologist project manager.

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

All project-related data will be recorded as GPS electronic data or paper recording of physical measurements in the field and stored on the consultant server and backed up offsite on a daily basis.

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 analyses that were 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 may include record drawings (as-builts) for each facility, existing 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 is required for completion of the project.

11.5 Data presentation procedures

Field data results 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

No audits will be conducted.

12.2 Responsible personnel

The City of Olympia PM will be conducting reviews of project progress in regard to the active field and data processing QC steps already detailed in Sections 8.1 and 11.1 above.

12.3 Frequency and distribution of report

Project status reports will be provided to the City of Olympia during the course of the study. A single draft report will be prepared for review by the City of Olympia and 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 SAM Coordinator at Ecology.

12.4 Responsibility for reports

The final report will be co-authored by William J. Taylor and Jennifer H. Saltonstall, L.Hg., 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., infiltration measurements and vegetation community records).

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 DQOs 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 infiltration tests and plant community documentation. Completeness and data quality for soil samples and vegetation characterization for each bioretention unit as described above will be required for all units monitored.

14.2 Data analysis and presentation methods

The results of the data collection will be presented in the methods, results, and discussion sections of the final report. Data will be presented in tabular and graphical form, and summary descriptive statistics provided.

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 discussion of the observations.

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

Infiltration and plant community performance of up to 50 bioretention facilities in the Puget Sound basin will be measured. Results will be compared to additional site data such as local bioretention soil mix composition, results of maintenance survey, surficial geology, vegetation density, health, and maintenance. Working hypotheses will be proposed for factors leading to the performance observed.

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.

Washington State Department of Ecology. 2009. Standard operating procedures for conducting stream hydrology site visits. EAP057. Olympia, WA.

Washington State Department of Ecology. 2019. Stormwater Management Manual for Western Washington. Publication number 19-10-021. Olympia, WA.

Washington State Geologist Licensing Board. 2006. Guidelines for preparing engineering geology reports in Washington. Olympia, WA.

16.0 Figures

Not applicable to this study.

17.0 Appendices

Appendix A - 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).

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).

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 (MQOs). 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).

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).

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.

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

USEPA, 1997. Glossary of Quality Assurance Terms and Related Acronyms. http://www.ecy.wa.gov/programs/eap/qa.html.

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. http://www.epa.gov/quality/qs-docs/g4-final.pdf.

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

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.

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

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
GIS	Geographic Information System software
GPS	Global Positioning System
i.e.	In other words
MQO	Measurement quality objective
NPDES	National Pollutant Discharge Elimination System
QA	Quality assurance
RM	River mile
SOP	Standard operating procedures
SWMMWW	Stormwater Management Manual for Western Washington
USGS	U.S. Geological Survey

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