Bioretention Hydrologic Performance Study Phase II

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City of Olympia, Project Sponsor

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Stormwater Action Monitoring (SAM) Program

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Assessment of Facilities Designed Using WWHM 2012

Final Report

Date: December 22, 2020

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1.0 Executive Summary

A bioretention facility is an engineered stormwater facility that treats stormwater by passing it through a specified soil media profile, and either retains or detains the treated stormwater for flow attenuation (Ecology 2014). While the use of bioretention facilities in new development and redevelopment in the Puget Sound region is increasing rapidly, little formal assessment of the hydrologic performance of locally constructed facilities can be found in the scientific literature. As population grows and developable area in the Puget Sound is increasingly scarce, and natural stream channels remain vulnerable to stormwater runoff, evidence is needed that stormwater control measures efficiently use the available space while achieving protection of local waters.

This Bioretention Hydrologic Performance (BHP) Study Phase II follows the previous BHP Study Phase I (Taylor et al., 2018). In that earlier study, ten bioretention facilities were also studied, but those facility designs used an earlier version of the *Western Washington Hydrology Model* (WWHM) than the current WWHM 2012 or used other models. Those previous models did not include the bioretention design element presently available in WWHM 2012 (Clear Creek Solutions, 2016). The BHP Study Phase I provided results from somewhat older facilities designed without the benefit of the new design approach, but also from facilities that had been in operation for a wider range of years than the recently constructed facilities studied under Phase II.

The Phase II study also included a number of retrofit facilities that provided a wider range of design conditions. Retrofit facilities are allowed a greater degree of professional judgement in design under the *Stormwater Management Manual for Western Washington* (SWMMWW) (Ecology 2014) and that was reflected in these facilities.

With this in mind, the three main goals of the BHP Study II were to:

1. Provide an overall assessment regarding how constructed bioretention facilities designed under the WWHM 2012 model are performing on a range of sites throughout Puget Sound, including retrofit designs.
2. From this assessment, identify major elements of the site designs and performance constraints that can help inform the design, modeling, and permit review process for more efficient and predictable facility performance.
3. Provide recommendations for engineers and jurisdiction reviewers to better model, design, and review future bioretention facility designs.

To conduct this assessment, ten constructed bioretention cells (designed using WWHM 2012) were selected from throughout the Puget Sound Basin. The design and construction assessment included:

- Review of original design documents and hydrologic model.
- Eight months of hydrologic monitoring of inflow, outflow, pooling, and groundwater elevations.
- Geotechnical and hydrogeologic sampling.
- Review of vegetation planting plans, installation, and assessment of plant survival.

- Modeling of the site hydrology using WWHM 2012 to evaluate the performance of the model and identify input variables and design features that affect hydrological performance.

Overall, the ten bioretention facilities assessed function adequately without unexpected shortcomings resulting in under capacity or local flooding. In contrast to Phase I sites, a number of the Phase II sites did have some overflow. These sites reflected conditions related to either small (<5 percent) bioretention-to-drainage area ratios, low overflow elevations, low native soil infiltration rates, or some combination of these, and all actually included underdrains.

It is recognized that measurement of constructed elements, hydrogeologic conditions, vegetation, dynamic inflows, and modeling of all these conditions can pose confounding interpretations. For greater detail on each of these elements, the reader is directed to the data compiled in the appendices. Photographs of each site are provided in the geotechnical reports in Appendices 3 through 12.

Notwithstanding this complexity, and the flexibility allowed in design of retrofit systems, the five simplest but highly influential recommendations affecting the performance of these facilities are:

1. Maintain a bioretention top area (surface area at the overflow elevation) which is at least 5 percent of the area draining to it for facilities that are underdrained or have less than 100-percent infiltration.
2. Maintain a minimum 6-inch overflow riser height above the designed bioretention surface.
3. Maintain a minimum 18-inch bioretention soil mix (BSM) depth and meet Ecology (2014) media particle size criteria.
4. Specify a planting plan of plantings that reflects the relatively dry and well-drained conditions of bioretention facilities.
5. A checklist should be developed for Puget Sound region-wide use by both engineers and permit reviewers that enables cross checking that infiltration rates and related model values are consistent between the model, the TIR, and the plan sheets.

1.1 Summary of Findings

<u>Representativeness of Sites Assessed</u>

The project site selection process began in 2018 after WWHM 2012 had been in use for a number of years. Twenty-five sites were identified that used the 2012 model version (Appendix 1). In contrast to the sites selected in the BHP I study, the ten selected sites were all recently constructed, one just a few months before monitoring began.

Over seventy bioretention cells across the 25 sites were evaluated through site visits in the field. After affirming a site was designed using WWHM 2012, the decisive selection criterion was the feasibility of monitoring flow at the cell inflow and outflow locations. As a result of the wide range of geographic locations and site conditions, the selected projects represent a wide cross section of meteorological, geomorphic, and hydrogeologic conditions, as well as drainage area ratios and included retrofit designs.

A summary of the site selection process is presented in Appendix 1. Figure 1 provides a map of the selected site locations. Table 1 provides a summary of site acronyms and locations corresponding to the geographic locations in Figure 1.

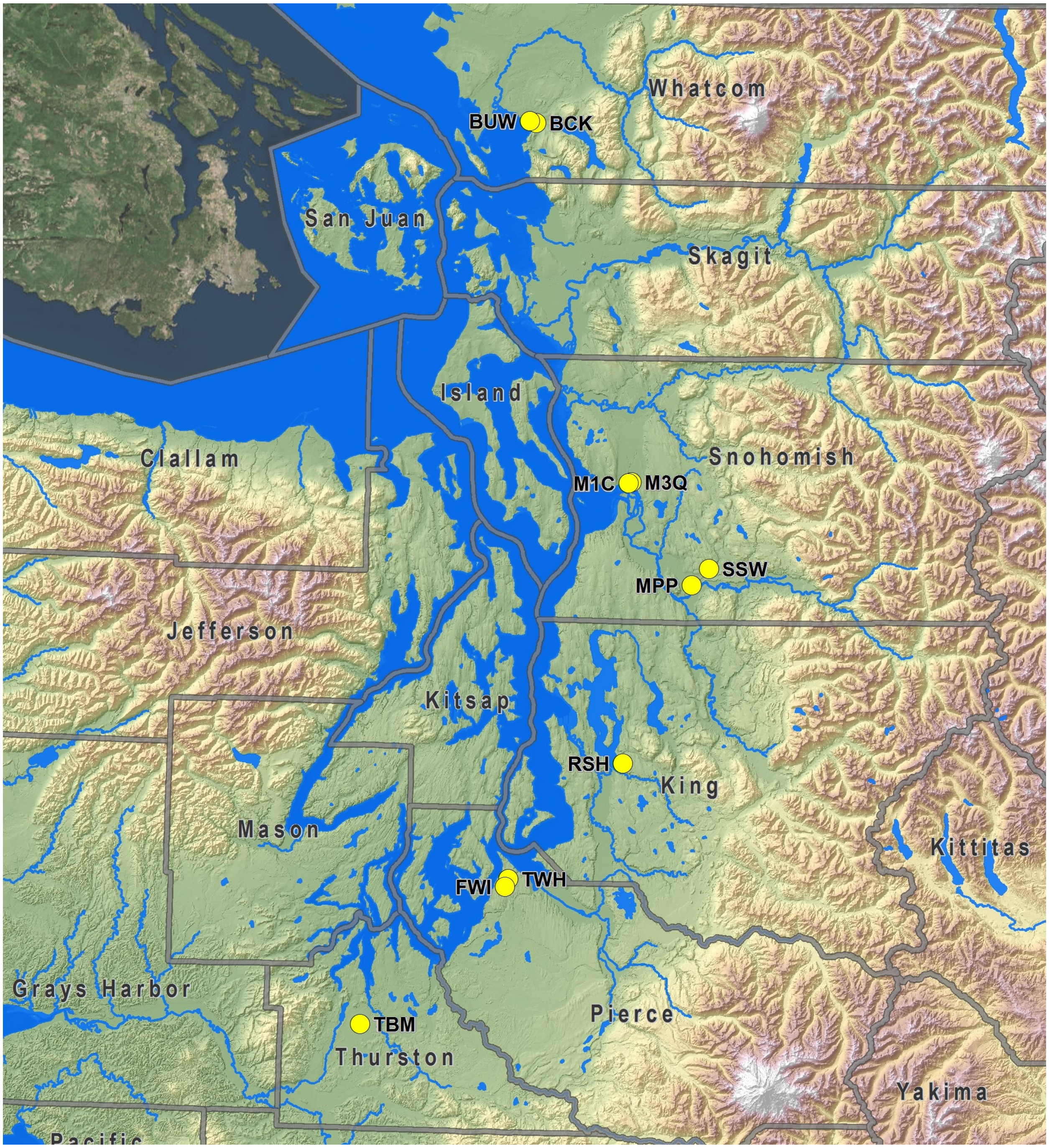


Figure 1. Distribution of Bioretention Monitoring Site Locations.

Table 1. Bioretention Hydrologic Performance Phase II Site Names and Acronyms Used in the Study

Site Number	Acronym	Jurisdiction and Site Name
1	BCK	Bellingham - Cornwall Avenue and Kentucky Street
2	BUW	Bellingham - Utter and Washington Streets
3	FWI	Fircrest - Wainwright Intermediate School
4	M1C	Marysville - 1st and Cedar
5	M3Q	Marysville - 3rd and Quinn
6	MPP	Monroe - Park Place Middle School
7	RSH	Renton - Sunset Community at Harrington Avenue
8	SSW	Snohomish County - Salem Woods Elementary School
9	TBM	Tumwater - Bush Middle School
10	TWH	Tacoma - Wilson High School

One notable difference between the BHP Phase II sites selected and those in BHP Phase I is the inclusion of five retrofit facilities of the ten selected, whereas in the BHP Phase I study there were no retrofit facilities. The significance of the retrofit facilities is they are not required to meet the same design criteria as for new and redevelopment (Ecology, 2019, cf. 2014); for retrofits the recommended BMPs "can be modified using best professional judgment to provide reasonable improvements in stormwater management."

<u>Quality Assurance Project Plan</u>

A Quality Assurance Project Plan (QAPP) was prepared for the BHP Phase II project as was done for Phase I. New project information and any new QAPP procedures were updated in the QAPP (Appendix 2).

<u>Design Conditions</u>

Design dimensions and other information for each of the ten sites was collected from the original design drawings and, when available, from hydraulic and geotechnical reports supporting the design. The modeling approaches were evaluated to assess the original modeling approach (model version, approach to modeling, etc.) to help ascertain whether design features and performance were consistent with the modeling approach taken.

<u>Constructed Dimensions and Infiltration Rates</u>

Constructed cell dimensions were measured in the field and found to be generally as per project design dimensions except for one significant element: three of the facilities (BCK, BUW, and TWH) had substantially less bioretention "top area" (surface area at the overflow elevation) than the design model and one had much more (MPP). The remaining six were generally similar. Table 2 presents the TIRs' reported design bioretention area and the field measured bioretention area determined during the flooding infiltration tests. Table 3 presents the reported design infiltration rate and the field-based infiltration rates measured during controlled flooding infiltration tests. Other minor differences were noted in the geotechnical assessment technical memoranda presented in Appendices 3 through 12. Inflow volumes were assessed through the WWHM 2012 model developed for each site. Field documentation of contributing areas was not conducted.

Table 2. TIR Reported and Field Measured Bioretention Top Area for Each of the Studied Sites

Site	TIR Reported Bioretention Top Area* (ft^2)	Field Measured Bioretention Top Area (ft^2)
BCK (r, u)	169	71
BUW (r, u)	211	38.5
FWI (u)	159	250
M1C (r)	130	132
M3Q (r)	200	200
MPP	684	1,320
RSH (r, u)	64	68
SSW	1,170	1,022
TBM	294	366
TWH (u)	2,070	1,269

TIR = Technical Information Reports
*Top area is defined as bioretention surface area at riser height
ft^2= square feet; (r) = retrofit; (u) = underdrained

Table 3. Comparison of Design and Measured Infiltration Rates

Site	Design Model BSM and Native Infiltration Rates (in/hr) (unmodified rates)	BSM and Native Field Infiltration Rate (in/hr)	Sizing Comparison: Subgrade Field Infiltration Rate Divided by Design Infiltration Rate	Subgrade Geologic Unit
BCK	15 (BSM) 12.3 (subgrade)	6.6 ~0.01 to 0.001	0.0008	Fill over Glaciomarine Drift
BUW	12 (BSM) 6 (subgrade)	300+ ~0.01 to 0.001	0.002	Glaciomarine Drift
FWI	6 (BSM) 1.5 (subgrade)	66 ~0.01 to 0.001	0.007	Glacial Till
M1C	6 (BSM) 2 (subgrade)	>subgrade 17	8.5	Outwash Sand
M3Q	6 (BSM) 2 (subgrade)	>subgrade 15	7.5	Outwash Sand
MPP	2 (BSM) 4 (subgrade)	>subgrade 3	1.5	Alluvium
RSH	5 (BSM) 1.2 (subgrade)	2 ~0.01 to 0.001	1.7	Outwash Sand
SSW	12 (BSM) 11.5(subgrade)	>subgrade 16	1.4	Outwash Sand
TBM	6 (BSM) 0.9 (subgrade)	>subgrade 8	8.9	Outwash Sand
TWH	N/A (BSM) 1.5 (subgrade)	11 ~0.01 to 0.001	0.007	Glacial Till

BSM = bioretention soil mix; in/hr = inches per hour; ~ = approximately; N/A = Not Applicable

Following is a summary of findings for the various disciplines evaluated at each of the sites.

Site Design Modeling Review

- All facilities were designed using WWHM 2012 (except one); however, one design using WWHM 2012 failed to use the bioretention element to represent bioretention facilities in the model. Others used the bioretention element but did not input the correct values that represent the actual design conditions.

- Where any site facility surface area to drainage area ratio was smaller than recommended (5 percent) the site did not meet performance standards.

- Using long-term county precipitation records and the SWMMWW-prescribed lower infiltration rates for the entire bioretention performance lifespan (rather than what was actually measured at the site), six of the facilities did not meet Minimum Requirement (MR) #5 (On-site Stormwater Management) and four of the facilities did not meet MR #6 (Runoff Treatment). (Note that the retrofit facilities were not required to meet MR5 or MR6.) It is recognized, however, that the SWMMWW-prescribed infiltration design rates are intended to represent infiltration near the end of the cell's life cycle (i.e. expecting that the infiltration rate will diminish over the life of the cell). As such, much of the performance of a facility's life span will still reflect the higher infiltration rates, thus potentially meeting these MRs for some period of time.

Hydrologic Monitoring

- Eight months of continuous wet season monitoring was completed from November 2018 to June 2019; however, these data were highly compromised by frequent freezing, snow accumulation, and owner maintenance practices during the winter. Full records were collected and delivered.

- Only three months of data—April 2019 through June 2019—was usable for comparison to modeling results.

- Volumetric runoff at each site is variable even for apparently near 100 percent impervious contributing areas. Measured continuous runoff records were overall considered less dependable than the simulated, so simulated inflow rates based on the measured rainfall record were used in the model evaluation. However, a regression of measured runoff volumes for a range of storm events still often had good R^2 values.

- Ponding and well point responses for infiltrating sites (not underdrained) showed good reflection of the BSM infiltration rates and subgrade conditions. Underdrained sites showed rapid runoff of infiltrated waters, resulting in well point elevations reflecting underdrain elevations.

- Evidence of water movement not captured in the modeling occurred through possible subsurface leakage into subsurface utility trenches.

- At one site near a tidal shoreline, well point data had a clear tidal signal, but groundwater did not affect measured infiltration rates.

- Counterintuitively, four of the five underdrained facilities generated surface overflows, while none of the non-underdrained facilities overflowed. These overflow conditions were ascribed to small facilities or low set overflows.

Geotechnical and Hydrogeologic Findings

- The sites covered a wide range of geomorphic and hydrogeologic conditions.
- Bioretention soil texture was generally coarser than current guidelines, resulting in greater infiltration rates than would be expected under the current media guidelines.
- A wide range of infiltration rates were measured, with infiltration rates for the bioretention media greater than site design values used in all but two cases.
- Compaction of the bioretention soil was documented in three facilities and is interpreted to have reduced the bioretention soil filtration rate in two underdrained facilities.
- Bark mulch floated and was redistributed during controlled infiltration testing and can be a source of clogging if conveyed to a small-diameter orifice-controlled outlet.
- Bioretention without underdrains on outwash sites provides recharge to shallow aquifer settings. Shallow aquifer levels remained below the facility base, and groundwater mounding did not affect infiltration rates.
- Bioretention on low-permeability sites resulted in mounding on hydraulically restrictive layers. The mounded water was collected by the underdrain, but overflows in four of the five underdrained facilities still occurred.

Vegetation Findings

- Phase II facilities studied were only very recently planted (within two years) so still showed original plantings.
- Plantings generally followed the specified planting plans.
- Bioretention soils and native soils drain rapidly in most cases and hydrophytic plants appeared not to survive well at one example site, even within two years of installation.
- Shrubs have higher survival rates than herbaceous vegetation and appear to reduce the need for the maintenance of cells.
- Laterally variable infiltration of inflows provided greater moisture to plants near the inflow points, and less in more distant areas resulting in differential survival in some of the facilities.

Modeling Findings

- Viewing long-term graphical trends, the WWHM 2012 models reproduced the monitored bioretention hydrologic performance data with accurate results.

- An additional bioretention "limiting" surface leaf layer was utilized to best represent four of the facilities. This suggested some surface infiltration was limiting in these facilities, while not necessarily visually obvious.
- Simulated inflow records as opposed to field monitored were deemed adequate to represent modeling of as-built conditions.

1.2 Recommendations for Improved Bioretention Designs and Performance

The BHP Study Phase I report provided similar findings to this Phase II study. The recommendations from Phase I still apply, and the reader is referred to that study for relevant related information (Taylor et al., 2018). The following recommendations are more specifically tied to the current Phase II study.

Given the above findings, major recommendations intended for engineers, geologists, and landscape architects, as well as stormwater site plan reviewers at local jurisdictions include:

<u>Design Features</u>

- Maintain large (>5 percent) bioretention top area to drainage basin ratios including field confirmation of contributing areas.
- Maintain a minimum 6-inch riser height above the cell bottom elevation.
- Maintain a minimum 18-inch BSM depth and meet Ecology (2014) media particle-size criteria.
- Conduct as-built surveys of inlets, overflows, contributing areas, and bioretention surface area.
- Conduct a field inflow test to confirm positive drainage into the cell inlets.
- Include a capped underdrain as a back-up discharge management option in jurisdictions that encourage infiltration in soils that have low infiltration rates.
- Evaluate and incorporate in the design approach the effects of uneven infiltration (see same issue regarding planting plans below).
- Provide careful review of the TIR, design plans, and models before permitting for construction. This review should include contributing area calculations and reviewing the design model to determine the appropriate minimum facility size as a percentage of drainage area and accurate BSM filtration and native infiltration rates.
- Review retrofit facilities for limiting site conditions and the expected performance absent meeting new development facility criteria.

<u>Geotechnical and Hydrogeologic Recommendations</u>

- Collect data specific to the facility location to understand shallow soil, geologic and groundwater conditions affecting subsurface infiltration rates.

- Use pilot infiltration testing at the facility location for estimating long-term design infiltration rates.
- Consider potential for lateral subsurface flow, and the ultimate path of the infiltrated water, for sites with low or spatially variable infiltration rates.
- Consider potential for utility corridor capture of infiltrated waters, particular in retrofit applications.
- Provide testing of the bioretention soil media for consistency with the specifications provided in the Ecology Manual, especially the #40, #100, and #200 grain-size fractions.
- Conduct geotechnical plan review of permit plans and during construction so that plans adequately incorporate geotechnical recommendations (e.g. are bioretention cells located near infiltration test locations or at different elevations; does the grading plan (improperly) remove the permeable horizon?).
- Conduct observations during construction to observe whether the subsurface geologic and groundwater conditions are consistent with the basis of design (e.g. if site design is based on outwash soils being present, and subsurface conditions are consolidated glacial till, a design change is required).
- Look for evidence of soil compaction. We speculate based on limited observations that soil compaction impacts are more common for narrow facilities. Evidence for surface compaction was exhibited in five of the ten facilities.
- Remediate compacted soil prior to acceptance. Soil compaction can occur during bioretention soil placement, irrigation installation, placement of inlet protection, or energy dispersion elevation, or from planting.
- Conduct a study of "aging" of facility infiltration rates over time, whether those rates are decreasing, increasing, or staying the same.

<u>Vegetation Recommendations</u>

- Use shrubs as they tend to compete better with noxious weeds and therefore should be used more frequently in units to reduce maintenance. Cells that were planted with only herbaceous species, or where the woody plants had been heavily browsed by deer, tend to grow a greater density of noxious weeds.
- Plant with a variety of shrubs and herbs. Herbaceous species tend to have poor survival rates in bioretention cells compared to shrubs. Where large shrubs may be inappropriate due to limited sight lines, consider using smaller shrubs such as Kelsey Dogwood (*Cornus sericea 'Kelseyi'*) and shinyleaf spirea (*Spiraea betufolia* var. *lucida*).
- Specify water-tolerant plants in bottom areas near the inflow, and fan out to more facultative, facultative upland plants farther away from the inflow.
- Do not use plants that commonly occur in wetlands. Wetland soils are anaerobic, waterlogged, and poorly draining; bioretention soil is very well draining. Wetland species that require

constant water-logged soil will not grow well in bioretention cells and should be avoided (except for *Carex obnupta*).

- Develop maintenance plans and contingency plans with the planting designs to allow adaptive changes. Designers should follow up on the effectiveness of the design a year or two after installation.

Modeling Recommendations

- Use a limiting "leaf litter layer" surface modeling layer in the model where non-wood mulch will be applied.
- To help assess design for retrofit and new facilities, Ecology should conduct a sensitivity analysis of the magnitude of effect of the variability of safety factor infiltration rates, contributing drainage area, and use of regional rainfall records on facility performance on long-range ability to meet MR #5 and MR #6.
- Double check the accuracy of the BSM and native soil infiltration rates input in the WWHM 2012 model and in the TIR for the site. Then reviewers should analyze results for compliance with MR #5 and MR #6 before approving new development site design.

1.3 Acknowledgement to Project Sponsor, SAM Participants, and Participating Jurisdiction Staff

This project has been a cooperative effort involving contributions from the Stormwater Action Monitoring (SAM) staff, and the participating SAM jurisdictions who reviewed the original proposal during the selection process. As the jurisdictional sponsor, the City of Olympia provided careful review of all deliverables and budget monitoring, resulting in greatly improved products, and remaining within the conditions of the Ecology contract. The SAM Coordinator and other Ecology technical staff likewise provided responsive reviews of draft submittals.

Local jurisdictions provided substantial collaboration through nominating candidate bioretention study sites and provided the background designs and reports needed to assess the multiple sites evaluated. Over 70 individual bioretention cells were visited as part of the selection process, nominated by over 25 jurisdictions, with dozens of jurisdictions contacted.

Finally, discussions with participating design engineers provided insight to design details and supporting documents for a greater understanding of the designs and constructed conditions.

2.0 Introduction

While the storage and infiltration capability of bioretention facilities is generally acknowledged, little data exists in the Puget Sound region to verify the hydrologic performance of these facilities, except now with the results from the BHP Phase I (Taylor et al., 2018). Use of bioretention is widespread in the Puget Sound region and is expected to increase in the region as a result of requirements of the National Pollutant Discharge Elimination System (NPDES) municipal permits and the 2014 SWMMWW (Ecology, 2014). State and local governments want confidence that new bioretention facilities constructed under the 2014 SWMMWW can be built to attain desired performance.

Meeting expected infiltration and overflow conditions from bioretention facilities ensures downstream receiving waters are protected to the extent planned and the desired inflow volumes are filtered for water quality treatment. The cumulative hydrologic benefit of bioretention facilities on receiving waters will depend on the hydrologic performance of each of the individual facilities within a basin.

The hydrologic performance of bioretention facilities may also affect the survival, composition, and health and maintenance of the facility vegetation, which may, in turn, have further impacts on infiltration and longevity of the facility. Conducting a performance assessment of bioretention facilities represents an adaptive management process to help ensure effective implementation of low impact development (LID) facilities in the Puget Sound region.

The intent of this study was to:

1. Conduct an overall assessment regarding how ten constructed bioretention facilities designed using WWHM 2012 are performing in sites throughout Puget Sound.
2. Use the detailed monitoring of each facility to identify major elements of the site designs and performance constraints to assist in the design and modeling to produce efficient and predictably performing facilities in the future.
3. Provide recommendations for design engineers and jurisdiction reviewers to better model, design, and review future bioretention facilities.

The overall BHP Phase II project involved an initial consideration of dozens of sites, site assessment of 25 candidate sites, discussions with local jurisdiction owners, design engineers, and maintenance staff; and site-specific documentation of ten cells for dimensions and elevations, soil structure, infiltration rate, vegetation conditions, modeling software, and measured hydrologic response of the facility. As part of our study, each site was modeled by our project team using WWHM 2012. Post-construction site conditions and eight-months' worth of monitoring data were used to assess model parameter values and new model elements (e.g., presence of a leaf litter layer) to provide insights to the model performance itself and facility performance.

As a result of the comprehensive nature of the assessment, it should be noted that, in addition to the physical measurements, hydrologic performance data, and modeling, insights and conclusions were also drawn by using anecdotal observations gained from owners, engineers, and operators of the facilities, as well as the investigators' own site-specific observations. While this study provided many recommendations for improved design and performance of bioretention facilities, new research questions emerged. These possible new questions were not evaluated here as the analyses would require unavailable or uncollected data or are beyond the scope of this project.

The following discussions of each of the site monitoring and modeling disciplines are summaries of the approaches and conclusions presented in the discipline technical memoranda provided in the appendices.

3.0 Site Selection and Study Design

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, or contact with BSM may not be adequate to provide water quality treatment.

Evaluation of bioretention performance from the BHP Phase II projects provides new feedback to the 2014 SWMMWW modeling design process, and to engineers' design approaches, to help optimize designs for greater expected accuracy and resulting benefits.

3.1 Project Goals

The project goal was to compare actual hydrologic performance of constructed bioretention facilities around the Puget Sound under a variety of storm conditions with the modeled performance from the same facility using WWHM 2012. Results demonstrated the relative importance of site characteristics, design, installation, maintenance, and modeling variables.

Communication goals for the project were to provide presentations and technical memoranda to the Stormwater Work Group (SWG) and Ecology to elicit feedback on the project. These tasks were completed during the course of the project. The final report was created to provide summary information to professional stormwater managers and their staff throughout the region.

In addition to providing presentations to the SWG, a communication goal was to present results to local jurisdiction designers, permit reviewers, and engineers, thereby more directly transfer the findings to these staff and private sector engineers designing and reviewing bioretention facilities. These presentations were organized through the regional permittees forums, including the North, Central, and Southwest permittees forums, the Washington Stormwater Center, and the Washington Chapter of the American Society of Civil Engineers.

3.2 Project Objectives

Specific objectives of the project included installing inflow and outflow monitoring instruments that accurately and precisely measure stage at primary hydraulic devices which can then be translated by a rating curve to flow. Stage (water depth) gages were installed for both surface ponding and subsurface soil saturation. Rain gages were installed, or nearby gages used, to measure actual rainfall at the site of the subject bioretention facility being monitored. Rainfall, stage, and flow were measured continuously during the wet season to enable evaluation of the design model using the actual rainfall, runoff, ponding depth, and facility flow-through conditions observed.

The change in the model parameter values required to accurately reproduce the monitored data revealed the accuracy of the model parameter values used in the original engineering design. The comparison of the hydrologic results to the minimum requirements also revealed the degree to which the results continued to meet or did not meet the hydrologic criteria of the 2014 SWMMWW.

Coincident with collecting stage and flow data and comparing the design model with a model based on actual performance, the secondary objectives were to collect data characterizing the BSM, shallow subgrade soils, infiltration rate, and vegetation community composition and density and maintenance activity. These additional data were used in conjunction with the observed hydrologic performance to support hypotheses regarding the possible mechanisms influencing the hydrologic results.

3.3 Site Selection Criteria and Selection Process

To initiate the facility selection process, a selection criteria matrix was developed to identify and prioritize the project site elements as they affected the site's potential selection. Candidate sites were identified through discussions with interested local jurisdictions and some privately owned facilities. Each of the candidate sites identified were assessed in the field for the selection criteria, and final selection based largely on the ability of the inflows to be accurately measured. A complete description of the process is provided in Appendix 1.

The names and project site acronyms for the ten sites are listed in Table 1. Sites will be referenced by site acronym throughout the report. A map of the ten selected site locations is presented in Figure 1.

4.0 Results and Discussion

The intent of the BHP Study was to compare original design plans for the expected dimensions, geotechnical and hydrogeologic conditions, hydrology, and vegetation plans with the actual measured conditions for all these disciplines.

The intent of this comparison was to identify major elements of the site designs and performance constraints to help inform the design and modeling process for more efficient and predictable facility performance.

With these design elements, we provide recommendations for engineers and jurisdiction reviewers to better model, design, and review future bioretention facility designs.

The methods and materials used for each of the disciplines studied are presented in the appendices for each of the disciplines addressed at all the sites in this study:

- Hydrologic Monitoring
- Geotechnical and Hydrogeology Assessment
- Vegetation Community
- Modeling Analysis of Observed Performance

A summary of the dimensional, geotechnical, hydrogeologic and modeled site conditions of the ten cells selected for monitoring is presented in Table 4 and Table 5 below. See also Table 3 for direct comparison of model and measured BSM filtration and native infiltration rates, and Table 2 for a comparison of model versus constructed bioretention top areas.

4.1 Hydrologic Monitoring

Continuous hydrologic monitoring of the hydrologic cycle through each of the ten cells was conducted for the period of October 2018 through mid-July 2019. The monitoring was conducted at 5-minute intervals including the following hydrologic elements:

- Rainfall
- Inflow to the bioretention cell
- Ponding stage
- Subsurface or groundwater stage
- Overflow surface outlet
- Underdrain outlet (where available)

Water levels for the flow monitoring locations were measured relative to the invert of the compound weirs installed in the inlet or outlet pipes and were also tied into a common local elevation. Water levels in the surface ponding and subsurface wells were tied into the same common local elevation.

Each of the rain gages and stage recording devices were downloaded on a monthly basis, and the instruments recalibrated to their respective zero-point elevations. Appendix 13 provides a detailed description of the methods, materials, and quality assurance/quality control (QA/QC) process for the hydrologic data collection and review process.

The intent of this detailed hydrologic monitoring in the study was to provide multiple points of information in the hydrologic response of the overall facility. This enabled cross comparison of the data from each of the points with one another and later with the hydrologic model to confirm an understanding of the overall hydrologic response of the system. With the careful QA/QC procedures used during data collection and review of the data, these data provide the substantiated basis for modeling and understanding of the overall performance of the facilities.

One of the findings (again as occurred in BHP Phase I) appears to be that the contributing areas of the facilities in some cases may be different (either larger or smaller) than the originally designed contributing area. The importance of this point is that the bioretention facility can perform only as designed if the size of the contributing inflow area is correct. It is important to double check the inflow area to ensure that model calculations and site design are accurate for the project site.

It also appears that site constraints may have affected the overall performance of some sites. Retrofits along streets are often constrained in size, slope, and elevation by rights-of-way or the need to tie into existing storm drain infrastructure. This led to one site with an inlet pipe that likely also discharged from the facility at times and some overflow structures that were barely above the bottom elevation of the facility. This made the sites difficult to monitor accurately but also likely indicate that the site constraints limit the effectiveness of the facility. In this study, the four sites that experienced overflows were all in fact underdrained; three of the four were retrofits installed in the road right-of-way or had till or low elevation overflows.

Table 4. Dimensional Constructed Conditions at Ten Monitored Bioretention Facilities

	Type of Facility	From Drainage Report, Stormwater TIR, and Civil Plans		Clear Creek Solutions Modeled in WWHM 2012		
Site	**New or Retrofit**	**Grading Plan Review (cut or fill)**	**Design Model BSM and Native Design Infiltration Rate (in/hr)**	**Drainage Area (pervious and impervious [ac])**	**Top Area* (ft^2)**	**Top to Drainage Percentage**
BCK (installed 2017)	Retrofit	Cut, ~3 feet	15 (BSM) 12.3 (subgrade)	0.27	71	0.6%
BUW (installed 2016)	Retrofit	Cut, ~3 feet	12 (BSM) 6 (subgrade)	0.93	38.5	0.1%
FWI (installed 2016)	New	Cut, ~3 feet	6 (BSM) 1.5 (subgrade)	0.33	250	1.7%
M1C (installed 2017)	Retrofit	Cut, ~3 feet	6 (BSM) 2 (subgrade)	0.03	132	10.1%
M3Q (installed 2017)	Retrofit	Cut, less than 5 feet	6 (BSM) 2 (subgrade)	0.02	200	23.0%
MPP (installed 2017)	New	Cut, 4 to 5 feet	2 (BSM) 4 (subgrade)	0.48	1,320	6.3%
RSH (installed 2017)	Retrofit	Cut, ~4 feet	5 (BSM) 1.2 (subgrade)	0.17	68	0.9%
SSW (installed 2018)	New	Cut, ~5 to 6 feet	12 (BSM) 11.5(subgrade)	0.40	1,022	5.9%
TBM (installed 2016)	New	Cut, less than 3 feet	6 (BSM) 0.9 (subgrade)	0.31	366	2.7%
TWH (installed 2016)	New	Cut, ~3 feet	1005 (BSM) 1.5 (subgrade)	1.62	1,269	1.8%

TIR = Technical Information Reports
WWHM = *Western Washington Hydrology Model*
BSM = bioretention soil mix
in/hr = inches per hour
ac = acres
*Top area is defined as bioretention surface area at riser height
ft^2 = square feet
~ = approximately
Note: BCK, BUW, and TWH had TIR/design report listed bioretention surface areas that were considerably larger than the field measured bioretention top area for each facility (see Table 2).

Table 5. Hydrogeologic Conditions at Ten Monitored Bioretention Facilities

Associated Earth Sciences, Inc. (AESI)						
Site	**Geologic Unit**	**Aquifer**	**BHP Study BSM Field-Based Infiltration Rate (in/hr)**	**BHP Study Subgrade Native Soil Field-Based Infiltration Rate (in/hr)**	**Surface Discharge Expected (Yes/No)**	**Comments**
BCK (installed 2017)	Glacio-marine Drift	Perched (interflow)	6.6	Uncertain; interpreted to be low and complicated by utility fill	Yes (under-drained)	Disconnect between design geotech and WWHM infiltration rate. Extra pipe not shown on plans. Mounded portion of cell base affecting ponding.
BUW (installed 2016)	Glacio-marine Drift	Perched (interflow)	300+	Low ~0.01 to 0.001	Yes (under-drained)	Cell base area is sloped, limiting ponding.
FWI (installed 2016)	Till	Perched (interflow)	66	Low ~0.01 to 0.001	Yes (under-drained)	No mulch present.
M1C (installed 2017)	Recessional Outwash	Shallow Regional	Higher than native soil	17	No (100% infiltration)	Tidal influence on groundwater did not affect cell performance.
M3Q (installed 2017)	Recessional Outwash	Shallow to deep groundwater	Higher than native soil	15	No (100% infiltration)	
MPP (installed 2017)	Alluvium	Shallow Regional	Higher than native soil	3	No (100% infiltration)	Field tested rate (3 in/hr) much lower than design infiltration rate testing (12 and 75 in/hr).
RSH (installed 2017)	Recessional	Perched (interflow)	2	Uncertain; interpreted to be limited by perching layer	Yes (under-drained)	Includes underdrain orifice; Overflow grate set low, near inlet, bypass of BSM possible.
SSW (installed 2018)	Recessional Outwash	Shallow Regional	Higher than native soil	16	No (100% infiltration)	Silty inflow observed from nearby construction.
TBM (installed 2016)	Recessional Outwash	Shallow Regional	Higher than native soil	8	No (100% infiltration)	
TWH (installed 2016)	Till	Perched (interflow)	11	Low ~0.01 to 0.001	Yes (under-drained)	Extra inflowing pipe not shown on plans.

BHP = Bioretention Hydrologic Performance; BSM = bioretention soil mix; in/hr = inches per hour;
WWHM = *Western Washington Hydrology Model*; % = percent; ~ = approximately

4.2 Geotechnical and Hydrogeologic Assessment

Data collected as part of the geotechnical and hydrogeologic assessments include key information on the imported bioretention soil and the native subgrade soil and shallow groundwater. Controlled field infiltration rate testing was conducted at each facility. Details are included in Appendices 3 through 12.

Hydrogeologic Setting and Infiltration Performance

The ten bioretention facilities cover a range of geologic settings: five facilities on glaciated upland terrain, four facilities on outwash plains and terraces, and one facility in an alluvial plain.

The five facilities on glaciated uplands (BCK, BUW, FWI, RSH, and TWH) were each constructed with an underdrain. Four were set in fine-grained till or glaciomarine drift sediments, and the majority of water was interpreted as leaving the cells through the underdrain, except in BCK where uncontrolled fill sediment is interpreted to be present and may be conveying infiltrated water from the cell. One facility (RSH) was set in recessional outwash sands on a glaciated upland, with a shallow perching layer present underneath the cell, limiting infiltration into the native sediments; most of the flow was observed to leave the cell via the underdrain, consistent with the hydrologic monitoring and modeling results. Four of these underdrained facilities overflowed during the course of hydrologic monitoring (all except FWI).

Of the four facilities on outwash plains or terraces (M1C, M3Q, SSW, and TBM), all were set in Vashon recessional outwash sands, and three (M1C, SSW, and TBM) had shallow groundwater, while one (M3Q) had moderately deep groundwater. All four of these facilities had measured infiltration rates into the native subgrade which were higher than the design rate. None of these facilities were underdrained, and none showed evidence of discharging water to an overflow.

One facility (MPP) was set in recent alluvium and had a field-based infiltration rate which was close to, and higher than, the design infiltration rate. However, the infiltration rate was much lower than field rates reported in the design documents.

We observe that infiltration facilities on fine-grained sediments such as glacial till and glaciomarine drift behave more as dispersion best management practices (BMPs) rather than infiltration BMPs due to lateral flow components.

Three of the facilities (BCK, RSH, and SSW) showed evidence of compaction from either the measured BSM infiltration rate being lower than the BSM design specification rate or from observations and qualitative soil probe data. This was unexpected for relatively recently constructed facilities.

Bioretention Soil

We tested mechanical grain-size distribution and percent organic matter by weight in accordance with *ASTM International* (ASTM) D422 and D2974, respectively, on samples of BSM and native sediment from each site. We also conducted a geotechnical T-probe survey of the facility base to qualitatively assess soil thickness and compaction.

Organic matter content and grain-size data from laboratory testing data are presented in Appendices 3 through 12 for each bioretention facility and compared against the 2014 SWMMWW-recommended specification for BSM. A summary of averaged organic matter and key grain-size testing results relative to the recommended specification is included in Table 6, below. Two samples were taken at each site. None of these sampled bioretention soils met the recommended specifications. The age of the facilities ranged from newly installed to two years at the time of sampling (Table 5). A graphical representation of these results is presented in Figure 2.

The amount of silt/clay-sized particles and fine sand are important for permeability. Too much fine material can slow drainage; too little results in very high infiltration rates. High infiltration rates affect water quality treatment assumptions and also can stress vegetation. Organic matter provides some water quality treatment, increases the water holding capacity of the soil to aid plant growth, and provides nutrients for plant growth.

Table 6. Averaged Organic Matter and Grain-Size Results Relative to Recommended Values

Site ID and 2014 SWMMWW Recommend Range	Bioretention Soil Characteristics*				Coefficient of Uniformity*	Coefficient of Curvature*
	Average	Average Grain Size, % Passing by Weight				
	% Organic Matter	#200 sieve	#100 sieve	#40 sieve	Cu	Cc
	5-8	**2-5**	**4–10**	**25-40**	**4+**	**1-3**
BCK	5.5	5.9	6.7	26.0	4.6	0.9
BUW	6.7	1.9	2.9	14.9	4.3	1.0
FWI	5.7	5.3	8.5	28.6	7.0	1.0
M1C	5.9	3.9	8.5	47.3	3.1	1.1
M3Q	6.3	4.3	6.5	35.8	3.1	1.0
MPP	10.0	3.3	5.8	20.1	5.8	1.0
RSH	5.4	5.5	14	45.9	6.1	0.9
SSW	15.5	5.4	10.2	29.6	9.6	1.0
TBM	6.5	4.1	5.9	18.3	6.7	0.9
TWH	7.4	3	5	34	2.6	1.0

SWMMWW = *Stormwater Management Manual for Western Washington*
*Averaged values (2 samples per site); values which do not meet the recommended specifications are indicated by gray shading.
% = percent

The bioretention soil was mostly within the recommended range for organic matter content. Two outliers were the Monroe School District sites MPP and SSW, both of which had higher than recommended organic content.

The gradation or grain-size distribution was variable. For infiltration performance, the key gradations are the finer-grain sizes represented by the #200, #100, and the #40 sieve sizes. The #200 was within the recommend range for five sites, and within 0.5 percent of range for four of the remaining five sites, with the exception of BCK, which had 0.9 percent more (5.9 percent) than the maximum recommended percentage (5 percent) passing. The #100 for most sites was also within range, though site RSH exceeded by 4 percent and BUW was low by 1.1 percent. The #40 sieve results were the most variable with exceedances on both ends of the range for half the sites. Two sites missed on all three gradations: Site RSH, which had a finer-grain size (higher percent passing) on the #200 #100 and #40, and BUW, which has a coarser-grain size (lower percent passing) on the #200, #100, and #40.

The uniformity coefficient (Cu) is a numerical expression of the variety in particle sizes in mixed soils. A value of Cu greater than 4 to 6 classifies the soil as well graded. When Cu is less than 4, it is classified as poorly graded or uniformly graded soil. The curvature coefficient (Cc) is estimated using the gradation curve through sieve analysis. When the value Cc is between 1 and 3, the soil is said to be well graded. Most sites had well-graded sands based on Cu. Both Marysville sites, M1C and M3Q, had low Cu, less well-graded, potentially a result of a same supplier source. All sites were at the low end of the Cc range, near 1, consistent with the mostly sand fraction of the bioretention soil.

Figure 2 illustrates the bioretention soil gradation and Ecology's recommend grain-size envelope.

The BSM infiltration rate exceeded the facility design rate in all cases except in BCK and RSH. In cell BCK, this may be due to the higher than recommended percentage of bioretention soil passing the #200 sieve. In cell RSH, we noted some compaction of the bioretention soil during soil probing, which may have limited the infiltration rate. Based on our qualitative assessment of compaction, we also observed an area of compacted bioretention soil in cell SSW; however, the compacted area comprised only a portion of the cell base and, although it may have reduced the infiltration rate in that portion of the cell base, the overall infiltration rate remained higher than the design rate. We interpret that the bioretention soil was generally in a loose condition in all other cells, and that excessive compaction did not otherwise limit infiltration rates through the bioretention soil.

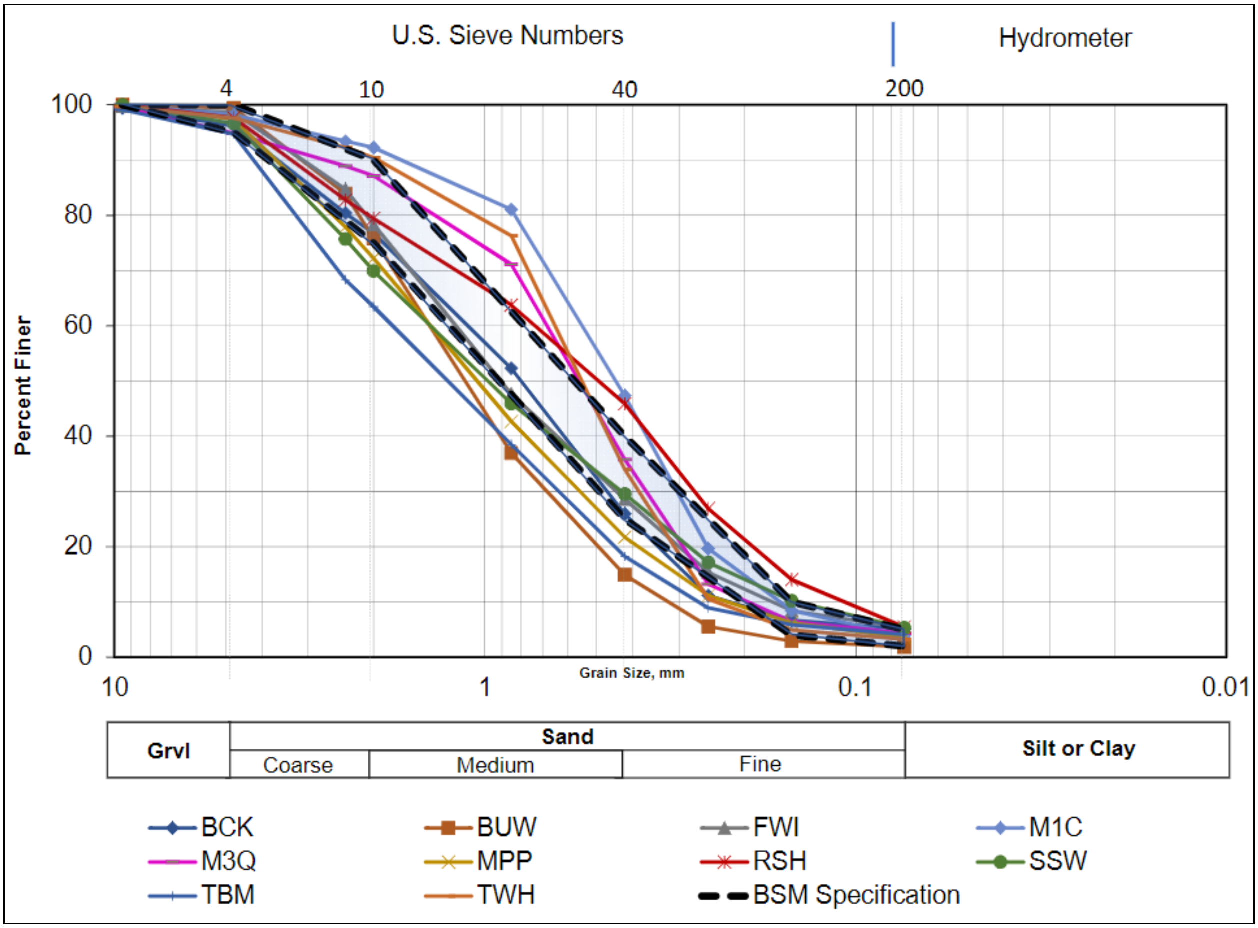


Figure 2. Graphical Representation of the Grain-Size Composition of BSM Samples Collected at Each of the Ten Facilities Studied. "BSM Specification" illustrates recommended gradation in the 2014 SWMMWW.

4.3 Vegetation Monitoring

Many of the cells studied had been planted only in the past year or two. Drawing conclusions on the overall health and survival of the plants is difficult since the plants have had limited time to establish and adjust to the hydrologic conditions in the cells. Also, many of the cells we looked at contained only herbaceous plant material, which makes it difficult to draw conclusions about woody material. However, results from both Phase I and Phase II were synthesized to help form some conclusions or recommendations for planting bioretention units.

Plants were identified and measured in ten cells. The plants were categorized as either woody or herbaceous and were further categorized by their need for water using the wetland indicator status (WIS), a common approach among plant biologists. Bioretention facilities are, by definition, not wetlands. This categorization allows us to characterize the apparent survival conditions experienced in each of the facilities. Table 7 provides the distribution of the surviving shrubs and herbaceous plants found in the ten facilities. Appendix 14 provides additional detail on the vegetation monitoring. In addition, the plants found in the cells were compared to the approved planting plan.

Many of the planting plans for the bioretention facilities specified various species and varieties of red-twig dogwood, including the dwarf variety, Kelsey. Red-twig dogwood is very versatile and tends to have high survival rates in the cells. The exception is in areas where deer are present. We observed red-twig dogwood that was heavily browsed by deer in one of the cells. Two of the cells specified salmonberry in the planting schedule. Within one of those cells, no salmonberry was observed and in the other cell twelve of the twenty (60 percent) salmonberry were tallied.

Only one cell in this study was growing the ornamental willow, dwarf arctic willow. In the first phase of this study, many of the cells were growing dwarf arctic willow. The willow may not have been used as extensively in this study due to its large size, but it does tend to have a high survival rate within bioretention cells. Most of the shrubs observed have a WIS of facultative wet (FACW) or facultative (FAC). Two evergreen huckleberries were installed in M3Q, accounting for the facultative up (FACU) percentage. M3Q was installed the previous year (2018), so the huckleberries had only been through one rainy season and may not survive long-term, depending on the future degree of inundation. Red twig dogwood and shinyleaf spirea provided the greatest stem density within the cells.

Results from the BHP Phase I study indicated that shrubs tend to have higher survival than herbaceous plants and are more adaptable to various hydrologic regimes. Frequently, bioretention cells are located in areas that require unobstructed site lines, such as in school yards or along roads. The large, native shrubs are often inappropriate for use in bioretention cells in these situations. The use of small or dwarf shrubs provides adaptability of woody vegetation while maintaining required site lines.

The herbaceous vegetation in this study was more diverse than the previous study. A few of the cells were planted only with native vegetation, but many were planted with a variety of ornamental and native vegetation. Most of these cells were recently planted so it is difficult to draw long-term conclusions from the cells and determine the success of the landscape plants. Slough sedge was the dominant obligate (OBL) plant in 4 of the cells, and 4 cells contained no OBL plants. This is in line with the previous study. Slough sedge is one of the few OBL plants that will survive in bioretention cells. In cells that were not irrigated, the slough sedge persisted near the inlet.

Cells M1C and BCK have the densest herbaceous vegetation communities. M1C is primarily an herbaceous cell and BCK contained only herbaceous vegetation. M1C is planted with all ornamental plants, such as Evercolor® Everillo sedge, Japanese iris, and bee balm. This cell has been installed for only a year, but the ornamental plants are providing a decent percentage of basal cover. The vegetation of cell BCK comprised primarily slough sedge and blue elk spreading rush. Both plants have provided good basal coverage within the cell.

Three of the cells had less than 10 percent basal cover, which is low for cover. The low percentage of cover in the cells is not caused by dense woody vegetation shading out the herbaceous vegetation. Site SSW was planted in the fall of 2018 and the plants had not been through a full growing season since the measurements were taken in late spring 2019. MPP has been planted for two years and was planted with OBL wet herbaceous plants and some shrubs around inlets. The soil under this cell is considered well-draining. Bioretention cells located on well-draining soils do not support OBL plants that typically live in hydric waterlogged soils; the plants are surviving but not thriving in the cell. The FWI cell also had low herbaceous cover. We did not observe any of the plants that were specified in the planting plan growing in this cell. We did record slough sedge growing in the cell; however, the most prevalent plant was thistle. Thistle, like other weedy plants, does not create a basal mass like slough sedge or rushes. Weedy plants do provide basal cover, but not at high percentages.

Cells with underdrains drain rapidly, and in some large cells, the cell drains before water can spread across the entire floor of the cell (TWH). If irrigation is not present in these cells, then a portion of the plants get watered only from precipitation. Cells with underdrains, especially large cells with underdrains, need to be planted with extremely adaptable plants that err on the side of having a WIS of FACU or UPL.

Most herbaceous volunteer plants within bioretention cells have a WIS of FACU; however, most installed herbaceous species have a WIS of FAC, FACW, or OBL. Bioretention cells should be installed with a range of WIS plants. Herbaceous plants that require more water, such as FACW plants, or slough sedge (the only OBL plant that has been successful in establishing in bioretention cells) should be located near the inlet for the water and plants farther from the inlet should have a WIS of FAC or FACU.

Maintenance plans and contingency plans should be developed along with the planting designs to allow adaptive changes. Designers should follow up on the effectiveness of the design a year or two after installation.

Table 7. Wetland Indicator Status Percent Distribution for Shrubs and Herbaceous Vegetation in the Ten Bioretention Facilities Studied

Percentage of Plants and Their Wetland Indicator Status (WIS) for the Surveyed Cells														
	Shrubs						Herbaceous							
	Total Woody Plants/ Stem Density	OBL	FACW	FAC	FACU	UPL	Total Quadrats/ Basal Cover	OBL	FACW	FAC	FACU	UPL	No Plants	Underdrain
BCK	NA						17/27%	47%*	17.6%		35.2%	11.7%		Yes
BUW	33/945		25.0%	75.0%			31/19%		80.6%	22.6%		16.1		Yes
FWI	2/2		100%				44/5.5%	34%*	38%	70%	100%			Yes
M1C	10/300		100.0%				33/24%		3.0%	100%	%			No
M3Q	7/62		71.4%	9.0%	28.5%		47/21%	34%*	23%	10%		15%		No
MPP	14/14			100%			80/9.2%	69%	13.8%		3.8	8.8%		No
RSH	NA						21/25.5%		100%			4.5%	19%	Yes
SSW	8/240		100.0%				192/6.0%	97.3%				12.6%		No
TBM	9/9		100%				64/34.2%		37.5%	25%	100%	33%		No
TWH	NA						222/25.8%	43%*	9.0%	55%	32%	6.0%		Yes

OBL = Obligate
FACW = Facultative Wet
FAC = Facultative
FACU = Facultative Upland
UPL = Upland
Quadrat = 25 centimeters (cm) x 25 cm portable frame used to estimate herbaceous cover
*OBL Community entirely or predominately composed of slough sedge (*Carex obnupta*)

4.4 Hydrologic Modeling

Each of the sites were initially assessed for drainage area-related information for use in the WWHM 2012 model (Appendix 15). The field monitoring then provided information that was used to create a WWHM 2012 model for each of the ten bioretention sites (Appendix 16). Dimensions of the bioretention facility (surface area, maximum depth of ponding) and the outlet control structure(s) were field-measured and compared with design drawings, if available. The elevation of the inlets, outlet riser, or weir, and the top of the facility were surveyed. The underdrain elevation and outlet diameter were also measured for the five sites that had an active underdrain.

The hydrologic monitoring data collection (previously discussed) provided observed/recorded time series data for rainfall, inflow, overflow, groundwater, and ponding at 5-minute intervals for use in the individual site models. The recorded inflow, overflow, groundwater, and ponding data were compared with the WWHM 2012's simulated inflow, overflow, groundwater, and ponding results. Due to snow and/or freezing air temperature conditions, the model results comparisons were limited to the months of April 2019 through June 2019. Graphical and statistical comparisons of the recorded and simulated data were made for this time period.

The geotechnical data collection provided information about the BSM found at each of the ten bioretention sites and the native soil infiltration rate, as measured onsite. Their general soil characteristics, as they related to water movement, provided guidance in the selection of appropriate engineered soil mixes for each of the ten bioretention sites. The native soil infiltration rate was also used in the same way to determine the appropriate infiltration value to include in each model.

The vegetation data collection was not used directly in the input to the individual site models. However, its potential impact on the hydrologic performance of each site was considered in terms of leaf litter impact on ponding and water infiltrating into the top bioretention soil layer. Also, vegetation influences evapotranspiration from the soil layer. WWHM 2012 assumes a standard evapotranspiration rate from the soil that may actually be dependent on the type and amount of vegetation.

All of the above field data were used in one way or another in either the WWHM 2012 model input for each of the ten bioretention sites or evaluating the model output. Table 8 summarizes the model input data.

The hydrologic performance of the ten bioretention facilities was well represented by WWHM 2012. The range in performance in terms of ponding depths and well point elevations met or exceeded the expected WWHM 2012 model results comparison with the monitored data more often than not.

Appendix 16 provides a detailed discussion of the WWHM 2012 modeling results and comparison with the monitored data.

Table 8. Model Input Data

Site	Drainage Area (ac)	Top Area (ft2)	Bottom Area (ft2)	Top Area to Drainage Percentage	Overflow Height (ft)	Modeled Depth (ft)	Native Soil Infiltration (in/hr)	Underdrain
BCK	0.27	71	60	0.6%	0.05	3.8	0.5	Yes
BUW	0.93	38.5	38.5	0.1%	0.05	2.8	0.05	Yes
FWI	0.33	250	159	1.7%	1.0	2.45	0.05	Yes
M1C	0.03	132	132	10.1%	0.6	1.3	17	No
M3Q	0.02	200	200	23.0%	0.95	6.25	15	No
MPP	0.48	1320	684	6.3%	3.6	2.15(1)	3	No
RSH	0.17	68	64	0.9%	0.3	3.6	0.5	Yes
SSW	0.40	1022	735	5.9%	1.4	2.8(2)	16	No
TBM	0.31	366	280	2.7%	1.1	3.85	8	No
TWH	1.62	1269	1200	1.8%	0.12	4.1(2)	0.05	Yes

ac = acres
ft^2 = square feet
ft = feet
in/hr = inches per hour
(1) The modeled depth includes 0.2 feet of surface leaf litter/mulch.
(2) The modeled depth includes 0.1 feet of surface leaf litter/mulch.

In general, the WWHM 2012 models of the ten bioretention sites reproduced the monitored BHP data with accurate results. Accurate results are defined as periods where the simulated results match closely with the recorded (monitored) data and other periods where the simulated results are sometimes high and sometimes low. There is no obvious bias high or low.

As in the Phase I study, it appears that there are two major model inputs that may be influencing the results. The vegetative litter cover (and/or mulch) noted at MPP, SSW, and TWM may be reducing the infiltration rate of the ponded water into the BSM. Except for these three sites, this vegetative litter cover/mulch was not explicitly modeled.

The other major model input that may be influencing the results is the evapotranspiration (ET) from the BSM. It is set in WWHM 2012 to equal 0.5*PET (Potential ET). There is evidence from the well point data that the 0.5 multiplier factor should be higher. That will help to remove water faster from the BSM layer.

5.0 Summary Discussion

The BHP Phase II study results and recommendations described here and in the appendices for hydrology, geotechnical and infiltration, vegetation, and modeling characteristics of bioretention facilities all show that the SWMMWW guidance and design process can be complex for designers and reviewers alike (see Appendix 17). However, a number of the simplest parts of the design can improve the likely performance of any one facility. Some of these recommendations are interrelated. For example, potential overflows will be jointly related to the percentage of the bioretention top area to drainage basin area, the proper depth of riser for a given facility, and the actual infiltration rate of the BSM.

The four most important aspects of the findings are:

1. Maintain a bioretention top area (surface area at the overflow elevation) which is at least 5 percent of the area draining to it for facilities that are underdrained or have less than 100-percent infiltration.

   This general recommendation indirectly represents the areal hydraulic loading rate of the contributing basin to the bioretention cell. As with any designed water or wastewater treatment facility, the result of this ratio will represent the resulting depth of water flowing into a facility and effects of that depth on the treatment processes in the facility. In the case of bioretention, the resulting depth will reflect potential for overflows and areal loading of any solids that may be transported into the cell and possible long-term clogging.

   It is recognized that retrofit designs are often constrained in their available footprint. The 5-percent "rule of thumb" is a guideline; actual site settings may allow for lower or require higher ratios. However, this recommendation provides additional emphasis to retrofit designers to optimize bioretention footprints where possible.

   We observed that soil compaction appeared to occur in the smaller, narrow retrofit cells. Soil compaction can occur during bioretention soil placement, irrigation installation, placement of inlet protection or energy dispersion elevation or from planting. Compaction along maintenance paths or edges is more impactful on small facilities. A larger or rounded facility will mitigate for edge or path compaction effects. Compaction in facilities with an already small infiltration area ratio to drainage area will exacerbate the condition by reducing the infiltration rate.

2. Maintain a minimum 6-inch riser height above the designed bioretention surface.

   The elevation of the overflow riser will represent the top area of the pool in the bioretention facility at overflow. The significance of this elevation is it is directly tied to the anticipated degree of infiltration volume (and therefore treatment volume as well) before overflow occurs. An improperly low overflow elevation will allow bypassing of flows prior to the opportunity for filtration through the BSM.

Other contributing factors to the effect of the overflow elevation are properly graded side slopes and longitudinal slope of the cell. If these slopes are steeper than as designed with the same toe elevation as in the plan, a correctly placed riser elevation may still result in less top area than designed, leading to a reduced loading rate as in 1 above.

3. Maintain a minimum 18-inch BSM depth and meet Ecology (2014) media particle size criteria.

   The BSM soil depth criteria include a recommended gradation that is very important to the resulting infiltration rate. The gradation controls the pore space available for infiltration and relatively coarser mixes can result in greater than expected infiltration rates. Not meeting the soil mix gradation was generally characteristic of both the BHP Phase I and Phase II samples, although less so in the more recently constructed Phase II facilities.

   Coarser BSM with higher infiltration rates contributes to horizontally uneven infiltration of inflowing waters, resulting in inconsistency with the infiltration expectations and uneven distribution of moisture available to the planted vegetation. This observation simply recognizes the reasonable expectation that inflows to the facility will tend to infiltrate first near the inflow point and will tend to do so until near-surface infiltration is saturated before surface flows progress across the facility. This adds a complex second dimension to the conceptual model and design plans regarding how bioretention facilities hydrologically perform.

4. Specify a planting plan of plantings that reflects the relatively dry and well-drained conditions of bioretention facilities.

   Planting plan success may be one of the most underrated aspects of bioretention design not only for its contribution to hydrologic performance but also for the institutional acceptance of bioretention as a green stormwater site design component.

   Vegetation is recognized to affect the maintenance of soil porosity through root structure and may facilitate pollutant removal. These benefits may add to the overall longevity of performance in bioretention. Separately, the organizational acceptance of bioretention was anecdotally recognized during our discussions with owners and engineers alike as partially limited by the perceived vegetation cost and maintenance requirements for long-term operation of the facilities.

   Separately, selection of plant species was often skewed to more hydrophilic (even wetland) WIS classifications, while the facilities themselves are well drained, do not maintain saturated soils, and are often highly exposed to evaporative and extreme heat conditions—without shade and exposed to wind and long periods of direct insolation. The horizontally uneven availability of moisture across the facility may also result in differential survival in a given cell.

   The resulting lack of survival from all these influences tends to result in shifts toward shrubs and away from herbaceous species, while being invaded by weedy species providing less ground cover and requiring more maintenance for aesthetic purposes. All these conditions provide challenges to the long-term success of planting plans in bioretention facilities.

5. A checklist should be developed for Puget Sound region-wide use by both engineers and permit reviewers that enables cross checking that infiltration rates and related model values are consistent between the model, the TIR, and the plan sheets.

   Review of the data input to the ten design models showed inconsistencies in some cases between the required BSM soils to be specified and the associated BSM filtration rates, or the native soil infiltration rates input to the model versus those measured onsite.

   The SWMMWW (2012) and the bioretention module guidelines call for use of SMMWW 12 BSM soil mix with a filtration rate of 12 inches per hour. This rate is then modified by the K_{sat} safety factor (2 or 4) that acts as a correction factor to account for an anticipated reduction in filtration rates over the life of the facility. In addition, the actual measured field native infiltration rate by the site design hydrogeologist provides a direct measure of the native infiltration and the value entered in the model should reflect that measured.

   Without these values entered correctly, the modeling of the facility using long-term rainfall records will obviously provide erroneous results in evaluating compliance with MR #5 and MR #6. A simplified checklist that helps both engineers and reviewers to confirm accurate data entry prior to evaluating conformance with MR #5 and MR #6 will reduce model input errors and assist in review and repeat modeling design efforts.

References

Clear Creek Solutions. WWHM 2012 User Manual. February 2016.

Taylor, W., D. Beyerlein, J. Saltonstall, B. Berkompas, A. Cline. 2018. Western Washington Bioretention Hydrologic Performance Study I. Stormwater Action Monitoring Program. Prepared for City of Bellingham and Washington Department of Ecology. Seattle, WA.

Washington Department of Ecology. 2014. 2012 Stormwater Management Manual for Western Washington, as amended in December 2014.

Washington Department of Ecology. 2019 Stormwater Management Manual for Western Washington. Publication No.19-10-021. July 2019.

APPENDIX 1

Bioretention Hydrologic Performance (BHP) Study Phase II Site Selection Process and List of Selected Sites Technical Memo - Deliverables 2.2 and 2.3 Combined. Taylor Aquatic Science. 2/5/2019

Taylor Aquatic
Science and Policy

Technical Memo

To: Andy Haub, Eric Christensen, City of Olympia
Brandi Lubliner, WDOE

From: William J. Taylor

Date: February 5, 2019

Re: Bioretention Hydrologic Performance (BHP) Study II
Site Selection Process and List of Selected Sites
Technical Memo – Deliverables 2.2 and 2.3 Combined

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

Background

The BHP Study II follows the BHP Study I (conducted with the City of Bellingham) and again involved contacting Puget Sound Basin jurisdictions to identify "candidate" bioretention facilities to be recommended for evaluation and possible selection in a set of ten facilities for performance monitoring.

The difference in the BHP II selection criteria from the first BHP Study was specifically to select sites designed using the Western Washington Hydrology Model version 2012 (WWHM 2012). The goal of this project is to evaluate the performance of the model, in addition to observe how the bioretention facilities are performing in the field.

As before, the selected sites are being monitored for inflow and outflowing stormwater flows. Site data is also being collected for groundwater and ponding levels, bioretention soil mix composition and infiltration rate, subsurface soil conditions, and vegetation composition and density as supporting information to evaluate the site performance.

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

Jurisdictions, and this time public school districts, selected for contact to nominate potential sites came from four different sources:

1. Jurisdictions indicating interest in the BHP study from previous contact or during the current SAM project selection process,

2. Public School Districts identified through the Office of Superintendent of Public Instruction

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

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

Over thirty school districts and over 15 jurisdictions were contacted through direct telephone contact with stormwater managers or associated engineers and water quality specialists to discuss the BHP study, and their recommendations on possible candidate sites within their jurisdiction.

Based on the initial criterion that candidate sites had to be designed using WWHM 2012, almost thirty facilities were recommended for site evaluation. Site design plans (including planting plans), technical information reports (TIRs) and modeling information was gathered for most of these facilities. Twenty-five facilities were then identified for conducting a site visit for final evaluation. Because most of the sites contained multiple cells each with their own conditions, the site visits for these twenty-five facilities resulted in visual evaluation of approximately seventy individual cells.

Site Field Evaluation

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

- Assessment of inflow and outflow locations for flow monitoring feasibility
- Qualitative soil media composition and soil probe depths

In a different process from the previous BHP study, we did not conduct vegetation assessments as all the sites were recently constructed, or were still unplanted as we were visiting the sites. It was decided to conduct the vegetation assessment in the following spring to allow final planting and an assessment of initial survival.

Site Selection Criteria

The same site selection criteria developed in the BHP I was used as a reference to review and make note of many of the site design conditions and parameters for the candidate sites. Attachment 1 also provides a list of monitoring, modeling, and geotechnical information for each of the candidate sites.

As with the BHP I study, the accessibility of flow monitoring to attain accurate hydrologic results was almost exclusively the deciding factor. The remaining criteria checklist items were nonetheless useful as a checklist reminder of factors affecting site performance and additional data collection needs.

Separate from the criteria checklist, we used the surficial geologic and jurisdictional representation as guides to select sites that represented a wide range in geologic and jurisdictional participation.

Final Sites Selected for Monitoring

The geographic distribution of the full set of 25 sites visited is presented in Figure 1, and the final set of selected sites is listed in Table 1 below, and shown in Figure 2. Attachment 1 provides a full list of the sites visited, selected, addresses and the associated jurisdiction contacts.

Table 1. The final set of sites selected under the BHP II project.

Jurisdiction	Project Name
Bellingham (BUW)	Columbia WQ Improvements
Bellingham (BCK)	Nevada – Kentucky Bike Boulevard
Marysville (M3Q)	1st and 3rd Street SW Retrofit
Marysville (M1C)	1st and 3rd Street SW Retrofit
Monroe S.D. (MPP)	Park Place Middle School
Monroe S.D. (SSW)	Salem Woods Elementary
Renton (RSH)	Green Connections
Tacoma S.D. (FWI)	Wainwright Intermediate
Tacoma S.D. (TWH)	Wilson High School
Tumwater S.D. (TBM)	Bush Middle School

Seasonal Schedule for Monitoring

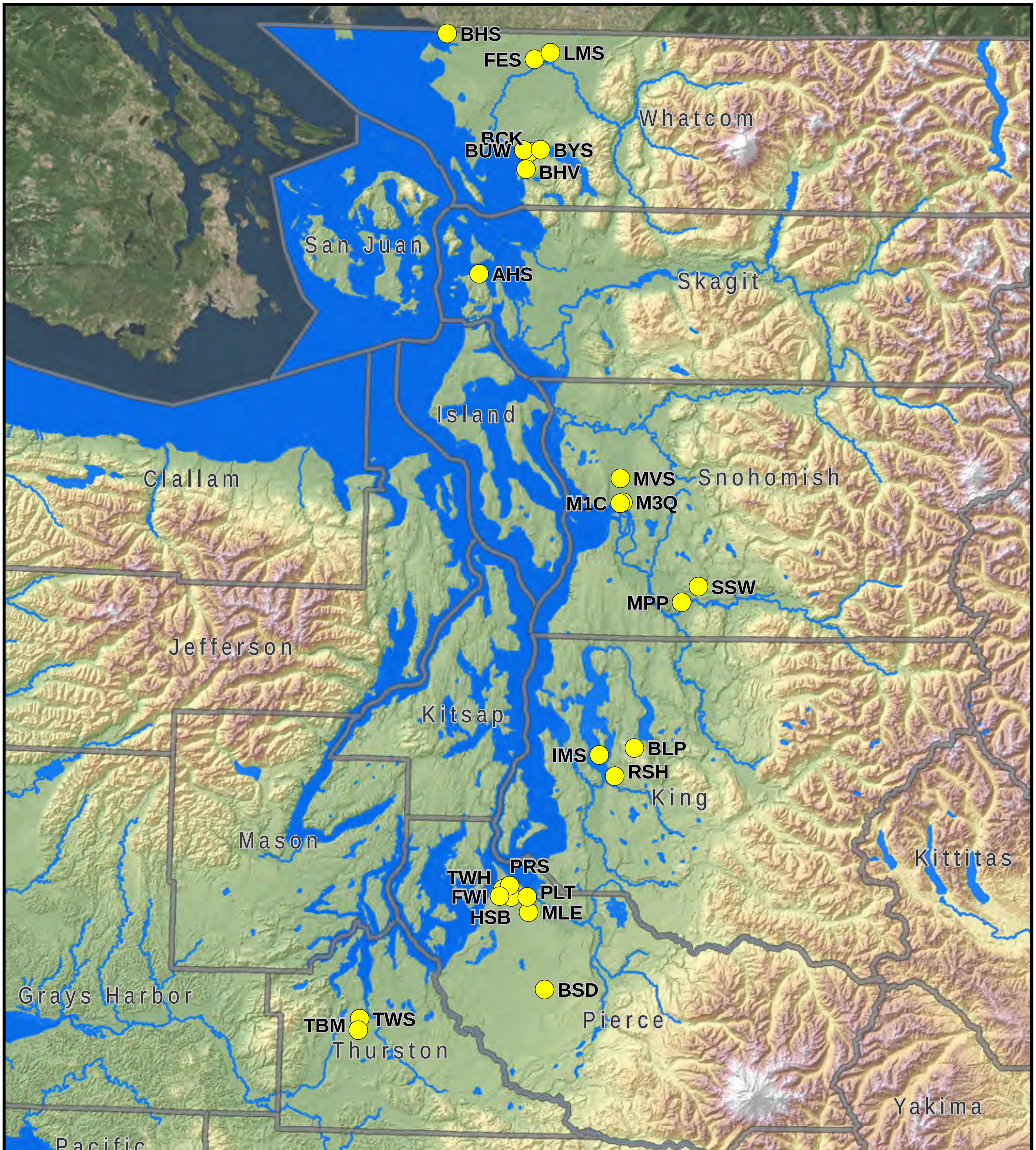
The monitoring phase of the project has begun, with virtually all the sites were installed and collecting continuous flow and rainfall data by October 15, 2018. The only exception was the two Bellingham sites which were installed on 10/22/18; and at the Bellingham BUW site one of the two inlet weirs was not installed until 11/6/18. The geotechnical site assessment work and field infiltration testing was completed during October and November 2018.

As with the BHP I Study, we recommend extending the period of monitoring from the current five months to eight months. The added value of observed groundwater conditions at many of the sites added value to analysis of the spring groundwater transition season.

If you have any questions, please feel free call me or Doug Beyerlein.

Bill Taylor

Taylor Aquatic Science and Policy



LEGEND:

- ALL SITES
- COUNTY

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MILES

DATA SOURCES / REFERENCES:
AERIAL: WORLD IMAGERY, ESRI, DIGITAL GLOBE 2017
UNIVERSITY OF WASHINGTON 10 METER COMPILED DEM FROM USGS1998 DEM QUARTER QUADS
WADNR: COUNTY BOUNDARY

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

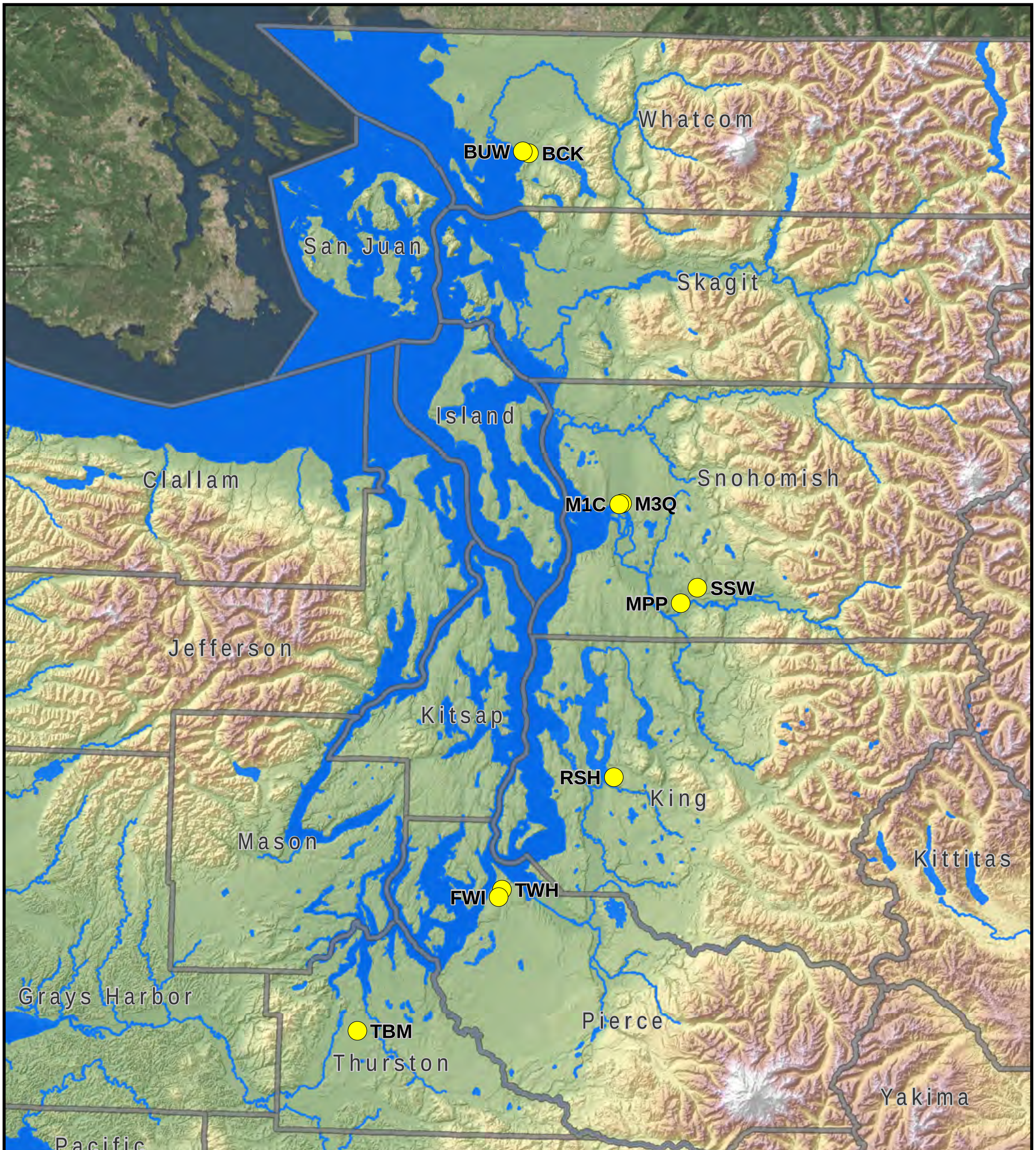
associated earth sciences incorporated

BIORETENTION SITES

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	1/19	1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\H007\150387H007 F1 BHPS_ALL.mxd



LEGEND:

- SELECTED SITES
- COUNTY

DATA SOURCES / REFERENCES:
AERIAL: WORLD IMAGERY, ESRI, DIGITAL GLOBE 2017
UNIVERSITY OF WASHINGTON 10 METER COMPILED DEM FROM USGS1998 DEM QUARTER QUADS
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LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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BIORETENTION SITES

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	1/19	2

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

Jurisdiction	Project Name	Location	Contact Name	Contact Phone
Anacortes (AHS)	Anacortes High School	1600 20th St, Anacortes	Marty Yates	360-293-1228
Bellevue (BLP)	Lewis Cr. Park Picnic Area	Lewis Creek Park	Kit Paulsen	425-452-4861
Bellingham (BUW)	Columbia WQ Improvements	Utter St. and Washington St.	Eli Mackiewicz	360-778-7955
Bellingham (BCK)	Nevada – Kentucky Bike Boulevard	Kentucky St. and Cornwall Avenue	Eli Mackiewicz	360-778-7955
Bellingham (BYS)	Yew St. SW Improvements	Yew St. between Texas and Alabama St.	Eli Mackiewicz	360-778-7955
Bellingham S.D. (BHV)	Happy Valley Elementary	1041 24th St., Bellingham	Eli Mackiewicz	360-778-7955
Bethel S.D. (BSD)	Shining Mountain Elementary	21615 38th Ave E, Spanaway	David Wells	253-683-6085
Blaine S.D. (BHS)	Blaine High School	1055 H Street, Blaine	Alan Pomeroy	360-332-0738
Lynden S.D. (FES)	Fisher Elementary	501 14th St., Lynden	Patty Fairbanks	360-303-0927
Lynden S.D. (LMS)	Lynden New Middle School	8750 Line Rd., Lynden	Patty Fairbanks	360-303-0927
Marysville (M3Q)	1st and 3rd Street SW Retrofit	3rd and Quinn St.	Adam Benton	360.363.8283
Marysville (M1C)	1st and 3rd Street SW Retrofit	1st and Cedar St.	Adam Benton	360-363-8283
Marysville (MVS)	Sonic Drive-In	3802 116th St NE	Adam Benton	360-363-8283
Mercer Island S.D. (IMS)	Islander Middle School	7447 84th Ave SE, Mercer Island	Tony Kuhn	206-230-6339
Monroe S.D. (MPP)	Park Place Middle School	1408 W Main St., Monroe	Heidi Hansen	360.804.2677
Monroe S.D. (SSW)	Salem Woods Elementary	12802 Wagner Rd., Snohomish Co.	Heidi Hansen	360.804.2677
Renton (RSH)	Green Connections	Harrington at NE 8th St.	Ron Straka	425-430-7248
Tacoma (HSB)	Homestreet Bank	1501 S. Union Ave.	Mieke Hoppin	253-573-2332
Tacoma (PLT)	Prairie Line Trail	S. Hood and Dock St.	Mieke Hoppin	253-573-2332
Tacoma	Proctor South Development	N. 25th Street and N. Madison Street	Mieke Hoppins	253-573-2332
Tacoma S.D. (MLE)	Mary Lyon Elementary	101 E. 46th St., Tacoma	Mieke Hoppin	253-573-2332
Tacoma S.D. (FWI)	Wainright Intermediate	130 Alameda Ave., Fircrest	Michael Knaack	253-571-3316
Tacoma S.D. (TWH)	Wilson High School	1202 N Orchard St., Tacoma	Michael Knaack	253-571-3316
Tumwater S.D. (TBM)	Bush Middle School	2120 83rd Ave SW, Tumwater	Tanya Baker	360-709-7009
Tumwater S.D.(TWS)	Tumwater Middle School	6335 Littlerock Rd SW, Tumwater	Tanya Baker	360-709-7009

Site Information for Monitoring Assessment

	Label	Jurisdiction	Site	Site Visit Date	Can inflow be easily monitored; 1 = Yes; 0 = No	Can inflow be monitored with simple modifications; 1 = Yes; 0 = No or Not applicable	Overall monitoring rating	Comments
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	0	1	Tier 1	1 inlet and 1 outlet both with easy weir installs or curb cut modification
2	M1C	Marysville	Marysville 1st Street LID	4/30/18, 5/1/18	0	1	Tier 1	Only 1 inlet from curb, can't monitor outlet flow excpet via morning glory weir if riser overtops. Can't monitor sidewalk inputs but they are likely very small
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18	1	1	No-Go	Received plan set only. Seasonal high GW depth ~5ft. owner said no
4	WHS	Tacoma	Wilson High School	4/30/18	1	1	Tier 1	Underdrained 2 inlets and 1 outlet pipe
5	HSB	Tacoma	Homestreet Bank	4/30/18	1	0	Tier 2	Underdrained could be monitored but lots of inputs Outlet comingled, owner status unknown
6	PRS	Tacoma	Proctor South	4/30/18	unk	unk	No-Go	Construction not finished at time of study
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018	unk	unk	No-Go	Constuction not finished at time of study
8	PLT	Tacoma	Prarie Line Trail	4/30/18	0	0	No-Go	Complcated stone weir walls and other confusion
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19	0	0	No-Go	Too many inlets and comingled outflow, other cell lined, parking lot too many linked cells
10	AHS	Anacortes	Anacortes High School	10/1/18	unk	unk	No-Go	Constuction not finished at time of study
11	FES	Lynden	Fisher Elementary School	7/20/2018	0	0	Tier 2	Lots of inlets, would need to monitor 1 and model 16, otherwise good
12	LMS	Lynden	Lynden New Middle School	7/20/2018	0	0	Tier 2	Can't monitor inflow as it is all sheet flow but very clearly defined drainage area likely best case for modeling inflow
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	1	1	Tier 1	2 inlets, 1 outlet. 1 inlet subject to some backwater
14	IMS	Mercer Island	Islander Middle School	8/15/2018	0	0	Tier 2	Multiple buried inlets with inverts below BSM level in cell
15	BYS	Bellingham	Yew St	7/20/2018	0	0	No-Go	Adjacent to permeable pavement sidewalk, likely recieves flow from sidewalk base-course. Too many ins and Outs
16	BHS	Blaine	Blaine High School	7/20/2018	1	0	No-Go	Owner said no
17		Tumwater	Tumwater Middle School	7/31/2018	1	0	No-Go	All sites either comingled outlfow or sheet flow to gravel to grass strip inflow
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	1	1	Tier 1	Small cell in back with 1 inlet is good candidate
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	1	1	Tier 1	Cell 6 has 1 inlet, no outlet, Cells 5 and 7 also considered but more complicated and more visible accessible for potential vandalism
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/18	1	1	Tier 1	Cell 2, 1 inlet, outlet is high overflow
21	BLP	Bellevue	Lewis Creek Park	8/15/2018	0	1	No-Go	2 cells. One has sheet flow from pervious & basecourse. Second has overflow from 1st plus 2 curb cuts from pervious. Inflow may be low.
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	0	1	Tier 1	Cell 4 with two inlets selected. Cell 1 underlain by utility. Cell 2 has some minor inflow from sheet flow. Cell 3 extends to include a narrow, vegetated ditch (part of bioretention cell?)
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018	0	0	Tier 2	Primarily sheet flow. Combined with piped inflow and outflow
24	BUW	Bellingham	Utter and Washington	9/28/2018	0	1	Tier 1	2 inlets 1 outlet, inlets are low but should work
25	RSH	Renton	Sunset Harrington	9/28/2018	0	1	Tier 1	2 inlets, unique underdrain with orifice flow control, outlet

Site Information for Modeling Assessment

	Label	Jurisdiction	Site	Site Visit Date	SWDM	SWM	Under-drains	Liner	Overflow	BSM Rate	BSM b	BSM n	Subgrade Design Rate	TIR Civil
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	Ecology 2014	WWHM 2012	no	No	Yes		1.5		2	Gray and Osborne, Inc
2	M1C	Marysville	Marysville 1st Street	4/30/18, 5/1/18	Ecology 2014	WWHM 2012	no	no	Yes		1.5		2	Gray and Osborne, Inc
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18		WWHM 2012	Yes	No	Yes		1.5		3.1	
4	TWH	Tacoma	Wilson High School	4/30/18	Tacoma SWMM 2012	WWHM 2012	Yes	No	Yes		1.5	0.4	1.5	Sitts & Hill Engineers, Oct 2014
5	HSB	Tacoma	Homestreet Bank	4/30/18	Tacoma SWMM 2016	WWHM 2012	Yes	No	Yes	12	>1.5			PACE, Oct 17, 2016
6	PRS	Tacoma	Proctor South	4/30/18	Tacoma SWMM 2016	WWHM 2012	Yes	No	Yes		1.5			BCRA, Oct 2016
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018		WWHM 2012								AHBL, Oct 2017
8	PLT	Tacoma	Prarie Line Trail	4/30/18		WWHM 2012								BCRA, June 2016
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19		WWHM 2012	yes	NE cell is lined						Freeland & Associates, May 2015
10	AHS	Anacortes	Anacortes High School	10/1/18		WWHM 2012								
11	FES	Lynden	Fisher Elementary School	7/20/2018	Ecology 2005, 2014	WWHM 2012	no	no		3			27.1	Freeland and Associates
12	LMS	Lynden	Lynden New Middle School	7/20/2018	Ecology 2005, 2014	WWHM 2012	no	no		3			14.73	Freeland and Associates
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	Ecology 2005, 2014	WWHM 2012	yes	no	yes	15	1.5		3 cells with 3 different design rates	City of Bellingham Public Works
14	IMS	Mercer Island	Islander Middle School	8/15/2018		WWHM 2012	yes	no	yes					LPD
15	BYS	Bellingham	Yew St	7/20/2018		WWHM 2012								
16	BHS	Blaine	Blaine High School	7/20/2018		WWHM 2012	yes							Freeland and Associates
17	TWS	Tumwater	Tumwater Middle School	7/31/2018	Tumwater DDECM 2010 and Ecology 2005	WWHM 2012, modeled not using bioretention settings	No - but design includes a rock-filled trench beneath BSM			3	1.5		6 biocells: Bio cell 2 and 5 have the highest % imp; bio cell 2: 1.7 iph; Bio cell 5: 2.0 iph	BCRA
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	Tumwater DDECM 2010 and Ecology 2005	WWHM 2012	No	No	No		1.5		0.9	BCRA
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	Ecology 2005, 2014	WWHM 2012	No	No	No	2	1.5			Harmsen
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/2018	Snohomish County Drainage Manual 2016	WWHM 2012	No	No	No	1.5	1.5			Harmsen
21	BLP	Bellevue	Lewis Creek Park	8/15/2018			Yes	r Fabric						SvR Design
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	Ecology 2014	WWHM 2012	Yes	No	Yes		1.5		1.5	AHBL
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018			no		yes					
24	BUW	Bellingham	Bellingham Columbia Neighborhood	9/28/2018	Ecology 2014	WWHM2012	Yes	No	Yes	12	1.75		0	PSE
25	RSH	Renton	Renton	9/28/2018	Ecology 2014	WWHM4	Yes	No	Yes	5	1.5		1.2	CH2MHILL

Site Information for Geotechnical Assessment

	Label	Jurisdiction	Site	Site Visit Date	Geotech	CF	Geology	Explorations	Inf Test Type	Hydrogeo	BSM rate < Native iph	Estimated Construction	Comments
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	PanGEO	NA	Rec. OW (per regional mapping)	EB	grain size	A1	no	2017	Shallow groundwater, less than 10 feet.
2	M1C	Marysville	Marysville 1st Street	4/30/18, 5/1/18	PanGEO	NA	Rec. OW (per regional mapping)	EB	grain size	A1	no	2017	Shallow groundwater, less than 5 feet, tidal influence
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18	Unk	unk	Rec. OW (per regional mapping)	unk	Infil. test indicated on plan sheet	unk	unk	2017	Received plan set only. Seasonal high GW depth ~5ft.
4	TWH	Tacoma	Wilson High School	4/30/18	AESI 2000, 2004, 2014	None	Till/Adv. OW	EB, EP	None	B2	no	2016	Underdrained. 2 inlets, only one shown on plans.
5	HSB	Tacoma	Homestreet Bank	4/30/18	Zipper Geo Associates, LLS.	None, "not suitable"	Fill/Till	EB	None, "not suitable"	B2	no	2017	Underdrained
6	PRS	Tacoma	Proctor South	4/30/18	GeoResources 4/21/2016 (referenced, not attached)	unk	Fill/Till	unk	unk	B2	no	NA	Not yet constructed at time of study. Geotech report not included in PDF attachments.
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018	GeoEngineers, Inc.	0.45	Rec. OW?/Till	EB	PIT	B2	no	NA	Not yet constructed at time of study.
8	PLT	Tacoma	Prarie Line Trail	4/30/18	unk	unk	unk	unk	unk	unk	unk	2017	Geotech report not included.
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19	Geotest	NA	Till over outwash	EB, EP	PIT	B2	No - zero field rate in till; did not test the advance	2016	Not suitable for flow monitoring; shallow ground water - one cell lined.
10	AHS	Anacortes	Anacortes High School	10/1/18	AESI	NA	hard silt	EB	none	EX		NA	Not yet constructed at time of study.
11	FES	Lynden	Fisher Elementary School	7/20/2018	Geotest	0.252	Rec outwash (Sumas)	EB, EP	grain size	A1/A2	Yes	2018	City conditioned the project to conduct PIT at the time of construction; no documentation of test received. GW ATD 19 to 20' bgs; mottled at 1.5, 4.5 to 5.5, not interpreted as gw per geotech.
12	LMS	Lynden	Lynden New Middle School	7/20/2018	Geotest	0.252	Rec outwash (Sumas)	EB, EP	grain size	A1/A2	Yes	2018	GW ATD 13 to 18' bgs; mottled at 10.5'.
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	MTC	0.18	B'ham drift and Fill	HA	grain size	EX	2 cells in GMD - no; 1 cell in fill - possibly	2017	Cells "field fit", may differ from plans. Overflow/underdrain present.
14	IMS	Mercer Island	Islander Middle School	8/15/2018	AESI	NA	pre-Vashon nonglacial	EB	none	F	No	2016	Qpvn at biocell #3, gw at ~10' in EB-7 ATD near Biocell #3; an MW was installed in the parking lot area. One inlet not field located, may join other inlet (but plans show separate).
15	BYS	Bellingham	Yew St	7/20/2018	unk	unk	fill	unk	unk	unk	unk	2016	Adjacent to permeable pavement sidewalk, likely recieves flow from sidewalk base-course. No geotech report received.
16	BHS	Blaine	Blaine High School	7/20/2018	unk	unk	unk	unk	unk	unk	unk	2018	Facility may not be complete - may be waiting on landscapers. Recieved plan sheet only.
17	TWS	Tumwater	Tumwater Middle School	7/31/2018	Landau	not stated	Rec. OW	EB, HA, direct push	grain size	A1	No	2016	Groundwater 10' bgs at time of report, monitoring ongoing. Groundwater TM calculated adjusted rates based on 1999 groundwater condition.
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	Landau	not stated	Rec. OW	EB	grain size	A1	No	2016	shallow groundwater; high groundwater hazard area
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	AESI	0.4	Alluvium	EP, IT, EB	PIT	D1	No	2017 and 2018	Two phases of construction - 1st set of cell was 2017, second set was 2018
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/2018	AESI	0.315	Rec. OW	EP, IT, EB	PIT	A1	no	2018	Only one inlet appears to be present, plans show two
21	BLP	Bellevue	Lewis Creek Park	8/15/2018	unk	unk	unk	unk	unk	unk	unk	2017	Received plan sets only.
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	AESI	.45, .045	Rec. OW., till	EP	PIT	A2	no	2016	Cell 1 underlain by utility. Cell 2 has some minor inflow from sheet flow. Cell 3 and 4 have inflow from 2 curb cuts each. Cell 3 extends to include a narrow, vegetated ditch (part of bioretention cell?)
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018	unk	unk	unk	unk	unk	unk	unk	2012-2013	No documents received.
24	BUW	Bellingham	Bellingham Columbia Neighborhood	9/28/2018	Element solutions	not stated	Fill, GMD and outwash	EB, EP	grain size, PIT	E2	no	2016	Underdrained.
25	RSH	Renton	Renton	9/28/2018	CH2MHILL	8 (or 0.125)	fill/ rec OW	EB, EP	PIT	A3	no	2017	Underdrained, through orifice.

APPENDIX 2

Deliverable Task 3.2, Quality Assurance Project Plan (QAPP), Bioretention Hydrologic Performance Study II, Taylor Aquatic Science and Clear Creek Solutions, Inc. 4/2019

Quality Assurance Project Plan

Bioretention Hydrologic Performance Study II

Date: April 2019

Prepared by:

William J. Taylor
Taylor Aquatic Science

Douglas Beyerlein, P.E. Clear
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Prepared for:

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Publication Information

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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 II

April 2019

Approved by:

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Signature: ______________________________ Date: ________
Eric Christensen, City of Olympia Project Manager

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2.0 Abstract

While the storage and infiltration capability of bioretention facilities is generally acknowledged, little data exists to verify the hydrologic performance of these facilities. Use of bioretention is widespread in the Puget Sound region and expected to increase as a result of requirements of the NPDES municipal permits. State and local governments are eager to evaluate and ensure that new bioretention facilities constructed under the Washington Department of Ecology's (Ecology) Stormwater Management Manual for Western Washington (SWMMWW; Ecology 2014) can be built to attain desired performance.

This study is the second of two related studies. The first Bioretention Hydrologic Performance (BHP) Study was a similar study of bioretention facilities designed using the design approaches in effect prior to the Ecology (2014) manual. The current BHP Study II is intended to document the hydrologic performance of bioretention facilities designed using the Western Washington Hydrology Model (WWHM) version 2012.

The result of the current study is intended to not only to show the apparent hydrologic performance of the facilities themselves, but the performance of the WWHM 2012 model in predicting the performance of the facility. Reasons for observed performance discrepancies will be identified to provide feedback on design, construction, maintenance, and/or modeling of bioretention facilities to attain desired performance.

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

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

Based on the range of selected facilities (Appendix A), lessons drawn from the study will inform our understanding of the suitability of these LID BMPs across a range of soil conditions and micro-climates. We will learn site-specific scale lessons regarding design, construction, maintenance, and modelling of bioretention facilities. The final report will provide a qualitative analysis on the larger set of facilities that were assessed for monitoring in the study. If

appropriate, the final report may also include recommendations for improvements to the WWHM 2012 bioretention modeling algorithms to better and more accurately represent observed actual field conditions.

3.0 Background

The goal of this study is to implement a regional bioretention infiltration effectiveness study 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 first BHP 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."

Prior to the SWMMWW (2012), the previous SWMMWW (2005) and the associated WWHM 3 did not include a module for modeling bioretention facilities. Since its inception in 2012, the newer model has been implemented and trainings provided for its use. The current study design then is intended to conduct performance studies that would indicate the accuracy of constructed bioretention facility performance relative to their design performance expectations based in the WWHM 2012 model, again for a geographically wide range of locations and conditions.

In addition to evaluation of the hydrologic model, the monitoring of flow through the facilities, in the shallow ground water, and the performance of the vegetation plantings will again provide performance monitoring to inform engineers

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 25 projects containing approximately seventy different facilities from throughout the Puget Sound region (see Appendix A for a summary of the site selection process, and the sites selected). All seventy facilities were evaluated in the field, and using supporting design drawings, hydrologic modeling parameters, geotechnical reports, and technical information reports (TIRs) when available. The set of overall bioretention facilities selected represent facilities from Bellingham to Tumwater 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.

3.2 Logistical problems

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

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

3.3 History of study area

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

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

3.4 Contaminants of concern

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

3.5 Results of previous studies

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

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

And,

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

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

3.6 Regulatory criteria or standards

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

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

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

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

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

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

4.0 Project Description

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

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

4.1 Project goals

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

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

4.2 Project objectives

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

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

4.3 Information needed and sources

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

4.4 Target population

The target population is constructed bioretention facilities in the Puget Sound basin that were designed using the WWHM 2012 hydrologic model.

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

4.5 Study boundaries

Study boundaries are the Puget Sound basin.

4.6 Tasks required

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

Tasks to be conducted in this project include:

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

4.7 Practical constraints

Practical constraints include:

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

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

1. Eric Christensen, Planning and Engineer Supervisor, City of Olympia.
   Manage execution of the contract with Ecology, including invoicing and progress reporting.

2. Douglas Beyerlein, P.E., Prime Consultant and Hydrologic Modeling Lead Clear Creek Solutions, Inc.
   Provide consultant team management, and team administration with the City of Olympia. 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 Aspect Consulting, Inc.
   Specify approaches and equipment, and conduct installation, maintenance, data collection, and management for all surface flow and rainfall data collection.

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

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

5.2 Special training and certifications

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

5.3 Project schedule

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

5.4 Limitations on schedule

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

5.5 Budget and funding

Proposed scope task and budget levels for Study II monitoring and reporting are provided in Table 1. Funding is from the Stormwater Action Monitoring (SAM) Program which is a cooperative of municipal stormwater permittees, and is administered by Ecology. The scope of work and the budget for tasks is provided in Appendix B.

Table 1. Tasks and Budget

Task	Description	Consultant Budget
1	Project Management	$16,240.00
2	Site Selection	$55,545.80
3	QAPP Update	$4,600.00
4	Performance Monitoring	$269,359.20
5	Data Analysis and Modeling	$44,280.00
6	Report and Findings	$88,180.00
	Contingency	$47,821.00
Total		$526,026.00

6.0 Quality Objectives

6.1 Decision Quality Objectives (DQOs)

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

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

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

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

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

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

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

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

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

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

6.2 Measurement Quality Objectives

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

6.2.1 Targets for Precision, Bias, and Sensitivity

6.2.1.1 Precision and Percent Error

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

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

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

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

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

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

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

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

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

6.2.1.2 Bias

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

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

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

6.2.1.3 Sensitivity

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

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

6.2.2 Targets for Comparability, Representativeness, and Completeness

6.2.2.1 Comparability

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

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

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

6.2.2.2 Representativeness

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

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

6.2.2.3 Completeness

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

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

7.0 Sampling Process Design (Experimental Design)

7.1 Study Design

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

Additionally, because the study population is bioretention facilities designed using WWHM 2012, field measurement of flows and subsurface groundwater conditions will allow direct evaluation of the performance of these facilities designed using WWHM 2012. In this way, this study provides feedback to both the constructed facility and the design model.

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

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

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

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

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

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

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

7.1.1 Field measurements

Field measurements to be collected include:

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

7.1.2 Sampling location and frequency

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

7.1.3 Parameters to be determined

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

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

7.2 Maps or diagram

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

7.3 Assumptions underlying design

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

8.0 Sampling Procedures

8.1 Field measurement and field sampling SOPs

8.1.1 Water level and flow data collection

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

8.1.1.1 Inlet Monitoring

Bioretention facilities in this study have three types of inlets: pipes, curb cuts or modeled inlets. Flow rates in piped inlets will be measured using Thel-mar weir inserts sized to fit the inlet pipes. A pressure transducer will measure water level behind the weir to determine the inlet flow rates. Curb cuts will require some modification as the flow through the cut will likely be too shallow to measure directly under all but the most extreme storm conditions. A plastic or rubber sheet will be used to line the curb cut and funnel the flow into a section of pipe. A pressure transducer and a Thel-mar weir insert at the downstream end of the pipe will be used to measure the inlet flow rate. There are a variety of shapes, sizes and expected flow rates for the curb cut inlets at the selected sites and the sheeting, pipes and Thel-mar weirs will need to be custom sized to each inlet.

Additionally a small splash pad may be required at the end of the pipe to prevent erosion from the concentrated flow point. Some inlet flows may be estimated using a model rather than measurement. Some facilities have multiple roof drain inlets and the cost to monitor all of the inlets may prove prohibitive. In such cases one or two inlet monitoring systems may be rotated to each inlet for one or two rainfall events to help adjust a runoff model based on rainfall. This adjusteded model will then estimate inflow into the bioretention facility based on the measured rainfall for an event.

8.1.1.2 Outlet Monitoring

Not all of the bioretention facilities have an outlet but those that do will require outlet monitoring. Six of the facilities in this study with an outlet pipe has an overflow structure with an outlet pipe and a sump below the pipe. Additionally, some facilities have an underdrain pipe that connects to this structure. A Thel-mar weir will be installed in the outlet and a transducer will be installed in a stilling well within the sump of the outlet structure to measure the water depth behind the weir. Two of the facilities (M1C and SSW) in the study have an outlet structure that comingles any outflow from the facility with flow from other adjacent facilities. Outflow at these sites will only occur if the facility ponds to the point of overflow and any overflow will be estimated using a morning glory weir equation based on the size and shape of the overflow structure. The last two facilities (MPP and TBM) do not have an outflow structure and would only discharge if the entire facility filled up and overflowed into the surrounding landscaping.

8.1.1.3 Groundwater and Ponding Depth Measurements

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

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

8.1.2 Rain Gauge

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

8.1.3 Site Maintenance

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

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

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

8.2 Geotechnical Engineering and Hydrogeologic Data Collection

8.2.1 Subsurface Exploration

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

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

8.2.2 Geotechnical Testing

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

8.2.3 Measure Infiltration Rates

Infiltration rates will be measured in one of two ways:

1. If adequate water supply is available and the facility footprint is relatively small, infiltration rates will be measured by full-scale testing (maintaining a constant level of water across the facility at a constant flow rate, and accurately measuring the wetted pool); or

2. When full-scale testing is not practical, infiltration rates will be measured using the Pilot Infiltration Test (PIT). The PIT is not a standard test but rather a practical field procedure recommended by Ecology. A PIT will be performed in the footprint of each bioretention facility per the guidelines for a Small- Scale Test as described in the SWMMWW (Ecology 2014).

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

8.3 Vegetation monitoring

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

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

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

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

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

Summary presentation and discussion of results will be used to provide qualitative inference on the possible role of vegetation and maintenance on the hydrologic performance at each of the monitored facilities.

Comparisons will be made to the observed composition of the vegetation community and the originally designed plant community where planting plans exist. Composition of the plant community can be used to infer the duration and frequency of inundation within the bioretention facility to further understand the hydrologic performance of the system.

8.4 Containers, preservation methods, holding times

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

8.5 Invasive species evaluation

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

8.6 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.

8.7 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.

8.8 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

8.9 Other activities

No other sampling activities are anticipated.

9.0 Measurement Methods

9.1 Field procedures table/field analysis table

Field procedures for flow monitoring are described in Section 8.1.1, Water level and flow data collection, and 8.8 Field log requirements above. These procedures will generally be followed for routine maintenance of flow over weirs, calibration of stage measurement instrumentation for weirs and well points, and downloading of data.

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

Similarly, soils sampling, infiltration rates measurements, and related observation procedures in the field will follow the ASTM and Ecology (2014) procedures identified in section 8.4 above.

9.2 Lab Procedures

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

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

10.0 Quality Control (QC) Procedures

10.1 Field and lab QC required

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

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

10.2 Corrective action processes

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

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

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

11.0 Data Management Procedures

11.1 Data recording/reporting requirements

11.1.1 Data management and verification

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

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

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

11.2 Lab data package requirements

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

11.3 Electronic transfer requirements

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

11.4 Acceptance criteria for existing data

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

11.5 Data presentation procedures

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

12.0 Audits and Reports

12.1 Number, frequency, type, and schedule of audits

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

12.2 Frequency and distribution of report

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

12.3 Responsibility for reports

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

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

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

13.2 Lab data verification

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

13.3 Validation requirements, if necessary

Not applicable to this study.

14.0 Data Quality (Usability) Assessment

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

14.1 Process for determining whether project objectives have been met

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

14.2 Data analysis and presentation methods

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

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

14.3 Treatment of non-detects

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

14.4 Sampling design evaluation

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

14.5 Documentation of assessment

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

15.0 References

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16.0 Appendices

Appendix A. Bioretention Hydrologic Performance (BHP) Study II Site Selection Process and List of Selected Sites. Technical Memo – Deliverable 2.2 and 2.3 Combined.

Appendix B. Contracted Scope of Work, City of Olympia and Washington Department of Ecology. 2017.

Appendix C. Glossary, Acronyms, and Abbreviations

Appendix A

Bioretention Hydrologic Performance (BHP) Study II Site Selection Process and List of Selected Sites. Technical Memo – Deliverable 2.2 and 2.3 Combined.

Taylor Aquatic
Science and Policy

Technical Memo

To: Andy Haub, Eric Christensen, City of Olympia
Brandi Lubliner, WDOE

From: William J. Taylor

Date: February 5, 2019

Re: Bioretention Hydrologic Performance (BHP) Study II
Site Selection Process and List of Selected Sites
Technical Memo – Deliverables 2.2 and 2.3 Combined

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

Background

The BHP Study II follows the BHP Study I (conducted with the City of Bellingham) and again involved contacting Puget Sound Basin jurisdictions to identify "candidate" bioretention facilities to be recommended for evaluation and possible selection in a set of ten facilities for performance monitoring.

The difference in the BHP II selection criteria from the first BHP Study was specifically to select sites designed using the Western Washington Hydrology Model version 2012 (WWHM 2012). The goal of this project is to evaluate the performance of the model, in addition to observe how the bioretention facilities are performing in the field.

As before, the selected sites are being monitored for inflow and outflowing stormwater flows. Site data is also being collected for groundwater and ponding levels, bioretention soil mix composition and infiltration rate, subsurface soil conditions, and vegetation composition and density as supporting information to evaluate the site performance.

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

Jurisdictions, and this time public school districts, selected for contact to nominate potential sites came from four different sources:

1. Jurisdictions indicating interest in the BHP study from previous contact or during the current SAM project selection process,

2. Public School Districts identified through the Office of Superintendent of Public Instruction

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

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

Over thirty school districts and over 15 jurisdictions were contacted through direct telephone contact with stormwater managers or associated engineers and water quality specialists to discuss the BHP study, and their recommendations on possible candidate sites within their jurisdiction.

Based on the initial criterion that candidate sites had to be designed using WWHM 2012, almost thirty facilities were recommended for site evaluation. Site design plans (including planting plans), technical information reports (TIRs) and modeling information was gathered for most of these facilities. Twenty-five facilities were then identified for conducting a site visit for final evaluation. Because most of the sites contained multiple cells each with their own conditions, the site visits for these twenty-five facilities resulted in visual evaluation of approximately seventy individual cells.

Site Field Evaluation

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

- Assessment of inflow and outflow locations for flow monitoring feasibility

- Qualitative soil media composition and soil probe depths

In a different process from the previous BHP study, we did not conduct vegetation assessments as all the sites were recently constructed, or were still unplanted as we were visiting the sites. It was decided to conduct the vegetation assessment in the following spring to allow final planting and an assessment of initial survival.

Site Selection Criteria

The same site selection criteria developed in the BHP I was used as a reference to review and make note of many of the site design conditions and parameters for the candidate sites. Attachment 1 also provides a list of monitoring, modeling, and geotechnical information for each of the candidate sites.

As with the BHP I study, the accessibility of flow monitoring to attain accurate hydrologic results was almost exclusively the deciding factor. The remaining criteria checklist items were nonetheless useful as a checklist reminder of factors affecting site performance and additional data collection needs.

Separate from the criteria checklist, we used the surficial geologic and jurisdictional representation as guides to select sites that represented a wide range in geologic and jurisdictional participation.

Final Sites Selected for Monitoring

The geographic distribution of the full set of 25 sites visited is presented in Figure 1, and the final set of selected sites is listed in Table 1 below, and shown in Figure 2. Attachment 1 provides a full list of the sites visited, selected, addresses and the associated jurisdiction contacts.

Table 1. The final set of sites selected under the BHP II project.

Jurisdiction	Project Name
Bellingham (BUW)	Columbia WQ Improvements
Bellingham (BCK)	Nevada – Kentucky Bike Boulevard
Marysville (M3Q)	1st and 3rd Street SW Retrofit
Marysville (M1C)	1st and 3rd Street SW Retrofit
Monroe S.D. (MPP)	Park Place Middle School
Monroe S.D. (SSW)	Salem Woods Elementary
Renton (RSH)	Green Connections
Tacoma S.D. (FWI)	Wainwright Intermediate
Tacoma S.D. (TWH)	Wilson High School
Tumwater S.D. (TBM)	Bush Middle School

Seasonal Schedule for Monitoring

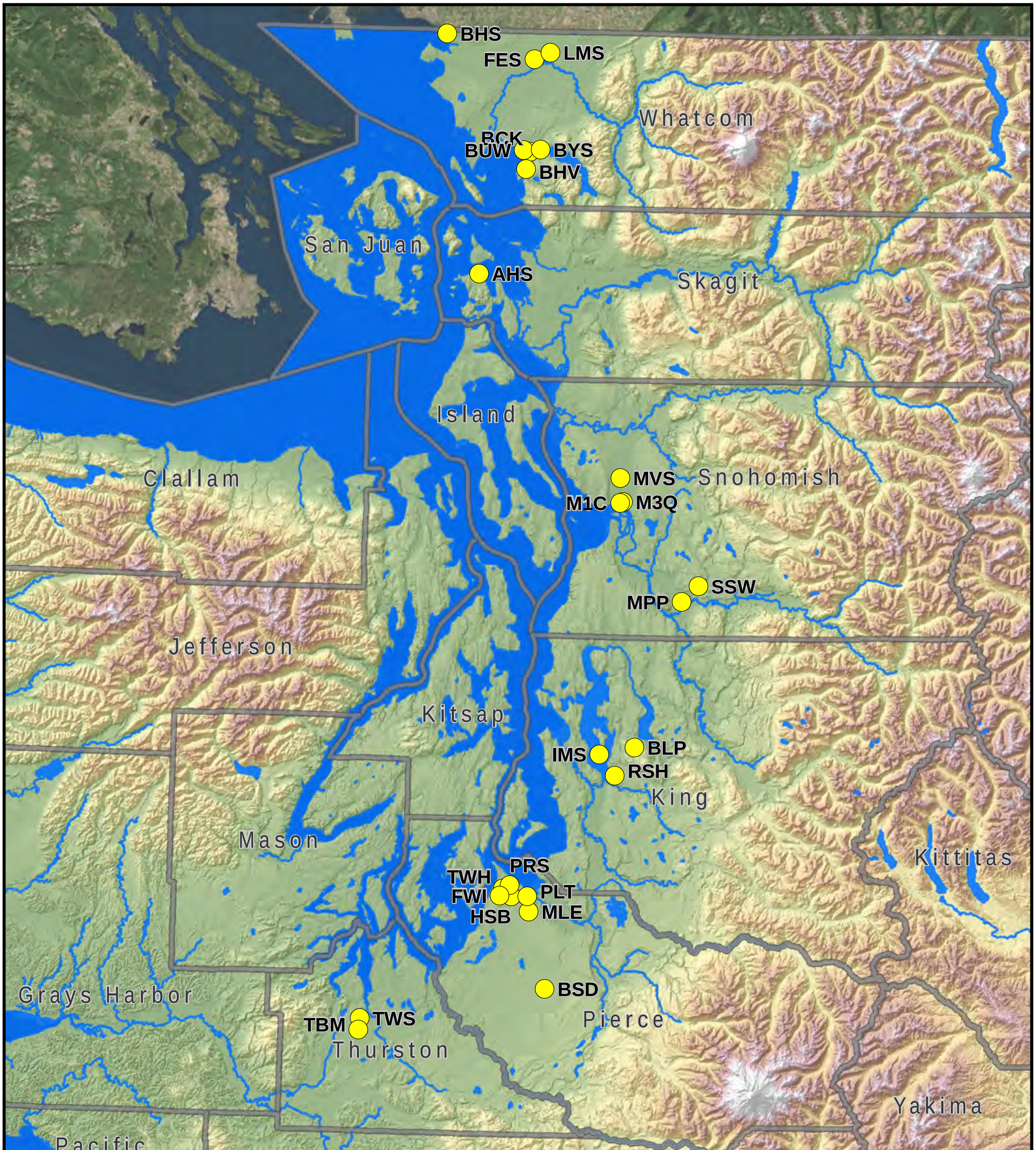
The monitoring phase of the project has begun, with virtually all the sites were installed and collecting continuous flow and rainfall data by October 15, 2018. The only exception was the two Bellingham sites which were installed on 10/22/18; and at the Bellingham BUW site one of the two inlet weirs was not installed until 11/6/18. The geotechnical site assessment work and field infiltration testing was completed during October and November 2018.

As with the BHP I Study, we recommend extending the period of monitoring from the current five months to eight months. The added value of observed groundwater conditions at many of the sites added value to analysis of the spring groundwater transition season.

If you have any questions, please feel free call me or Doug Beyerlein.

Bill Taylor

Taylor Aquatic Science and Policy



LEGEND:

- ALL SITES
- COUNTY

DATA SOURCES / REFERENCES:
AERIAL: WORLD IMAGERY, ESRI, DIGITAL GLOBE 2017
UNIVERSITY OF WASHINGTON 10 METER COMPILED DEM FROM USGS1998 DEM QUARTER QUADS
WADNR: COUNTY BOUNDARY

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 10 20
MILES

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

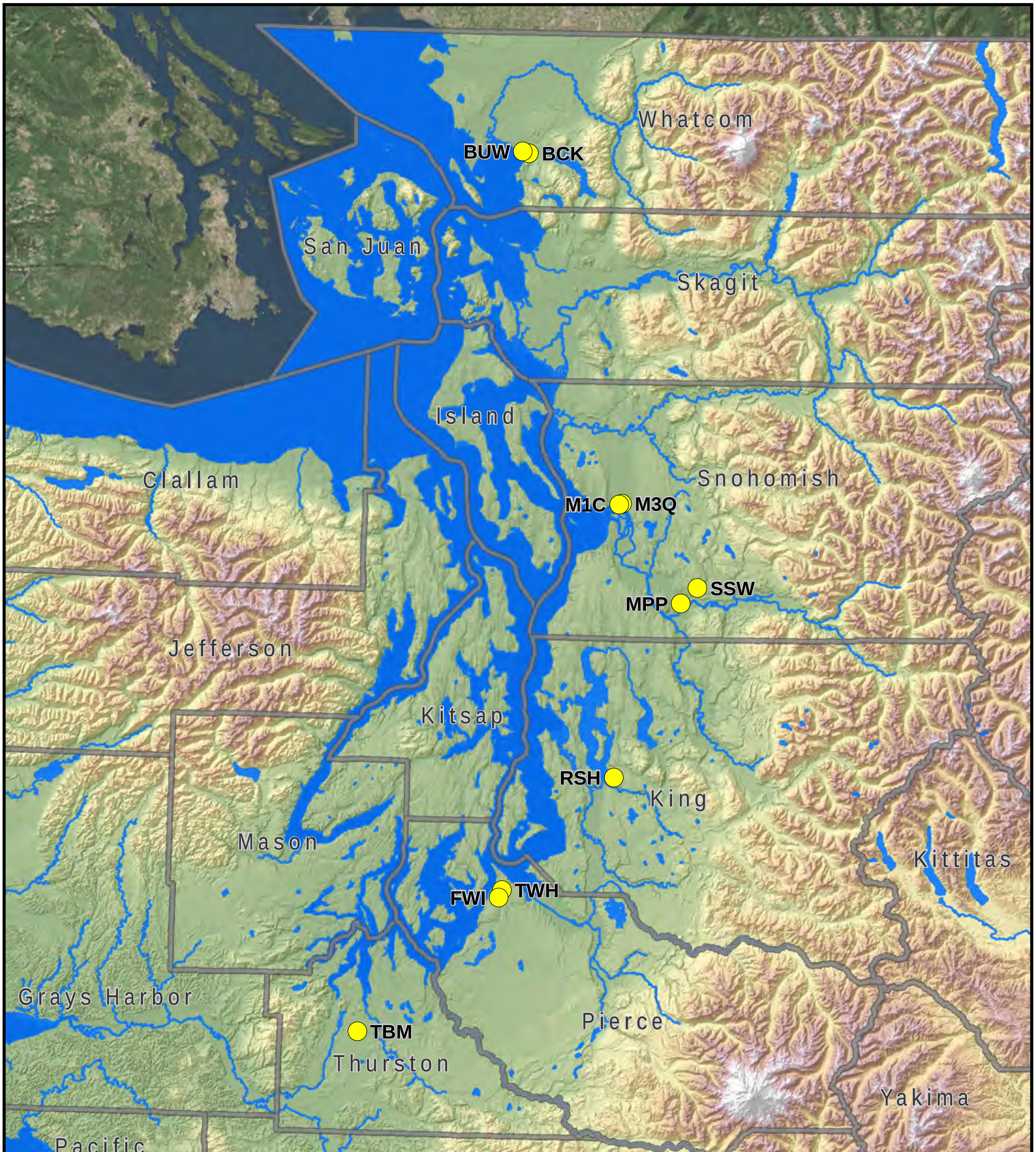
associated earth sciences incorporated

BIORETENTION SITES

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	1/19	1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\H007\150387H007 F1 BHPS_ALL.mxd



LEGEND:

SELECTED SITES

COUNTY

DATA SOURCES / REFERENCES:
AERIAL: WORLD IMAGERY, ESRI, DIGITAL GLOBE 2017
UNIVERSITY OF WASHINGTON 10 METER COMPILED DEM FROM USGS1998 DEM QUARTER QUADS
WADNR: COUNTY BOUNDARY

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

associated earth sciences incorporated

BIORETENTION SITES

BIORETENTION HYDROLOGIC PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	1/19	2

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\H007\150387H007 Fx BHPS.mxd

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

Jurisdiction	Project Name	Location	Contact Name	Contact Phone
Anacortes (AHS)	Anacortes High School	1600 20th St, Anacortes	Marty Yates	360-293-1228
Bellevue (BLP)	Lewis Cr. Park Picnic Area	Lewis Creek Park	Kit Paulsen	425-452-4861
Bellingham (BUW)	Columbia WQ Improvements	Utter St. and Washington St.	Eli Mackiewicz	360-778-7955
Bellingham (BCK)	Nevada – Kentucky Bike Boulevard	Kentucky St. and Cornwall Avenue	Eli Mackiewicz	360-778-7955
Bellingham (BYS)	Yew St. SW Improvements	Yew St. between Texas and Alabama St.	Eli Mackiewicz	360-778-7955
Bellingham S.D. (BHV)	Happy Valley Elementary	1041 24th St., Bellingham	Eli Mackiewicz	360-778-7955
Bethel S.D. (BSD)	Shining Mountain Elementary	21615 38th Ave E, Spanaway	David Wells	253-683-6085
Blaine S.D. (BHS)	Blaine High School	1055 H Street, Blaine	Alan Pomeroy	360-332-0738
Lynden S.D. (FES)	Fisher Elementary	501 14th St., Lynden	Patty Fairbanks	360-303-0927
Lynden S.D. (LMS)	Lynden New Middle School	8750 Line Rd., Lynden	Patty Fairbanks	360-303-0927
Marysville (M3Q)	1st and 3rd Street SW Retrofit	3rd and Quinn St.	Adam Benton	360.363.8283
Marysville (M1C)	1st and 3rd Street SW Retrofit	1st and Cedar St.	Adam Benton	360-363-8283
Marysville (MVS)	Sonic Drive-In	3802 116th St NE	Adam Benton	360-363-8283
Mercer Island S.D. (IMS)	Islander Middle School	7447 84th Ave SE, Mercer Island	Tony Kuhn	206-230-6339
Monroe S.D. (MPP)	Park Place Middle School	1408 W Main St., Monroe	Heidi Hansen	360.804.2677
Monroe S.D. (SSW)	Salem Woods Elementary	12802 Wagner Rd., Snohomish Co.	Heidi Hansen	360.804.2677
Renton (RSH)	Green Connections	Harrington at NE 8th St.	Ron Straka	425-430-7248
Tacoma (HSB)	Homestreet Bank	1501 S. Union Ave.	Mieke Hoppin	253-573-2332
Tacoma (PLT)	Prairie Line Trail	S. Hood and Dock St.	Mieke Hoppin	253-573-2332
Tacoma	Proctor South Development	N. 25th Street and N. Madison Street	Mieke Hoppins	253-573-2332
Tacoma S.D. (MLE)	Mary Lyon Elementary	101 E. 46th St., Tacoma	Mieke Hoppin	253-573-2332
Tacoma S.D. (FWI)	Wainright Intermediate	130 Alameda Ave., Fircrest	Michael Knaack	253-571-3316
Tacoma S.D. (TWH)	Wilson High School	1202 N Orchard St., Tacoma	Michael Knaack	253-571-3316
Tumwater S.D. (TBM)	Bush Middle School	2120 83rd Ave SW, Tumwater	Tanya Baker	360-709-7009
Tumwater S.D.(TWS)	Tumwater Middle School	6335 Littlerock Rd SW, Tumwater	Tanya Baker	360-709-7009

Site Information for Monitoring Assessment

	Label	Jurisdiction	Site	Site Visit Date	Can inflow be easily monitored; 1 = Yes; 0 = No	Can inflow be monitored with simple modifications; 1 = Yes; 0 = No or Not applicable	Overall monitoring rating	Comments
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	0	1	Tier 1	1 inlet and 1 outlet both with easy weir installs or curb cut modification
2	M1C	Marysville	Marysville 1st Street LID	4/30/18, 5/1/18	0	1	Tier 1	Only 1 inlet from curb, can't monitor outlet flow excpet via morning glory weir if riser overtops. Can't monitor sidewalk inputs but they are likely very small
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18	1	1	No-Go	Received plan set only. Seasonal high GW depth ~5ft. owner said no
4	WHS	Tacoma	Wilson High School	4/30/18	1	1	Tier 1	Underdrained 2 inlets and 1 outlet pipe
5	HSB	Tacoma	Homestreet Bank	4/30/18	1	0	Tier 2	Underdrained could be monitored but lots of inputs Outlet comingled, owner status unknown
6	PRS	Tacoma	Proctor South	4/30/18	unk	unk	No-Go	Construction not finished at time of study
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018	unk	unk	No-Go	Constuction not finished at time of study
8	PLT	Tacoma	Prarie Line Trail	4/30/18	0	0	No-Go	Complcated stone weir walls and other confusion
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19	0	0	No-Go	Too many inlets and comingled outflow, other cell lined, parking lot too many linked cells
10	AHS	Anacortes	Anacortes High School	10/1/18	unk	unk	No-Go	Constuction not finished at time of study
11	FES	Lynden	Fisher Elementary School	7/20/2018	0	0	Tier 2	Lots of inlets, would need to monitor 1 and model 16, otherwise good
12	LMS	Lynden	Lynden New Middle School	7/20/2018	0	0	Tier 2	Can't monitor inflow as it is all sheet flow but very clearly defined drainage area likely best case for modeling inflow
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	1	1	Tier 1	2 inlets, 1 outlet. 1 inlet subject to some backwater
14	IMS	Mercer Island	Islander Middle School	8/15/2018	0	0	Tier 2	Multiple buried inlets with inverts below BSM level in cell
15	BYS	Bellingham	Yew St	7/20/2018	0	0	No-Go	Adjacent to permeable pavement sidewalk, likely recieves flow from sidewalk base-course. Too many ins and Outs
16	BHS	Blaine	Blaine High School	7/20/2018	1	0	No-Go	Owner said no
17		Tumwater	Tumwater Middle School	7/31/2018	1	0	No-Go	All sites either comingled outlfow or sheet flow to gravel to grass strip inflow
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	1	1	Tier 1	Small cell in back with 1 inlet is good candidate
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	1	1	Tier 1	Cell 6 has 1 inlet, no outlet, Cells 5 and 7 also considered but more complicated and more visible accessible for potential vandalism
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/18	1	1	Tier 1	Cell 2, 1 inlet, outlet is high overflow
21	BLP	Bellevue	Lewis Creek Park	8/15/2018	0	1	No-Go	2 cells. One has sheet flow from pervious & basecourse. Second has overflow from 1st plus 2 curb cuts from pervious. Inflow may be low.
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	0	1	Tier 1	Cell 4 with two inlets selected. Cell 1 underlain by utility. Cell 2 has some minor inflow from sheet flow. Cell 3 extends to include a narrow, vegetated ditch (part of bioretention cell?)
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018	0	0	Tier 2	Primarily sheet flow. Combined with piped inflow and outflow
24	BUW	Bellingham	Utter and Washington	9/28/2018	0	1	Tier 1	2 inlets 1 outlet, inlets are low but should work
25	RSH	Renton	Sunset Harrington	9/28/2018	0	1	Tier 1	2 inlets, unique underdrain with orifice flow control, outlet

Site Information for Modeling Assessment

	Label	Jurisdiction	Site	Site Visit Date	SWDM	SWM	Under-drains	Liner	Overflow	BSM Rate	BSM b	BSM n	Subgrade Design Rate	TIR Civil
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	Ecology 2014	WWHM 2012	no	No	Yes		1.5		2	Gray and Osborne, Inc
2	M1C	Marysville	Marysville 1st Street	4/30/18, 5/1/18	Ecology 2014	WWHM 2012	no	no	Yes		1.5		2	Gray and Osborne, Inc
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18		WWHM 2012	Yes	No	Yes		1.5		3.1	
4	TWH	Tacoma	Wilson High School	4/30/18	Tacoma SWMM 2012	WWHM 2012	Yes	No	Yes		1.5	0.4	1.5	Sitts & Hill Engineers, Oct 2014
5	HSB	Tacoma	Homestreet Bank	4/30/18	Tacoma SWMM 2016	WWHM 2012	Yes	No	Yes	12	>1.5			PACE, Oct 17, 2016
6	PRS	Tacoma	Proctor South	4/30/18	Tacoma SWMM 2016	WWHM 2012	Yes	No	Yes		1.5			BCRA, Oct 2016
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018		WWHM 2012								AHBL, Oct 2017
8	PLT	Tacoma	Prarie Line Trail	4/30/18		WWHM 2012								BCRA, June 2016
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19		WWHM 2012	yes	NE cell is lined						Freeland & Associates, May 2015
10	AHS	Anacortes	Anacortes High School	10/1/18		WWHM 2012								
11	FES	Lynden	Fisher Elementary School	7/20/2018	Ecology 2005, 2014	WWHM 2012	no	no		3			27.1	Freeland and Associates
12	LMS	Lynden	Lynden New Middle School	7/20/2018	Ecology 2005, 2014	WWHM 2012	no	no		3			14.73	Freeland and Associates
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	Ecology 2005, 2014	WWHM 2012	yes	no	yes	15	1.5		3 cells with 3 different design rates	City of Bellingham Public Works
14	IMS	Mercer Island	Islander Middle School	8/15/2018		WWHM 2012	yes	no	yes					LPD
15	BYS	Bellingham	Yew St	7/20/2018		WWHM 2012								
16	BHS	Blaine	Blaine High School	7/20/2018		WWHM 2012	yes							Freeland and Associates
17	TWS	Tumwater	Tumwater Middle School	7/31/2018	Tumwater DDECM 2010 and Ecology 2005	WWHM 2012, modeled not using bioretention settings	No - but design includes a rock-filled trench beneath BSM			3	1.5		6 biocells: Bio cell 2 and 5 have the highest % imp; bio cell 2: 1.7 iph; Bio cell 5: 2.0 iph	BCRA
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	Tumwater DDECM 2010 and Ecology 2005	WWHM 2012	No	No	No		1.5		0.9	BCRA
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	Ecology 2005, 2014	WWHM 2012	No	No	No	2	1.5			Harmsen
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/2018	Snohomish County Drainage Manual 2016	WWHM 2012	No	No	No	1.5	1.5			Harmsen
21	BLP	Bellevue	Lewis Creek Park	8/15/2018			Yes	r Fabric						SvR Design
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	Ecology 2014	WWHM 2012	Yes	No	Yes		1.5		1.5	AHBL
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018			no		yes					
24	BUW	Bellingham	Bellingham Columbia Neighborhood	9/28/2018	Ecology 2014	WWHM2012	Yes	No	Yes	12	1.75		0	PSE
25	RSH	Renton	Renton	9/28/2018	Ecology 2014	WWHM4	Yes	No	Yes	5	1.5		1.2	CH2MHILL

Site Information for Geotechnical Assessment

	Label	Jurisdiction	Site	Site Visit Date	Geotech	CF	Geology	Explorations	Inf Test Type	Hydrogeo	BSM rate < Native iph	Estimated Construction	Comments
1	M3Q	Marysville	3rd Street LID and Roadway improvement Project	4/30/18, 5/1/18	PanGEO	NA	Rec. OW (per regional mapping)	EB	grain size	A1	no	2017	Shallow groundwater, less than 10 feet.
2	M1C	Marysville	Marysville 1st Street	4/30/18, 5/1/18	PanGEO	NA	Rec. OW (per regional mapping)	EB	grain size	A1	no	2017	Shallow groundwater, less than 5 feet, tidal influence
3	MVS	Marysville	Sonic Drive-In	4/30/18, 5/1/18	Unk	unk	Rec. OW (per regional mapping)	unk	Infil. test indicated on plan sheet	unk	unk	2017	Received plan set only. Seasonal high GW depth ~5ft.
4	TWH	Tacoma	Wilson High School	4/30/18	AESI 2000, 2004, 2014	None	Till/Adv. OW	EB, EP	None	B2	no	2016	Underdrained. 2 inlets, only one shown on plans.
5	HSB	Tacoma	Homestreet Bank	4/30/18	Zipper Geo Associates, LLS.	None, "not suitable"	Fill/Till	EB	None, "not suitable"	B2	no	2017	Underdrained
6	PRS	Tacoma	Proctor South	4/30/18	GeoResources 4/21/2016 (referenced, not attached)	unk	Fill/Till	unk	unk	B2	no	NA	Not yet constructed at time of study. Geotech report not included in PDF attachments.
7	MLE	Tacoma	Mary Lyon Elementary School	7/31/2018	GeoEngineers, Inc.	0.45	Rec. OW?/Till	EB	PIT	B2	no	NA	Not yet constructed at time of study.
8	PLT	Tacoma	Prarie Line Trail	4/30/18	unk	unk	unk	unk	unk	unk	unk	2017	Geotech report not included.
9	BHV	Bellingham SD	Happy Valley Elementary School	7/20/19	Geotest	NA	Till over outwash	EB, EP	PIT	B2	No - zero field rate in till; did not test the advance	2016	Not suitable for flow monitoring; shallow ground water - one cell lined.
10	AHS	Anacortes	Anacortes High School	10/1/18	AESI	NA	hard silt	EB	none	EX		NA	Not yet constructed at time of study.
11	FES	Lynden	Fisher Elementary School	7/20/2018	Geotest	0.252	Rec outwash (Sumas)	EB, EP	grain size	A1/A2	Yes	2018	City conditioned the project to conduct PIT at the time of construction; no documentation of test received. GW ATD 19 to 20' bgs; mottled at 1.5, 4.5 to 5.5, not interpreted as gw per geotech.
12	LMS	Lynden	Lynden New Middle School	7/20/2018	Geotest	0.252	Rec outwash (Sumas)	EB, EP	grain size	A1/A2	Yes	2018	GW ATD 13 to 18' bgs; mottled at 10.5'.
13	BCK	Bellingham	Cornwall Kentucky	7/20/2018	MTC	0.18	B'ham drift and Fill	HA	grain size	EX	2 cells in GMD - no; 1 cell in fill - possibly	2017	Cells "field fit", may differ from plans. Overflow/underdrain present.
14	IMS	Mercer Island	Islander Middle School	8/15/2018	AESI	NA	pre-Vashon nonglacial	EB	none	F	No	2016	Qpvn at biocell #3, gw at ~10' in EB-7 ATD near Biocell #3; an MW was installed in the parking lot area. One inlet not field located, may join other inlet (but plans show separate).
15	BYS	Bellingham	Yew St	7/20/2018	unk	unk	fill	unk	unk	unk	unk	2016	Adjacent to permeable pavement sidewalk, likely recieves flow from sidewalk base-course. No geotech report received.
16	BHS	Blaine	Blaine High School	7/20/2018	unk	unk	unk	unk	unk	unk	unk	2018	Facility may not be complete - may be waiting on landscapers. Recieved plan sheet only.
17	TWS	Tumwater	Tumwater Middle School	7/31/2018	Landau	not stated	Rec. OW	EB, HA, direct push	grain size	A1	No	2016	Groundwater 10' bgs at time of report, monitoring ongoing. Groundwater TM calculated adjusted rates based on 1999 groundwater condition.
18	TBM	Tumwater	George Washington Bush Middle School	7/31/2018	Landau	not stated	Rec. OW	EB	grain size	A1	No	2016	shallow groundwater; high groundwater hazard area
19	MPP	Monroe SD	Park Place Middle School	7/31/2018	AESI	0.4	Alluvium	EP, IT, EB	PIT	D1	No	2017 and 2018	Two phases of construction - 1st set of cell was 2017, second set was 2018
20	SSW	Monroe SD	Salem Woods Elementary School	7/31/2018	AESI	0.315	Rec. OW	EP, IT, EB	PIT	A1	no	2018	Only one inlet appears to be present, plans show two
21	BLP	Bellevue	Lewis Creek Park	8/15/2018	unk	unk	unk	unk	unk	unk	unk	2017	Received plan sets only.
22	FWI	Tacoma SD	Wainwright Intermediate	8/15/2018	AESI	.45, .045	Rec. OW., till	EP	PIT	A2	no	2016	Cell 1 underlain by utility. Cell 2 has some minor inflow from sheet flow. Cell 3 and 4 have inflow from 2 curb cuts each. Cell 3 extends to include a narrow, vegetated ditch (part of bioretention cell?)
23	BSD	Bethel SD	Shining Mountain ES	8/15/2018	unk	unk	unk	unk	unk	unk	unk	2012-2013	No documents received.
24	BUW	Bellingham	Bellingham Columbia Neighborhood	9/28/2018	Element solutions	not stated	Fill, GMD and outwash	EB, EP	grain size, PIT	E2	no	2016	Underdrained.
25	RSH	Renton	Renton	9/28/2018	CH2MHILL	8 (or 0.125)	fill/ rec OW	EB, EP	PIT	A3	no	2017	Underdrained, through orifice.

Appendix B

Contracted Scope of Work, City of Olympia and Washington Department of Ecology. 2017.

PROFESSIONAL SERVICES AGREEMENT
FOR
STORMWATER MANAGEMENT SERVICES

This Professional Services Agreement ("Agreement") is effective as of the date of the last authorizing signature affixed hereto. The parties ("Parties") to this Agreement are the City of Olympia, a Washington municipal corporation ("City"), and Clear Creek Solutions, Inc., a Washington corporation ("Contractor").

A. The City seeks the temporary professional services of a skilled independent contractor capable of working without direct supervision, in the capacity of stormwater treatment investigations; and

B. The Contractor has the requisite skill and experience necessary to provide such services.

NOW, THEREFORE, the Parties agree as follows:

1. Services.

Contractor shall provide the services more specifically described in Exhibit "A," attached hereto and incorporated by this reference ("Services"), in a manner consistent with the accepted practices for other similar services, and when and as specified by the City's representative.

2. Term.

The term of this Agreement shall commence upon the effective date of this Agreement and shall continue until the completion of the Services, but in any event no later than January 1, 2020 ("Term"). This Agreement may be extended for additional periods of time upon the mutual written agreement of the City and the Contractor.

3. Termination.

Prior to the expiration of the Term, this Agreement may be terminated immediately, with or without cause by the City.

4. Compensation.

A. Total Compensation. In consideration of the Contractor performing the Services, the City agrees to pay the Contractor an amount not to exceed Five Hundred Twenty-Six Thousand, Twenty-Six and No/100 Dollars ($526,026) as described in Exhibit "B".

B. Method of Payment. Payment by the City for the Services will only be made after the Services have been performed, a voucher or invoice is submitted in the form specified by the City, which invoice shall specifically describe the Services performed, the name of Contractor's personnel performing such Services, the hourly labor charge rate for such personnel, and the same is approved by the appropriate City representative. Payment shall be made on a monthly basis, thirty (30) days after receipt of such voucher or invoice.

C. Contractor Responsible for Taxes. The Contractor shall be solely responsible for the payment of any taxes imposed by any lawful jurisdiction as a result of the performance and payment of this Agreement.

5. Compliance with Laws.

Contractor shall comply with and perform the Services in accordance with all applicable federal, state, and City laws including, without limitation, all City codes, ordinances, resolutions, standards and policies, as now existing or hereafter adopted or amended.

6. Assurances.

The Contractor affirms that it has the requisite training, skill and experience necessary to provide the Services and is appropriately accredited and licensed by all applicable agencies and governmental entities, including but not limited to being registered to do business in the City of Olympia by obtaining a City of Olympia business registration.

7. Independent Contractor/Conflict of Interest.

It is the intention and understanding of the Parties that the Contractor is an independent contractor and that the City shall be neither liable nor obligated to pay Contractor sick leave, vacation pay or any other benefit of employment, nor to pay any social security or other tax which may arise as an incident of employment. The Contractor shall pay all income and other taxes due. Industrial or any other insurance that is purchased for the benefit of the City, regardless of whether such may provide a secondary or incidental benefit to the Contractor, shall not be deemed to convert this Agreement to an employment contract. It is recognized that Contractor may be performing professional services during the Term for other parties; provided, however, that such performance of other services shall not conflict with or interfere with Contractor's ability to perform the Services. Contractor agrees to resolve any such conflicts of interest in favor of the City.

8. Equal Opportunity Employer.

A. In all Contractor services, programs or activities, and all Contractor hiring and employment made possible by or resulting from this Agreement, there shall be no unlawful discrimination by Contractor or by Contractor's employees, agents, subcontractors or representatives against any person based on any legally protected class status including but not limited to: sex, age (except minimum age and retirement provisions), race, color, religion, creed, national origin, marital status, veteran status, sexual orientation, gender identity, genetic information or the presence of any disability, including sensory, mental or physical handicaps; provided, however, that the prohibition against discrimination in employment because of disability shall not apply if the particular disability prevents the performance of the essential functions required of the position.

This requirement shall apply, but not be limited to the following: employment, advertising, layoff or termination, rates of pay or other forms of compensation, and selection for training, including apprenticeship. Contractor shall not violate any of the terms of Chapter 49.60 RCW, Title VII of the Civil Rights Act of 1964, the Americans with Disabilities Act, Section 504 of the Rehabilitation Act of 1973 or any other applicable federal, state or local law or regulation regarding non-discrimination. Any material violation of this provision shall be grounds for termination of this Agreement by the City and, in the case of the Contractor's breach, may result in ineligibility for further City agreements.

B. In the event of Contractor's noncompliance or refusal to comply with the above nondiscrimination plan, this Contract may be rescinded, canceled, or terminated in whole or in part, and the Contractor may be declared ineligible for further contracts with the City. The Contractor, shall, however, be given a reasonable time in which to correct this noncompliance.

C. To assist the City in determining compliance with the foregoing nondiscrimination requirements, Contractor must complete and return the *Statement of Compliance with Non-Discrimination* attached as Exhibit C. If the contract amount is $50,000 or more, the Contractor shall execute the attached Equal Benefits Declaration - Exhibit D.

9. Confidentiality.

Contractor agrees not to disclose any information and/or documentation obtained by Contractor in performance of this Agreement that has been expressly declared confidential by the City. Breach of confidentiality by the Contractor will be grounds for immediate termination.

10. Indemnification/Insurance.

A. Indemnification / Hold Harmless. Contractor shall defend, indemnify and hold the City, its officers, officials, employees and volunteers harmless from any and all claims, injuries, damages, losses or suits including attorney fees, arising out of or resulting from the acts, errors or omissions of the Contractor in performance of this Agreement, except for injuries and damages caused by the sole negligence of the City.

Should a court of competent jurisdiction determine that this Agreement is subject to RCW 4.24.115, then, in the event of liability for damages arising out of bodily injury to persons or damages to property caused by or resulting from the concurrent negligence of the Contractor and the City, its officers, officials, employees, and volunteers, the Contractor's liability, including the duty and cost to defend, hereunder shall be only to the extent of the Contractor's negligence. It is further specifically and expressly understood that the indemnification provided herein constitutes the Contractor's waiver of immunity under Industrial Insurance, Title 51 RCW, solely for the purposes of this indemnification. This waiver has been mutually negotiated by the parties. The provisions of this section shall survive the expiration or termination of this Agreement.

B. Insurance. The Contractor shall procure and maintain for the duration of the Agreement, insurance against claims for injuries to persons or damage to property which may arise from or in connection with the performance of the work hereunder by the Contractor, its agents, representatives, or employees.

C. No Limitation. Contractor's maintenance of insurance as required by the agreement shall not be construed to limit the liability of the Contractor to the coverage provided by such insurance, or otherwise limit the City's recourse to any remedy available at law or in equity.

D. Minimum Scope of Insurance. Contractor shall obtain insurance of the types described below:

1. Automobile Liability insurance covering all owned, non-owned, hired and leased vehicles. Coverage shall be at least as broad as ISO occurrence form (ISO) form CA 00 01 or a substitute form providing equivalent liability coverage. If necessary, the policy shall be endorsed to provide contractual liability coverage.

2. Commercial General Liability insurance shall be at least as broad as ISO occurrence form CG 00 01 and shall cover liability arising from premises, operations, independent contractors, stop gap liability, personal injury and advertising injury. The City shall be named as an additional insured under the Contractor's Commercial General Liability insurance policy with respect to the work performed for the City using an additional insured endorsement at least as broad as ISO CG 20 26.

3. Workers' Compensation coverage as required by the Industrial Insurance laws of the State of Washington.

4. Professional Liability insurance appropriate to the Contractor's profession.

E. Minimum Amounts of Insurance. Contractor shall maintain the following insurance limits:

1. Automobile Liability insurance with a minimum combined single limit for bodily injury and property damage of $1,000,000 per accident.

2. Commercial General Liability insurance shall be written with limits no less than $1,000,000 each occurrence, $2,000,000 general aggregate.

3. Professional Liability insurance shall be written with limits no less than $1,000,000 per claim and $1,000,000 policy aggregate limit.

F. Other Insurance Provisions. The Contractor's Automobile Liability and Commercial General Liability insurance policies are to contain, or be endorsed to contain that they shall be primary insurance as respect the City. Any Insurance, self-insurance, or insurance pool coverage maintained by the City shall be excess of the Contractor's insurance and shall not contribute with it.

G. Acceptability of Insurers. Insurance is to be placed with insurers with a current A.M. Best rating of not less than A:VII.

H. Verification of Coverage. Contractor shall furnish the City with original certificates and a copy of the amendatory endorsements, including but not necessarily limited to the additional insured endorsement, evidencing the insurance requirements of the Contractor before commencement of the work.

I. Notice of Cancellation. The Contractor shall provide the City with written notice of any policy cancellation, within two (2) business days of their receipt of such notice.

J. Failure to Maintain Insurance. Failure on the part of the Contractor to maintain the insurance as required shall constitute a material breach of contract, upon which the City may, after giving five (5) business days' notice to the Contractor to correct the breach, immediately terminate the contract or, at its discretion, procure or renew such insurance and pay any and all premiums in connection therewith, with any sums so expended to be repaid to the City on demand, or at the sole discretion of the City, offset against funds due the Contractor from the City.

K. City's Full Access to Contractor Limits. If the Contractor maintains higher insurance limits than the minimums shown above, the City shall be insured for the full available limits of Commercial General and Excess or Umbrella liability maintained by the Contractor, irrespective of whether such limits maintained by the Contractor are greater than those required by this contract or any certificate of insurance furnished to the City evidences limits of liability lower than those maintained by the Contractor.

11. Work Product.

Any deliverables identified in the Scope of Work or otherwise identified in writing by the City that are produced by Contractor in performing the Services under this Agreement and which are delivered to the City shall belong to the City. Any such work product shall be delivered to the City by Contractor at the termination or cancellation date of this Agreement, or as soon thereafter as possible. All other documents are owned by the Contractor.

12. Treatment of Assets.

A. Title to all property furnished by the City shall remain in the name of the City.

B. Title to all nonexpendable personal property and all real property purchased by the Contractor, the cost of which the Contractor is entitled to be reimbursed as a direct item of cost under this Contract, shall pass to and vest in the City, or if appropriate, the state or federal department supplying funds therefor, upon delivery of such property by the vendor. If the Contractor elects to capitalize and depreciate such nonexpendable personal property in lieu of claiming the acquisition cost as a direct item of cost, title to such property shall remain with the Contractor. An election to capitalize and depreciate or claim acquisition cost as a direct item of cost shall be irrevocable.

C. Nonexpendable personal property purchased by the Contractor under the terms of this Contract in which title is vested in the City shall not be rented, loaned or otherwise passed to any person, partnership, corporation/association or organization without the prior expressed written approval of the City or its authorized representative, and such property shall, unless otherwise provided herein or approved by the City or its authorized representative, be used only for the performance of this Contract.

D. As a condition precedent to reimbursement for the purchase of nonexpendable personal property, title to which shall vest in the City, the Contractor agrees to execute such security agreements and other documents as shall be necessary for the City to perfect its interest in such property in accordance with the "Uniform Commercial Code--Secured Transactions" as codified in Article 9 of Title 62A, the Revised Code of Washington.

E. The Contractor shall be responsible for any loss or damage to the property of the City including expenses entered thereunto which results from negligence, willful misconduct, or lack of good faith on the part of the Contractor, or which results from the failure on the part of the Contractor to maintain and administer in accordance with sound management practices that property, to ensure that the property will be returned to the City in like condition to that in which it was furnished or purchased, fair wear and tear excepted.

F. Upon the happening of loss or destruction of, or damage to, any City property, the Contractor shall notify the City or its authorized representative and shall take all reasonable steps to protect that property from further damage.

G. The Contractor shall surrender to the City all property of the City within thirty (30) days after rescission, termination or completion of this Contract unless otherwise mutually agreed upon by the parties.

13. <u>Books and Records</u>.

The Contractor agrees to maintain books, records, and documents which sufficiently and properly reflect all direct and indirect costs related to the performance of the Services and maintain such accounting procedures and practices as may be deemed necessary by the City to assure proper accounting of all funds paid pursuant to this Agreement. These records shall be subject, at all reasonable times, to inspection, review or audit by the City, its authorized representative, the State Auditor, or other governmental officials authorized by law to monitor this Agreement.

Records owned, used, or retained by the City that meet the definition of a “public record” pursuant to RCW 42.56.010 are subject to disclosure under Washington’s Public Records Act. Should the Contractor fail to provide records created or used by Contractor in its work for the City within ten (10) days of the City’s request for such records, Contractor shall indemnify, defend, and hold the City harmless for any public records judgment, including costs and attorney’s fees, against the City involving such withheld records.

14. <u>Non-Appropriation of Funds</u>.

If sufficient funds are not appropriated or allocated for payment under this Agreement for any future fiscal period, the City will not be obligated to continue the Agreement after the end of the current fiscal period, and this Agreement will automatically terminate upon the completion of all remaining Services for which funds are allocated. No penalty or expense shall accrue to the City in the event this provision applies.

15. General Provisions.

A. Entire Agreement. This Agreement contains all of the agreements of the Parties with respect to any matter covered or mentioned in this Agreement and no prior agreements shall be effective for any purpose.

B. Modification. No provision of this Agreement, including this provision, may be amended or modified except by written agreement signed by the Parties.

C. Full Force and Effect; Severability. Any provision of this Agreement that is declared invalid or illegal shall in no way affect or invalidate any other provision hereof and such other provisions shall remain in full force and effect. Further, if it should appear that any provision hereof is in conflict with any statutory provision of the State of Washington, the provision appears to conflict therewith shall be deemed inoperative and null and void insofar as it may be in conflict therewith, and shall be deemed modified to conform to such statutory provision.

D. Assignment. Neither the Contractor nor the City shall have the right to transfer or assign, in whole or in part, any or all of its obligations and rights hereunder without the prior written consent of the other Party.

1. If the Contractor desires to assign this Contract or subcontract any of its work hereunder, the Contractor shall submit a written request to the City for approval not less than fifteen (15) days prior to the commencement date of any proposed assignment or subcontract.

2. Any work or services assigned or subcontracted for hereunder shall be subject to each provision of this Contract.

3. Any technical/professional service subcontract not listed in this Contract, which is to be charged to the Contract, must have prior written approval by the City.

4. The City reserves the right to inspect any assignment or subcontract document.

E. Successors in Interest. Subject to the foregoing Subsection, the rights and obligations of the Parties shall inure to the benefit of and be binding upon their respective successors in interest, heirs and assigns.

F. Attorney Fees. In the event either of the Parties defaults on the performance of any term of this Agreement or either Party places the enforcement of this Agreement in the hands of an attorney, or files a lawsuit, the prevailing party shall be entitled to its reasonable attorneys' fees, costs and expenses to be paid by the other Party.

G. No Waiver. Failure or delay of the City to declare any breach or default immediately upon occurrence shall not waive such breach or default. Failure of the City to declare one breach or default does not act as a waiver of the City's right to declare another breach or default.

H. Governing Law. This Agreement shall be made in and shall be governed by and interpreted in accordance with the laws of the State of Washington.

I. Authority. Each individual executing this Agreement on behalf of the City and Contractor represents and warrants that such individuals are duly authorized to execute and deliver this Agreement on behalf of the Contractor or the City.

J. Notices. Any notices required to be given by the Parties shall be delivered at the addresses set forth below. Any notices may be delivered personally to the addressee of the notice or may be deposited in the United States mail, postage prepaid, to the address set forth below. Any notice so posted in the United States mail shall be deemed received three (3) days after the date of mailing.

K. Captions. The respective captions of the Sections of this Agreement are inserted for convenience of reference only and shall not be deemed to modify or otherwise affect any of the provisions of this Agreement.

L. Performance. Time is of the essence in performance of this Agreement and each and all of its provisions in which performance is a factor. Adherence to completion dates set forth in the description of the Services is essential to the Contractor's performance of this Agreement.

M. Remedies Cumulative. Any remedies provided for under the terms of this Agreement are not intended to be exclusive, but shall be cumulative with all other remedies available to the City at law, in equity or by statute.

N. Counterparts. This Agreement may be executed in any number of counterparts, which counterparts shall collectively constitute the entire Agreement.

O. Equal Opportunity to Draft. The parties have participated and had an equal opportunity to participate in the drafting of this Agreement, and the Exhibits, if any, attached. No ambiguity shall be construed against any party upon a claim that that party drafted the ambiguous language.

P. Venue. All lawsuits or other legal actions whatsoever with regard to this agreement shall be brought in Thurston County, Washington, Superior Court.

Q. Ratification. Any work performed prior to the effective date that falls within the scope of this Agreement and is consistent with its terms is hereby ratified and confirmed.

R. Certification Regarding Debarment, Suspension, and Other Responsibility Matters.

1. By signing the agreement below, the Contractor certifies to the best of its knowledge and belief, that it and its principals:

a. Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any federal department or agency;

b. Have not within a three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission or fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (federal, state, or local) transaction or contract under a public transaction; violation of federal or state antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

c. Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (federal, state, or local) with commission of any of the offenses enumerated in paragraph 1.b. of this certification; and

d. Have not within a three (3) year period preceding this application/proposal had one or more public transactions (federal, state, or local) terminated for cause or default.

2. Where the Contractor is unable to certify to any of the statements in this certification, such Contractor shall attach an explanation to this proposal.

S. Early Retirement from the State of Washington- Certification. By signing this form, you certify that no one being directly compensated for their services pursuant to this Agreement has retired from the Washington State Retirement System using the 2008 Early Retirement Factors with restrictions on returning to work.

CITY OF OLYMPIA

By: ____________________
Steven Hall, City Manager
P.O. Box 1967
Olympia WA 98507-1967
Date of Signature: 12/2/2017

APPROVED AS TO FORM:

____
City Attorney

I certify that I am authorized to execute this contract on behalf of the Contractor.

CLEAR CREEK SOLUTIONS, INC.

By: ____________________
Douglas Beyerlein, P.E.
Chief Financial Officer
15800 Village Green Drive #3
Mill Creek, WA 98012
(425) 225-5997
Date of Signature: 12/1/2017

EXHIBIT A

CLEAR CREEK SOLUTIONS, INC.

Bioretention Hydrologic Performance (BHP) Study II - Monitoring Facilities Designed Using the 2012 Ecology SWM Manual

Scope of Work

Task 1 Project Management (\$16,240 November 2017 – December 2019)

1. Prepare consultant contract scopes and contracting.
   This task will involve conducting the process to procure and manage consultant services for the project.

2. Prepare quarterly progress reports.
   This task will involve completing reporting responsibilities to Ecology.

3. Coordinate communication with Ecology and partner jurisdictions and consultants.
   This task is to communicate with jurisdictions and consultants related to administration of the contract.

Deliverable 1.1: Document contracting, coordination with team, and communications via quarterly progress report by City of Olympia with consultant support.

Task 2 Prepare Site Selection Criteria and Conduct Selection Process (\$54,540 November 2017 – January 2018)

1. Develop site selection criteria checklist.
   This task will be to update the existing site selection criteria checklist in coordination with Ecology staff, consultants, and participating jurisdiction partners.

Deliverable 2.1: Site selection criteria checklist submitted to Ecology. Target date: December 2017.

2. Communicate selection criteria to partners; receive and organize candidate sites; visit sites.
   This task will involve communicating with the individual partners submitting candidate sites; collecting and evaluating background engineering and construction data; visiting candidate sites to conduct the on-site selection checklist, scoring the complete list of

candidate sites and making selections of sites to be monitored. Nominal goals are to identify up to 20 candidate sites and select up to ten sites to be monitored for five months.

Deliverable 2.2: Summary of results of site evaluation and list of final sites submitted to Ecology. Target date: January 2018.

3. Write report on the site selection process and results including sections on: site selection criteria, candidate sites, site visit checklist results, scoring results, and proposed list of sites to be monitored.

Deliverable 2.3: Report on the site selection process submitted to Ecology. Target date: January 2018.

Task 3 Update Quality Assurance Project Plan (QAPP) ($4,600 November 2017 – February 2018)

1. Update the QAPP used for phase I of the BHP Study for all sites and overall project analysis. The revised QAPP will follow Ecology's *Guidelines and Specifications for Preparing Quality Assurance Project Plans for Environmental Studies*, February 2001 (Ecology Publication No. 01-03-003). The revised QAPP will be submitted to the Department of Ecology with time for revision, comment and approval.

Deliverable 3.1: BHP Study II draft QAPP for all sites addressing monitoring methods and analysis delivered to Ecology. Target date: January 2018.

2. Respond to Ecology's and other technical reviewers' comments and finalize QAPP and Phase II scope.

Deliverable 3.2: Final QAPP delivered to Ecology. Target date: February 2018.

Task 4 Monitoring Implementation: Site Sampling, Monitoring Installation, and Downloading; Multiple Technical Memos ($270,865, January - June 2018)

1. Based upon the QAPP, select and procure monitoring equipment capable of meeting the requirements of this study. Utilize existing equipment where possible if it meets the

study requirements and objectives.

Deliverable 4.1: Proposed equipment list and approximate cost. Target Date: January 2018.
Deliverable 4.2: Proposed purchase plan meeting State open bidding and procurement processes where applicable. Target Date: January 2018. CITY OF OLYMPIA task.
Deliverable 4.3: Documentation of bidding process showing the bid selection and reasoning for any deviation from use of the lowest responsible bidder. Target Date: February 2018. CITY OF OLYMPIA task.
Deliverable 4.4: Invoice and receipt of procured equipment. Target Date: February 2018. CITY OF OLYMPIA task.

2. Based upon the QAPP, testing of the sites shall be conducted to provide the information necessary to meet the goals of this study. This includes but is not limited to:

    a) Geotechnical/soils design and current conditions, infiltration tests
    b) Review of facility hydrologic design and current conditions
    c) Sampling and analysis of vegetation design and current condition

Deliverable 4.5: Testing and memo report on geotechnical review with attached individual facility site testing reports. Target Date: March 2018.
Deliverable 4.6: Review and memo report on hydrologic design review with individual reports for each facility. Target Date: March 2018.
Deliverable 4.7: Sampling and memo report on vegetative investigations with individual reports for each facility. Target Date: March 2018.

3. Equipment shall be installed in conformance with the QAPP to provide monitoring at up to ten bioretention stormwater cells for up to five months. Monitoring of facility performance shall include:

    a) Rainfall, continuous
    b) Temperature, continuous
    c) Evapotranspiration factors, calculated
    d) Groundwater elevation, observation
    e) Water input to the facility, continuous
    f) Water output from the facility, observation or continuous – by facility

    Completed Monitoring Installation: Target Date: February 2018.

Deliverable 4.8: Monitoring quarterly report section: A monitoring section of the quarterly reports (Deliverable 1.1) will be included once monitoring begins to summarize the status of flow, rainfall and soil monitoring. Information provided will include the number of monitoring events and sites, relevant issues with monitoring, reasons why events were missed, and electronic spreadsheet of raw data files. Target Date: Quarterly 2018-2019.

Task 5 Data Analysis, Modeling, and Technical Memos (\$44,280, July - December 2018)

This task consists of maintaining, managing and utilizing data from the study to provide relevant information on the hydrologic function of bioretention facilities. Analysis of the individual facilities should be used to inform and support conclusions for the design, use, and hydrologic performance of bioretention facilities on a wide scale for Western Washington.

Deliverable 5.1: Meeting with Stormwater Work Group members, Ecology staff and City of Olympia staff to discuss results of monitoring, adequacy of data set and next steps for analysis. Target Date: September 2018 or as determined by Ecology.

Deliverable 5.2: Provide technical memo summarizing the development of models for each bioretention based on as-built construction, confirmed drainage area and site field conditions (depth of soil mix, groundwater, native soil infiltration, etc.). The memo will also propose analysis framework and endpoints. Target Date: September 2018 or as determined by Ecology.

Deliverable 5.3: As-Built WWHM2012 (or agreed upon newer version) model of each bioretention facility in the study. Target Date: September 2018.

Deliverable 5.4: Technical memo on the conclusions of the study for review and comments prior to creation of final report. This should include:

- Issues with existing designs or construction practices
- Recommendations for bioretention designs and design methodologies
- Recommendations for revised construction practices
  Development of an anticipated hydrologic performance matrix based on multiple variables of design, soils, vegetation, etc. Target Date: November 2018.

Deliverable 5.5: Meeting with Stormwater Work Group members, Ecology staff and City of Olympia staff to discuss Technical Memo and provide feedback prior to final reporting. Target Date: December 2018 or as determined by Ecology.

Task 6 Final Report and Findings Communication (\$87,680, January – December 2019)

This task is the provision of a final report that provides information on the totality of this project. This task has added conducting county-based presentations for counties and their associated cities throughout the sampling area. The final report will at a minimum contain the following:

- Design study goals
- Selections process
- A synopsis of the QAPP along with information on any necessary deviations from the proposed plan
- Study results from the monitoring with explanation of any uncharacteristic or any unexpected results
- Site information for each of the facilities with location and photo. The information should include at a minimum: design performance versus actual performance, deviations between design and construction that led to the differential
- Final recommendations from the technical memo and meetings in Task 5.

Deliverable 6.1: Electronic Draft Final Report for review and comments by Ecology, City of Olympia and SWG. Target Date February 2019.
Deliverable 6.2: Presentation to the SWG. Target Date March 2019.
Deliverable 6.3: Three printed copies of Final Report, one electronic version of Final Report plus all data files, reports and miscellaneous data relevant to the project. Target Date May 2019.
Deliverable 6.4: Communication flyer and fact sheet for SAM Communications and website. Target Date: June 2019.
Deliverable 6.5: Conduct a "road show" presenting results for counties and associated cities in each county. Target Date: September 2019.

End of Exhibit A

Exhibit B

CLEAR CREEK SOLUTIONS, INC.
Bioretention Hydrologic Performance (BHP) Study II - Monitoring Facilities Designed Using the 2012 Ecology SWM Manual

Project Budget and Schedule

A summary of the project task budgets and schedule is as follows (see above for greater detail). The project costs are based on an even finer resolution breakdown of each task in a detailed costing spreadsheet (not presented here but available):

Task	Budget	Schedule
Task 1. Project Management	$16,240	November 2017 – December 2019
Task 2 Prepare Site Selection Criteria and Conduct Selection Process	$54,540	November 2017 – January 2018
Task 3 Update Quality Assurance Project Plan (QAPP)	$4,600	November 2017 – February 2018
Task 4 Monitoring Implementation; Site Sampling, Monitoring Installation, and Downloading; Multiple Discipline Technical Memo Summaries	$270,865 (includes equipment cost of $9,993 and ODCs of $16,214)	January 2018 – June 2018
Task 5 Data Analysis, Modeling, and Technical Memos	$44,280	July – December 2018
Task 6 Final Report and Findings Communication	$87,680	January – December 2019
Total Project Cost	$478,205	November 2017 – December 2019
10% Contingency	$47,821	
Total Project Cost w/Contingency	$526,026	

Total project costs are $526,026. This includes hourly labor costs, travel, supplies, lab analysis and 10% contingency.

Exhibit C

STATEMENT OF COMPLIANCE WITH NON-DISCRIMINATION REQUIREMENT

The Olympia City Council has made compliance with the City's *Non-Discrimination in Delivery of City Services or Resources* ordinance (OMC 1.24) a high priority, whether services are provided by City employees or through contract with other entities. It is important that all contract agencies or vendors and their employees understand and carry out the City's non-discrimination policy. Accordingly, each City contract for services contains language that requires an agency or vendor to agree that it shall not unlawfully discriminate against an employee or client based on any legally protected status, which includes but is not limited to: race, creed, religion, color, national origin, age, sex, marital status, veteran status, sexual orientation, gender identity, genetic information, or the presence of any disability. Indicate below the methods you will employ to ensure that this policy is communicated to your employees, if applicable.

Clear Creek Solutions, Inc. affirms compliance with the City of Olympia's non-discrimination ordinance and contract provisions. **Please check all that apply:**

- ☐ Non-discrimination provisions are posted on printed material with broad distribution (newsletters, brochures, etc.).
  What type, and how often? ____________________
- ☐ Non-discrimination provisions are posted on applications for service.
- ☐ Non-discrimination provisions are posted on the agency's web site.
- ☒ Non-discrimination provisions are included in human resource materials provided to job applicants and new employees.
- ☐ Non-discrimination provisions are shared during meetings.
  What type of meeting, and how often? ____________________
- ☐ If, in addition to two of the above methods, you use other methods of providing notice of non-discrimination, please list:
  ____
  ____

- ☐ If the above are not applicable to the contract agency or vendor, please check here and sign below to verify that you will comply with the City of Olympia's non-discrimination ordinance.

Failure to implement the measures specified above or to comply with the City of Olympia's non-discrimination ordinance constitutes a breach of contract

By signing this statement, I acknowledge compliance with the City of Olympia's non-discrimination ordinance.

[signature] 12/1/2017

(Signature) (Date)

Douglas Beyerlein

Print Name of Person Signing

Alternative Section for Sole Proprietor: I am a sole proprietor and have reviewed the statement above. I agree not to discriminate against any client, or any future employees, based on any legally protected status.

____________________ ____________________

(Sole Proprietor Signature) (Date)

Exhibit D

EQUAL BENEFITS COMPLIANCE DECLARATION

Contractors on City contracts estimated to cost $50,000 or more shall comply with the City of Olympia Municipal Code, Chapter 3.18. This provision requires that if contractors provide benefits, they do so without discrimination based on age, sex, race, creed, color, sexual orientation, national origin, or the presence of any physical, mental or sensory disability, or because of any other status protected from discrimination by law. Contractors must have policies in place prohibiting such discrimination, prior to contracting with the City.

I declare that the Contractor listed below complies with the City of Olympia Equal Benefits Ordinance, that the information provided on this form is true and correct, and that I am legally authorized to bind the Contractor.

Clear Creek Solutions, Inc.
Contractor Name

[signature]
Signature

Douglas Beyerlein
Name (please print)

12/1/2017
Date

CFO
Title

Appendix C

Glossary, Acronyms, and Abbreviations

Appendix C -- Glossary, Acronyms, and Abbreviations

Quality Assurance Glossary

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

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

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

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

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

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

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

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

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

Examples of data types commonly validated would be:

- Gas Chromatography (GC)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

References

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Glossary – General Terms

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

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

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

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

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this

report.

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

Units of Measurement

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

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

APPENDIX 3

Deliverable Task 4.5, Site BCK, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Cornwall Avenue and Kentucky Street, Bellingham, Washington. Associated Earth Sciences, Inc. 6/11/2019

Technical Memorandum

Date:	June 11, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site BCK, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Cornwall Avenue and Kentucky Street, Bellingham, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Facility Site #2 of the ES-0512 Nevada Kentucky Bike Boulevard Project, located in the city of Bellingham, Washington (Figure BCK F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 11, 2018, infiltration testing on November 14, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure BCK F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the ES-0512 Nevada Kentucky Bike Boulevard Project, located in the city of Bellingham, Washington as shown on the attached "Vicinity Map" (Figure BCK F1). The project site is located along the right-of-way of several streets in the City of Bellingham including Cornwall Avenue and Kentucky Street.

Our specific area of study for this project includes bioretention facility Site #2 located on the southeast of the intersection of Cornwall Avenue and Kentucky Street referred to as cell BCK for this study. The BCK site is bordered by Cornwall Avenue on the west, Kentucky Street on the north, and sidewalk and lawns surrounding Bellingham High School on the south and east. Site topography is generally level. No on-site surface water features are present. As described in the *Stormwater Memo* (City of Bellingham Public Works Department, May 16, 2016) the site is in the Whatcom Creek watershed.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Cornwall Avenue Infiltration Sampling," Materials Testing and Consulting, Inc., MTC Project No. 16W027-01, May 12, 2016.
- *ES-512 Stormwater Memo*, City of Bellingham Public Works Department, May 16, 2016.
- *ES-0512 Nevada Kentucky Bike Boulevard 100% Design Drawings*, City of Bellingham Public Works Department, May 6, 2016.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell BCK consists of an approximately rectangular-shaped bioretention cell with approximately 169 square feet of base area, as shown on Figure BCK F2, "Facility and Exploration Plan." We understand that the site was developed under the Stormwater Management Manual for Western Washington (SMMWW) 2014 for design and construction of stormwater facilities and modeled using WWHM2012 (Draft WWHM2012 Project Report, City of Bellingham, May 16, 2016) with a design infiltration rate of 12.3 inches per hour (in/hr) in the subgrade. Land use within the drainage basin is primarily roadway. Per sheet 23, *Bioretention Facility and Project Details, ES-0512 Nevada Kentucky Bike Boulevard* (City of Bellingham Public Works Department, December 15, 2015), the facility design includes 3 inches of mulch overlying 18 inches of bioretention soil mix overlying a 6-inch "choker course," overlying 16 inches of drain rock. The facility contains a 4-inch-diameter perforated underdrain pipe bedded in the choker course. The underdrain discharges to a catch basin, which also features a beehive grate at ground surface which acts as an overflow structure. The catch basin discharges to the City storm drain system. The upstream end of the perforated underdrain pipe is specified as being capped, with no cleanout present.

The facility is designed to infiltrate 99.99 percent of inflow into the subgrade. Stormwater enters the facility through one 6-inch green polyvinyl chloride (PVC) pipe (not shown on plan sheets) and one 1.3-foot curbcut from the east side of Cornwall Avenue. If water ponds up on the bioretention soil, the ponded water would discharge into the beehive grate located near the southern end of the cell, and then into the City storm drain system. The beehive grate is specified as 0.33 feet below the curb, with no stickup or ponding depth specified. The facility was constructed and began receiving runoff after August 2016 based on review of historic aerial imagery. We understand that the cell was "field-fit" to the site as part of a retrofit project, and therefore may differ from the plan sheets.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure BCK F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the top of the curb on the northeast corner of the facility (identified on the "BCK Level Survey Data" map in Appendix D) defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: One curbcut and one 6-inch PVC pipe.
    - Curbcut: The primary inflow to the facility is a 1.3-foot curbcut, consistent with project plans, which discharges onto a cement slope and from there onto a bioretention soil-covered cement pad. A small amount of water was discharging at the time of our November 14, 2018 site visit, and formed a pool of water at the inlet.

    - Undocumented inflow: A second inflow is a 6-inch PVC pipe entering the north end of the facility. The pipe is not shown on project plans. AESI observed that the pipe receives inflow from three storm drain grates, two of which are installed next to the sidewalk, in landscaping areas north of cell BCK, and the northernmost of which is installed on the southern side of Kentucky Street, east of the Kentucky Street intersection with Cornwall Avenue. AESI observed that flow from all three storm drains enters cell BCK via the 6-inch pipe, and observed no other storm drain connections from or into the storm drain catch basins.

- Overflow: The overflow consists of a 22-inch by 24-inch concrete catch basin with a beehive grate. The rim of this grate was up to approximately 0.3 feet below the high point of the facility base, and was set in a cement pad surrounded by cobles. The bioretention soil around the cobbles was slightly above the level of the cement pad.

- AESI investigated the loose bioretention soil thickness present in cell BCK using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a series of transects across the facility, with transects generally spaced 3 feet apart. Penetration of the T-probe generally ranged from approximately 0.8 to 2 feet, and averaged 1.5 feet. Probe penetration data is included in Appendix D to this document.

- AESI observed that the facility base is not flat as shown on the plan sheet details. Instead, it is generally constructed with a deep center and sides that slope up to closer to curb height. AESI observed that, when ponding water in the facility, the water generally only covers the lowest portion of the bioretention soil in the facility. The effective base of the bioretention facility is therefore approximately 1.5 foot wide, running along the length of the facility.

- AESI observed that the approximately 1.5-foot-wide base of the bioretention facility is not level along the length of the facility, and slopes up from the inlet area to the midpoint, causing water to pool. The base then slopes down from the midpoint to the south toward the overflow. The overflow beehive grate is at a lower elevation than the high point of the facility base, causing water to readily flow into the overflow beehive grate once it passes the high point of the facility base.

Table 1
Summary of Cell BCK
Level Survey Data

Location	Elevation (feet, project datum)
Inlet#2 (N) - 6" Green Pipe top/end @ weir	99.47
Inlet#2 (N) - 6" Green Pipe invert	98.98
Inlet#1 (W) - 6"Green Pipe top/end	100.04
Curbcut N	100.09
Curbcut low S	100.05
Curb top N of curbcut	100.49
Curb top S of curbcut	100.43
WP-1 TOC	101.15
Ponding Tube TOC (DL)	99.82
Ponding Tube TOC (Baro)	99.8
WP-1 Ground surface	99.09 to 99.1
Overflow beehive center	99.45
Overflow outer rim NE	98.93
Overflow outer rim SE	98.93
Overflow outer rim SW	98.96
Overflow outer rim NW	98.95
Overflow PVC TOC (DL)	98.22
Overflow PVC TOC (Baro)	98.19

WP: well point; TOC: top of casing; PVC: polyvinyl chloride; DL: datalogger

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- Easterbrook, D.J., 1976, *Geologic Map of Western Whatcom County, Washington*: U.S. Geological Survey (USGS), Miscellaneous Investigations Series Map I-854-B, scale 1:62,500.
- Natural Resource Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed January 2019.
- *Soil Survey of Whatcom County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington State Department of Natural Resources and Washington State University Agricultural Research Center, 1992.
- Newcomb, R.C. et al., *Ground-water Resources of Western Whatcom County, Washington*, U.S. Geological Survey (USGS) Open File Report 50-7, 1950.

5.1 Regional Topography and Project Grading

The project site is situated on a terrace in the Bellingham Basin. Whatcom Creek, a modern stream, has incised the terrain south and west of the site about 30 to 40 feet, creating relatively steep slopes within about 800 feet west of the bioretention cells. Elevations in the vicinity range from about 70 to 80 feet.

On a closer scale, the area near cell BCK is relatively level, and at elevations of approximately 74 to 75 feet. The BCK cell is surrounded by curbs on the west side, and level with the sidewalk on the east side. Cornwall Avenue slopes gently down to the south, and Kentucky Street slopes gently to the west in the vicinity of cell BCK.

The project site was previously developed with the construction of Cornwall Avenue, Kentucky Street, and Bellingham High School. Various utilities are present in the vicinity of the site. The geotechnical report (Materials Testing and Consulting, Inc., 2016) identified fill sediments to a depth of 3.2 feet in the vicinity of the BCK facility. Native grade is unknown, however minor cutting (about 3 feet) into the previously-constructed sidewalk and lawn area would have been required during construction, and previous construction of utilities and development in the area would have required previous cutting and filling to place the fill found by Materials Testing and Consulting, Inc.

5.2 Regional Geology and Background Geotechnical Information

According to D.J. Easterbrook, 1976, *Geologic Map of Western Whatcom County, Washington*: U.S. Geological Survey (USGS), Miscellaneous Investigations Series Map I-854-B, scale 1:62,500, the site vicinity is underlain by Bellingham Drift (Everson Interstade). As described on the geologic map, this consists of blue-gray, unsorted, pebbly sandy silt and pebbly clay, with glaciomarine drift mantling upland areas. This is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- Bellingham Drift (Everson Interstade, Qb): Blue-gray, unsorted, unstratified, pebbly, sandy silt and pebbly clay. Derived from rock debris melted out of floating ice and deposited on sea floor. Locally contains mollusks and wood, radiocarbon dated between 11,000 and 12,000 years B.P., glaciomarine drift mantles upland areas between flood plains below elevations of 600 feet.

Background geotechnical information includes three geotechnical explorations, labeled HA-1 through HA-3 (Materials Testing and Consulting, Inc., 2016) from within 200 feet of cell BCK dated May 12, 2016, which reached depths of about 3.5 feet below current grades, and describe material generally consisting of silty clay with some sand and trace gravel. Materials Testing and Consulting, Inc. interpreted the material as Bellingham Drift, which is consistent with the geologic mapping in the area. Shallow fill soils were encountered in one exploration in the immediate vicinity of BCK.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the *Soil Survey of Whatcom County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington State Department of Natural Resources (DNR) and Washington State University Agricultural Research Center, 1992. The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of urban land - Whatcom-Labounty complex. Urban land is land that has been heavily modified by development. Whatcom and Labounty soils form over glaciomarine drift.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in *Groundwater Resources of Western Whatcom County, Washington* (R.C. Newcomb et al., 1950). Newcomb et al. (1950) indicates that perched groundwater conditions can occur locally, particularly over till, silts, and clays.

On a closer scale, the site is as described in the *Stormwater Memo* (City of Bellingham, May 16, 2016) as within the Whatcom Creek watershed. Whatcom Creek discharges ultimately to Bellingham Bay approximately 3,000 feet southwest of cell BCK. No groundwater was observed in the hand-auger borings by Materials Testing and Consulting, Inc. at the time of exploration on April 28, 2016. Perched groundwater conditions often vary seasonally based on recent rainfall.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Two hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and to the underlying material - one into the aggregate, and one into native sediments. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure BCK F2, "Facility and Exploration Plan." Global Positioning System (GPS) coordinates for the explorations were taken using a hand-held GPS, and are summarized in Appendix B.

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell BCK were completed on October 11, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring number 1 (BCK-HA-1), which was completed in the northern perimeter of the cell, near the inflow, and hand-auger boring number 2 (BCK-HA-2), which was completed near the center of the cell, encountered approximately 1 to 1.5 feet of bioretention soil. BCK-HA-1 encountered sediment interpreted as glaciomarine drift underlying the bioretention soil, to a total depth of 3 feet. BCK-HA-2/WP encountered gravel underlying the bioretention soil, to a total depth of 1.9 feet.

6.2 Well Points

A well point was installed in BCK-HA-2/WP. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell BCK
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
BCK-HA-2/WP	BCK-HA-2/WP	6.2	1.25 inch nominal	2	4.2

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Washington State Department of Ecology (Ecology) *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). One sample of material interpreted as representative of the subgrade was tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell BCK
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
BCK-HA-1	0..1-0.5	Bioretention Soil	5.9	SAND, some silt, trace gravel (SP-SM)	5.3	4.7	1.0	Sand
BCK-HA-1	1.0-1.3	Glaciomarine Drift		Very silty SAND, some gravel (SM)	43.5			Sandy clay to loam
BCK-HA-2/WP	0.1-0.3	Bioretention Soil	5.1	SAND, some gravel, trace silt (SP)	4.9	4.5	0.9	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 5.1 and 5.9 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a "SAND" with trace to some silt and trace to some gravel based on ASTM D2487 Unified Soil Classification System (USCS). The respective fines content as measured on the No. 200 sieve was 4.9 to 5.3 percent, on the higher end of recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 4.5 to 43.7, meeting the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 0.9 to 1, lower than the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix contained slightly more than the recommended range of gravel, and slightly more than the recommended range of silt. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell BCK Site Data

Parameter	Recommended Range	Cell BCK
Organic Content (by weight)	5 to 8 percent	5.5
Cu coefficient of uniformity	4 or greater	4.6
Cc coefficient of curvature	1 to 3	0.9
Sieve Size	**Percent Passing**	
3/8" (9.51 mm)	100	99.4
#4 (4.76 mm)	95 to 100	96.2
#10 (2.0 mm)	75 to 90	76.8
#40 (0.42 mm)	25 to 40	26.0
#100 (0.15 mm)	4 to 10	6.7
#200 (0.074 mm)	2 to 5	5.9

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In cell BCK, no samples of the subgrade could be obtained for this study due to the import gravel beneath the bioretention cell and difficulties hand auguring in this material. In BCK-HA-1, a sample was obtained from the lower side slope of the cell was sieved, interpreted to be native glaciomarine drift. The tested material correlates to a very silty SAND, some gravel with 43.5 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the USDA soil texture. The grain-size distributions were normalized to the No. 10 sieve—i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 47 percent for the native glaciomarine drift.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell BCK with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Water levels were monitored using an existing staff gauge (SG-1) marked in 0.01-foot increments installed adjacent BCK-HA-2/WP, a second temporary metal staff gauge (SG-2) marked in 0.01-foot increments installed near the inlets, and within the well point with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell BCK is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell BCK

AESI performed infiltration testing on November 14, 2018. Heavy rainfall was noted during the beginning of testing, and flow from both of the inlets was present early in testing.

During this test, flow was initially maintained at about 3 gpm, then shut off when the combination of inflow from the hose and inflow due to rainfall caused the facility to begin to overflow into the beehive grate. After rainfall stopped approximately 1.5 hours into the test, flow was held steady at approximately 3 gpm, and the facility did not overflow. During the final approximately 30 minutes of testing, flow was increased to approximately 10 gpm, and the facility began to overflow. Throughout the test, AESI never observed discharge from the underdrain into the overflow catch basin. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. Initially, the water pooled near the inflows, and approached the well point (BCK)HA-2/WP) which had been installed near the high point of the facility base. When water reached the well point, it flowed past and downhill to the overflow grate, with minimal ponding at the well point. As rainfall decreased and AESI reduced the flow rate used for testing, water stopped flowing past the well point until the end of testing when AESI again increased the flow rate. Approximately 760 gallons of water were used.

Water in the well point was monitored with a data logger during the infiltration test and responded to inflow. Groundwater was present at a depth of about 3 feet beneath the bioretention cell prior to the start of inflow, and likely represents perched water in the base course of the facility. The water level in the well point responded to inflow immediately, and rose to minimum depth of approximately 2.5 feet during the course of testing. AESI interprets this response to indicate that water from the infiltration test generally infiltrated rapidly through the bioretention soil and then perched in the facility base-course. At the end of testing, when AESI discharged approximately 10 gpm into the facility, this flow of water exceeded the capacity of the bioretention soil, and began pooling until it flowed into the overflow structure.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the inlet area of the facility infiltrated into the bioretention soil such that its depth decreased from approximately 0.4 to 0.12 feet over the course of an hour.

The constant-head test infiltration rate in Table 5 is calculated based on the flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the bioretention soil. Because no flow was observed to discharge from the underdrain pipe into the overflow catch basin over the course of the test, the fate of the water is somewhat uncertain. The subgrade beneath the cell was not well documented. The hand auger completed outside of the cell base entered sediment with a high fines content. AESI interprets that water collecting in the facility base course and flowed laterally, some infiltrating into the subgrade and some likely captured in fill/utility corridors.

Table 5
Cell BCK
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
BCK (bioretention soil)	60	421	757	0.3	6.6	3.4
BCK (subgrade)	Perched water response in well point				Uncertain, interpreted to be low; likely affected by utility corridors	

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Portions of Cell BCK were inconsistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is consistent with the plans. No ponding level is specified in site design documents.

- Bioretention soil:
    - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.5 feet as indicated on the plan. On the edges of the facility the bioretention soil was occasionally thinner than this.
    - Composition: The soil mix generally met the recommended guidelines for organic content and sand gradation, although the soil mix contained slightly more than the recommended range of fine gravel and silt, and had a slightly low coefficient of curvature.

- Subgrade conditions: The subgrade is interpreted to consist of glaciomarine drift, with fill soils present.

- Bioretention soil field infiltration rate:
    - Measured at about 6.6 in/hr.
    - No water was observed in the underdrain, so the field infiltration rate is interpreted to represent the bioretention soil rate. The rate is lower than typical and some compaction was noted during the soil probing.

- Subgrade infiltration rate: Interpreted to be affected by unknown areas of fill sediments. Infiltration is likely primarily into the undocumented fill sediments.

- Inflow: The BCK facility receives inflow from a PVC pipe which is not indicated on project plan sheets. This pipe is connected to several storm drains, which are not indicated on project plan sheets. It is unclear if the modeled drainage area included the area drained by these storm drains.

- Base Area: AESI observed that the bioretention soil is not level across the facility base. Based on our measurements the wetted base area was approximately 60 square feet during infiltration testing with a flow of approximately 10 gpm, with water flowing into the overflow structure. This is less than the 169-square-foot base area per design.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall
6/11/19

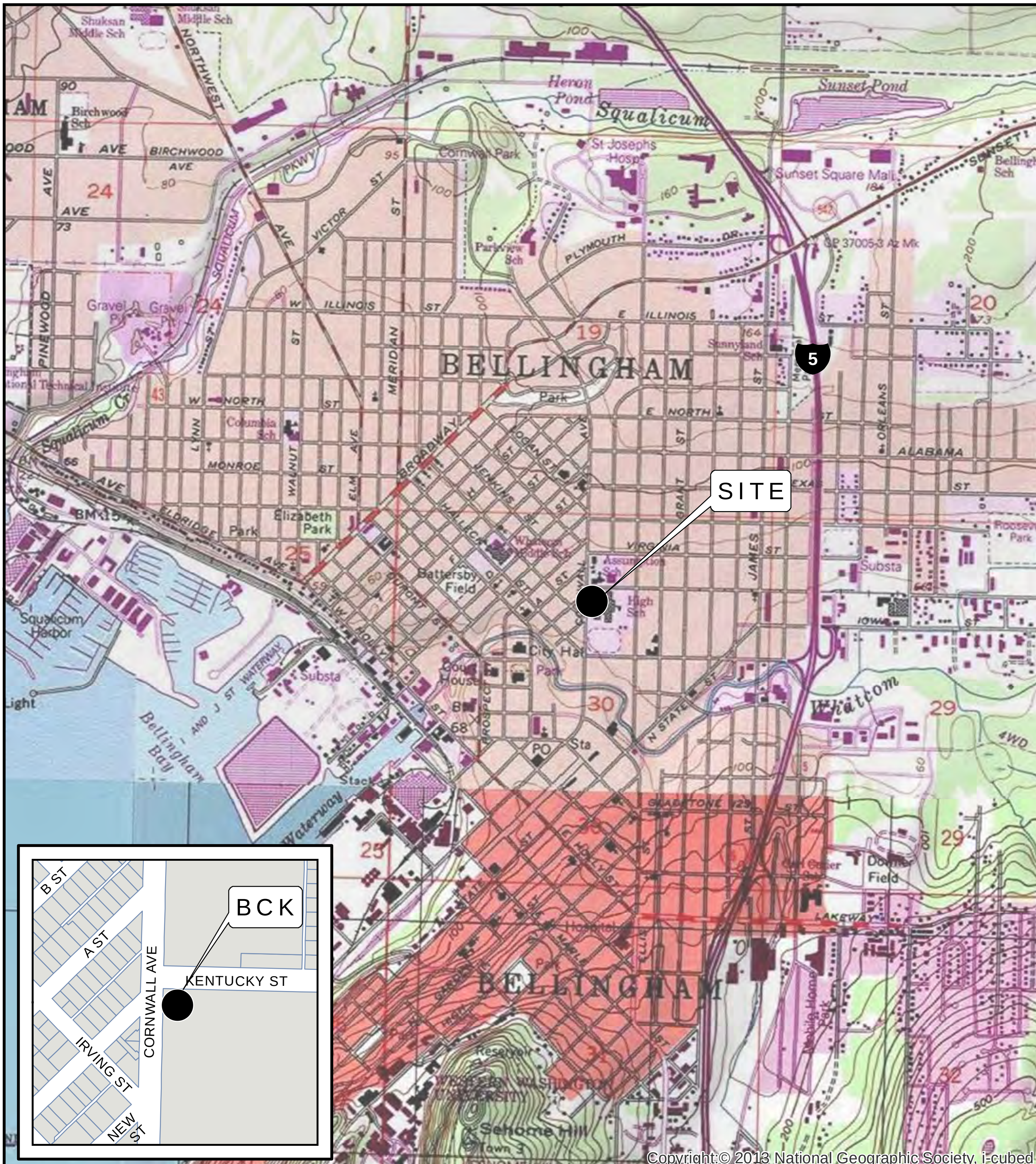
Anton D. Ypma
Staff Geologist

Suzanne S. Cook, L.G.
Senior Project Geologist

Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure BCK F1:	Vicinity Map
	Figure BCK F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

JHS/ld - 150387H007-10 - Projects\20150387\KH\WP



DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
WHATCOM CO: PARCELS, CITY - 4/17
CITY OF BELLINGHAM: STREETS, 3/17
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 1000 2000
FEET

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

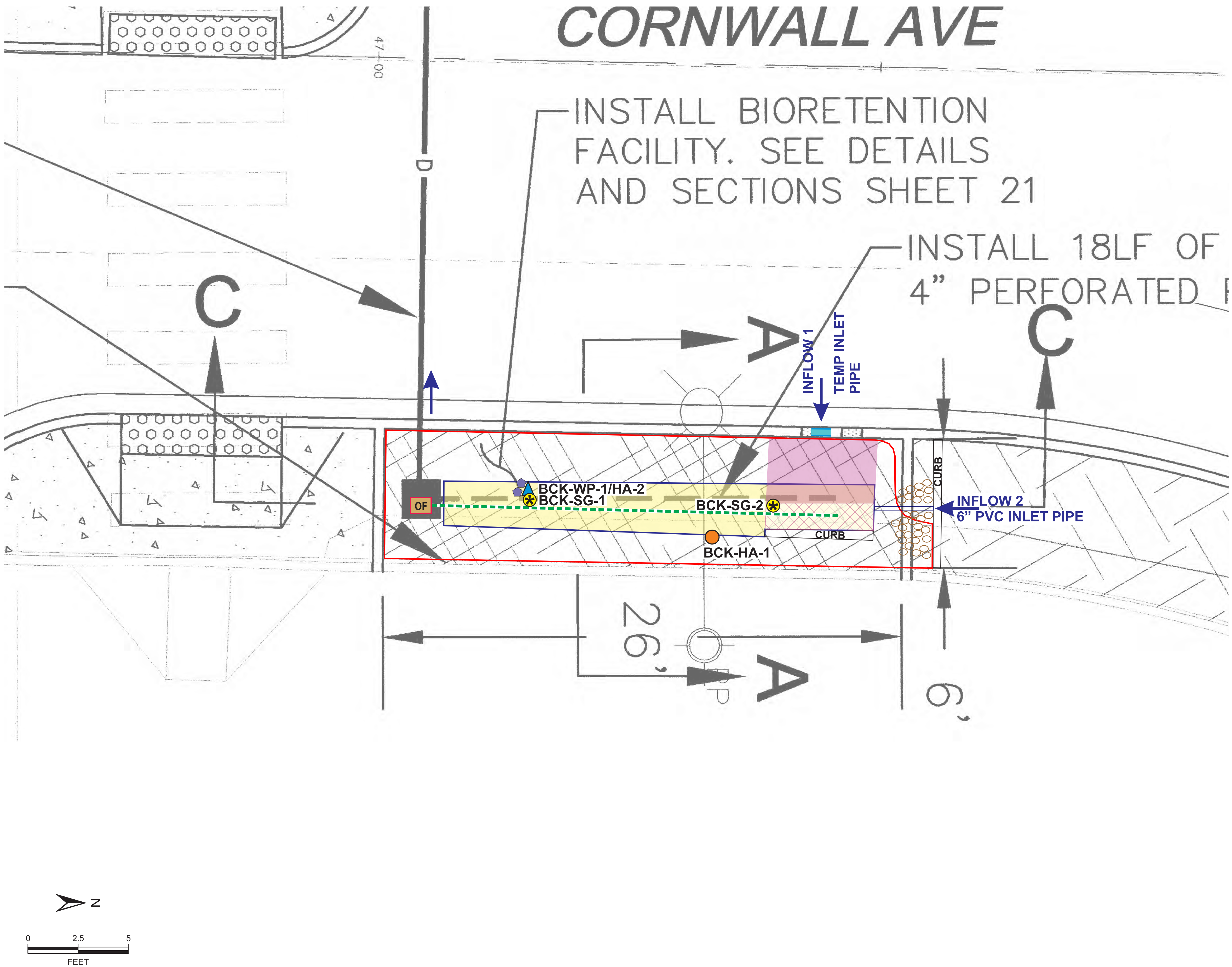
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, BCK SITE
BELLINGHAM, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BCK F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_BCK.mxd



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- CONCRETE SPLASH PAD
- COBBLES SET IN CONCRETE
- AREA OF BURIED ROCKS

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: CITY OF BELLINGHAM PUBLIC WORKS DEPT, ES-0512 NEVADA KENTUCKY BIKE BLVD, BIORETENTION FACILITIES PLAN, SHEET 21 OF 26, 5/2015

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

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN
BCK SITE
BIORETENTION HYDROLOGIC PERFORMANCE
BELLINGHAM, WASHINGTON

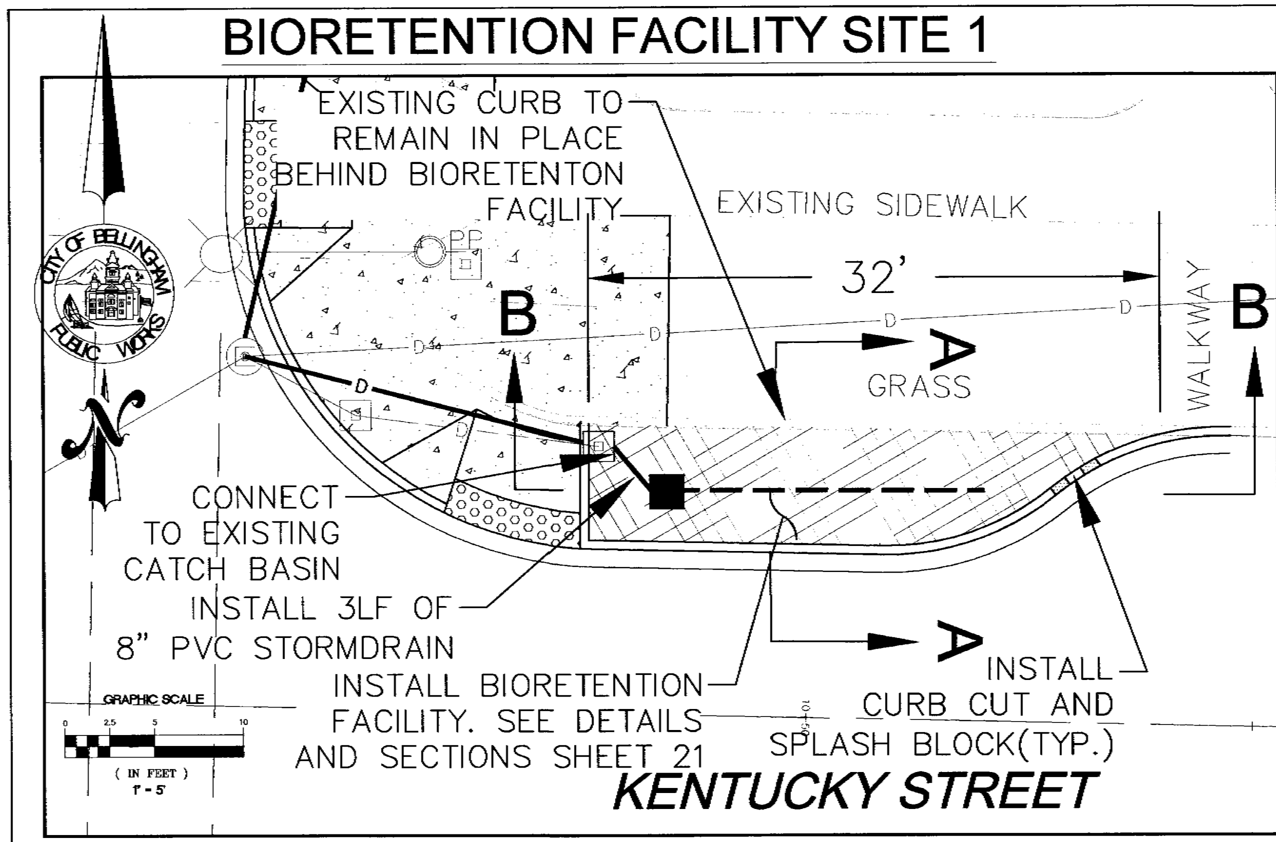
PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BCK F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: BCK F2

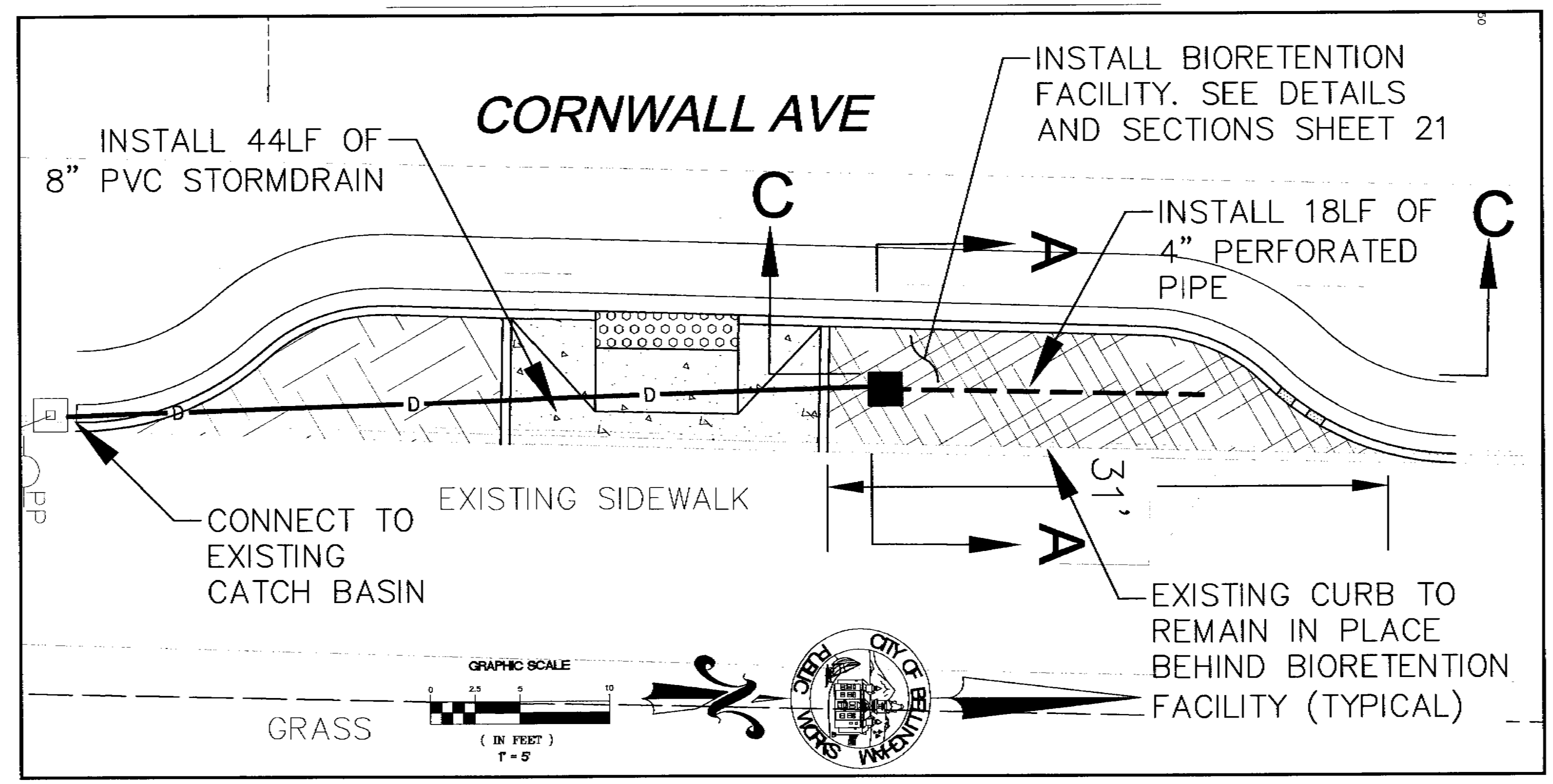
APPENDIX A

Project Civil Plans

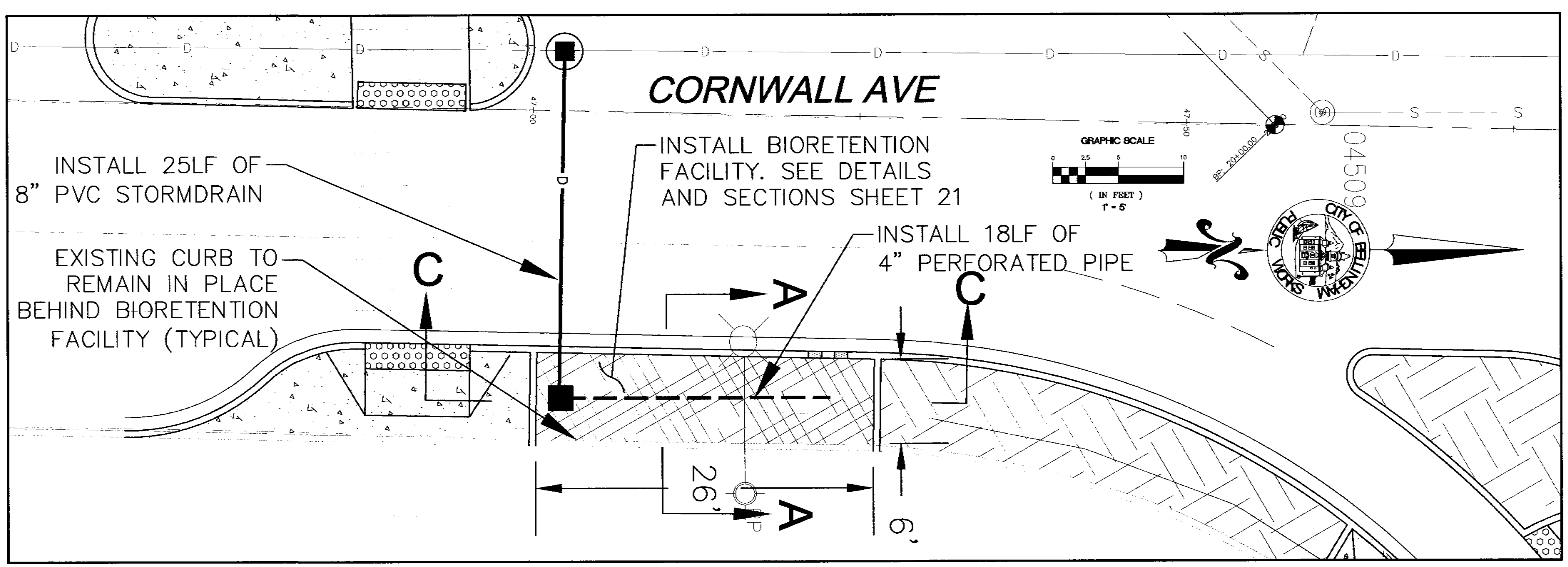
BIORETENTION FACILITY SITE 1



BIORETENTION FACILITY SITE 3



BIORETENTION FACILITY SITE 2



6 MAY 2016

Date	No	Revision	By
	4		
	3		
	2		
	1		

PROJECT ENGINEER F.A.
DESIGNED/DRAWN E.L.H.
INSPECTOR

DIRECTOR OF PUBLIC WORKS T.A.C.
CITY ENGINEER
ASSISTANT DIRECTOR E.C.J.

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION

SCALE
Horiz. 1"= 5'
Vert. 1"= N/A

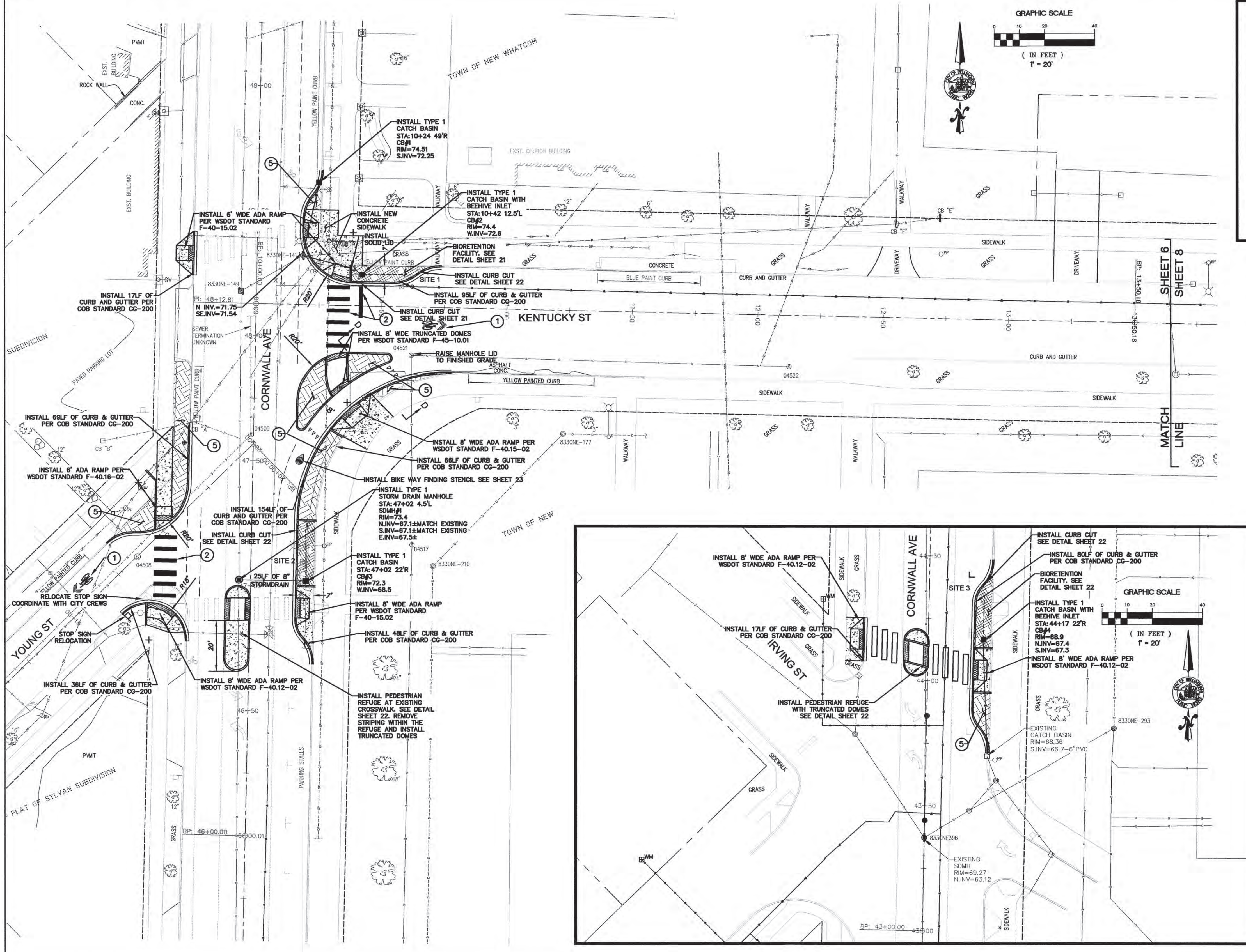
DATUM

Job. No. ES-0512
Date MAY, 2015
Field Bk. 1013-1

ES-0512 NEVADA KENTUCKY BIKE BLVD.
BIORETENTION FACILITIES PLAN

SHEET 21 OF 26

CONTACT PERSON: ______, PROJECT ENGINEER AT 778-7900



STORM SEWER TABLE			
STRUCTURE NO.	RIM ELEV. (N)	INVERT ELEV'S.	PIPE SIZE/TYPE OF PIPE(DIRECTION)
8330NE-396	69.27	63.21	15" CONC. (N)
8330NE-149	74.57	68.21 68.29 68.46	15" CONC. (S) 15" CONC. (N) 12" CONC. (NE)
1729	81.52	75.32	15" CONC. (S)
8330NE-293	72.11	65.64	12" PVC (N)
8330NE-210	74.63	67.39 67.58	12" PVC (S) 12" PVC (NE)
8330NE-177	74.27	67.92 67.74	12" PVC (SW) 12" PVC (E)
8330NE-141	74.35	70.37 71.54 71.50 72.35	12" CONC. (SW) 6" CONC. (NE) 8" PVC (SE) 3" CONC. (NE)
CB "A"	73.09	71.09 68.88±	6" CONC. (W) 8" CONC.(SE NOT VISIBLE, GATED)
CB "B"	73.17	72.17	6" CONC. (E)
CB "C"	74.06	72.04 72.15	8" PVC (NW) 8" PVC (SE)
CB "D"	73.80	72.36	8" PVC (W)
CB "E"	75.27	73.05	6" PVC (SW)
CB "F"	75.69	72.72 72.83 72.89	8" CONC. (W) 12" CPEP (N) 6" PVC (E)

* * STRUCTURES SHOWN W/ASTERISK'S HAVE STANDING WATER IN STRUCTURE

CONSTRUCTION NOTES

① INSTALL SHARED LANE MARKING SYMBOL PER CITY OF BELLINGHAM STANDARD TC-316

② INSTALL STOP BAR AND CROSSWALK PER CITY OF BELLINGHAM STANDARD TC-310

③ INSTALL BICYCLE DETECTOR SYMBOL PER CITY OF BELLINGHAM STANDARD TC-317

④ NEW STOP SIGN TO BE INSTALLED BY CITY CREWS

⑤ INSTALL MINIMUM 6" OF NATIVE SOILS, 4" MINIMUM TOP SOIL, TOP WITH SOD.

⑥ INSTALL EXTRUDED CURB WITH CURB CUTS EVERY 25' PER CITY OF BELLINGHAM STANDARD CG-212

6 MAY 2016

Date	No	Revision	By
	4		
	3		
	2		
	1		

PROJECT ENGINEER F.A.
DESIGNED/DRAWN E.L.H.
INSPECTOR

DIRECTOR OF PUBLIC WORKS T.A.C.
CITY ENGINEER
ASSISTANT DIRECTOR E.C.J.

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION

SCALE
Horiz. 1"= 20'
Vert. 1"= N/A

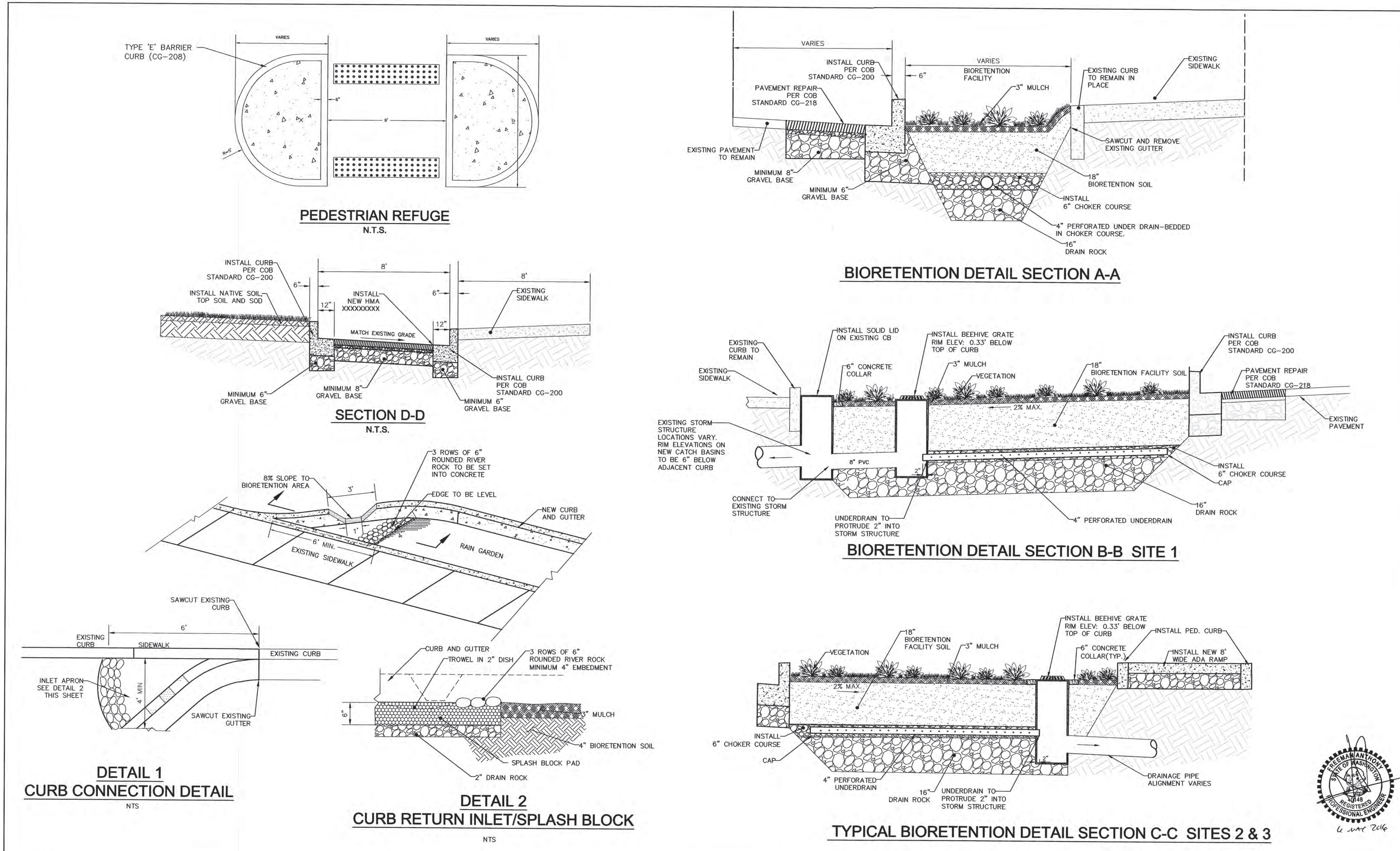
DATUM
NAVD 88
NAD 83/98

Job. No. ES-0512
Date MAY, 2015
Field Bk. 1013-1

ES-0512 NEVADA KENTUCKY BIKE BLVD.
KENTUCKY ST & CORNWALL ST. PLAN

SHEET 7 OF 26

CONTACT PERSON: FREEMAN ANTHONY P.E. , PROJECT ENGINEER AT 778-7900



No	Revision	By	Date
4			
3			
2			
1			

PROJECT ENGINEER FA
DESIGNED/DRAWN ELH
INSPECTOR XX

DIRECTOR PUBLIC WORKS T.A.C.
CITY ENGINEER R.A.R.
ASSISTANT DIRECTOR E.C.J.

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION

SCALE
Horiz. 1"= 20'
Vert. 1"= NA

DATUM

Job. No. ES-0512
Date 12-15-2015
Field Bk. 1013

ES-0512 NEVADA KENTUCKY BIKE BLVD.
BIORETENTION FACILITY AND PROJECT DETAILS

SHEET 23 OF 26

CONTACT PERSON: FREEMAN ANTHONY P.E., PROJECT ENGINEER AT 778-7900

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	BCK-HA-1	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Bellingham, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/11/18,10/11/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Fine Mulch					
				Bioretention Soil Mix					
		S-1		Loose, slightly moist, medium SAND, trace to some gravel, trace silt; organic rich; massive (SP).					
				Glaciomarine Drift					
		S-2		Stiff, slightly moist, grayish brown, very silty, fine SAND to very sandy, SILT, trace gravel; gravel interpreted as dropstones (SM-ML).					
		S-3							
				Bottom of exploration boring at 3 feet.					
5									

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	BCK-HA-2/WP	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Bellingham, WA
Elevation (Top of Well Casing): 101.2 (Project Datum)
Surface Elevation (ft): 99.1 (Project Datum)
Water Level Elevation: Dry
Date Start/Finish: 10/11/18,10/11/18
Drilling/Equipment: Hand Auger
Hole Diameter (in): 4 inches
Hammer Weight/Drop: N/A

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Threaded steel pipe 1.25 inches I.D. with threaded and vented PVC cap -2 to 1.1 feet				**Fine Mulch**
		Fine mulch 0 to 0.1 feet				**Bioretention Soil Mix** Loose, slightly moist, medium SAND, trace to some gravel, trace silt; organic rich; massive (SP).
		Bioretention soil mix 0.1 to 1.5 feet				
		Gravel fill 1.5 to 1.9 feet				**Underdrain Gravel Bedding** Loose, angular GRAVEL (0.5 to 1 inch); partially mixed with bioretention soil mix (GP).
		Driven into existing sediments 1.9 to 4.5 feet				Boring terminated at 1.9 feet Well completed at 4.5 feet on 10/11/18. Refusal due to caving. Steel drive point placed in borehole and hand-driven with slide hammer to depth of 3.6 feet.
		Stainless steel jacket cover stainless steel #60 gauze welded to perforated steel pipe 1.4 to 3.9 feet				
		Threaded steel pipe 1.25 inches I.D. and drive point 3.9 to 4.5 feet				
5		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 6.2 feet.				

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/11/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- BCK			

Moisture Content

Sample ID	HA-1 (0.1'-0.5')	HA-2 (0.1'-0.3')
Wet Weight + Pan	830.04	864.86
Dry Weight + Pan	791.49	832.48
Weight of Pan	434.52	536.76
Weight of Moisture	38.55	32.38
Dry Weight of Soil	356.97	295.72
% Moisture	9.7	9.9

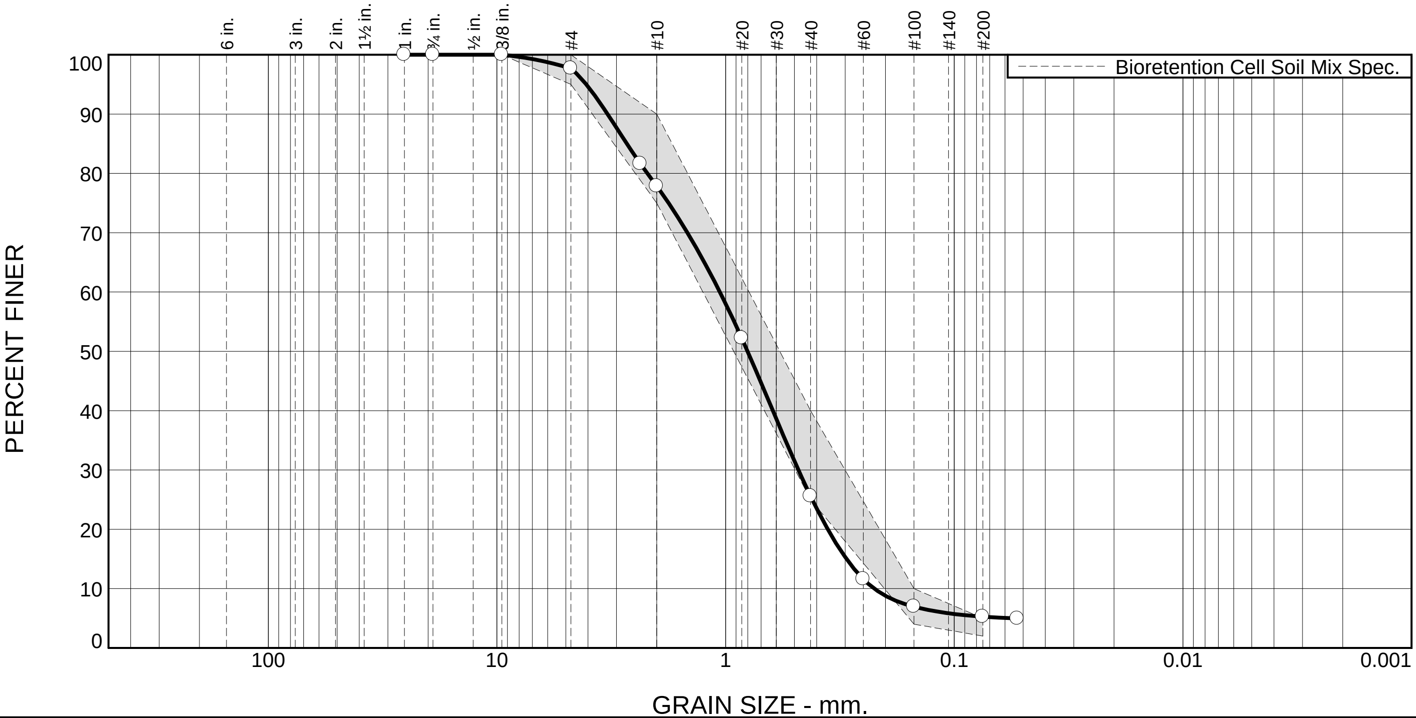
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	467.15	611.75
Dry Soil After Burn + Pan	454.26	600.50
Weight of Pan	247.04	391.90
Wt. Loss Due to Ignition	12.89	11.25
Actual Wt. Of Soil After Burr	207.22	208.60
% Organics	5.9	5.1

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.3	19.9	52.2	20.3	5.3	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1	100.0		
0.75	100.0		
.375	100.0	100.0	
#4	97.7	95.0 - 100.0	
#8	81.6		
#10	77.8	75.0 - 90.0	
#20	52.2		
#40	25.6	25.0 - 40.0	
#60	11.6		
#100	7.0	4.0 - 10.0	
#200	5.3	2.0 - 5.0	X
#270	4.9		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.2822 D_{85}= 2.7043 D_{60}= 1.0597
D_{50}= 0.8015 D_{30}= 0.4806 D_{15}= 0.2959
D_{10}= 0.2238 C_u= 4.73 C_c= 0.97

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

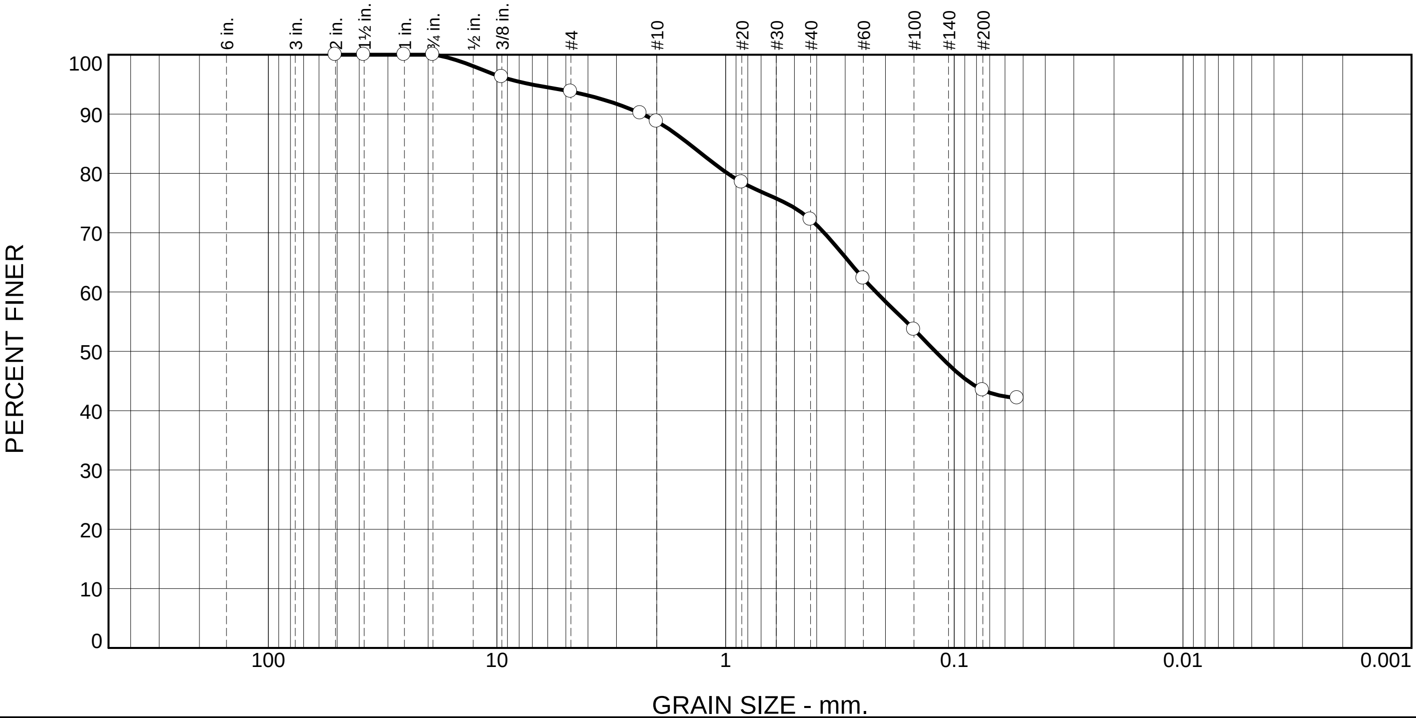
Date Received: 10/16/2018 **Date Tested:** 10/18/2018
Tested By: MS
Checked By: JHS
Title:

Source of Sample: (BCK) Bellingham- Cornwall and Kentucky **Depth:** 0.1'-0.5' **Date Sampled:** 10/11/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	6.2	5.0	16.6	28.7	43.5	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	96.3		
#4	93.8		
#8	90.1		
#10	88.8		
#20	78.5		
#40	72.2		
#60	62.3		
#100	53.7		
#200	43.5		
#270	42.1		

* (no specification provided)

Material Description

Very silty SAND, some gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 2.3179 D_{85}= 1.4481 D_{60}= 0.2200
D_{50}= 0.1211 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 10/16/2018 **Date Tested:** 11/12/2018

Tested By: BN

Checked By: JHS

Title:

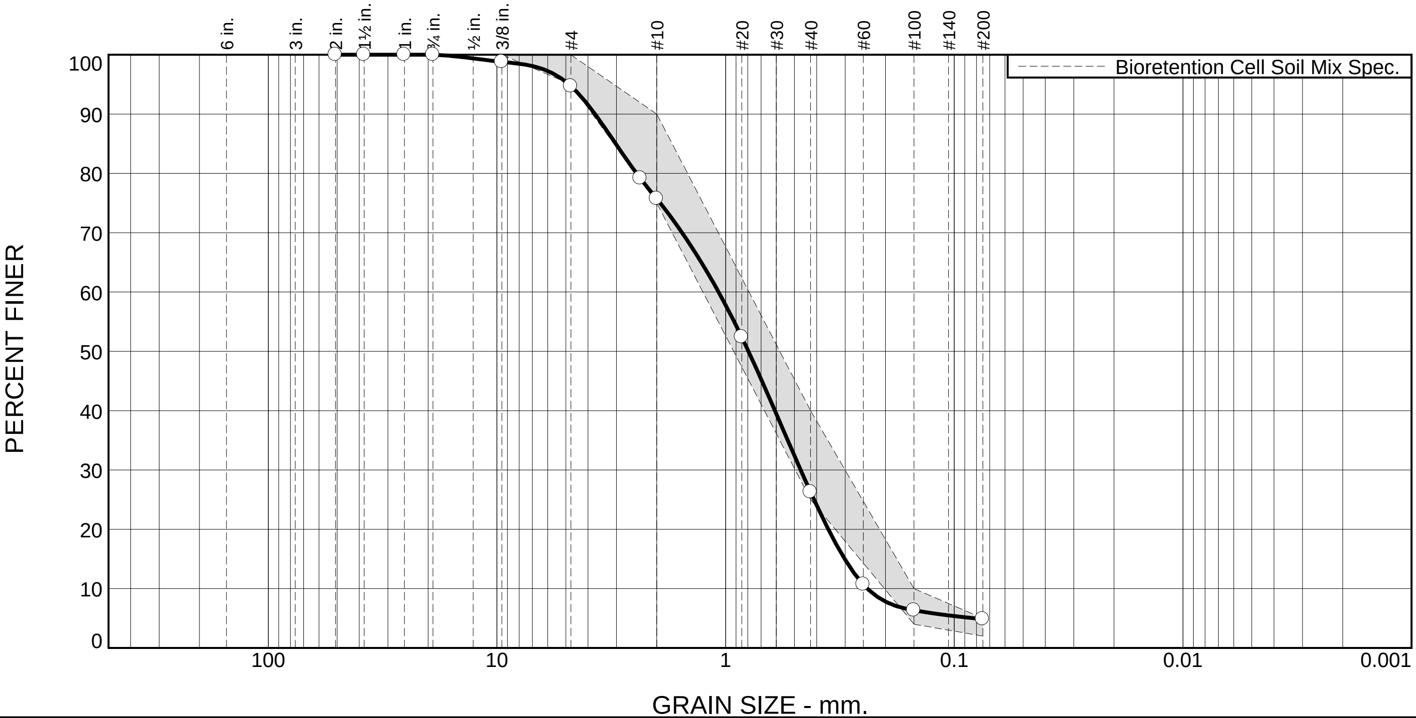
Source of Sample: (BCK) Bellingham- Cornwall and Kentucky **Depth:** 2.5'-3' **Date Sampled:** 10/11/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.3	19.0	49.4	21.4	4.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	98.8	100.0	X
#4	94.7	95.0 - 100.0	X
#8	79.2		
#10	75.7	75.0 - 90.0	
#20	52.4		
#40	26.3	25.0 - 40.0	
#60	10.7		
#100	6.4	4.0 - 10.0	
#200	4.9	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some gravel, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.7253 D_{85}= 3.0237 D_{60}= 1.0736
D_{50}= 0.7941 D_{30}= 0.4697 D_{15}= 0.3015
D_{10}= 0.2402 C_u= 4.47 C_c= 0.86

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/16/2018 **Date Tested:** 11/12/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (BCK) Bellingham- Cornwall and Kentucky **Depth:** 0.1'-0.3' **Date Sampled:** 10/11/2018
Sample Number: HA-2

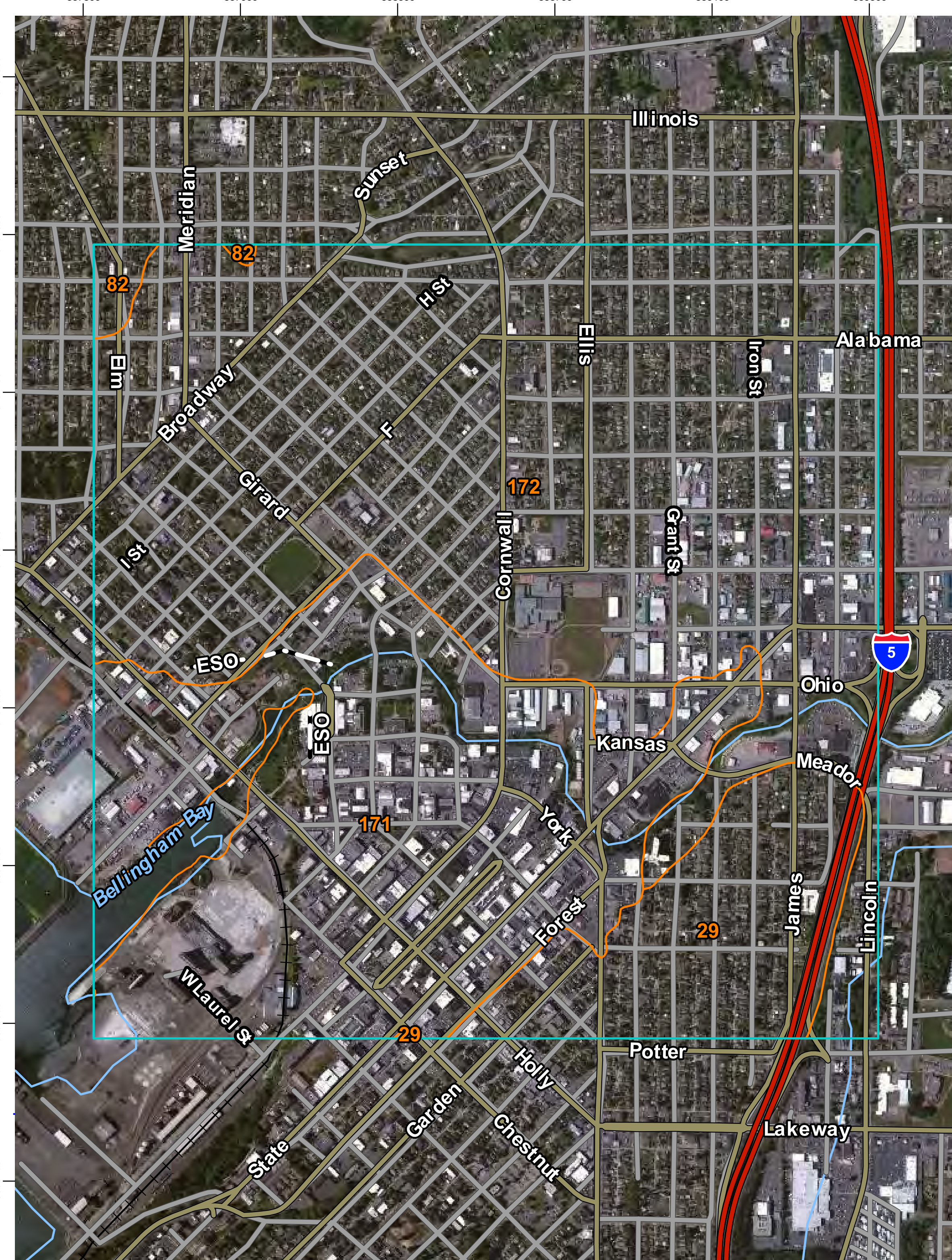
associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Map Scale: 1:15,500 if printed on A portrait (8.5" x 11") sheet.

N

Meters: 0, 200, 400, 800, 1200

Feet: 0, 500, 1000, 2000, 3000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features

- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Whatcom County Area, Washington
Survey Area Data: Version 18, Sep 10, 2018

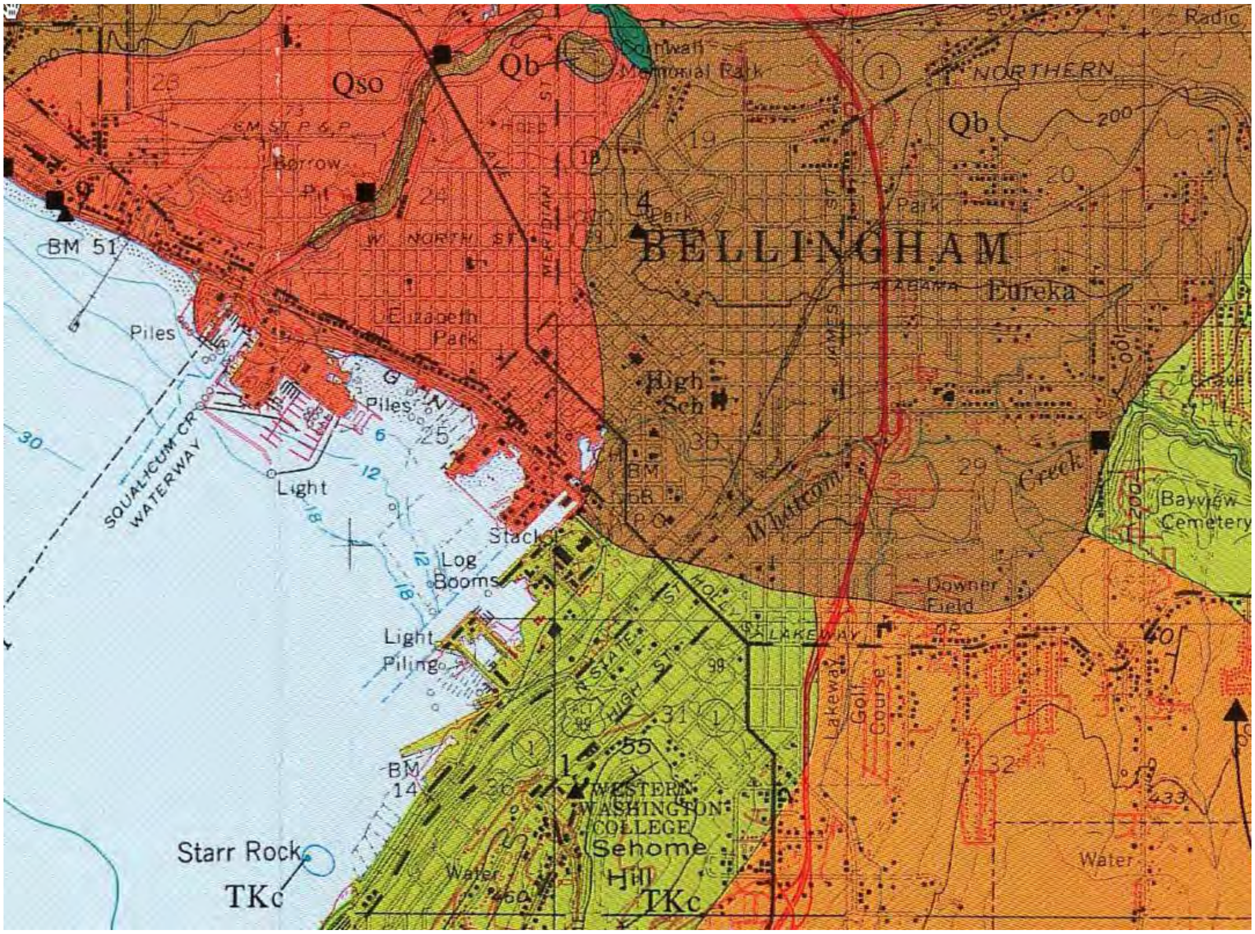
Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jul 9, 2010—Aug 28, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
29	Chuckanut-Urban land complex, 5 to 20 percent slopes	98.4	9.9%
82	Kickerville-Urban land complex, 0 to 3 percent slopes	7.2	0.7%
171	Urban land	314.2	31.5%
172	Urban land-Whatcom-Labounty complex, 0 to 8 percent slopes	560.1	56.2%
Totals for Area of Interest		**996.9**	**100.0%**



Excerpt from:

Easterbrook, D.J., 1976, Geologic map of western Whatcom County, Washington: U.S. Geological Survey, Miscellaneous Investigations Series Map I-854-B, scale 1:62,500

Appendix A: Site Plan with Test Locations

Source: City of Bellingham Public Works-Engineering
Overlay by MTC: KWP
Not to Scale – Shown is approximate
Not for Construction

Materials Testing & Consulting 777 Chrysler Drive Burlington, WA 98233	**Site Map and Test Locations** Cornwall Avenue Infiltration Sampling Cornwall Avenue & Kentucky Street Bellingham, WA	**FIGURE** **1**

Appendix B: Exploration Logs

Unified Soil Classification System Chart

Major Divisions			Graph	USCS	Typical Description
Coarse Grained Soils More Than 50% Retained On No. 200 Sieve	**Gravel** More Than 50% of Coarse Fraction Retained On No. 4 Sieve	Clean Gravels		GW	Well-graded Gravels, Gravel-Sand Mixtures
				GP	Poorly-Graded Gravels, Gravel-Sand Mixtures
		Gravels With Fines		GM	Silty Gravels, Gravel-Sand-Silt Mixtures
				GC	Clayey Gravels, Gravel-Sand-Clay Mixtures
	Sand More Than 50% of Coarse Fraction Passing No. 4 Sieve	Clean Sands		SW	Well-graded Sands, Gravelly Sands
				SP	Poorly-Graded Sands, Gravelly Sands
		Sands With Fines		SM	Silty Sands, Sand-Silt Mixtures
				SC	Clayey Sands, Clay Mixtures
Fine Grained Soils More Than 50% Passing The No. 200 Sieve	**Silts & Clays**	Liquid Limit Less Than 50		ML	Inorganic Silts, rock Flour, Clayey Silts With Low Plasticity
				CL	Inorganic Clays of Low To Medium Plasticity
				OL	Organic Silts and Organic Silty Clays of Low Plasticity
	Silts & Clays	Liquid Limit Greater Than 50		MH	Inorganic Silts of Moderate Plasticity
				CH	Inorganic Clays of High Plasticity
				OH	Organic Clays And Silts of Medium to High Plasticity
Highly Organic Soils				PT	Peat, Humus, Soils with Predominantly Organic Content

Sampler Symbol Description

- Standard Penetration Test (SPT)
- Shelby Tube
- Grab or Bulk
- California (3.0" O.D.)
- Modified California (2.5" O.D.)

Stratigraphic Contact

- Distinct Stratigraphic Contact Between Soil Strata
- Gradual Change Between Soil Strata
- Approximate location of stratagraphic change

- Groundwater observed at time of exploration
- Measured groundwater level in exploration, well, or piezometer
- Perched water observed at time of exploration

Modifiers

Description	%
Trace	>5
Some	5-12
With	>12

Soil Consistency

Granular Soils		Fine-grained Soils	
Density	***SPT Blowcount***	***Consistency***	***SPT Blowcount***
Very Loose	0-4	Very Soft	0-2
Loose	4-10	Soft	2-4
Medium Dense	10-30	Firm	4-8
Dense	30-50	Stiff	8-15
Very Dense	> 50	Very Stiff	15-30
		Hard	> 30

Grain Size

DESCRIPTION		SIEVE SIZE	GRAIN SIZE	APPROXIMATE SIZE
Boulders		> 12"	> 12"	Larger than a basketball
Cobbles		3 - 12"	3 - 12"	Fist to basketball
Gravel	Coarse	3/4 - 3"	3/4 - 3"	Thumb to fist
	Fine	#4 - 3/4"	0.19 - 0.75"	Pea to thumb
Sand	Coarse	#10 - #4	0.079 - 0.19"	Rock salt to pea
	Medium	#40 - #10	0.017 - 0.079"	Sugar to rock salt
	Fine	#200 - #40	0.0029 - 0.017"	Flour to Sugar
Fines		Passing #200	< 0.0029"	Flour and smaller

Materials Testing & Consulting, Inc. 777 Chrysler Drive Burlington, WA 98233	**Exploration Log Key** Cornwall Avenue Infiltration Sampling Cornwall Avenue & Kentucky Street Bellingham, WA	**FIGURE** **2**

Materials Testing and Consulting 805 Dupont St, Suite 5 Bellingham, WA	Boring Log HA-1 (Page 1 of 1)
Cornwall Avenue Infiltration Cornwall Ave & Kentucky St City of Bellingham, WA-Public Works MTC Job #: 16W027-01	Date Started : 4/28/2016 Date Completed : 4/28/2016 Sampling Method : Grab Sample Location : Kentucky St: 2.4' S of curb, 7.3' E of sidewalk Logged By : KWP

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	Samples	Water Level	Percent Moisture	% Finer #200 Sieve
0	AC		ASPHALT PAVEMENT: Top Course 0.17', Base Course 0.21'.				
	CP		CONCRETE PAVEMENT				
1	ML		SANDY SILT, some clay, soft to firm, damp, trace organics (roots), some orange mottling at base of concrete. GRAY BROWN **WEATHERED BELLINGHAM DRIFT** Mottling absent after 1.5' BPG				
2	ML		SILTY CLAY, some sand, stiff to hard with depth, damp. GRAY **BELLINGHAM DRIFT** Trace gravel, 1/2", subround.	X			
			Trace gravel, 1/2", subround.				
3				X		28.3	97.3
			Terminated at planned depth. TD: 3.4' No groundwater encountered during excavations.				
4							
5							

05-09-2016 Z:\Burlington Office\Geotechnical Services\2 Bham\2016 Projects\Cornwall Infiltration CoB\HA logs\HA-1.bor

Materials Testing and Consulting 805 Dupont St, Suite 5 Bellingham, WA	Boring Log HA-2 (Page 1 of 1)
Cornwall Avenue Infiltration Cornwall Ave & Kentucky St City of Bellingham, WA-Public Works MTC Job #: 16W027-01	Date Started : 4/28/2016 Date Completed : 4/28/2016 Sampling Method : Grab Sample Location : Cornwall Ave N: 3' W of curb, 12' N of crosswalk Logged By : KWP

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	Samples	Water Level	Percent Moisture	% Finer #200 Sieve
0	AC		ASPHALT PAVEMENT: Top Course 0.2', Base Course 0.06'.				
	CP		CONCRETE PAVEMENT				
1	GW-GM		GRAVEL with sand, some silt, medium-dense, damp to wet, trace to some organics (roots), gravel to 1/2" subround. BROWN **STRUCTURAL FILL-PIT RUN**				
			Trace to some cobbles to 4", round to subround, continue to TD.				
2				X			
3				X		5.6	5.1
			Terminated at planned depth. TD: 3.2' No groundwater encountered during excavations.				
4							
5							

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Materials Testing and Consulting 805 Dupont St, Suite 5 Bellingham, WA	Boring Log HA-3 (Page 1 of 1)
Cornwall Avenue Infiltration Cornwall Ave & Kentucky St City of Bellingham, WA-Public Works MTC Job #: 16W027-01	Date Started : 4/28/2016 Date Completed : 4/28/2016 Sampling Method : Grab Sample Location : Cornwall Ave S: 2.9' W of curb, 4.4' S of storm drain Logged By : KWP

Depth in Feet	USCS	GRAPHIC	DESCRIPTION	Samples	Water Level	Percent Moisture	% Finer #200 Sieve
0	AC		ASPHALT PAVEMENT				
	CP		CONCRETE PAVEMENT				
1–2	CL-ML		SILTY CLAY, firm, damp, trace organics (roots), some orange mottling. BROWN **WEATHERED BELLINGHAM DRIFT** Orange mottling increase to moderate. Density increase to stiff-very stiff.	X (at 2)			
3	CL-ML		SILTY CLAY, some sand, trace gravel, very stiff, damp, lacks mottling, gravel to 1/2", subround. GRAY **BELLINGHAM DRIFT**	X		27.2	85.9
4–5			Terminated at planned depth. TD: 3.4' No groundwater encountered during excavations.				

05-09-2016 Z:\Burlington Office\Geotechnical Services\2 Bham\2016 Projects\Cornwall Infiltration CoB\HA logs\HA-3.bor

APPENDIX D

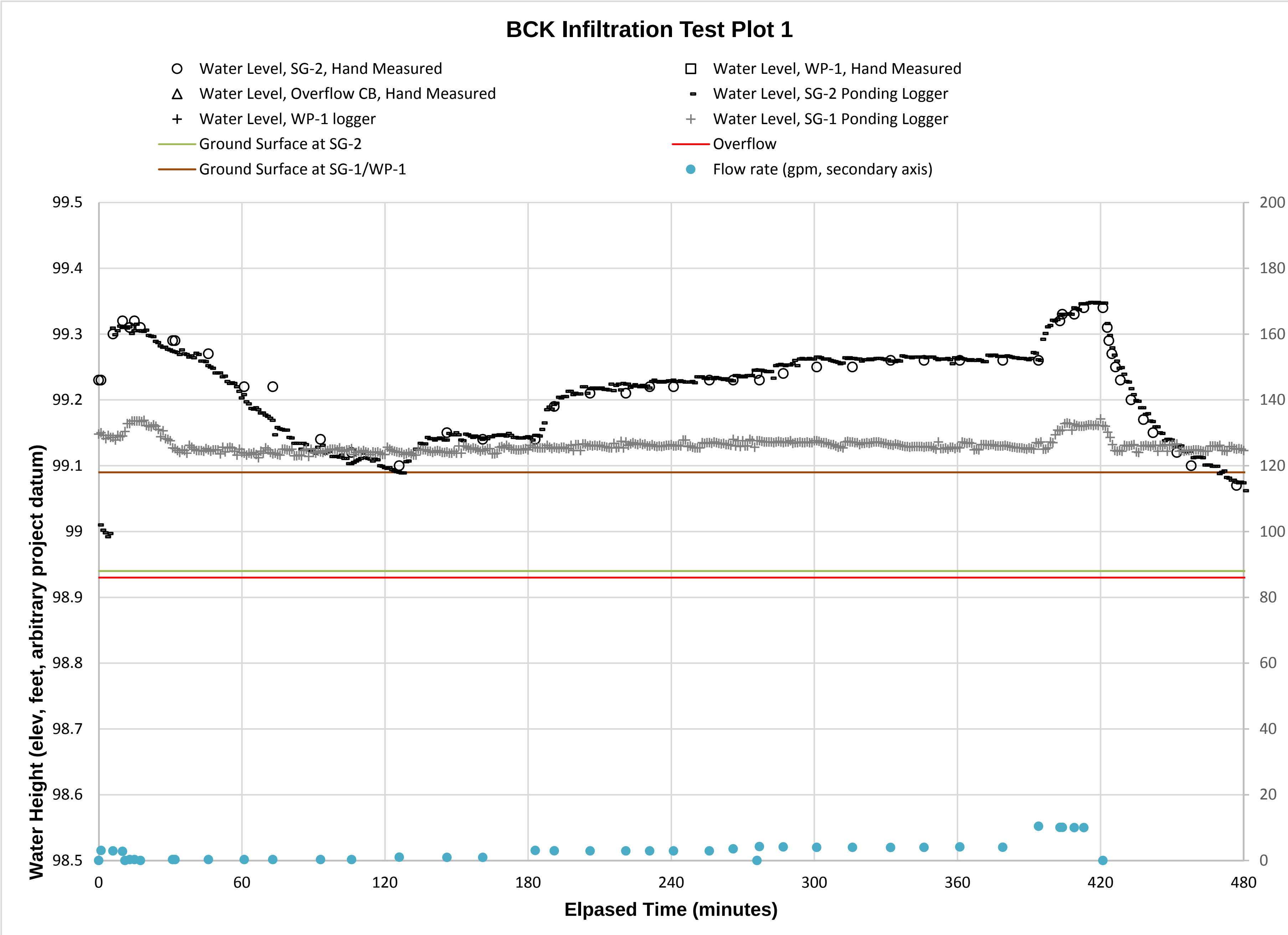
Soil Probe, Level Survey, and Field Infiltration Testing Data

Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM8,9
Date:	11/14/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	60.0
Test No.:	BCK	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Glaciomarine Drift/Fill

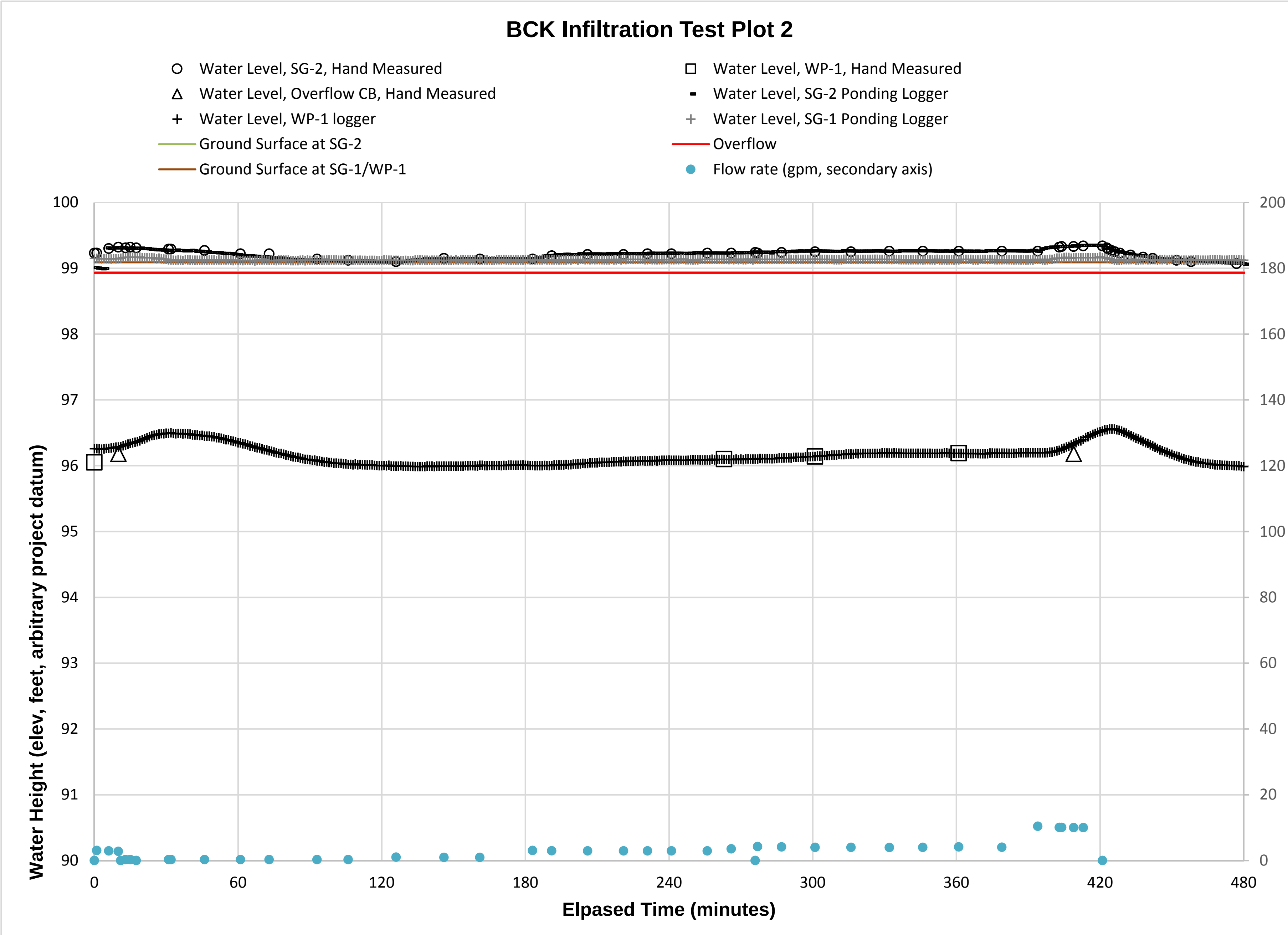
Time (24-hr)	Flow Rate (gpm)	SG-2 Stage (feet)	Totalizer (gallons)	Comments
8:29	0	0.29	0	Flow on, FM9. Raining.
8:30	3.07	0.29	0	
8:35	2.92	0.36	18.59	
8:39	2.78	0.38	29.29	
8:40	0		33.39	Flow off FM9
8:42	0.3	0.37	33.39	Flow on FM8
8:44	0.3	0.38	34.79	
8:46	0	0.37	35.45	Water entering overflow grate. Flow off.
9:00	0.3	0.35	35.45	No flow observed in underdrain. Discahrge to overflow grate stopped. Flow resumed.
9:01	0.3	0.35	35.86	
9:15	0.3	0.33	40.11	
9:30	0.3	0.28	44.6	
9:42	0.3	0.28	48.49	Flow off.
10:02	0.3	0.2	54.39	Rain stops.
10:15	0.3	0.18	58.05	No flow observed in underdrain.
10:35	1	0.16	63.94	
10:55	0.96	0.21	82.03	
11:10	0.94	0.2	96.87	
11:32	3.06	0.2	117.23	
11:40	2.94	0.25	139.13	Wetted area approx. 2.5ft x 7ft.
11:55	2.92	0.27	183.33	
12:10	2.92	0.27	227.65	
12:20	2.92	0.28	256.97	
12:30	2.93	0.28	285.62	
12:45	2.92	0.29	330.23	No rain. No underdrain flow observed.
12:52				
12:55	3.55	0.29	359	
13:05	0	0.3	393	
13:06	4.24	0.29	43	
13:16	4.13	0.3	57	
13:30	4	0.31	113	
13:45	3.98	0.31	172	
14:01	3.96	0.32	236	
14:15	3.98	0.32	292	
14:30	4.12	0.32	353	No rain. No underdrain flow observed.
14:48	4.04	0.32	425	
15:03	10.43	0.32	492	Flow rate increased.
15:12	10.05	0.38	577	Flow approaching overflow grate.

15:13	10.05	0.39		Flow entering overflow grate. No nunderdrain flow observed. No rain.
15:18	10	0.39	637	
15:22	10	0.4	384.91	
15:30	0	0.4	757.16	Flow off
15:31		0.37		
15:32		0.35		
15:33		0.33		
15:35		0.31		
15:37		0.29		
15:41		0.26		
15:47		0.23		
15:51		0.21		Observed slow inflow from backed-up water in northern inlet pipe.
16:01		0.18		
16:07		0.16		
16:26		0.13		
16:30		0.12		

	Average Infiltration Rate (in/hr) during last hour of inflow:	6.6
	Average Infiltration Rate (in/hr) during falling head:	3.4



BCK Infiltration Test Plot 1
Water Level, SG-2, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, SG-2 Ponding Logger
Water Level, WP-1 logger
Water Level, SG-1 Ponding Logger
Ground Surface at SG-2
Overflow
Ground Surface at SG-1/WP-1
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
99.5
99.4
99.3
99.2
99.1
99
98.9
98.8
98.7
98.6
98.5
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elapsed Time (minutes)



BCK Infiltration Test Plot 2
Water Level, SG-2, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, SG-2 Ponding Logger
Water Level, WP-1 logger
Water Level, SG-1 Ponding Logger
Ground Surface at SG-2
Overflow
Ground Surface at SG-1/WP-1
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
Elpased Time (minutes)
100
99
98
97
96
95
94
93
92
91
90
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480

APPENDIX E

Site Photos

Cell BCK overview, overflow in lower center of photo

Cell BCK overview, curbcut inlet shown

Cell BCK, curb cut inlet and undocumented inlet (green pipe). Above photo is prior to install of weir. Lower photo is after weir install and during infiltration testing.

APPENDIX 4

Deliverable Task 4.5, Site BUW, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Utter Street and Washington Street, Bellingham, Washington. Associated Earth Sciences, Inc. 6/11/2019

Technical Memorandum

Date:	June 11, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site BUW, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Utter Street and Washington Street, Bellingham, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Facility Cell #5 of the Colombia Water Quality Improvements Project, located in the city of Bellingham, Washington (Figure BUW F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 11, 2018, infiltration testing on November 15, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure BUW F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Colombia Water Quality Improvements Project, located in the city of Bellingham, Washington as shown on the attached "Vicinity Map" (Figure BUW F1). The project site is located along the right-of-way of several streets in the City of Bellingham including Utter Street and Washington Street.

Our specific area of study for this project includes bioretention cell #5 located on the southeast of the intersection of Utter Street and Washington Street referred to as cell BUW for this study. The BUW site is bordered by Washington Street on the west, Utter Street to the south, and sidewalk and single-family residences to the north and east. Site topography is generally level, sloping gently downhill to the south. No on-site surface water features are present. As described in the Drainage Report (Columbia Neighborhood Water Quality Improvements, November 10, 2016) the site drains to Bellingham Bay.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Columbia Neighborhood Water Quality Improvement Project, Preliminary Geotechnical Conditions Assessment," Bellingham, Washington, Element Solutions, October 26, 2016.
- "Columbia Neighborhood Water Quality Improvements,", Pacific Surveying and Engineering, November 10, 2016.
- "Columbia Neighborhood Water Quality Improvements Project (EV-0120)," Memorandum, Pacific Surveying and Engineering, July 28, 2017.
- "Columbia Water Quality Improvements,", Pacific Surveying and Engineering, October 30, 2017.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell BUW consists of an approximately rectangular-shaped bioretention cell with approximately 211 square feet of base area, as shown on Figure BUW F2, "Facility and Exploration Plan." We understand that the site was developed under the Washington State Department of Ecology (Ecology) 2014 *Stormwater Management Manual for Western Washington* (2014 Ecology Manual) for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 6 inches per hour (in/hr) in the bioretention soil. It was unclear whether an infiltration rate was applied to the native subgrade. The facility has an underdrain as part of the design. Land use within the drainage basin is primarily lawn and roadway. Per Sheet C22, "Bioretention Cell Details, Columbia Water Quality Improvements," Pacific Surveying and Engineering, October 30, 2017, the facility design includes 3 inches of mulch and 18 inches of bioretention soil mix overlying a 6-inch "choker course," overlying 18 inches of mineral aggregate for bioretention cells. The facility contains a 4-inch-diameter perforated underdrain pipe bedded in the mineral aggregate. The underdrain discharges to a catch basin, which also features a beehive grate with a rim 0.3 feet above the level of the base of the facility. The catch basin discharges to the City storm drain system. The upstream end of the perforated underdrain pipe terminates in another catch basin within the bioretention cell.

The facility is designed to discharge 98.22 percent of inflow through the underdrain. Stormwater enters the facility through two curbcuts along the eastern side of Utter Street. Only one curbcut, on the northern end of the cell, is depicted on plan sheet C16 (Pacific Surveying and Engineering, October 30, 2016). If water ponds up on the bioretention soil, the ponded water would discharge into the beehive grate located near the south end of the cell, and then into the City storm drain system. The rim of the Type I Catch Basin was designed to be 0.3 feet higher than the cell base to create 0.3 feet of ponding depth. The facility was constructed and began receiving runoff after July 2017, based on review of historic aerial imagery.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure BUW F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the east rim of the storm manhole cover on Utter Street, near the bioretention cell (identified on the "BUW Level Survey Data" map in Appendix D) defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: Two curbcuts are present along the west side of the cell:
    - Primary: The primary inflow (Inlet 1) to the facility is a 1-foot curbcut, consistent with project plans, which discharges onto a rounded rock energy dissipation pad approximately 3 feet wide and 3 feet long. A small amount of water was discharging during the brief period of rain at the time of our November 15, 2018 site visit.

    - Undocumented inflow: A second inflow (Inlet 2) to the facility is a 1-foot curbcut entering near the southern end of the facility near the overflow beehive grate. This inlet has an approximately 4-foot-wide by 3-foot-long energy dissipater pad, and the inlet and pad are not shown on project plan sheets. A small amount of water was discharging during the brief period of rain at the time of our November 15, 2018 site visit.

- Overflow: The overflow consists of a22-inch by 25-inch concrete catch basin with a beehive grate (SDCB#29A). The rim of this grate is 0.5 inches to 2.5 inches above the base of the facility, lower than the 0.3 feet specified on the plan sheets. During our November 15, 2018 site visit, while discharging water to the curb of the street uphill (north) of the northern inlet, we observed a portion of the water flowing through the southern inlet and directly into the overflow beehive grate, as discussed under "Infiltration Testing."

- AESI investigated the loose bioretention soil thickness present in cell BUW using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in an approximately 3-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.2 to 1.7 feet and averaged 1.5 feet. Probe penetration data is included in Appendix D to this document.

- AESI observed that the facility base generally slopes down to the south, such that the overflow rim elevation (99.14-foot low point) is below the level of the cell base on the northern, uphill, end.

Table 1
Summary of Cell BUW
Level Survey Data

Location	Elevation (feet, project datum)
Inlet #2 (S), curb top (S)	99.69
Inlet #2 (S), curb top (N)	99.85
Inlet #2 (S) curbcut S/low, inside lip	99.30
Overflow outer rim, SW corner/low	99.14
Overflow inside rim @ notch (W)	99.01
Inlet #2 (S) green pipe top/end	99.80
Inlet #1 (N) curb top (S)	100.17
Inlet #1 (N) curbcut center/low, inside lip	99.64
Inlet #1 (N) curb top (N)	100.10
Inlet #1 (N) green pipe top/end	100.22
WP-1 TOC	101.30
Ponding Tube TOC (Baro)	100.78
Ponding Tube TOC (DL)	100.04

WP: well point; TOC: top of casing; DL: datalogger

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under “Project and Site Description.”
- Easterbrook, D.J., 1976, *Geologic Map of Western Whatcom County, Washington*: U.S. Geological Survey (USGS), Miscellaneous Investigations Series Map I-854-B, scale 1:62,500, Natural Resource Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed January 2019.

- *Soil Survey of Whatcom County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington State Department of Natural Resources (DNR) and Washington State University Agricultural Research Center, 1992.
- Newcomb, R.C. et al., *Ground-water Resources of Western Whatcom County, Washington*, U.S. Geological Survey (USGS) Open File Report 50-7, 1950.

5.1 Regional Topography and Project Grading

The project site is situated on a generally level terrace in the Bellingham Basin, near Bellingham Bay. Squalicum Creek and Whatcom Creek, modern streams, have incised the terrain approximately 2,500 feet northwest and 3,000 feet southeast of the site by up to about 50 feet. The streams both discharge into Bellingham Bay. Elevations on the larger project site range from about 70 to 80 feet.

On a closer scale, the area near cell BUW is relatively level, situated at about elevation 75 feet. The site is located about 1,500 feet northeast from the coastline of Bellingham Bay. Sidewalk and road areas surround the cell on the south, east, and west. Grass is present on the short northern edge. A curb separates the paved surfaces from the cell.

The project site was previously developed with the construction of Utter and Washington streets, and single-family residences in the area. Various utilities are present in the vicinity of the site, including a buried water main which runs underneath the cell on the Utter Street (west) side. Native grade is unknown, however minor cutting (about 3 feet) into the previously constructed sidewalk and lawn area would have been required during construction, and previous construction of utilities and development in the area would have required previous cutting and filling to place the utilities present under the site.

5.2 Regional Geology and Background Geotechnical Information

According to D.J. Easterbrook, 1976, *Geologic Map of Western Whatcom County, Washington*: U.S. Geological Survey, Miscellaneous Investigations Series Map I-854-B, scale 1:62,500, the site vicinity is underlain by outwash sand and gravel (Sumas Stade). As described on the geologic map, these consist of sands and gravels. Bellingham Drift (Everson Interstade) is present in the vicinity. As described on the geologic map, this consists of blue-gray, unsorted, pebbly sandy silt and pebbly clay, with glaciomarine drift mantling upland areas. This is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- <u>Bellingham Drift (Everson Interstade, Qb)</u>: Blue-gray, unsorted, unstratified, pebbly, sandy silt and pebbly clay. Derived from rock debris melted out of floating ice and deposited on sea floor. Locally contains mollusks and wood, radiocarbon dated between 11,000 and 12,000 years B.P., Glaciomarine Drift mantles upland areas between flood plains below elevations of 600 feet.

- Outwash sand and gravel (Sumas Stade): Former outwash plain underlain by cobble and boulder gravel near Canadian border, grading southwestward to sand near Lynden. Sandy gravel between Everson and Laurel, grading to sand westward.

Background geotechnical information includes boring B2 (Element Solutions, 2016) within 20 feet of cell BUW dated January 17, 2016, which reached depths of about 16.5 feet below current grades. The explorations described in the geotechnical report (Element Solutions, 2016) identified fill (asphalt and concrete) overlying a sequence of sand, silt, and clay layers in the vicinity of the BUW site. Static groundwater was encountered at approximately 5 feet at the time of exploration. Element Solutions did not make geologic unit interpretations.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the *Soil Survey of Whatcom County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington State Department of Natural Resources (DNR) and Washington State University Agricultural Research Center, 1992. The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of urban land - Whatcom-Labounty complex. Urban land is land that has been heavily modified by development. Whatcom and Labounty soils form over glaciomarine drift.

As described in the Pacific Surveying and Engineering, "Columbia Neighborhood Water Quality Improvements," Design Report, November 10, 2016, the pre-developed condition was modeled as type C soils and impervious surfaces, consistent with mapped soil and background geotechnical data.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in *Groundwater Resources of Western Whatcom County, Washington* (R.C. Newcomb et al., 1950). Newcomb et al. (1950) indicates that glacial outwash can be an aquifer where saturated, and that perched groundwater conditions can occur locally within these units, particularly over till, silts, and clays such as those comprising glaciomarine drift.

On a closer scale, as described in the Drainage Report (Pacific Surveying and Engineering, 2016), the site discharges ultimately to Bellingham Bay. Limited background groundwater level data was collected in boreholes near the BUW site; however, perched groundwater was encountered at approximately 5 feet below ground surface in both borings accomplished within "Zone A" which the BUW site is situated within. One of these exploration borings was located within approximately

20 feet of the location of cell BUW. Groundwater is expected to perch at this shallower depth under the developed conditions due to stormwater infiltration from the bioretention cells.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and to the underlying material – two into the aggregate, and one into native sediments. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI’s offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, “Standard Recommended Practice for Description of Soils.” The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure BUW F2, "Facility and Exploration Plan. Global Positioning System (GPS) coordinates for the explorations were taken using a handheld GPS, and are summarized in Appendix B.

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell BUW were completed on October 11, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring number 1 (BUW-HA-1/WP) and number two (BUW-HA-2), were completed in the base of the cell, generally in the southern and northern ends, respectively. The borings encountered bioretention soil mix to depths of 1.5 and 1.2 feet, respectively, overlying drain rock. Hand-auger boring number 3 (BUW-HA-3), situated on the upper edge of the cell, encountered 0.3 feet of shredded wood chips and 1.7 feet of bioretention soil mix, overlying silt and very silty fine sand interpreted as glaciomarine drift at a depth of 2 feet, extending to the bottom of the exploration at a depth of 3 feet. No seepage or caving was observed, except within the loose drain rock and bioretention soil mix.

6.2 Well Points

A well point was installed in BUW-HA-1/WP. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell BUW
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
BUW-HA-1/WP	BUW-HA-1/WP	5.1	1.25 inch nominal	2	3.1

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology Manual. One sample of material interpreted as representative of the subgrade was tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell BUW
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
BUW-HA-1	0.2-0.5	Bioretention Soil	6.9	SAND, trace silt, trace gravel	1.7	4.0	1.0	SAND
BUW-HA-2	0.2-0.5	Bioretention Soil	6.5	SAND, trace silt, trace gravel	2.0	4.5	1.0	SAND
BUW-HA-3	2.1-2.6	Glaciomarine Drift		Very silty SAND, trace gravel	46.1			Sandy clay to silt loam

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture; *No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 6.5 and 6.9 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a "SAND" with trace to some silt and trace gravel based on ASTM D2487 Unified Soil Classification System (USCS). The respective fines content as measured on the No. 200 sieve was 1.7 to 2 percent, on the lower end or lower than the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 4 to 4.5, meeting the recommended value of equal to or greater than 4. The coefficient of curvature was 1, at the low end of the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix was generally coarser-grained with more than the recommended range of medium- to coarse-grained sand and not enough fine-grained sand. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell BUW Site Data

Parameter	Recommended Range	Cell BUW
Organic Content (by weight)	5 to 8 percent	6.7 percent by weight
Cu coefficient of uniformity	4 or greater	4.3
Cc coefficient of curvature	1 to 3	1
Sieve Size	**Percent Passing**	
3/8" (9.51 mm)	100	100
#4 (4.76 mm)	95 to 100	99.5
#10 (2.0 mm)	75 to 90	75.9
#40 (0.42 mm)	25 to 40	14.9
#100 (0.15 mm)	4 to 10	2.9
#200 (0.074 mm)	2 to 5	1.9

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In BUW-HA-1, a sample of native glaciomarine drift was sieved. The tested material correlates to a very silty SAND, trace gravel with 46.1 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the USDA soil texture. The grain-size distributions were normalized to the No. 10 sieve—i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 50.4 percent for the native glaciomarine drift.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell BUW with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Water levels were monitored using a staff gauge (SG-1) marked in 0.01-foot increments installed adjacent BUW-HA-1/WP, a second temporary metal staff gauge (SG-2) marked in 0.01-foot increments installed near the overflow beehive grate, within the well point with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell BUW is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell BUW

AESI performed infiltration testing on November 15, 2018. Light rainfall was noted for approximately 1 hour during testing and the rainfall contributed only minor inflow during that time. Due to the high infiltration rate of the bioretention soil and lack of surface pooling, the inflow was moved a few times during the test to observe cell performance, as described below.

Initially, inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. Throughout the test, beginning approximately 40 minutes into testing, AESI observed discharge from the underdrain.

Weirs for flow monitoring were in place at the time of testing. During this test, flow was initially maintained at about 47 gpm, increased to 120 gpm temporarily and shut off after the inflow began to backwater the flow monitoring device in the northern inlet, and flow back along the road, into the southern inlet, and into the southern portion of the facility at the base of the southern inlet. During this time, water did not saturate the entire length of the facility base; it saturated only a portion of the base around each inlet.

AESI then directed discharge into the roadway along the curb immediately next to the northern inlet. AESI observed that, when discharging approximately 78 gpm to the curb, a portion of the flow entered the northern inlet, and a portion of the flow bypassed the northern inlet and entered the southern inlet. Approximately 5 gpm of the water bypassing the northern curbcut and entering the southern curbcut flowed directly into the overflow beehive grate near the southern curbcut. At this flow rate, water also bypassed the southern inlet, pooled on the road, and entered the storm drain south of the southern inlet. AESI observed that with the flow reduced to approximately 41 gpm, bypass of the southern inlet and weir did not occur, and no flow directly to overflow was observed. When the flow was increased to 45 gpm, the portion of the flow bypassing the northern inlet to the southern inlet began to bypass the southern inlet and flow into the storm drain south of the inlet.

For the final approximately 100 minutes of testing, AESI moved the discharge hose to near the well point, and discharged water at approximately 120 gpm.

Approximately 31,000 gallons of water were used.

Water in the well point was monitored with a data logger during the infiltration test and responded to inflow. Groundwater was not observed beneath the bioretention cell prior to the start of inflow. The water level in the well point responded to inflow within several minutes, and rose to a depth of approximately 1.5 feet below ground surface at the well point. AESI interprets this response to indicate that water from the infiltration test infiltrated rapidly through the bioretention soil, perched on the native subgrade, and then filled the facility base-course before entering the underdrain.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 1 minute.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the bioretention soil. AESI observed the discharge from the underdrains, indicating that the majority of inflow was leaving the facility via the underdrains and little to no inflow was infiltrating into the subgrade.

Table 5
Cell BUW
Infiltration Test Results

Test No.	Surface Area (square feet, ponding)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
BUW (bioretention soil)	37	441	31,121	0.2	310	147
BUW (subgrade)	Perched water response in well point				Unknown; interpreted to be low based on the underdrain outflow	

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Portions of Cell BUW were inconsistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is lower relative to the facility base than shown on the plans, but is otherwise generally consistent with the plans. Site design documents indicate that the ponding level was designed as 0.3 feet. AESI observed that the facility base generally slopes down to the south, such that the overflow rim elevation is below the level of the cell base on the northern, uphill, end. There is an additional curbcut on the south side of the cell.

- Bioretention soil:
  - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.5 feet as indicated on the plan.
  - Composition: The soil tested in generally the recommended guidelines for organic content and was generally coarser-grained with more than the recommended range of medium- to coarse-grained sand and not enough fine-grained sand.

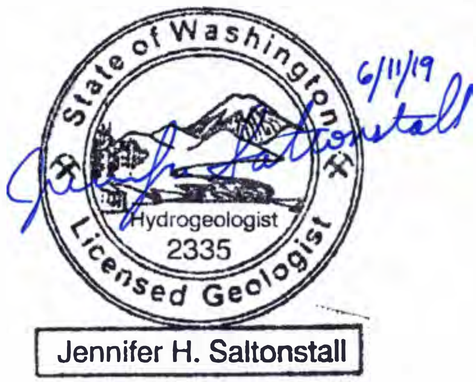
- Subgrade conditions: The subgrade is interpreted to consist of glaciomarine drift, with fill soils present in the vicinity of existing utilities.

- Bioretention soil field infiltration rate:
  - Measured at about 310 in/hr.
  - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the bioretention soil infiltration rate.

- Subgrade infiltration rate: Interpreted to be low and affected by unknown areas of fill sediments. The majority of flow is interpreted to leave the cell via the underdrain.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.



Anton D. Ypma
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Principal Geologist/Hydrogeologist

Attachments:	Figure BUW F1:	Vicinity Map
	Figure BUW F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

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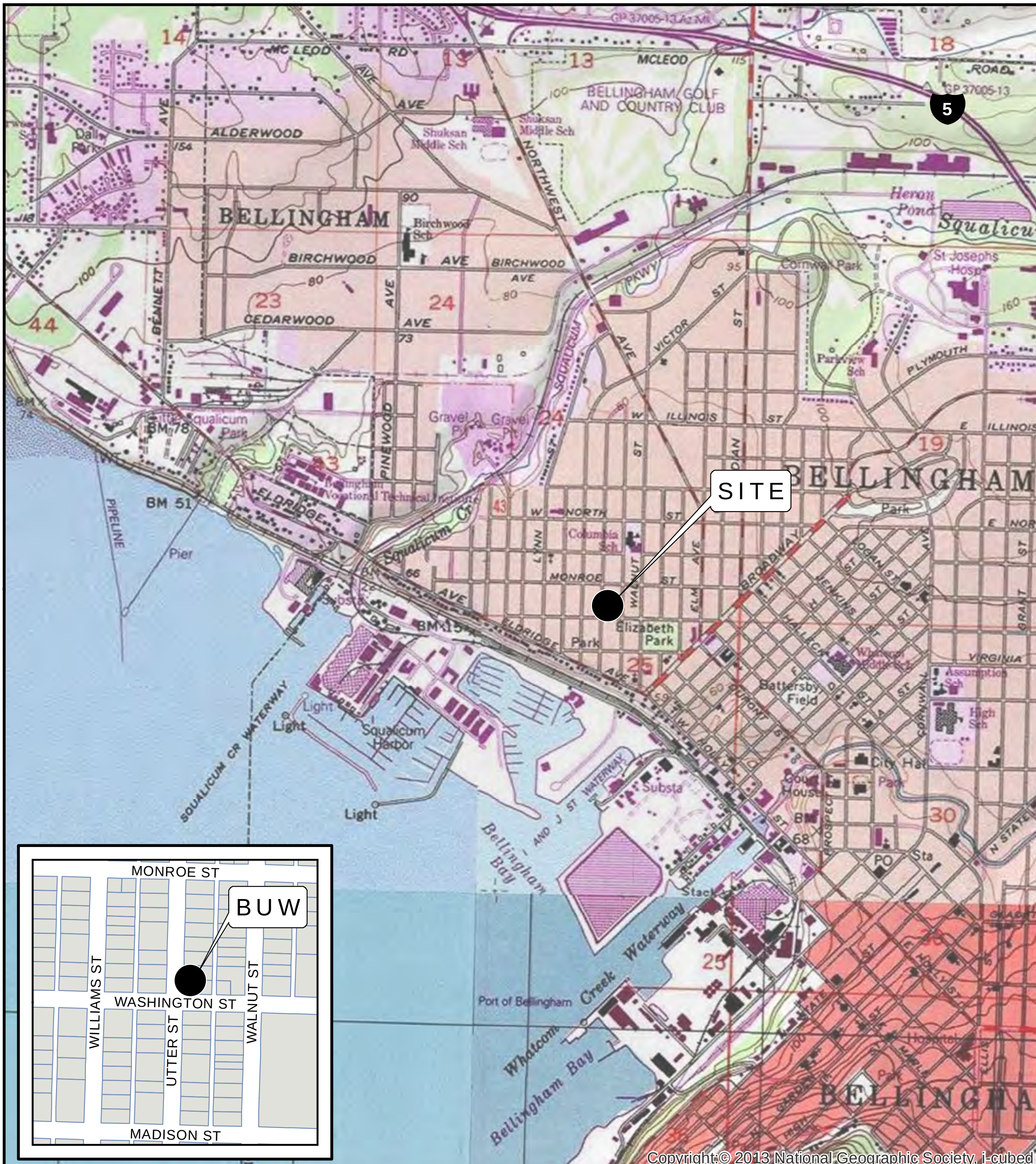
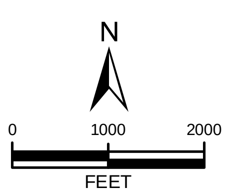




DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
WHATCOM CO: PARCELS, CITY - 4/17
CITY OF BELLINGHAM: STREETS, 3/17
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

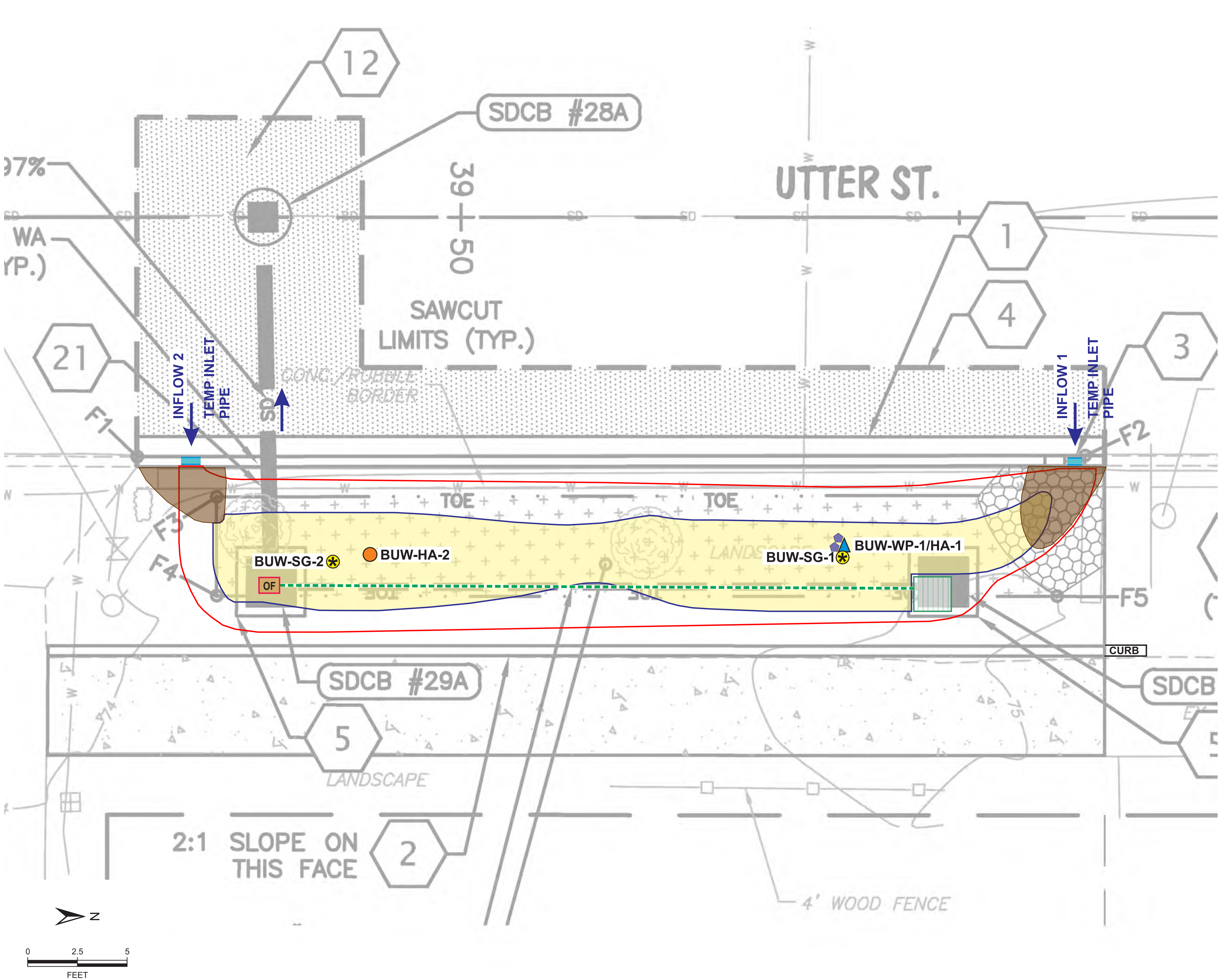
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, BUW SITE
BELLINGHAM, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BUW F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_BUW.mxd



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- ENERGY DISSIPATER
- UNDERDRAIN CLEANOUT

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: CITY OF BELLINGHAM PUBLIC WORKS DEPT, COLUMBIA WATER QUALITY IMPROVEMENTS, DRAINAGE IMPROVEMENTS, UTTER STREET 2, SHEET C16 OF C32, 10/30/17

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associated earth sciences incorporated

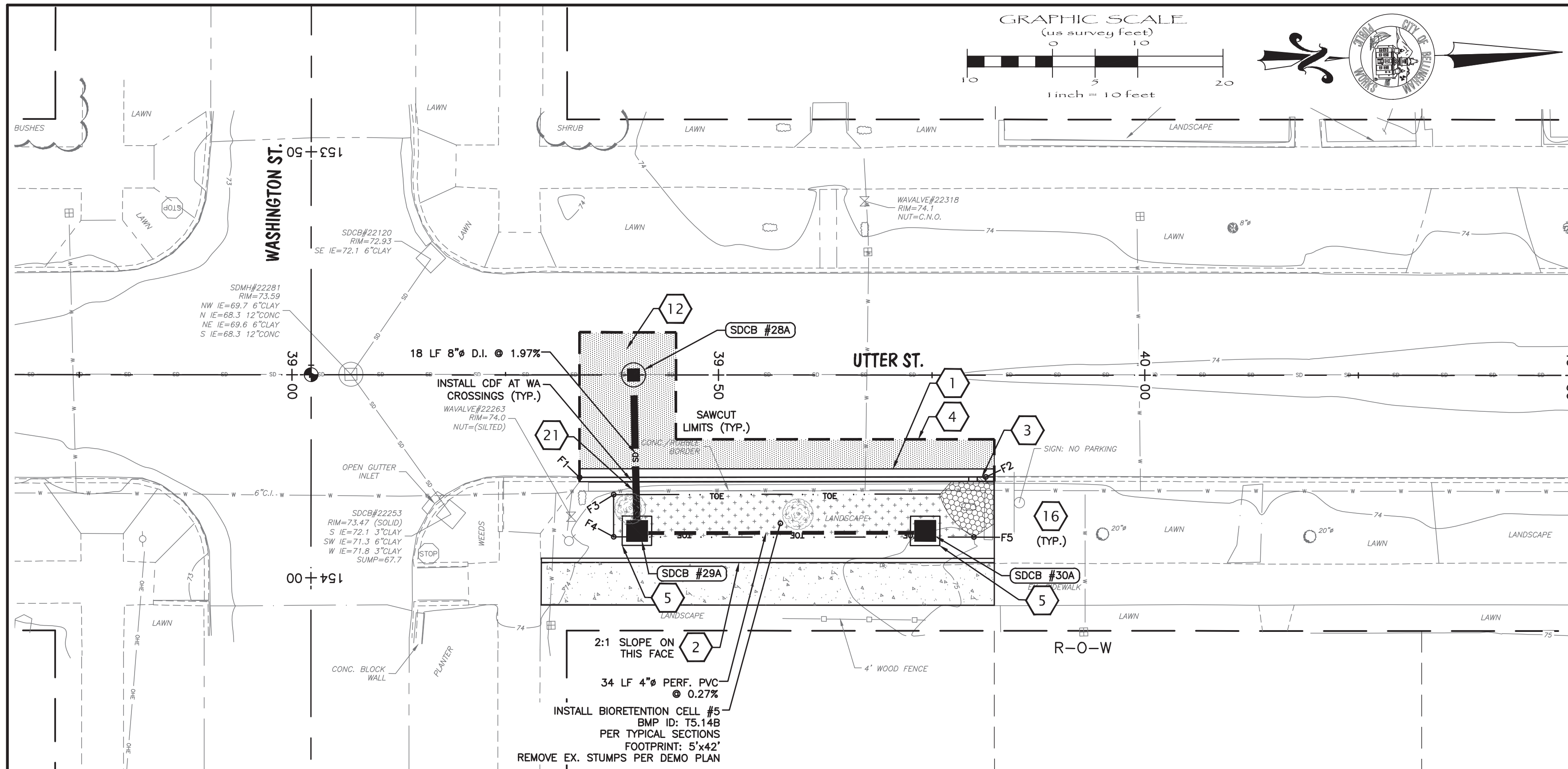
FACILITY AND EXPLORATION PLAN
BUW SITE
BIORETENTION HYDROLOGIC PERFORMANCE
BELLINGHAM, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BUW F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: BUW F2

APPENDIX A

Project Civil Plans



BIORETENTION CELL #5
ALL WORK INCLUDED IN SCHEDULE 'A'
H SCALE: 1"=10'

POINT TABLE			
	DESCRIPTION	STATION/OFFSET (F/C IN CURBLINE)	FL ELEV.
F1	MATCH EX.	STA 39+33.7, 12.0' R UTTER	73.34
F2	CURB INLET FL	STA 39+81.3, 12.0' R UTTER	73.62
F3	BIOCELL FG	STA 39+37.7, 14.0' R UTTER	72.89
F4	BIOCELL FG	STA 39+37.7, 19.0' R UTTER	72.89
F5	BIOCELL FG	STA 39+79.9, 19.0' R UTTER	73.39

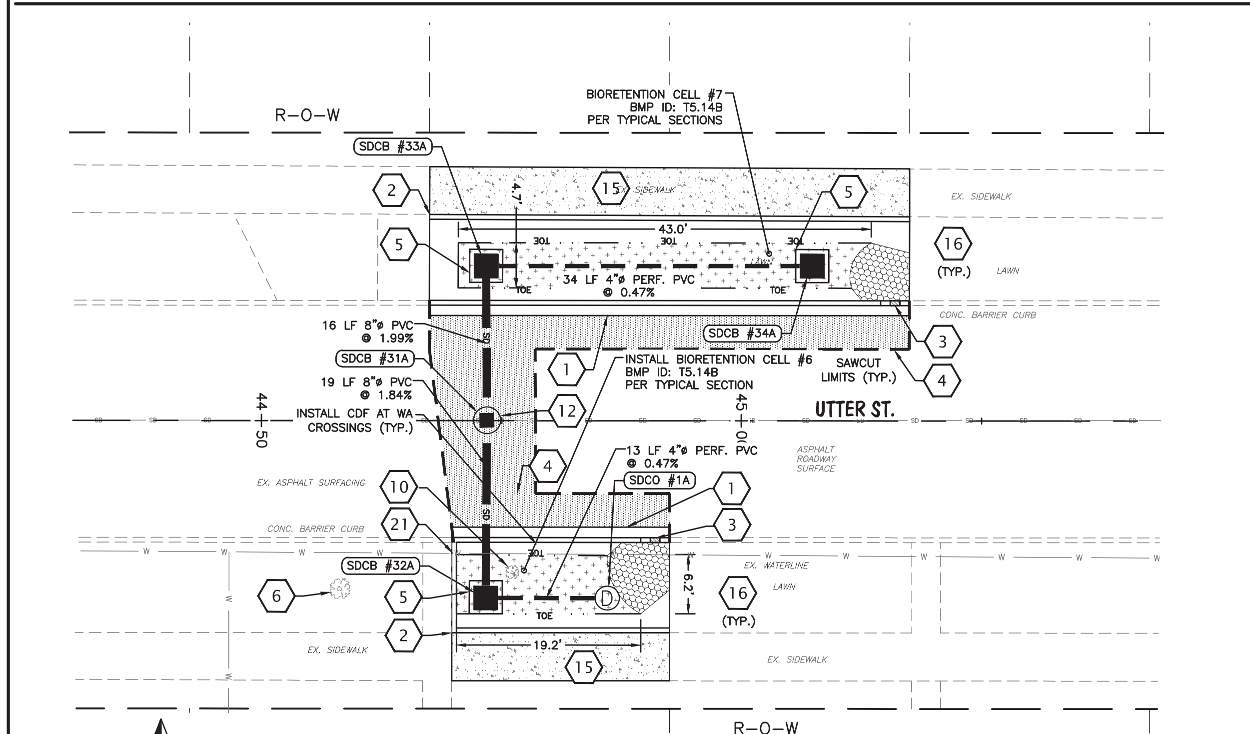
GRADING NOTE

NO VERTICAL GRADING INFORMATION PROVIDED FOR BIORETENTION CELL #5 – #8. CONTRACTOR TO FIELD FIT GRADING OF BIORETENTION CELLS BASED ON DETAIL ON SHEET C22 AND COORDINATE WITH ENGINEER TO DETERMINE GRADES.

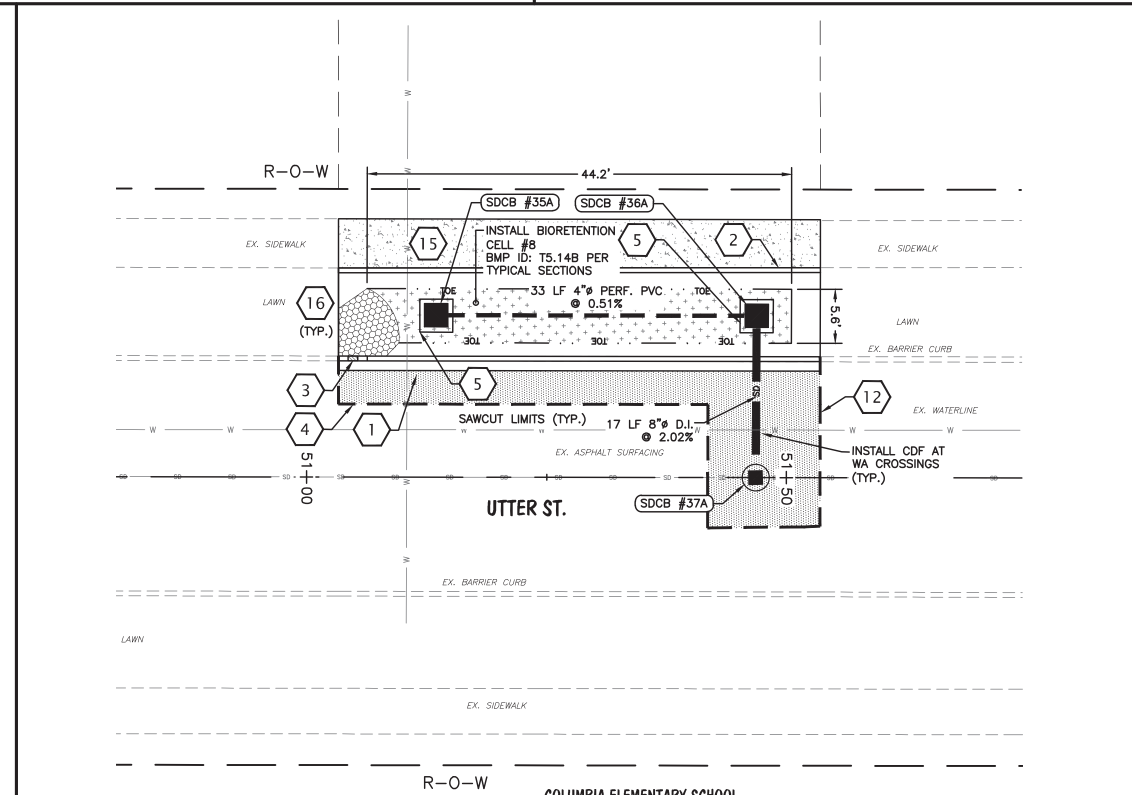
CONSTRUCTION NOTES:

1. INSTALL 18" CONC. CURB & GUTTER PER COB DETAIL CG-200
2. INSTALL BARRIER CURB PER COB DETAIL CG-208
3. INSTALL CURB INLET AND HAND PLACED, MORTARED, RIVER ROCK APRON PER TYPICAL BIORETENTION CELL DETAIL
4. SAWCUT AND REMOVE EXISTING ASPHALT OR CONCRETE PER DEMOLITION PLAN. REPAIR PAVEMENT PER COB DETAIL CG-218 (CURB REPLACEMENT)
5. INSTALL 6" CONCRETE COLLAR PER DETAIL
6. DO NOT DISTURB EXISTING TREES/LANDSCAPING
10. REMOVE EX. TREE IN PLANTER
12. SAWCUT, REMOVE AND REPAIR CONC. OR ASPHALT PER COB DETAIL ST-180 HORIZONTAL PAVEMENT REPAIR (STREET CROSSING)
15. REPLACE EX. SIDEWALK PER COB DETAIL CG-230
16. INSTALL 8" TOPSOIL AND SEEDED LAWN ON DISTURBED AREAS (TYP.)
21. POTHOLE EXISTING UTILITY TO VERIFY DEPTH.

= PROPOSED ASPHALT SURFACING
= PROPOSED CONCRETE SURFACING
= PROPOSED BIORETENTION CELL FOOTPRINT



BIORETENTION CELLS #6 AND #7
ALL WORK INCLUDED IN SCHEDULE 'A'
H SCALE: 1"=10'



BIORETENTION CELL #8
ALL WORK INCLUDED IN SCHEDULE 'A'
H SCALE: 1"=10'

STORM DRAINAGE NOTES:

SDCB #28A
STA 39+40, 0.0' L @ C/S
TYPE 2-48" SOLID RING & COVER
RIM: 73.87
IE-E: (8"ø D.I.) 70.31
EX. IE-S: (12" CONC.) 68.39

SDCB #29A
STA 39+40.4, 18.3' R @ C/S
TYPE 1, BEEHIVE GRATE
RIM: 73.22
IE-N: (4"ø PERF. PVC) 70.67
IE-W: (8"ø D.I.) 70.67

SDCB #30A
STA 39+74.2, 18.3' R @ C/S
TYPE 1, SOLID LID
RIM: 73.31
IE-S: (4"ø PERF. PVC) 70.76

FIELD VERIFY RIM ELEVATIONS:

SDCB #31A
STA 44+73.4, 0.0' L @ C/S
TYPE 2-48" SOLID RING & COVER
RIM: 75.28
IE-W: (8"ø PVC) 71.22
IE-E: (8"ø PVC) 71.54
EX. IE: (12"ø PVC) 69.93
EX. IE: (12"ø PVC) 69.93

SDCB #32A
STA 44+73.3, 18.5' R @ C/S
TYPE 1, BEEHIVE GRATE
RIM: 74.85
IE-W: (8"ø PVC) 71.88
IE-N: (4"ø PERF. PVC) 72.07

SDCB #33A
STA 44+73.4, 16.1' L @ C/S
TYPE 1, BEEHIVE GRATE
RIM: 74.85
IE-N: (4"ø PERF. PVC) 72.23
IE-E: (8"ø PVC) 71.54

SDCB #34A
STA 45+07.3, 16.1' L @ C/S
TYPE 1, SOLID LID
RIM: 74.95
IE-S: (4"ø PERF. PVC) 72.07

SDCO #1A
STA 44+85.99, 18.48' R @ CTR STR
RIM: 74.75
IE-S: (4"ø PERF. PVC) 72.13

FIELD VERIFY RIM ELEVATIONS:

SDCB #35A
STA 51+13.4, 16.9' L @ C/S
TYPE 1, SOLID LID
RIM: 75.38
IE-N: (4"ø PERF. PVC) 73.21

SDCB #36A
STA 51+46.8, 16.8' L @ C/S
TYPE 1, BEEHIVE GRATE
RIM: 75.66
IE-E: (8"ø D.I.) 72.86
IE-S: (4"ø PERF. PVC) 73.04

SDCB #37A
STA 51+46.7, 0.0' R @ C/S
TYPE 2-48" SOLID RING & COVER
RIM: 76.39
IE-W: (8"ø D.I.) 73.20
EX. N-IE: (8" CONC.) 70.63
EX. S-IE: (8" CONC.) 70.63
(CONNECT TO EX. PIPES)

PACIFIC SURVEYING & ENGINEERING
1812 CORNWALL AVE., BELLINGHAM, WA 98225
PHONE: 360.671.7387 FAX: 360.671.4685

JEFFREY A. VANDERYACHT — STATE OF WASHINGTON — 37432 — REGISTERED PROFESSIONAL ENGINEER — 10-30-2017

BID SET DRAWINGS

Date	No	Revision	By

PROJECT ENGINEER: JVY
DESIGNED/DRAWN: SJG
DIRECTOR OF PUBLIC WORKS: TAC
CITY ENGINEER: CMAS

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT

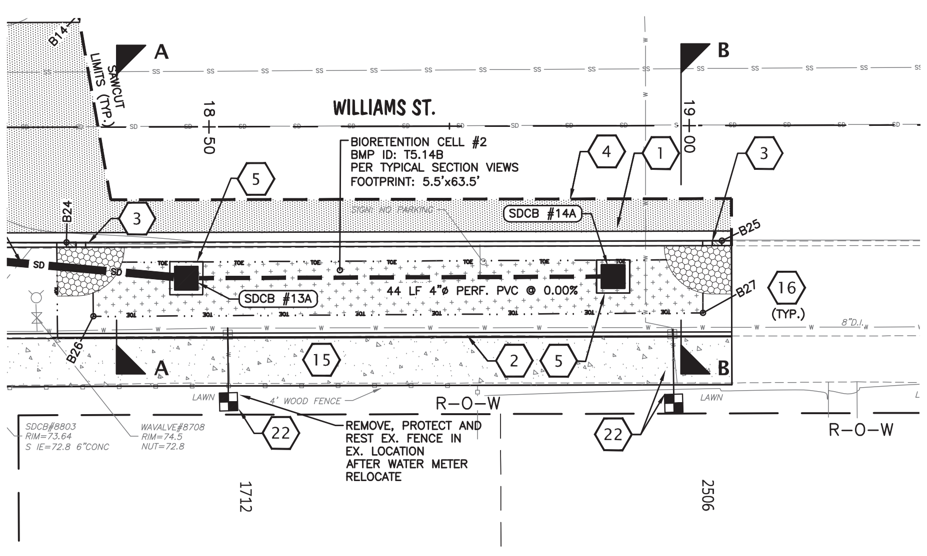
SCALE — Horiz.: GRAPHIC SCALE; Vert.: GRAPHIC SCALE
DATUM — HORIZ.=NAD 83/07; VERT.=NAVD 88
Job. No. EV-0120, 2014221
Date OCT. 30, 2017
Field Bk. #1022 SERIES

COLUMBIA WATER QUALITY IMPROVEMENTS
DRAINAGE IMPROVEMENTS - UTTER STREET 2

SHEET C16 OF C32

CONTACT PERSON: CRAIG MUELLER, P.E. , PROJECT ENGINEER AT 360-778-7922 FILE PATH: P:\Pse Project\2014221\DWGs_SHEET\2014221_ecP_BD.dwg

GRAPHIC SCALE
(us survey feet)
1 inch = 10 feet

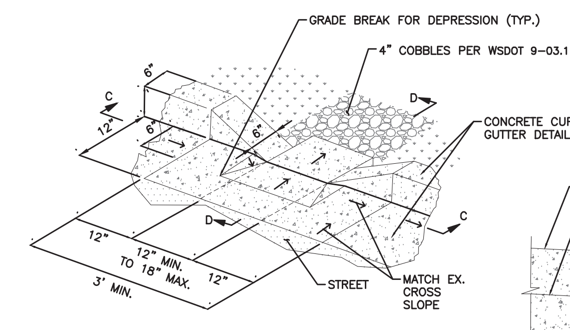


TYPICAL BIORETENTION CELL PLAN VIEW
H SCALE: 1"=10'

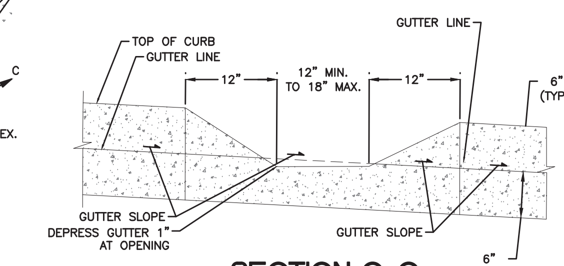
CONSTRUCTION NOTES:

1. INSTALL 18" CONC. CURB & GUTTER PER COB DETAIL CG-200
2. INSTALL BARRIER CURB PER COB DETAIL CG-208
3. INSTALL CURB INLET AND HAND PLACED, MOTARED, QUARRY SPALL APRON PER TYPICAL BIORETENTION CELL DETAIL
4. SAWCUT AND REMOVE EXISTING ASPHALT OR CONCRETE PER DEMOLITION PLAN. REPAIR PAVEMENT PER COB DETAIL CG-218 (CURB REPLACEMENT)
5. INSTALL 6" CONCRETE COLLAR PER DETAIL
15. REPLACE EX. SIDEWALK PER COB DETAIL CG-230
16. INSTALL 8" TOPSOIL AND SEEDED LAWN ON DISTURBED AREAS (TYP.)
21. POTHOLE EXISTING UTILITY TO VERIFY DEPTH.
22. RELOCATE EX. WATER METER PER DETAIL WA-830. INSTALL 1" COPPER PIPE TO LENGTH.

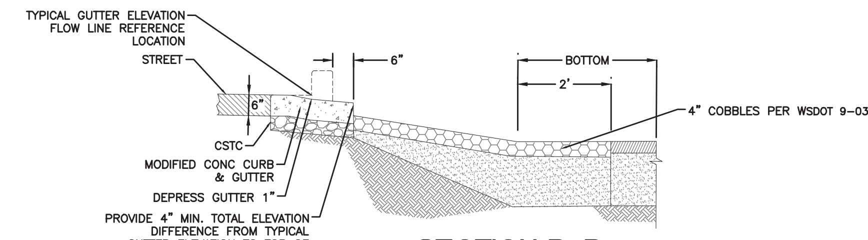
= PROPOSED ASPHALT SURFACING
= PROPOSED CONCRETE SURFACING
= PROPOSED BIORETENTION CELL FOOTPRINT



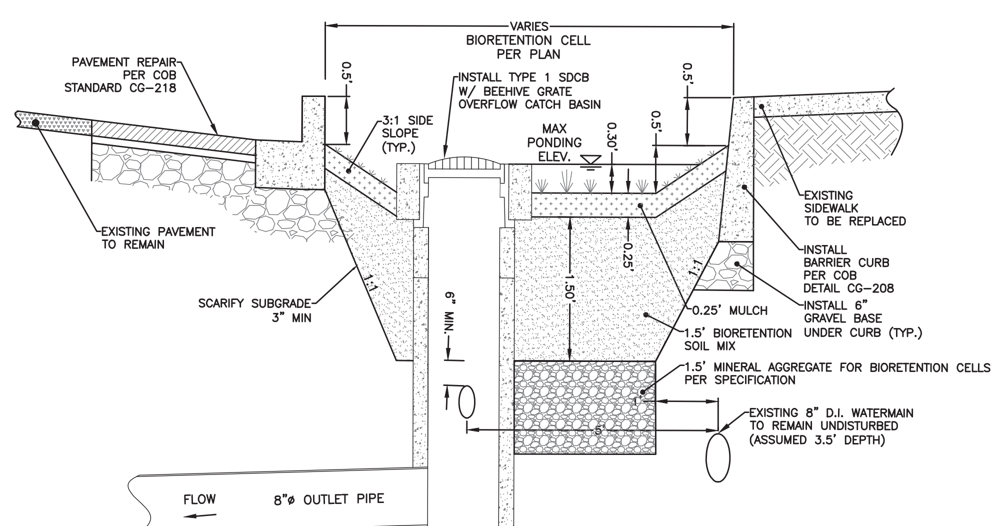
INLET CURB CUT OPENING
NTS



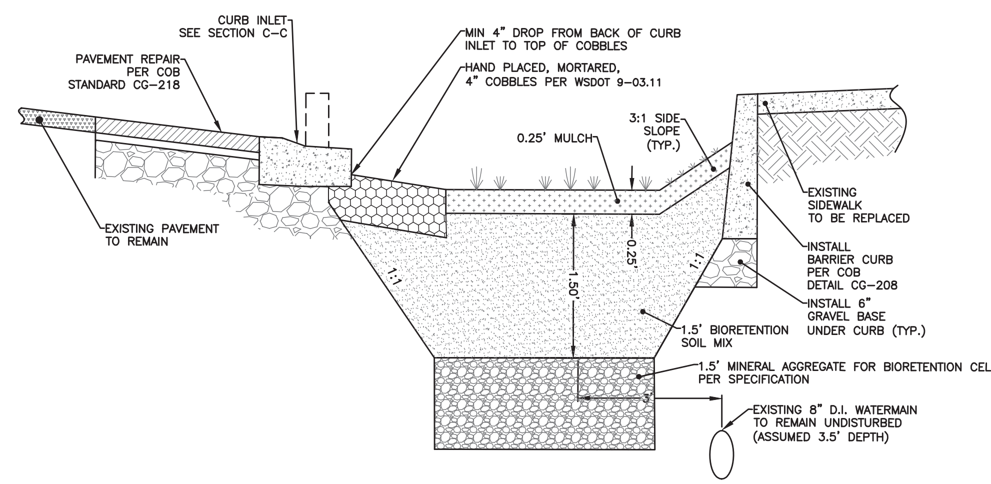
SECTION C-C
NTS



SECTION D-D
NTS



TYPICAL BIORETENTION SECTION A-A
H SCALE: 1"=10'



TYPICAL BIORETENTION SECTION B-B
H SCALE: 1"=10'

PACIFIC SURVEYING & ENGINEERING
1812 CORNWALL AVE., BELLINGHAM, WA 98225
PHONE: 360.671.7387 FAX: 360.671.4685

JEFFREY A. VANDER YACHT, STATE OF WASHINGTON, 37432, REGISTERED PROFESSIONAL ENGINEER, 10-30-2017

BID SET DRAWINGS

Date	No	Revision	By

PROJECT ENGINEER JVY — DESIGNED/DRAWN SIG — DIRECTOR OF PUBLIC WORKS TAC — CITY ENGINEER CMAS

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT

SCALE: Horiz. GRAPHIC SCALE; Vert. GRAPHIC SCALE

DATUM: HORIZ.=NAD 83/07; VERT.=NAVD 88

Job. No. EV-0120, 2014221 — Date OCT. 30, 2017 — Field Bk. #1022 SERIES

COLUMBIA WATER QUALITY IMPROVEMENTS
BIORETENTION CELL DETAILS

SHEET C22 OF C32

CONTACT PERSON: CRAIG MUELLER, P.E. , PROJECT ENGINEER AT 360-778-7922 FILE PATH: P:\Pse Project\2014221\DWGs_SHEET\2014221_ecP_B0.dwg

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

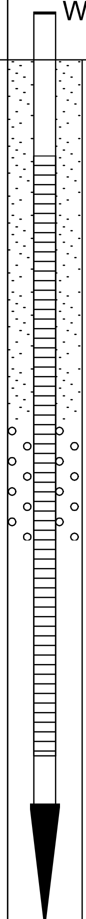
Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	BUW-HA-1/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Bellingham, WA
Elevation (Top of Well Casing)	101.3 (Project Datum)	Surface Elevation (ft)	99.3 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/11/18,10/11/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft) | Water Level | WELL CONSTRUCTION | S T | Blows/ 6" | Graphic Symbol | DESCRIPTION



Well construction:

Threaded steel pipe 1.25 inches I.D. with threaded and vented PVC cap -2 to 0.2 feet
Shredded wood chips 0 to 0.1 feet
Top of well point at 0.2 feet

Bioretention soil mix 0.1 to 1.5 feet

Gravel fill 1.5 to 2 feet

Driven into existing sediments 2 to 3.6 feet.

Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 0.4 to 2.9 feet

Threaded steel pipe 1.25 inches I.D. and drive point 2.9 to 3.6 feet

Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 5.1 feet.

Description:

Shredded Wood Chips

Bioretention Soil Mix

Loose, moist, dark brown medium, SAND, trace silt, trace gravel; organic rich; massive (SP).

Underdrain Gravel Bedding

Loose, angular gravel (0.5 to 0.75 inch), partially mixed with bioretention soil mix.

Boring terminated at 2 feet
Well completed at 3.6 feet on 10/11/18.
Steel drive points placed in borehole and hand driven with slide hammer to depth of 3.6 feet.

5

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	BUW-HA-2	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Bellingham, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/11/18,10/11/18
Hole Diameter (in): 4 inches

Depth (ft)	ST	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Shredded Wood Chips					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace silt, trace gravel; organic rich; massive (SP).					
		S-2		**Underdrain Gravel Bedding** Loose, angular gravel (0.5 to 0.75 inch), partially mixed with bioretention soil mix.					
				Bottom of exploration boring at 1.5 feet.					
5									

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	BUW-HA-3	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Bellingham, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/11/18,10/11/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Shredded Wood Chips					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace silt, trace gravel; organic rich; abundant fine roots; massive (SP).					
		S-2		**Glaciomarine Drift** Stiff, slightly moist, brownish gray, very silty, medium SAND, trace gravel (SM).					
				Bottom of exploration boring at 3 feet.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/11/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- BUW			

Moisture Content

Sample ID	**HA-1 (0.2'-0.5')**	**HA-2 (0.2'-0.5')**
Wet Weight + Pan	**983.51**	**783.83**
Dry Weight + Pan	**925.90**	**699.81**
Weight of Pan	**534.24**	**392.48**
Weight of Moisture	**57.61**	**84.02**
Dry Weight of Soil	**391.66**	**307.33**
% Moisture	**12.8**	**21.5**

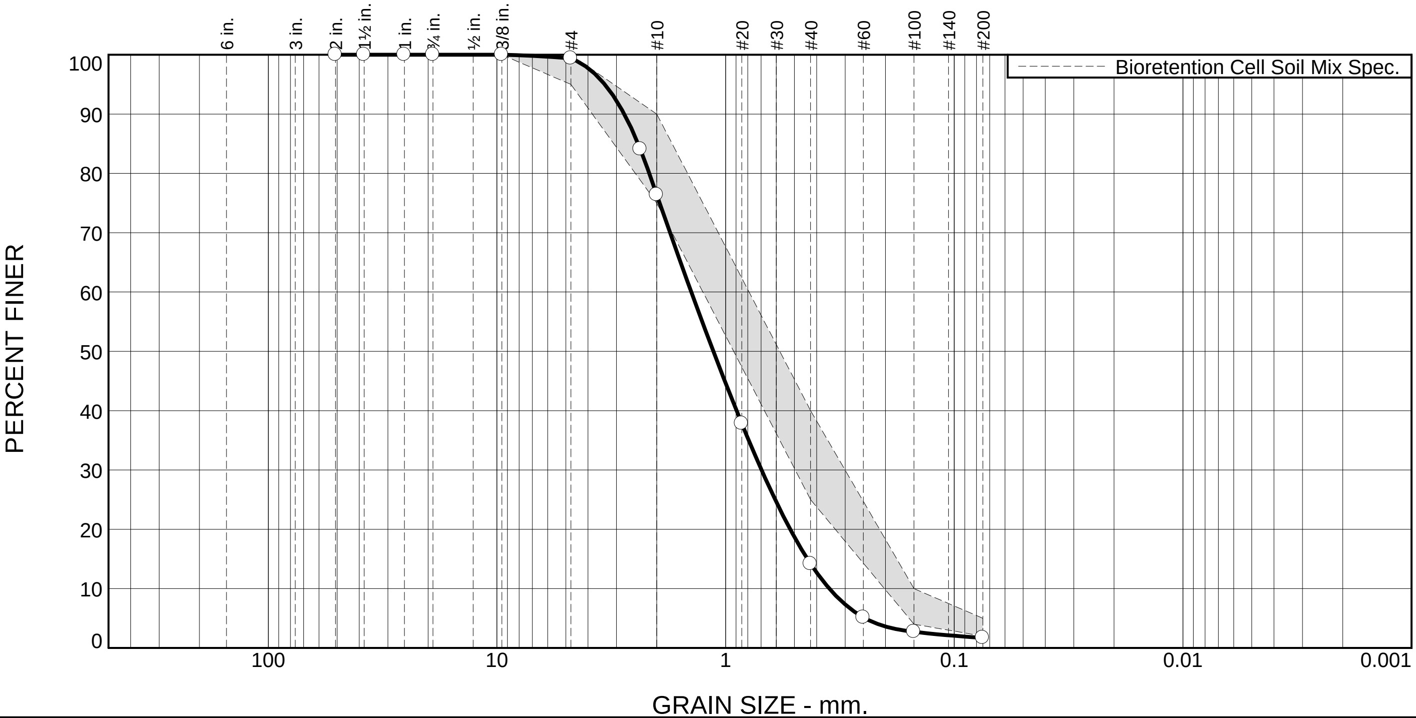
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	**623.06**	**631.32**
Dry Soil After Burn + Pan	**607.01**	**615.87**
Weight of Pan	**391.92**	**391.91**
Wt. Loss Due to Ignition	**16.05**	**15.45**
Actual Wt. Of Soil After Burr	**215.09**	**223.96**
% Organics	**6.9**	**6.5**

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.6	23.0	62.2	12.5	1.7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	99.4	95.0 - 100.0	
#8	84.1		
#10	76.4	75.0 - 90.0	
#20	37.8		
#40	14.2	25.0 - 40.0	X
#60	5.1		
#100	2.7	4.0 - 10.0	X
#200	1.7	2.0 - 5.0	X

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=**

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7742 D_{85}= 2.4138 D_{60}= 1.4126
D_{50}= 1.1314 D_{30}= 0.6964 D_{15}= 0.4388
D_{10}= 0.3518 C_u= 4.02 C_c= 0.98

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/16/2018 **Date Tested:** 11/12/2018

Tested By: BN

Checked By: JHS

Title:

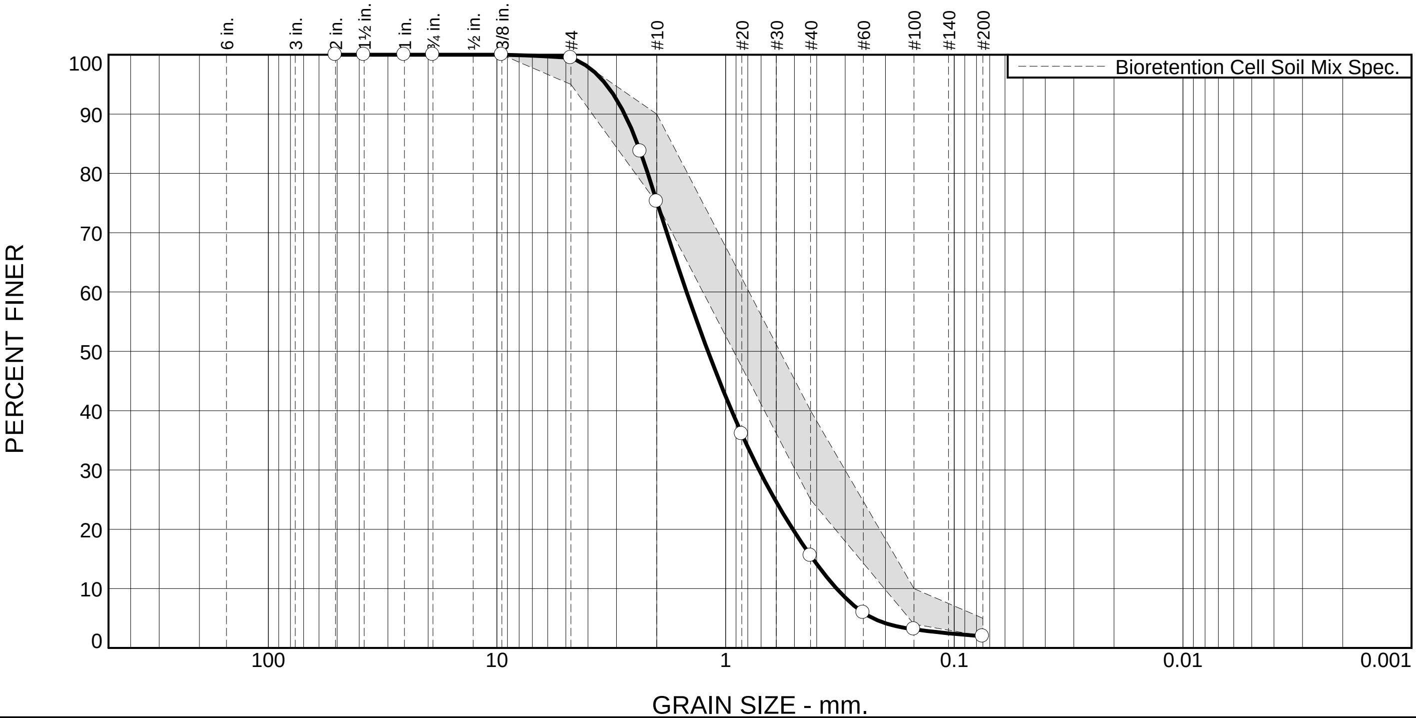
Source of Sample: (BUW) Bellingham- Utter and Washington **Depth:** 0.2'-0.5' **Date Sampled:** 10/11/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.5	24.2	59.7	13.6	2.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	99.5	95.0 - 100.0	
#8	83.7		
#10	75.3	75.0 - 90.0	
#20	36.1		
#40	15.6	25.0 - 40.0	X
#60	6.0		
#100	3.1	4.0 - 10.0	X
#200	2.0	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7655 D_{85}= 2.4287 D_{60}= 1.4805
D_{50}= 1.1945 D_{30}= 0.7142 D_{15}= 0.4149
D_{10}= 0.3270 C_u= 4.53 C_c= 1.05

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/19/2018 **Date Tested:** 11/12/2018

Tested By: BN

Checked By: JHS

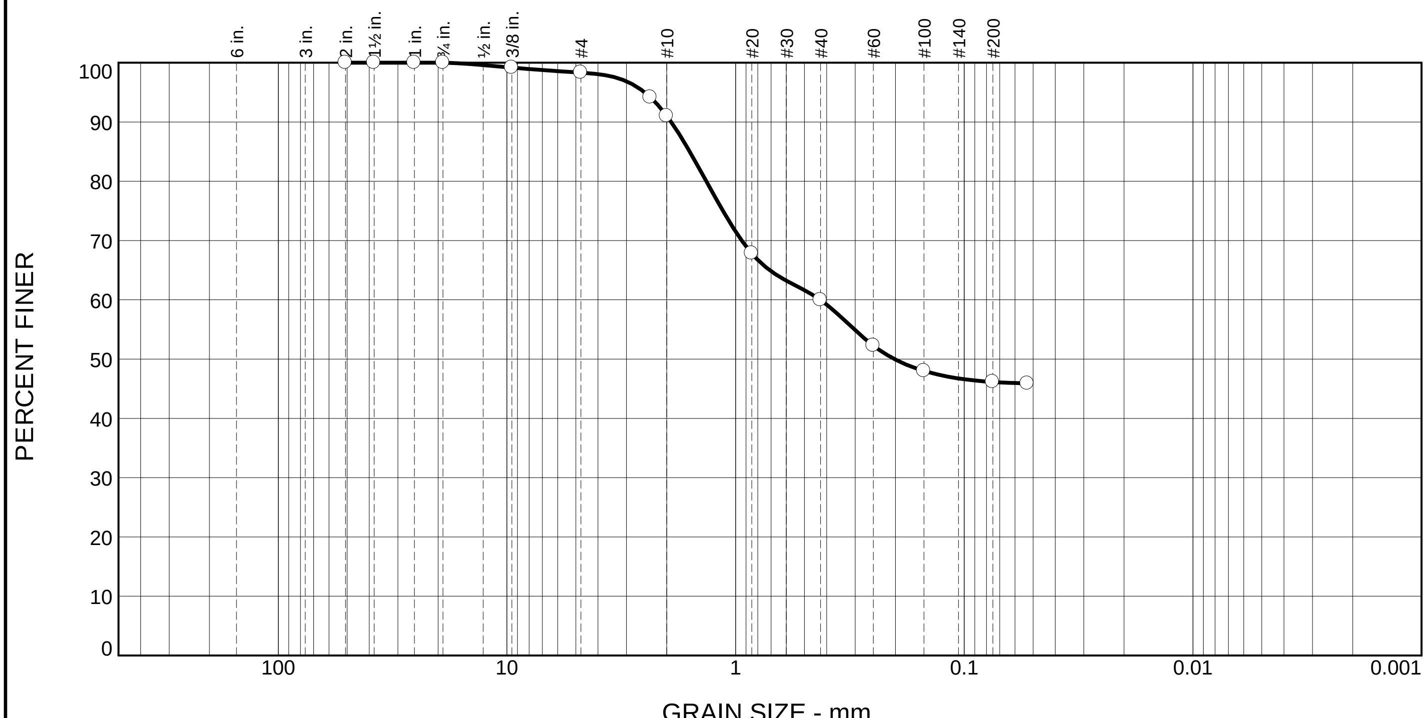
Title:

Source of Sample: (BUW) Bellingham- Utter and Washington **Depth:** 0.2'-0.5' **Date Sampled:** 10/11/2018
Sample Number: HA-2

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.7	7.3	31.0	13.9	46.1	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	99.2		
#4	98.3		
#8	94.2		
#10	91.0		
#20	67.8		
#40	60.0		
#60	52.3		
#100	48.0		
#200	46.1		
#270	45.9		

* (no specification provided)

Material Description

very silty SAND, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 1.9138 D_{85}= 1.5881 D_{60}= 0.4265
D_{50}= 0.2020 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 10/16/2018 **Date Tested:** 10/18/2018

Tested By: MS

Checked By: JHS

Title:

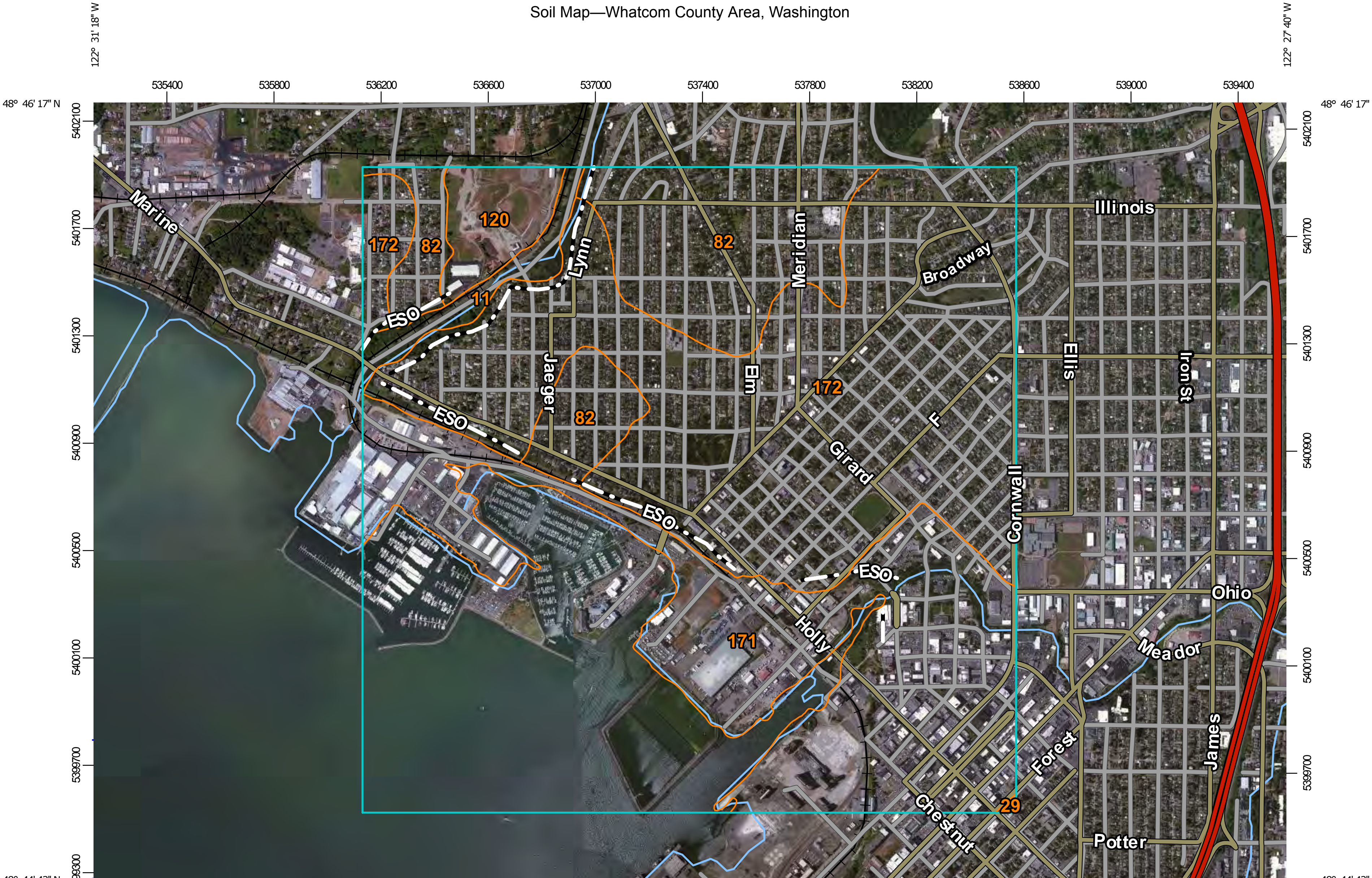
Source of Sample: (BUW) Bellingham- Utter and Washington **Depth:** 2.1'-2.6' **Date Sampled:** 10/11/2018
Sample Number: HA-3

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Map Scale: 1:20,400 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0, 300, 600, 1200, 1800

Feet: 0, 500, 1000, 2000, 3000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Whatcom County Area, Washington
Survey Area Data: Version 18, Sep 10, 2018

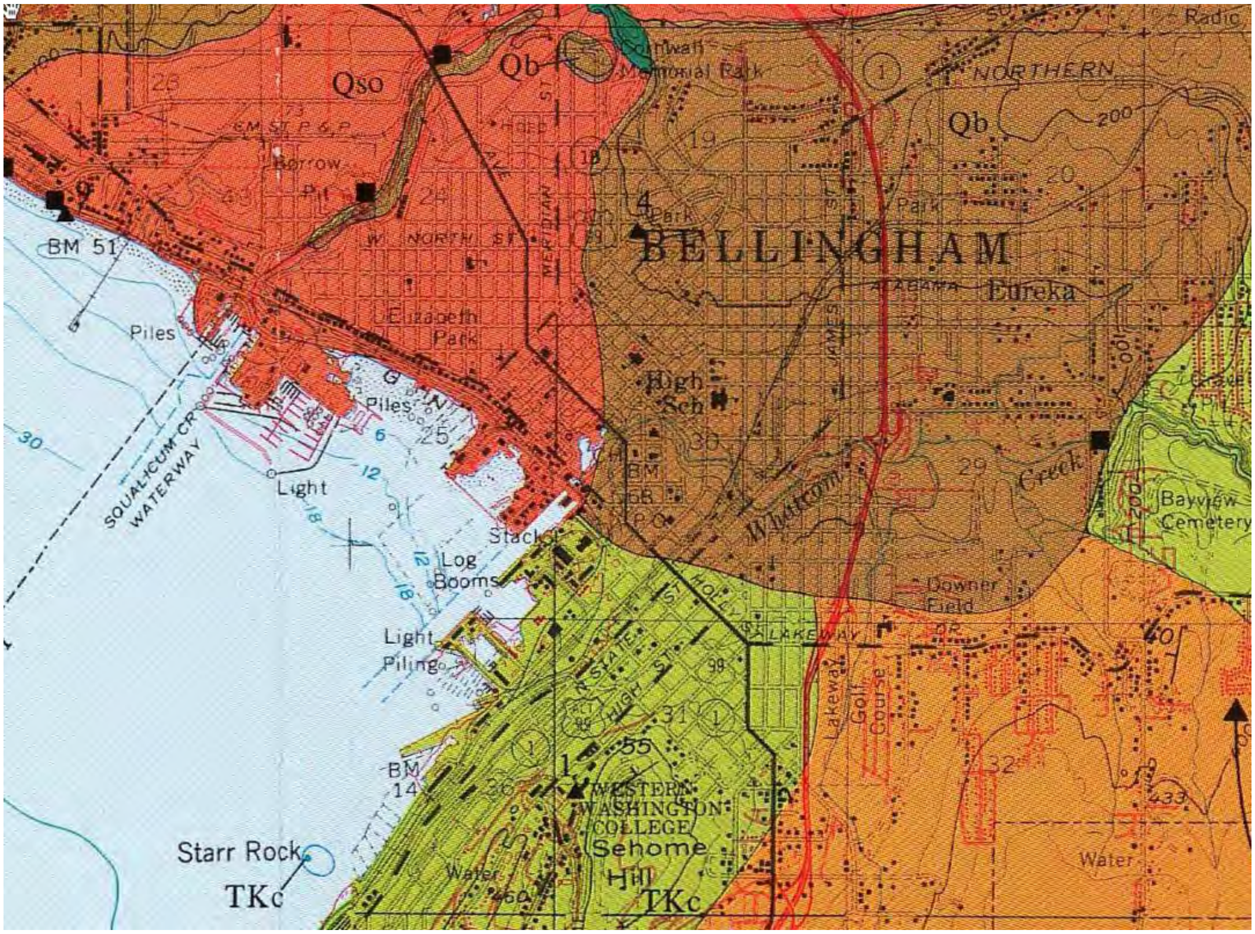
Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jul 9, 2010—Aug 28, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

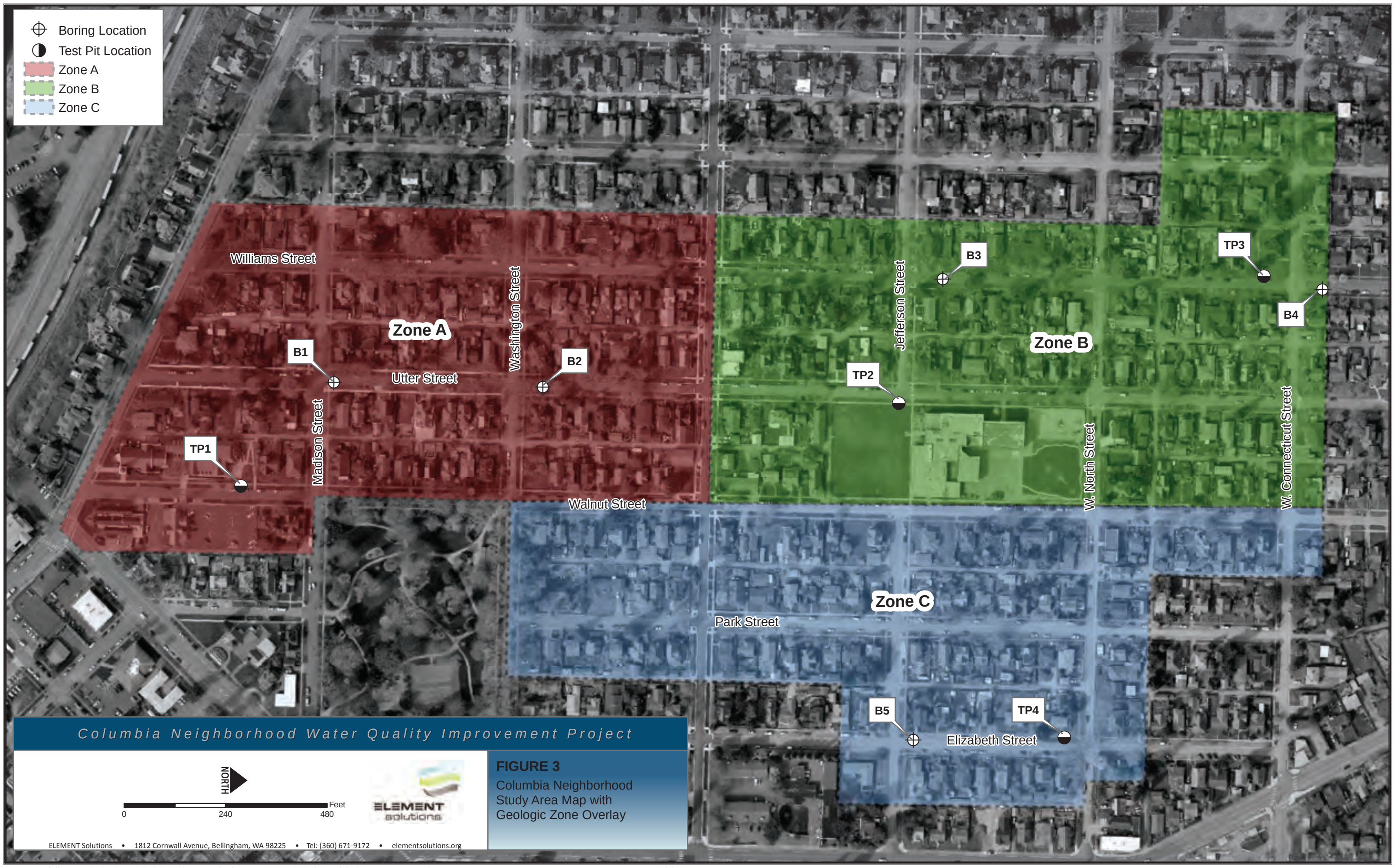
Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
11	Bellingham silty clay loam, 0 to 2 percent slopes	25.0	1.7%
29	Chuckanut-Urban land complex, 5 to 20 percent slopes	0.7	0.0%
82	Kickerville-Urban land complex, 0 to 3 percent slopes	187.2	12.8%
120	Pits, gravel	38.3	2.6%
171	Urban land	333.2	22.9%
172	Urban land-Whatcom-Labounty complex, 0 to 8 percent slopes	527.8	36.2%
Totals for Area of Interest		**1,457.1**	**100.0%**



Excerpt from:

Easterbrook, D.J., 1976, Geologic map of western Whatcom County, Washington: U.S. Geological Survey, Miscellaneous Investigations Series Map I-854-B, scale 1:62,500



Document Path: \\pseserver\projects\Pse Project\2014221\ENVRMNT\Borings_2-17-2016_2-18-2016\Figures\Fig_3_ZoneMap_11x17.mxd

Date: 3/3/2016

Appendix II

1) Test Pit Logs (TP1-TP4) - December 17, 2015
2) Borehole Logs (B1-B5) - February 17 to 18, 2016
3) Laboratory Test Data - GeoTest Services, Inc., March 3, 2016

Element Solutions
1812 Cornwall Avenue
Bellingham, WA 98225
Telephone: 360-671-9172
Fax: 360-671-4685

TEST PIT NUMBER TP1

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Infiltration Test Pits
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 12/7/15 **COMPLETED** 12/7/15
GROUND ELEVATION 69.7 ft **TEST PIT SIZE** 16 square feet
EXCAVATION CONTRACTOR Ram Construction
GROUND WATER LEVELS:
EXCAVATION METHOD Kubota KX121-3 Excavator
AT TIME OF EXCAVATION ---
LOGGED BY MG **CHECKED BY** PP
AT END OF EXCAVATION ---
NOTES
AFTER EXCAVATION ---

DEPTH (ft)	SAMPLE TYPE NUMBER	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	
0 – 1		OL		(OL)	
1				1.0	68.7
1 – 3		CL		(CL) Firm to stiff silty CLAY; tan, with some redoximorphic mottling.	
3				3.0	66.7

Bottom of test pit at 3.0 feet.

Element Solutions
1812 Cornwall Avenue
Bellingham, WA 98225
Telephone: 360-671-9172
Fax: 360-671-4685

TEST PIT NUMBER TP2

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Infiltration Test Pits
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 12/7/15 **COMPLETED** 12/7/15
GROUND ELEVATION 76.8 ft **TEST PIT SIZE** 12 square feet
EXCAVATION CONTRACTOR Ram Construction
GROUND WATER LEVELS:
EXCAVATION METHOD Kubota KX121-3 Excavator
AT TIME OF EXCAVATION ---
LOGGED BY MG **CHECKED BY** PP
AT END OF EXCAVATION ---
NOTES
AFTER EXCAVATION ---

DEPTH (ft)	SAMPLE TYPE NUMBER	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	Depth	Elevation
0 – 1		OL		ORGANIC SOIL, (OL)	1.0	75.8
1 – 2.3		CL-ML		(CL-ML) Silty CLAY with some gravel and sand.	2.3	74.6
2.3 – 3		GW		(GW) Well graded GRAVEL with sand and some fines.	3.0	73.8

Bottom of test pit at 3.0 feet.

Element Solutions
1812 Cornwall Avenue
Bellingham, WA 98225
Telephone: 360-671-9172
Fax: 360-671-4685

TEST PIT NUMBER TP3

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Infiltration Test Pits
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 12/7/15 **COMPLETED** 12/7/15
GROUND ELEVATION 76.3 ft **TEST PIT SIZE** 12 square feet
EXCAVATION CONTRACTOR Ram Construction
GROUND WATER LEVELS:
EXCAVATION METHOD Kubota KX121-3 Excavator
AT TIME OF EXCAVATION ---
LOGGED BY MG **CHECKED BY** PP
AT END OF EXCAVATION ---
NOTES
AFTER EXCAVATION ---

DEPTH (ft)	SAMPLE TYPE NUMBER	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	Depth	Elevation
0		OL		GRAVELLY ORGANIC SOIL, (OL)	0.8	75.5
1 2 3		GW		(GW) Well graded GRAVEL with sand and some fines; occasional cobbles and construction debris (FILL).	3.0	73.3

Bottom of test pit at 3.0 feet.

Element Solutions
1812 Cornwall Avenue
Bellingham, WA 98225
Telephone: 360-671-9172
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TEST PIT NUMBER TP4

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Infiltration Test Pits
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 12/7/15 **COMPLETED** 12/7/15
GROUND ELEVATION 80.1 ft **TEST PIT SIZE** 12 square feet
EXCAVATION CONTRACTOR Ram Construction
GROUND WATER LEVELS:
EXCAVATION METHOD Kubota KX121-3 Excavator
AT TIME OF EXCAVATION ---
LOGGED BY MG **CHECKED BY** PP
AT END OF EXCAVATION ---
NOTES
AFTER EXCAVATION ---

DEPTH (ft)	SAMPLE TYPE NUMBER	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION	Elevation
0 – 1.0		OL		ORGANIC SOIL, (OL) topsoil fill	79.1
1.0 – 2.5		CL-ML		(CL-ML) Silty CLAY with fine sand and occasional gravel; tan to dusky yellowish brown.	77.6
2.5 – 3.0		GW		(GW) Well-graded GRAVEL with sand and some fines; tan to light brown.	77.1

Bottom of test pit at 3.0 feet.

Element Solutions
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BORING NUMBER B1

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Drainage Improvement Project
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 2/17/16 **COMPLETED** 2/17/16
GROUND ELEVATION 70.67 ft NAVD 88 **HOLE SIZE** 3 inches
DRILLING CONTRACTOR Holocene Drilling Inc.
GROUND WATER LEVELS:
DRILLING METHOD Hollow Stem Auger (HSA)
▽ **AT TIME OF DRILLING** 7.50 ft / Elev 63.17 ft
LOGGED BY MG **CHECKED BY** PP
▼ **AT END OF DRILLING** 5.00 ft / Elev 65.67 ft
NOTES
AFTER DRILLING ---

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
0.0		Asphalt (FILL).										
		Concrete (FILL).										
		SAND with fines (SP/SM).	GB									
2.5		Stiff; tan silty CLAY with trace fine sand (CL/ML).	SS	89	5-8-7 (15)							
		Medium dense; medium grained SAND with some silt (SP/SM). 1% gravel, 75% sand, 24% silt (composite sieve, 2.5-6.4 feet bgs).										
5.0	▼		SS	100	4-6-5 (11)							
		Stiff; tan silty CLAY. Blocky fracture, desiccated (CL).										
7.5	▽	Loose to medium dense; poorly graded SAND with some silt (SP). 2% gravel, 86% sand, 12% fines (composite sieve, 7.5-11 feet bgs).	SS	100	7-5-7 (12)							
10.0			SS	100	3-3-5 (8)							
12.5		Firm; tan CLAY with silt and fine sand, some redox mottling observed (CL/ML). 16% sand, 84% fines.	SS	100	3-3-3 (6)							
		Loose; medium grained silty SAND (SP/SM).										

Bottom of borehole at 14.0 feet.

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BORING NUMBER B2

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Drainage Improvement Project
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 2/17/16 **COMPLETED** 2/17/16
GROUND ELEVATION 74.88 ft NAVD 88 **HOLE SIZE** 3 inches
DRILLING CONTRACTOR Holocene Drilling Inc.
GROUND WATER LEVELS:
DRILLING METHOD Hollow Stem Auger (HSA)
▽ **AT TIME OF DRILLING** 7.50 ft / Elev 67.38 ft
LOGGED BY MG **CHECKED BY** PP
▼ **AT END OF DRILLING** 5.00 ft / Elev 69.88 ft
NOTES
AFTER DRILLING ---

DEPTH (ft)	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)
0.0	Asphalt (FILL).			
	Concrete (FILL).			
	Sand with fines (SP/SM).			
2.5	Firm to stiff; tan CLAY with redox mottling, silty with trace fine sand (CL).	SS	78	2-4-8 (12)
	Sandy clayey SILT grading to silty SAND at 4' bgs (SP/SM).			
	Medium dense; medium to coarse grained SAND with some gravel (SW/GW).			
5.0	▼	SS	56	9-13-9 (22)
	Tan CLAY with blocky fracture, some redox mottling (CL).			
7.5	▽			
	Medium dense to dense; gravelly well-graded SAND with some silt grading to fine sand at 16.3' bgs (SW/SM). 15% gravel, 78% sand, 7% fines.	SS	72	10-22-26 (48)
10.0		SS	83	13-15-18 (33)
12.5		SS	100	12-14-15 (29)
15.0		SS	94	5-9-10 (19)
	CLAY (CL).			

Bottom of borehole at 16.5 feet.

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BORING NUMBER B3

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Drainage Improvement Project
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 2/18/16 **COMPLETED** 2/18/16
GROUND ELEVATION 75.21 ft NAVD 88 **HOLE SIZE** 3 inches
DRILLING CONTRACTOR Holocene Drilling Inc.
GROUND WATER LEVELS:
DRILLING METHOD Hollow Stem Auger (HSA)
AT TIME OF DRILLING --- No groundwater observed during/after drilling.
LOGGED BY MG **CHECKED BY** PP
AT END OF DRILLING ---
NOTES
AFTER DRILLING ---

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	FINES CONTENT (%)
0.0		Asphalt (FILL).										
		Concrete (FILL).										
		Medium dense; poorly graded GRAVEL with sand and occasional cobbles (GP/GW).										
2.5			SS	44	5-6-7 (13)							
5.0		Note: Coarse gravel and cobbles, rough drilling F/~5' T/ ~8' bgs.										
			GB									
7.5												
10.0		52% gravel, 45% sand, 3% fines (composite sieve, 10-16.5 feet bgs).	SS	61	7-13-15 (28)							
12.5			SS	56	12-14-14 (28)							
15.0			SS	56	11-12-11 (23)							

Bottom of borehole at 16.5 feet.

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BORING NUMBER B4

CLIENT City of Bellingham Public Works Department
PROJECT NAME Columbia Neighborhood Drainage Improvement Project
PROJECT NUMBER 2014221
PROJECT LOCATION Columbia Neighborhood - Bellingham, WA
DATE STARTED 2/18/16 **COMPLETED** 2/18/16
GROUND ELEVATION 76.63 ft NAVD 88 **HOLE SIZE** 3 inches
DRILLING CONTRACTOR Holocene Drilling Inc.
GROUND WATER LEVELS:
DRILLING METHOD Hollow Stem Auger (HSA)
AT TIME OF DRILLING --- No groundwater observed during/after drilling.
LOGGED BY MG **CHECKED BY** PP
AT END OF DRILLING ---
NOTES
AFTER DRILLING ---

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
0.0		Asphalt (FILL).										
		Pit run (FILL).										
		Loose to dense; poorly graded GRAVEL with silt, sand and occasional cobbles (GP). 55% gravel, 36% sand, 9% fines.										
2.5			SS	22	6-5-4 (9)							
5.0			SS	22	4-9-15 (24)							
7.5			SS	22	5-5-14 (19)							
10.0			SS	22	14-19-24 (43)							
12.5			SS	56	14-15-11 (26)							

Bottom of borehole at 14.0 feet.

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BORING NUMBER B5

CLIENT City of Bellingham Public Works Department

PROJECT NAME Columbia Neighborhood Drainage Improvement Project

PROJECT NUMBER 2014221

PROJECT LOCATION Columbia Neighborhood - Bellingham, WA

DATE STARTED 2/18/16 **COMPLETED** 2/18/16

GROUND ELEVATION 80.07 ft NAVD 88 **HOLE SIZE** 3 inches

DRILLING CONTRACTOR Holocene Drilling Inc.

GROUND WATER LEVELS:

DRILLING METHOD Hollow Stem Auger (HSA)

▽ **AT TIME OF DRILLING** 6.00 ft / Elev 74.07 ft

LOGGED BY MG **CHECKED BY** PP

AT END OF DRILLING ---

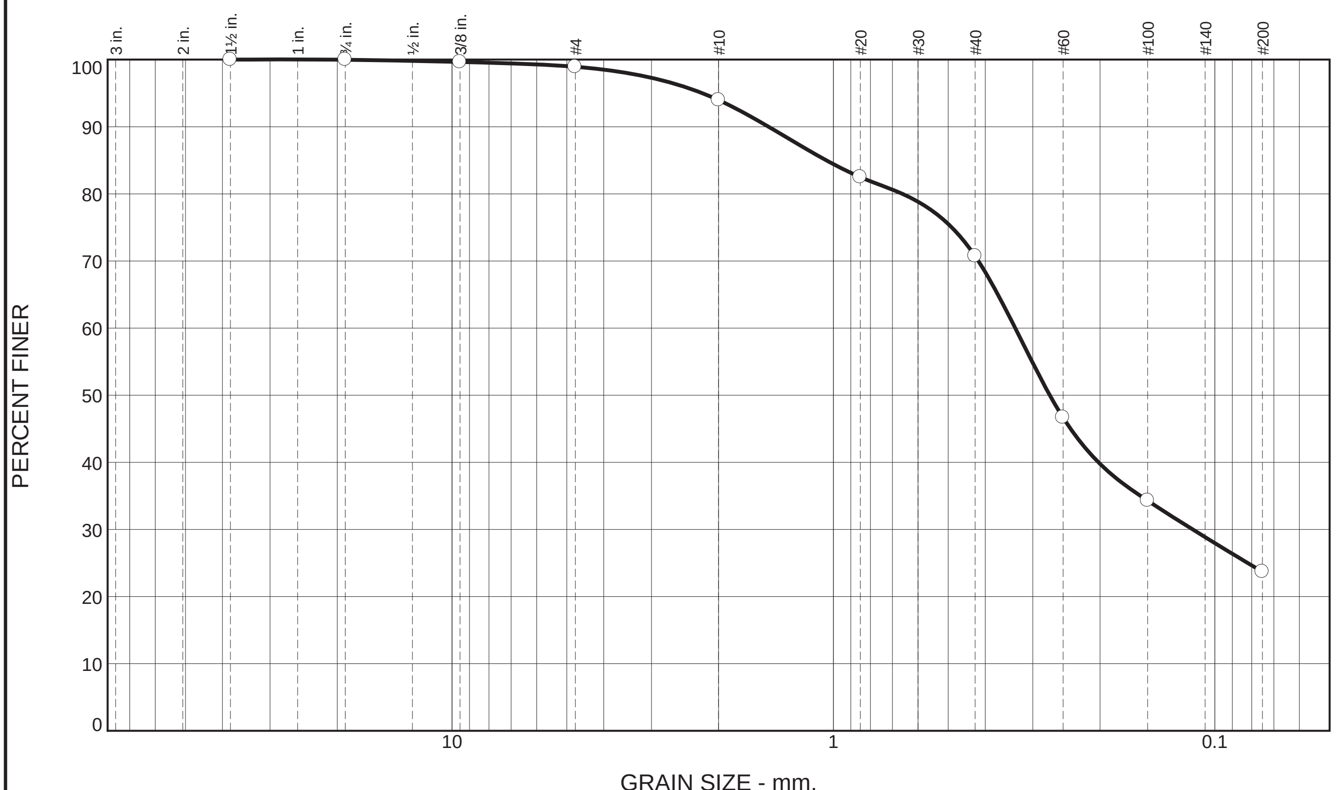
NOTES

▼ **0.1hrs AFTER DRILLING** 5.75 ft / Elev 74.32 ft

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
0.0		Asphalt (FILL).										
		Concrete (FILL).										
		Asphaltic road bed material (FILL).										
2.5		Disturbed ground (FILL); medium dense; silty CLAY with redox mottling, gravel and silt. Note: Approx 1" diameter metal pipe (unmarked inactive utility) encountered at ~6' bgs; temporarily halted drilling, continued drilling T/ TD after confirming utility was inactive.	SS	39	3-7-13 (20)							
5.0		Blow count exaggerated over interval (5' - 6.5') due to buried pipe.	NR	0	17-40-43 (83)							
		Medium dense; angular, well graded GRAVEL (GW).										
7.5		Stiff; silty CLAY with trace very fine sand (CL/ML).	SS	83	10-9-4 (13)							
		Firm to stiff; glaciomarine drift CLAY (CL).										
10.0			SS	100	2-3-7 (10)							
12.5		Loose; fine to very fine SAND with silt (SP/SM).	SS	100	3-2-4 (6)							
		Very soft; glaciomarine drift CLAY (CL).										
15.0			SS	100	1-1-1 (2)							

Bottom of borehole at 16.5 feet.

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	0	1	5	23	47	24

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	100		
3/8"	100		
#4	99		
#10	94		
#20	83		
#40	71		
#60	47		
#100	34		
#200	24		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-1 at 2.5-6.4 feet
silty sand

Atterberg Limits

PL= NP LL= NV PI=

Coefficients

D_{90}= 1.4790 D_{85}= 1.0442 D_{60}= 0.3337
D_{50}= 0.2708 D_{30}= 0.1143 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

Specification was not provided by client.

Location: Columbia Neighborhood Geotechnical - B-1 at 2.5-6.4 feet
Sample Number: 7367 **Date:** 2-18-2016

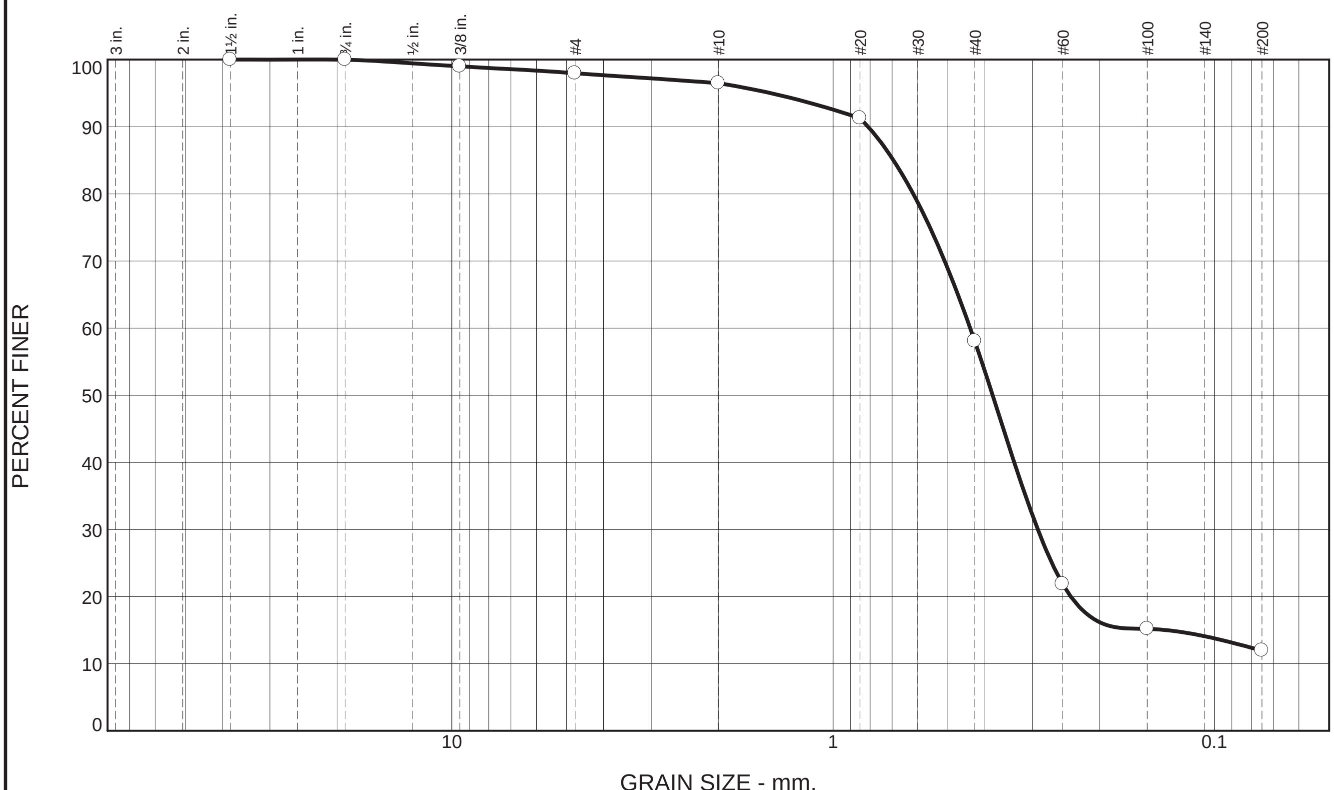
GEOTEST

Client: Element Solutions
Project: General Services

Project No: 16-0077 **Figure** SA006

Tested By: SE **Checked By:** DL

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	0	2	2	38	46	12

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	100		
3/8"	99		
#4	98		
#10	96		
#20	91		
#40	58		
#60	22		
#100	15		
#200	12		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-1 at 7.5-11.5 feet
poorly graded sand with silt

Atterberg Limits

PL= NP LL= NV PI=

Coefficients

D_{90}= 0.8091 D_{85}= 0.6945 D_{60}= 0.4369
D_{50}= 0.3816 D_{30}= 0.2906 D_{15}= 0.1337
D_{10}= C_u= C_c=

Classification

USCS= SP-SM AASHTO=

Remarks

Specification was not provided by client.

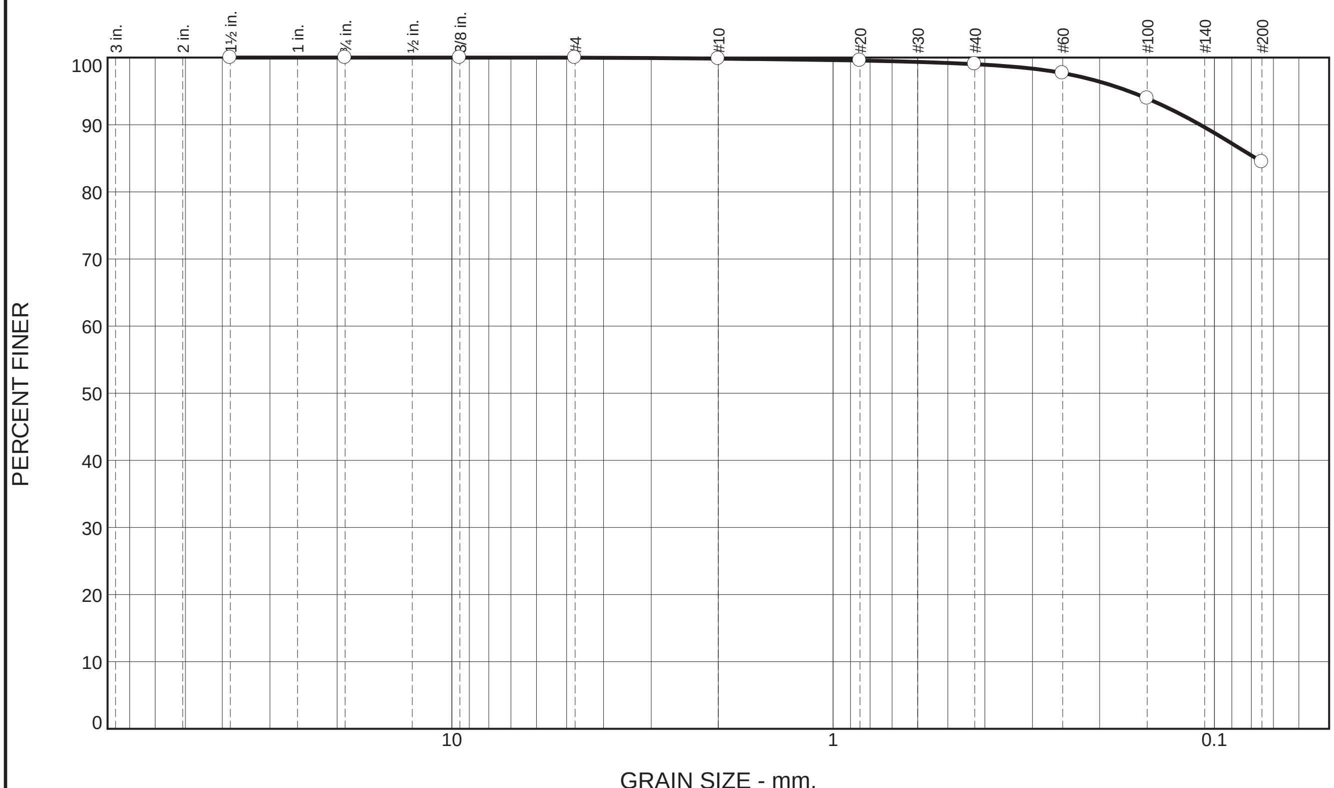
Location: Columbia Neighborhood Geotechnical - B-1 at 7.5-11.5 feet
Sample Number: 7368
Date: 2-18-2016

GEOTEST

Client: Element Solutions
Project: General Services
Project No: 16-0077
Figure SA007

Tested By: SE **Checked By:** DL

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	0	0	0	1	15	84

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	100		
3/8"	100		
#4	100		
#10	100		
#20	100		
#40	99		
#60	98		
#100	94		
#200	84		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-1 at 12.5-13.5 feet
silt with sand

Atterberg Limits

PL= NP LL= NV PI=

Coefficients

D_{90}= 0.1092 D_{85}= 0.0777 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= ML AASHTO=

Remarks

Specification was not provided by client.

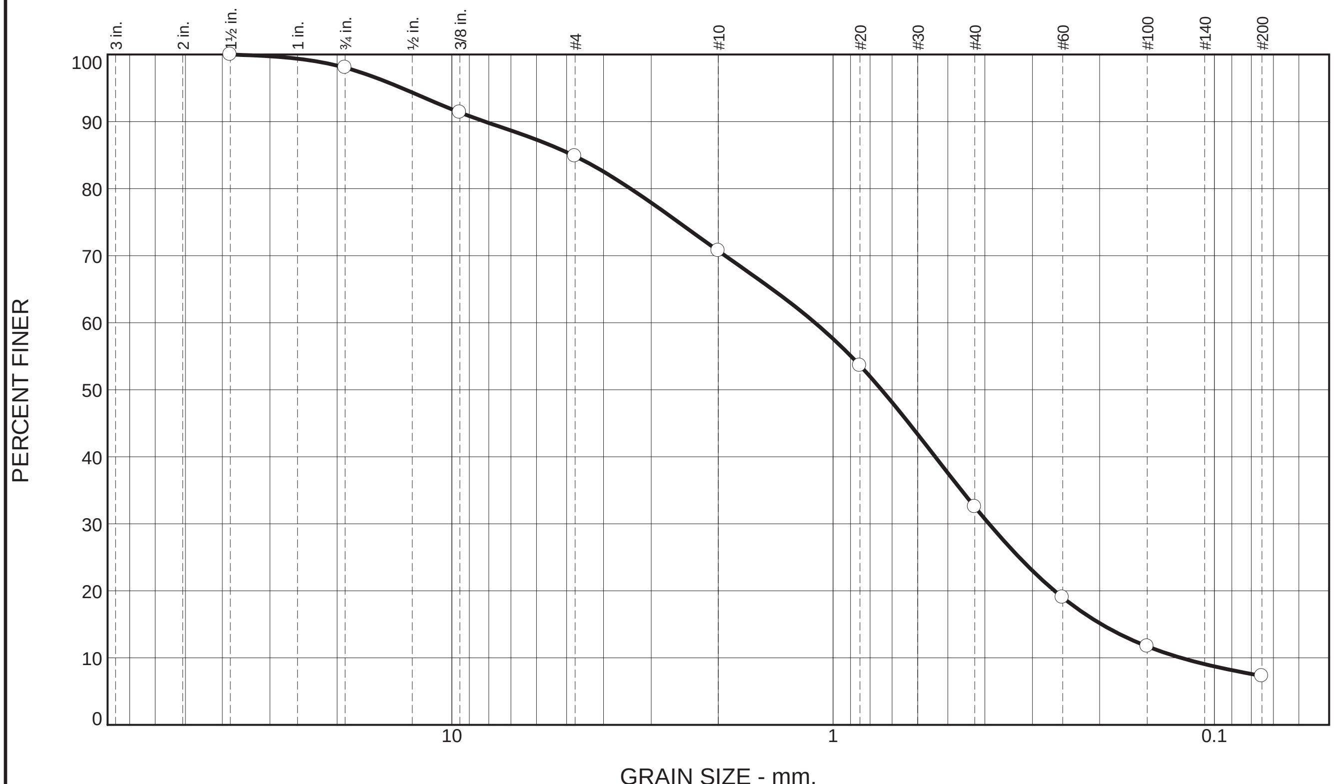
Location: Columbia Neighborhood Geotechnical - B-1 at 12.5-13.5 feet
Sample Number: 7365 **Date:** 2-18-2016

GEOTEST

Client: Element Solutions
Project: General Services
Project No: 16-0077 **Figure** SA004

Tested By: SE **Checked By:** DL

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	2	13	14	38	26	7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	98		
3/8"	91		
#4	85		
#10	71		
#20	54		
#40	33		
#60	19		
#100	12		
#200	7.3		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-2 at 10-14 feet
well-graded sand with silt and gravel

Atterberg Limits

PL= NP LL= NV PI=

Coefficients

D_{90}= 8.1909 D_{85}= 4.8158 D_{60}= 1.1162
D_{50}= 0.7465 D_{30}= 0.3901 D_{15}= 0.1977
D_{10}= 0.1223 C_u= 9.13 C_c= 1.11

Classification

USCS= SW-SM AASHTO=

Remarks

Specification was not provided by client.

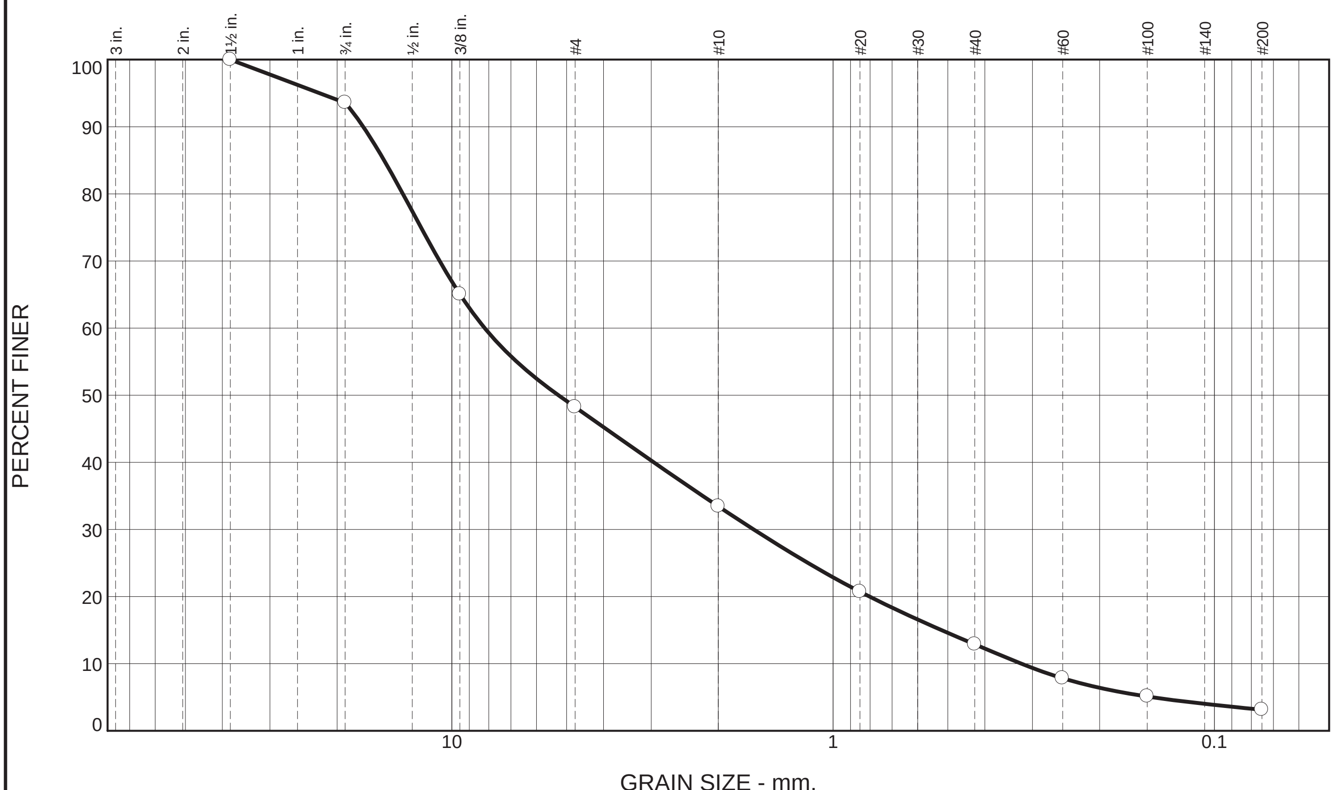
Location: Columbia Neighborhood Geotechnical - B-2 at 10-14 feet
Sample Number: 7366
Date: 2-18-2016

GeoTest

Client: Element Solutions
Project: General Services
Project No: 16-0077 **Figure** SA005

Tested By: SE **Checked By:** DL

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	6	46	15	20	10	3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	94		
3/8"	65		
#4	48		
#10	33		
#20	21		
#40	13		
#60	8		
#100	5		
#200	3.1		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-3 at 10-16.5 feet
poorly graded gravel with sand

Atterberg Limits

PL= LL= NV PI=

Coefficients

D_{90}= 17.0758 D_{85}= 15.0584 D_{60}= 8.1953
D_{50}= 5.2524 D_{30}= 1.6161 D_{15}= 0.5193
D_{10}= 0.3209 C_u= 25.54 C_c= 0.99

Classification

USCS= GP AASHTO=

Remarks

Specification was not provided by client.

Location: Columbia Neighborhood Geotechnical - B-3 at 10-16.5 feet
Sample Number: 7369

Date: 2-18-2016

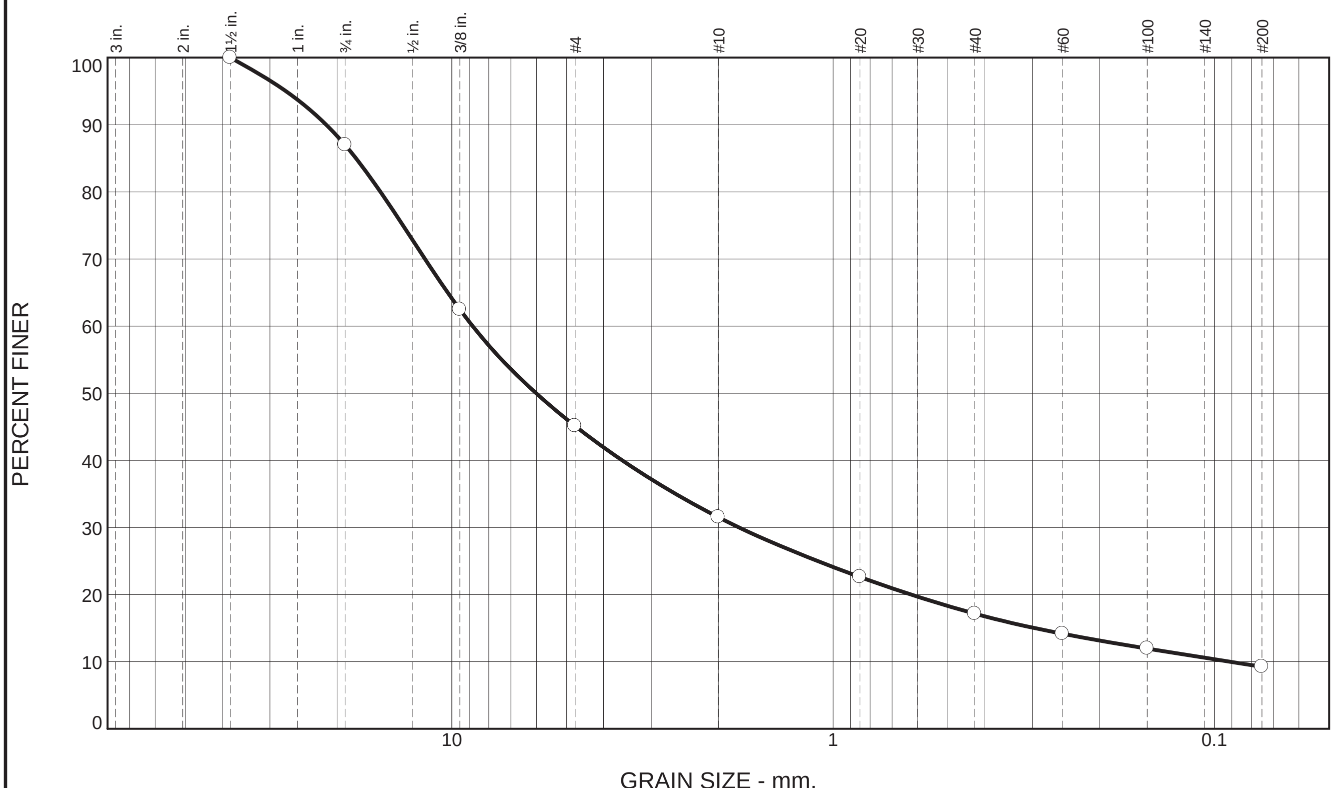
GEOTEST

Client: Element Solutions
Project: General Services

Project No: 16-0077 **Figure** SA008

Tested By: SE **Checked By:** DL

Sieve Analysis Test Report - ASTM C136/C117



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	Silt
0	13	42	13	15	8	9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1-1/2"	100		
3/4"	87		
3/8"	62		
#4	45		
#10	32		
#20	23		
#40	17		
#60	14		
#100	12		
#200	9.2		

* (no specification provided)

Material Description

Columbia Neighborhood Geotechnical
B-4 at 5-14 feet
poorly graded gravel with silt and sand

Atterberg Limits

PL= NP LL= NV PI=

Coefficients

D_{90}= 21.3511 D_{85}= 17.8449 D_{60}= 8.8187
D_{50}= 6.0182 D_{30}= 1.7651 D_{15}= 0.2960
D_{10}= 0.0912 C_u= 96.66 C_c= 3.87

Classification

USCS= GP-GM AASHTO=

Remarks

Specification was not provided by client.

Location: Columbia Neighborhood Geotechnical - B-4 at 5-14 feet
Sample Number: 7364
Date: 2-18-2016

Client: Element Solutions
Project: General Services
Project No: 16-0077 **Figure** SA003

Tested By: SE **Checked By:** DL

APPENDIX D

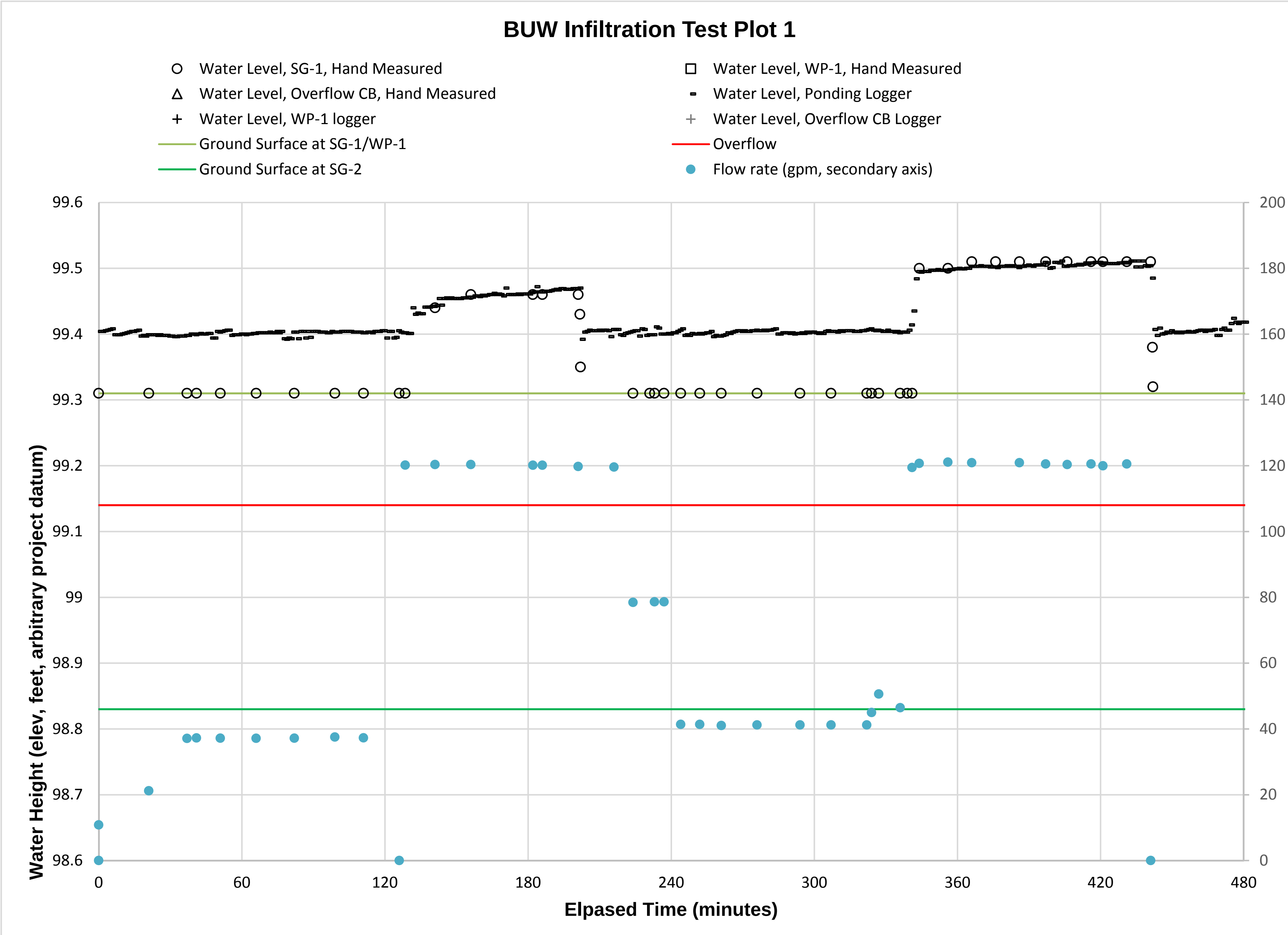
Soil Probe, Level Survey, and Field Infiltration Testing Data

Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5, 9
Date:	11/15/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	37.0
Test No.:	BUW	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Glaciomarine drift/Fill

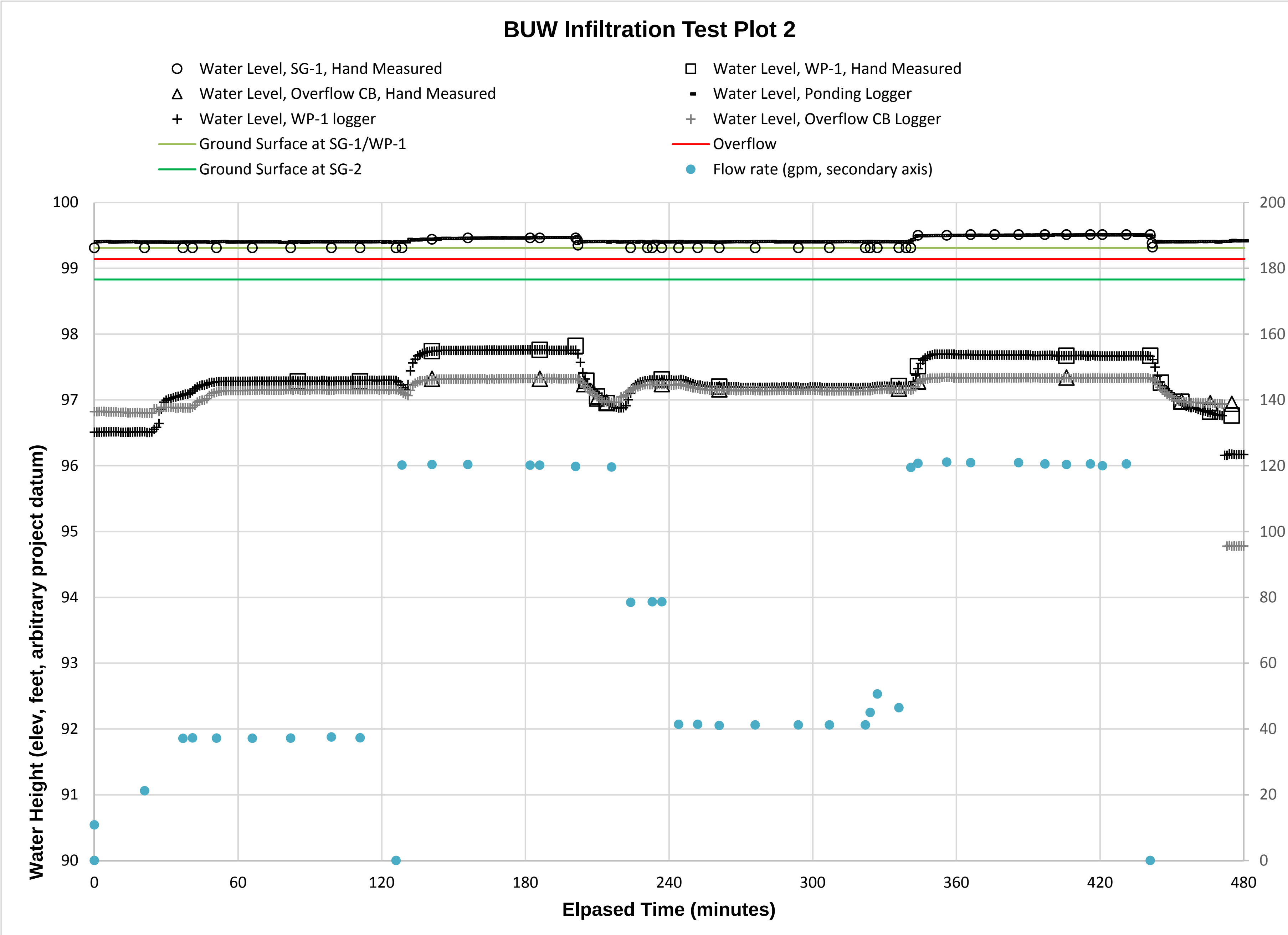
Time (24-hr)	Flow Rate (gpm)	SG-1 Stage (feet)	Totalizer (gallons)	Comments
	0		0	Initial hydrant flush by City, water enters cell.
			0	Hydrant leaking aprox. 0.5 gpm, continues throughout test, leak flows to cell.
8:39	10.82	0	0	Flow on
9:00	21.2	0	220.19	
9:16	37.12	0	557.89	
9:20	37.24	0		Underdrain flow observed.
9:30	37.17	0	1056	Underdrain flowing, minimal ponding.
9:45	37.15	0	1613	Installed SG-2 near overflow grate.
10:01	37.19	0	2233	
10:04				
10:18	37.52	0	2850	
10:30	37.3	0	3299	
10:45	0	0	3853	Flow off,remove FM9
10:47	120.18	0	3853	Flow on FM5
10:48				North inlet weir backwatered.
11:00	120.34	0.13	5322	Underdrain pipe backed up with silty water. At northern inlet, ~5gpm (visual estimate) is flowing back out inlet to curb and back in via southern inlet.
11:15	120.34	0.15	7090	Water in overflow nearly at top of weir.
11:41	120.15	0.15	10240	Water discharge from underdrain is silty.
11:45	120.15	0.15	10665	Wetted area ~35 sq ft
12:00	119.76	0.15	12516	
12:00		0.12		
12:01		0.04		Water in underdrain is becoming less silty
12:01		dry		
12:03				
12:04				Light rain begins.
12:09				
12:13				Light rain continues
12:15	119.6		12516	Flow redirected to curb
12:19				Water flowing past N curb cut to S curb cut, into overflow
12:23	78.45	0		water bypassing south weir, pooling on road
12:30		0		

12:32	78.62	0	14060	Sides of curb cut lining adjusted, no bypass. Overflow receiving appro 5 gpm.
12:36	78.62	0	14390	~2gpm flowing past south curb cut to storm drain
12:43	41.4	0		
12:51	41.4	0	15316	Rain stopped
13:00	41.04	0	15666	
13:15	41.22	0	16286	
13:33	41.22	0	17020	
13:46	41.22	0	17604	
14:01	41.22	0	18189	
14:03	45			
14:06	50.6			
14:15	46.46	0	18854	
14:18				
14:20	119.44		19094	Discharge moved into cell near WP-1
14:23	120.71	0.19	19416	
14:35	121.08	0.19	20858	
14:45	120.9	0.2	22064	
14:55	12090	0.2	23270	
15:05	120.9	0.2	24503	
15:16	120.52	0.2	25882	
15:25	120.34	0.2	26966	
15:35	120.52	0.2	28074	
15:40	119.96	0.2	28716	
15:50	120.52	0.2	29890	
16:00	0	0.2	31121	Flow off
16:00		0.07		
16:00		0.01		
16:01				
16:04				
16:13				
16:25				
16:34				
16:45				

	Average Infiltration Rate (in/hr) during last hour of inflow:	310
	Average Infiltration Rate (in/hr) during falling head:	147



BUW Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Water Level, Overflow CB Logger
Ground Surface at SG-1/WP-1
Overflow
Ground Surface at SG-2
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
Elpased Time (minutes)
99.6
99.5
99.4
99.3
99.2
99.1
99
98.9
98.8
98.7
98.6
0
60
120
180
240
300
360
420
480
200
180
160
140
120
100
80
60
40
20
0


BUW Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Water Level, Overflow CB Logger
Ground Surface at SG-1/WP-1
Overflow
Ground Surface at SG-2
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
100
99
98
97
96
95
94
93
92
91
90
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)

APPENDIX E

Site Photos

Cell BUW, primary curb cut inlet. Above photo is prior to install
of weir. Lower photo is after weir install and during infiltration testing.

Above photo: BUW secondary curbcut. Overflow beehive just visible in vegetation, upper right.
Lower Photo: close up of overflow structure.

APPENDIX 5

Deliverable Task 4.5, Site FWI Geotechnical/Soils Assessment Design Data and Current Conditions, Wainwright Intermediate School, Fircrest, Washington. Associated Earth Sciences, Inc. 6/11/2019

Technical Memorandum

Date:	June 11, 2019	**From:**	Anton Ypma Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site FWI Geotechnical/Soils Assessment Design Data and Current Conditions, Wainwright Intermediate School, Fircrest, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Facility Cell #4 of the Wainwright Intermediate School Project, located in the city of Fircrest, Washington (Figure FWI F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 2, 2018, infiltration testing on October 25, 2018, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle-size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure FWI F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Wainwright Intermediate School Project, located in Fircrest, Washington as shown on the attached "Vicinity Map" (Figure FWI F1). The Wainwright Intermediate School is located on a pair of parcels totaling 7.27 acres. The site is bordered by single-family residences on the north, west, and south, and by single-family residences and Almaeda Avenue to the east. Site topography is generally gently sloping down towards the south. No on-site surface water features are present. Per the Washington State Source Water Assessment Program (SWAP) Mapping Application, the site is located within the 1-year time of travel for the City of Fircrest Well #9, a Group A water supply well. Our specific area of study for this project includes bioretention cell #4 located on the northern portion of campus in the parking lot traffic island, referred to as cell FWI for this study.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Subsurface Exploration, Infiltration Assessment, and Geotechnical Engineering Evaluation, Wainwright Elementary School Renovation," Associated Earth Sciences, Inc., December 2014.
- "Stormwater Site Plan, Wainwright Intermediate School," AHBL, March 2015, Revised May 2015.
- Wainwright Intermediate School, Bid Set, DLR Group, May 29, 2015.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell FWI consists of an approximately triangular-shaped bioretention cell with approximately 159 square feet of base area, as shown on Figure FWI F2, "Facility and Exploration Plan." We understand that the site was developed under the Washington State Department of Ecology (Ecology) 2014 *Stormwater Management Manual for Western Washington* (2014 Ecology Manual) for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 1.5 inches per hour (in/hr) in the native subgrade. Land use within the drainage basin is primarily roadway and parking area. Per Storm Drainage Notes and Details, plan sheet C4.3 (DLR Group, May 29, 2015), the facility design includes 18 inches of bioretention soil mix overlying a minimum 1-foot-thick rock-filled trench. The rock-filled trench contains a 6-inch-diameter perforated underdrain pipe bedded in "¾ to 1½ inch" washed rock. The underdrain pipe is a minimum of 0.5 feet above the base of the washed rock layer. The underdrain pipe discharge to another stormwater detention cell.

The facility is designed to infiltrate 96.25 percent of inflow into the subgrade. Stormwater enters the facility through two curbcuts. If water ponds up on the bioretention soil, the ponded water would discharge into a yard drain (YD 25) with a beehive grate located near the southern perimeter, and then into the on-site stormwater system. The rim of the yard drain was designed to be 1 foot higher than the cell base to create 1 foot of ponding depth. The facility was constructed during 2016 and is likely to have begun receiving inflow in 2017.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure FWI F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the top of the concrete lamp post base on the east side of the cell (identified on the "FWI Level Survey Data" map in Appendix D) defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: Two curbcuts allow inflow into cell FWI.
    - The eastern inlet (Inlet 1) to the facility is a 2-foot curbcut consistent with project plans, which discharges onto a rounded rock energy dissipation pad approximately 5.5 to 8.5 feet wide and 11.5 feet long. Minor leaf litter was present, concentrated near the inlet.
    - The western inlet (Inlet 2) to the facility is a 2-foot curbcut, consistent with project plans which discharges onto a rounded rock energy dissipation pad approximately 6 to 9 feet wide and 10.5 feet long. Minor leaf litter with vegetation growth and silt were present. A rill, 0.5 to 1 foot wide and 1 to 2 inches deep, was observed where flow was concentrated between grass clumps in the inlet. The rill did not extend to the cell base.
    - AESI observed that the plan sheets indicate that the energy dissipater pads shall consist of 6-inch streambed cobbles. AESI observes that the energy dissipater pads generally consist of approximately ¾-inch to 1½-inch gravel with cobbles.

- Overflow: The overflow consists of a yard drain (YD 25) with a beehive grate. The rim of this grate was approximately 1.4 feet above the adjacent base of the facility, and approximately 1 foot above the majority of the facility base area. One pipe exits the yard drain to convey water to the storm drain system.

- AESI observed that the base of the facility is not level. The low point in the base of the facility, near the overflow and the western inlet, was approximately 0.4 feet lower than the majority of the facility base area.

- AESI investigated the loose bioretention soil thickness present in cell FWI using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 4-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.1 to 1.7 feet and averaged 1.5 feet. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell FWI
Level Survey Data

Location	Elevation (feet, project datum)
WP-1 TOC	96.04
WP-1 GS (S)/Temp SG#1	94.28
Ponding Tube TOC (Baro)	95.74
Ponding Tube TOC (DL)	95.17
Overflow PVC TOC LOW (W)	95.22
Inlet (W) 8" green pipe top/end	95.56
Inlet (W) Curbcut LOW (N)	95.36
Inlet (E) 6" green pipe top/end	96.41
Inlet (E) Curbcut LOW (S)	96.26
In CB PVC TOC (DL)	95.54
In CB PVC TOC (Baro)	94.95
CB inside lip, SE corner	95.87

TOC: top of casing; GS: ground surface; DL: datalogger; PVC: polyvinyl chloride; CB: catch basin

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- *Draft Geologic Map for the Steilacoom 7.5 Minute Quadrangle*, U.S. Geological Survey (USGS), 2006.
- Natural Resource Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed February 2019.
- *Soil Survey of Pierce County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1979.
- Griffin, W.C., Sceva, J.E., Swenson, H.A., and Mundroff, M.J., *Water Resources of the Tacoma Area, Washington*, United States Department of the Interior, Geological Survey, 1962.

5.1 Regional Topography and Project Grading

The project site is situated on an undulating upland. The nearest surface water feature is China Lake approximately half a mile northeast of the site. Elevations on the larger project site range from about 290 feet on the northern edge, to 278 feet on the southern edge of the property.

On a closer scale, the area near cell FWI is at an elevation of 283 to 285 feet, and land use consists of a parking lot and drive lane which generally slopes down to the south and west. A curb separates the paved surfaces from the cell.

The project site was previously developed as Wainwright Intermediate School which was remodeled in 2016. The bioretention cells in the parking lot area, including cell FWI, were installed as part of the remodel. Minor cutting (about 3 feet) was needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the current draft U.S. Geological Survey (USGS) *Geologic Map for the Steilacoom 7.5 Minute Quadrangle* (USGS - Miscellaneous Field Investigation, 2006), the project site lies within an extensive zone of Vashon recessional outwash. This material is deposited by stream channels that emanate from a stagnant or receding glacier. Recessional outwash typically consists of loose to medium dense sands with varying amounts of silt and gravel. Thicknesses can range from a few feet to several tens of feet. Recessional outwash is commonly underlain by dense to very dense deposits of lodgement till or advance outwash. Vashon lodgement till is mapped in the site vicinity, and was deposited directly from basal, debris-laden, glacial ice during the Vashon Stade of the Fraser Glaciation, approximately 12,500 to 15,000 years ago. The high relative density characteristic of the Vashon lodgement till is due to its consolidation by the massive weight of the glacial ice from which it was deposited.

Background geotechnical information includes exploration logs EP-2 from approximately 50 feet south of cell FWI, and IT-2 from the location of bioretention cell #3, approximately 100 feet south of cell FWI. EP-2, dated October 29, 2014, and IT-2, dated December 2, 2014, both encountered sediments interpreted as till to the total depth explored of 6 and 10 feet, respectively. EP-1, approximately 150 feet northwest of cell FWI, encountered 1 foot of artificially-placed fill, and Vashon recessional outwash sediments to a depth of 6.5 feet, directly overlying Vashon lodgement till. Shallow fill soils were encountered in other explorations to a maximum depth of 5 feet.
This interpretation is generally consistent with the geologic mapping in the area.

- Vashon Recessional Outwash (Qvr): Where encountered in geotechnical explorations onsite, this deposit typically comprised loose to medium dense, weakly stratified sands, with minor amounts of silt and gravel. Recessional outwash was deposited during the retreat of glacial ice, and has not been glacially overridden.

- Vashon Lodgement Till (Qvt): Five of the eleven exploration pits previously observed onsite encountered medium dense to very dense glacial lodgement till below the site. This deposit typically consisted of silty sands with varying amounts of gravel, although the till surface was weathered to a silt in some locations. Depths to the till horizon ranged from zero (in EP-2 near cell FWI) to about 12 feet (in EP-3 near the southern edge of the property).

We inferred that the till horizon lies closely below the termination depths of most other exploration pits, reflecting a general dip toward the south or southwest.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the *Soil Survey of Pierce County Area, Washington* (Natural Resource Conservation Service [NRCS], 1979) and soils mapping from the NRCS web portal (NRCS, 2019). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Alderwood gravelly sandy loam soils. Alderwood formed from the weathering of glacial till, and typically perches shallow groundwater within the weathered soil horizon. NRCS describes the permeability as moderately well drained (NRCS, 2019) in the upper portion of the soil unit.

As described in the stormwater site plan (AHBL, 2015), the pre-developed condition was modeled as Type C soils. This is consistent with the 2014 Ecology Manual, which classifies the Alderwood soil as hydrologic soil group C.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in *Water Resources of the Tacoma Area, Washington* (Griffin et al., 1962). Griffin et al. (1962) indicates that recessional outwash is typically a productive aquifer, while the Vashon lodgement till typically perches water.

On a closer scale, in our previous explorations onsite, we observed slow groundwater seepage at a depth of approximately 6 feet in EP-3 near the southern edge of the site, and some orange mottling at depths ranging from about 1 to 8 feet in several other exploration pits. Groundwater is expected to perch at this shallower depth under the developed conditions due to stormwater infiltration from the bioretention cells and other site infiltration features.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and underlying aggregate rock. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure FWI F2, "Facility and Exploration Plan." Global Positioning System (GPS) coordinates for the explorations were taken using a handheld GPS, and are summarized in Appendix B.

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell FWI were completed on October 2, 2018. Light rainfall was noted, beginning shortly after the time of exploration.

Hand-auger boring number 1 (FWI-HA-1), which was completed in the southern portion of the cell, near the inflow, and hand-auger boring number 2 (FWI-HA-2), which was completed in the northern portion of the cell, encountered approximately 1.4 feet of bioretention soil, overlying material interpreted as drain rock to a total depth of 1.9 and 1.6 feet, respectively. Hand-auger boring number 3 (FWI-HA-3), situated in the eastern edge of the bioretention cell, encountered 2.4 feet of bioretention soil mix, overlying drain rock to a total depth of 2.5 feet. No seepage or caving were observed.

6.2 Well Points

A well point was installed in FWI-HA-1. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell FWI
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
FWI-HA-1/WP	FWI-HA-1	4.7	1.25 inch nominal	1.8	2.9

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology Manual. No material representative of the subgrade was encountered in our hand-auger explorations. The data is summarized in Table 3.

Table 3
Summary of Cell FWI
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
FWI-HA-1	0.1-0.5	Bioretention Soil	5.2	SAND, some silt, trace gravel (SP-SM)	5.2	6.9	0.9	Sand
FWI-HA-2	0.1-0.5	Bioretention Soil	5.0	SAND, some silt, trace gravel (SP-SM)	5.1	6.9	1.0	Sand
FWI-HA-3	0.1-0.5	Bioretention Soil	7.0	SAND, some silt, trace gravel (SP-SM)	5.5	7.3	0.9	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 5 and 7 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with some silt and trace gravel based on ASTM D2487 Unified Soil Classification System (USCS). The respective fines content as measured on the No. 200 sieve was 5.1 to 5.5 percent, higher than the recommended range of 2 to 5 percent. The remaining grain size fraction was within the recommended ranges. The coefficient of uniformity ranged from 6.9 to 7.3, meeting the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 0.9 to 1, lower than the recommended range of greater than or equal to 1 and less than or equal to 3. The tested bioretention soil was a poorly-graded sand.

7.2 Subgrade

In cell FWI, no samples of the subgrade could be obtained for this study due to the import gravel beneath the bioretention soil and difficulties hand auguring in this material. Based on the existing geotechnical information from previous explorations onsite, the subgrade could consist of either Vashon recessional outwash and/or Vashon lodgement till.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell FWI Site Data

Parameter	Recommended Range	Cell FWI
Organic Content (by weight)	5 to 8 percent	5.7 percent by weight
Cu coefficient of uniformity	4 or greater	7
Cc coefficient of curvature	1 to 3	0.9
Sieve Size	**Percent Passing**	
3/8” (9.51 mm)	100	99.7
#4 (4.76 mm)	95 to 100	98.6
#10 (2.0 mm)	75 to 90	78.4
#40 (0.42 mm)	25 to 40	28.6
#100 (0.15 mm)	4 to 10	8.5
#200 (0.074 mm)	2 to 5	5.3

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a “soaking period,” to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the “constant-head” phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the “falling-head” portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell FWI with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Water levels were monitored using a staff gauge (SG-1) marked in 0.01-foot increments installed adjacent to the well point, a second temporary metal staff gauge (SG-2) marked in 0.01-foot increments installed near in the deep point of the facility for the duration of the test, and within the well point with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The underdrain catchbasin was observed during testing to visually observe underdrain flow. The area of the pool was measured periodically during testing.

The infiltration test in cell FWI is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell FWI

AESI performed infiltration testing on October 25, 2018. Intermittent rainfall was noted during testing, and no flow from the inflow curbcuts was present.

During this test, flow was initially maintained at 12 to 50 gpm, then increased to 100 gpm, and finally increased to approximately 152 gpm (the maximum flow rate from the hydrant) for the remaining duration of test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the energy dissipation pad by the eastern inlet. Initially, the water pooled near in the deep point of the cell, while spreading across the majority of the base in a shallow pool less than 0.1 foot deep. After approximately 270 minutes, flow was increased to the maximum level, and the pool across the majority of the base grew to a depth of approximately 0.5 feet by the end of testing.

After approximately 7 hours, the water level in the wetted area was about 0.47 feet as measured on SG-1. The wetted pool area had been generally stable for about 2 hours, and had filled in the low areas near Inlet 1 and Inlet 2 covering an area of about 200 square feet. Approximately 45,000 gallons of water were used.

AESI observed that after approximately 15 minutes into the test the underdrain was active for the remaining duration of the test, and visually estimated that flow from the underdrain appeared similar to the inflow to the facility, indicating that most to all inflow left the cell via the underdrain.

Water in WP-1 was monitored with a data logger during the infiltration test and responded to inflow. Water was present at about 2 feet beneath the bioretention cell prior to the start of inflow, and likely represents perched water in the base of the drain rock. The water level in WP-1 responded to inflow after about 25 minutes, and rose approximately 1.3 feet during the course of testing. AESI interprets this response to indicate that water from the infiltration test infiltrated rapidly through the bioretention soil, perched on the native subgrade, and then mounded within the gravel base course before entering the underdrain.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 8 minutes for the majority of the facility, with a small amount in the deepest part of the facility near the overflow taking an additional approximately 35 minutes to drain.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the bioretention soil. AESI visually estimated that flow from the underdrain appeared similar to the inflow to the facility, indicating that the majority of inflow was leaving the facility via the underdrain and little to no inflow was infiltrating into the subgrade.

Table 5
Cell FWI
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
FWI (bioretention soil)	200	420	44,808	0.45	66	43
FWI (subgrade)	Perched water response in well point				Unknown; interpreted to be low based on the underdrain outflow	

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell FWI was generally consistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is generally consistent with the plans. Site design documents indicate that the ponding level was designed as 1 foot. Although the overflow sticks up 1.4 feet from the ground surface immediately around it, it is approximately 1 foot above the ground surface in the majority of the cell base.

- Bioretention soil:
    - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.5 feet as indicated on the plan.
    - Composition: The soil tested in generally the recommended guidelines for organic content and sand gradation, although the soil mix contained slightly more than the recommended range of silt and had a slightly low coefficient of curvature.

- Subgrade conditions: The subgrade could consist of either Vashon recessional outwash and/or Vashon lodgement till, based on previous explorations onsite. Based on the response of WP-1 during infiltration testing, and our observation that inflow appeared visually similar to the flow from the underdrain, we interpret that the subgrade has a low infiltration rate, and is most likely Vashon lodgement till.

- Bioretention soil field infiltration rate:
    - Measured at about 66 in/hr.
    - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the bioretention soil infiltration rate.

- Native subgrade infiltration rate: not measured. Previous infiltration testing in the weathered Vashon lodgement till onsite approximately 100 feet south of cell FWI measured an infiltration rate of 0.4 in/hr (AESI, 2014) with the water interpreted to be moving laterally during testing.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall
6/11/19

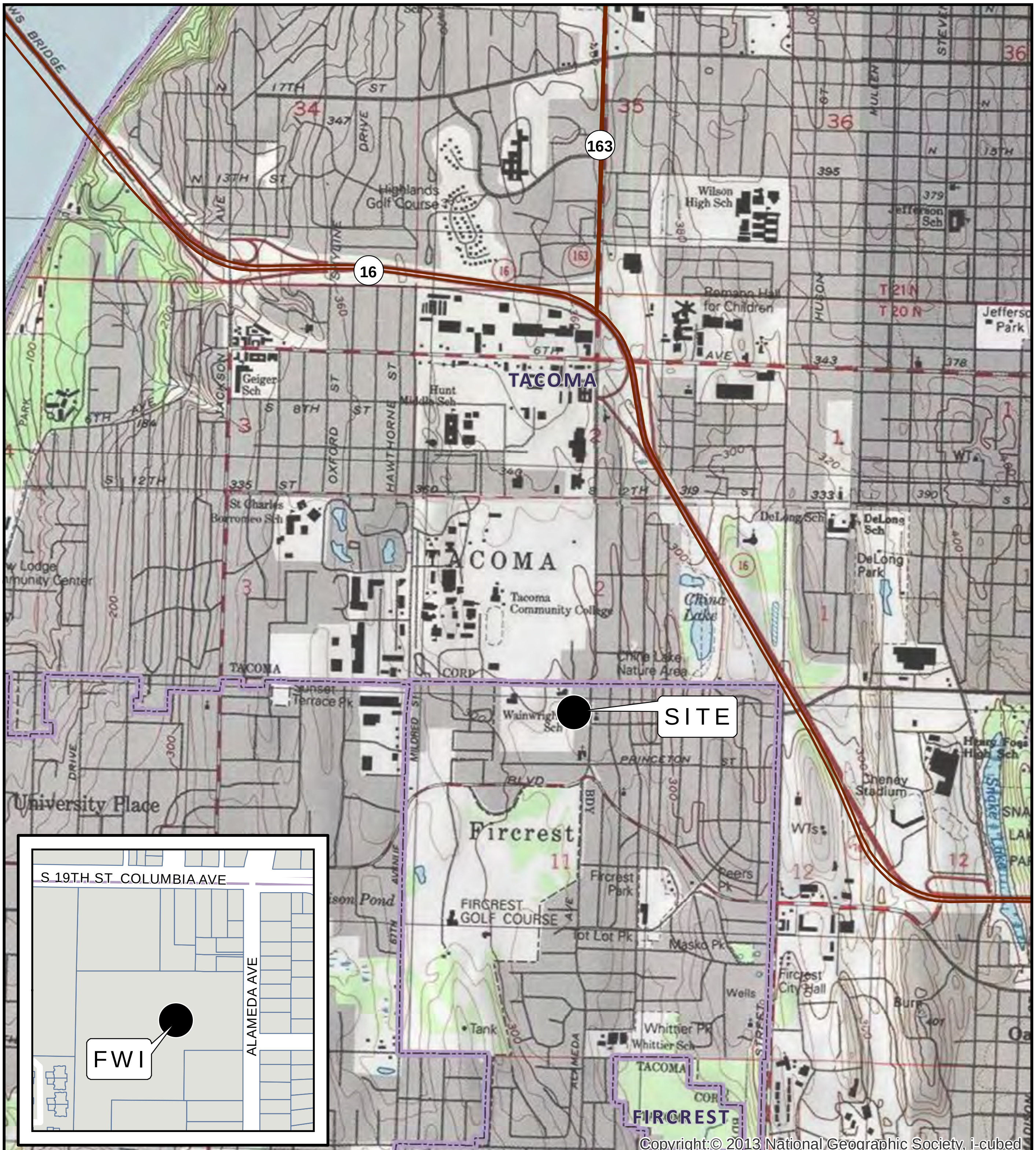
Anton D. Ypma
Staff Geologist

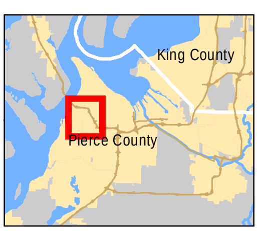
Suzanne S. Cook, L.G.
Senior Project Geologist

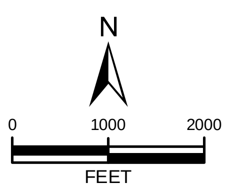
Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure FWI F1:	Vicinity Map
	Figure FWI F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

JHS/ld
150387H007-7
Projects\20150387\KH\WP







DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
PIERCE CO: STREETS, CITY LIMITS, PARCELS 1/18

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

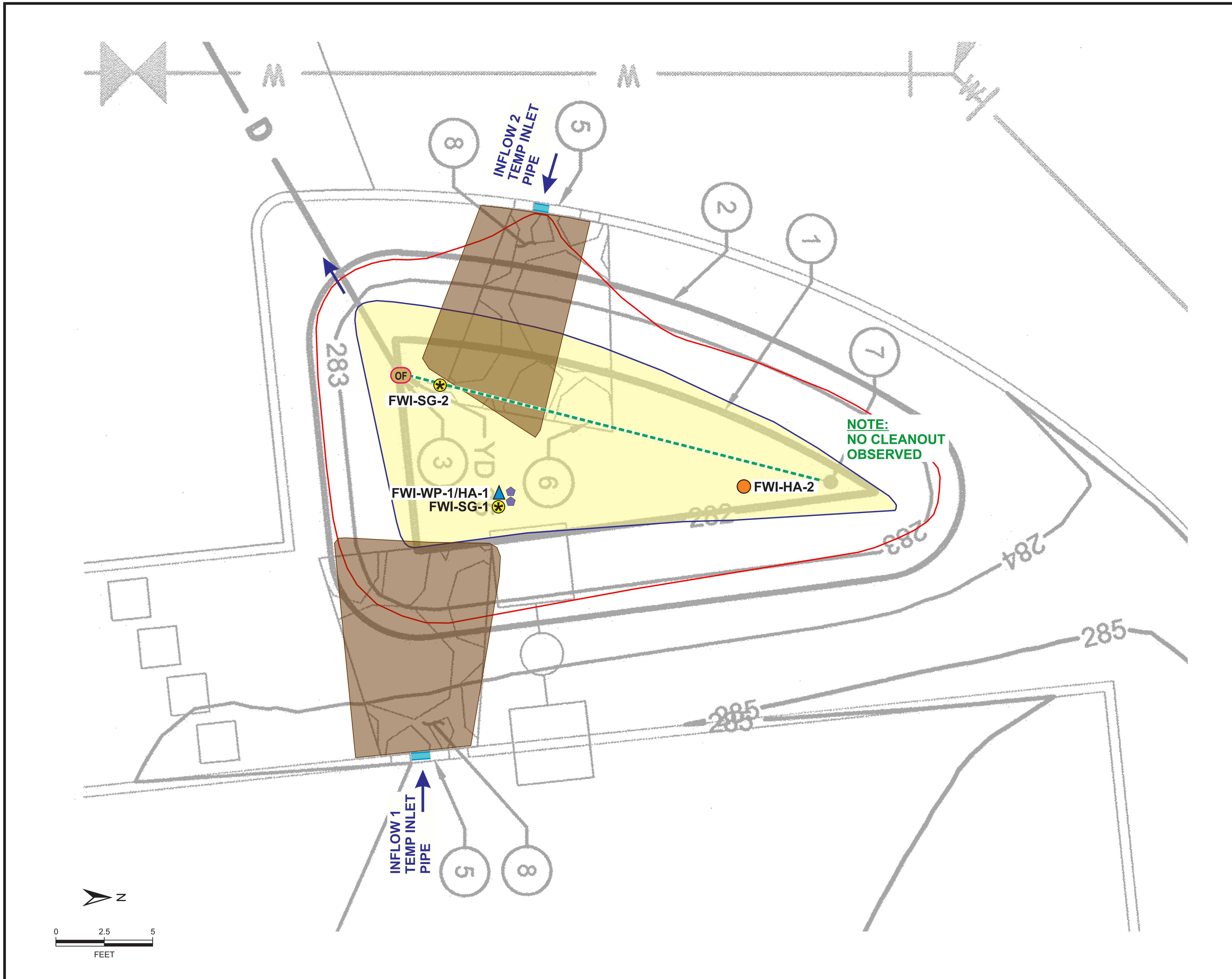
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, FWI SITE
FIRCREST, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	FWI F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_FWI.mxd



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 12" PVC YARD DRAIN
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: AHBL, DLR GROUP, WAINWRIGHT INTERMEDIATE SCHOOL , TACOMA PUBLIC SCHOOLS, STORM DRAINAGE NOTES AND DETAILS, SHEET C4.3, 5/29/15

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

associated earth sciences incorporated

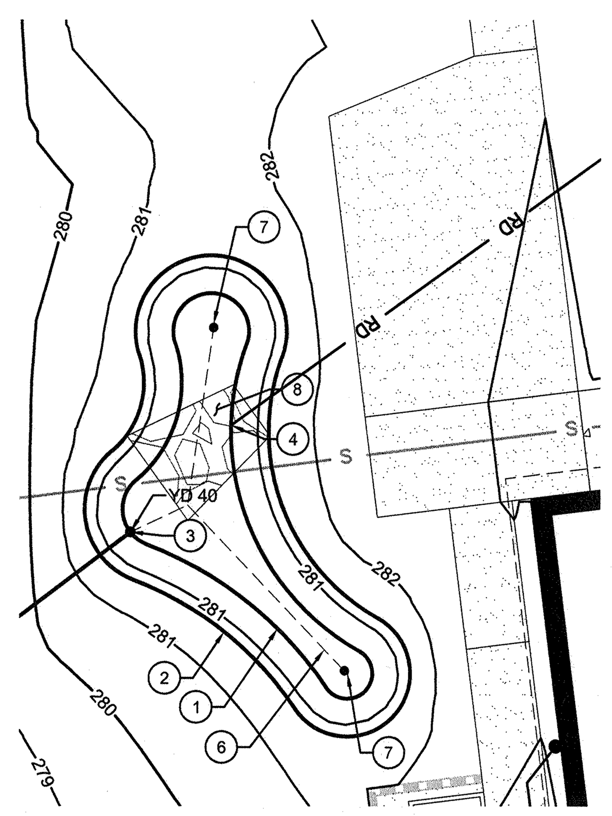
FACILITY AND EXPLORATION PLAN
FWI SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TACOMA, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	FWI F2

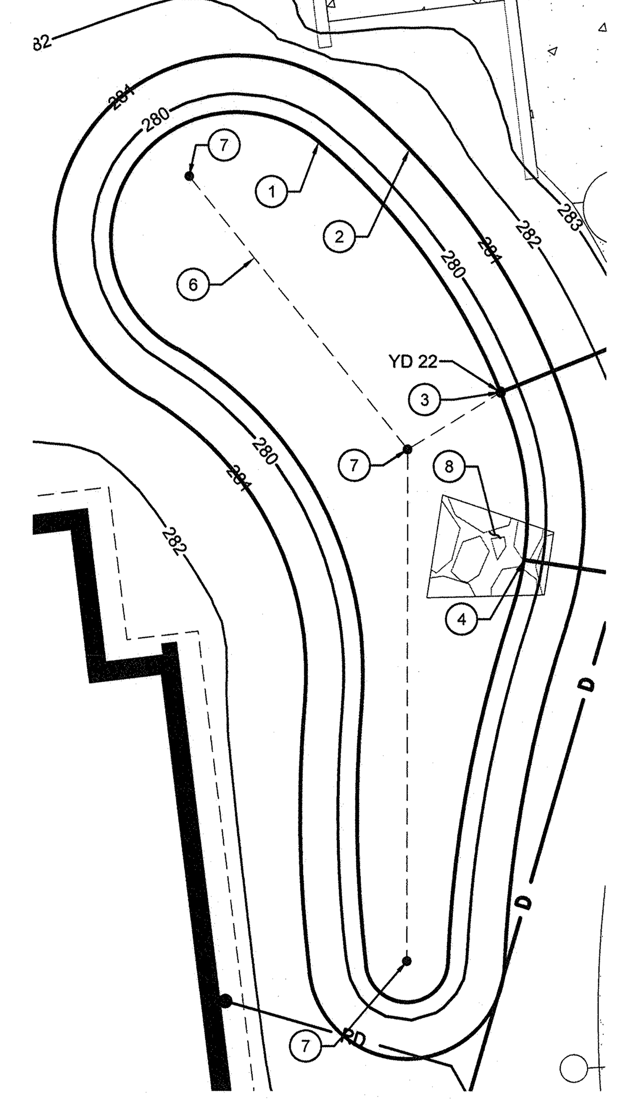
150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: FWI F2

APPENDIX A

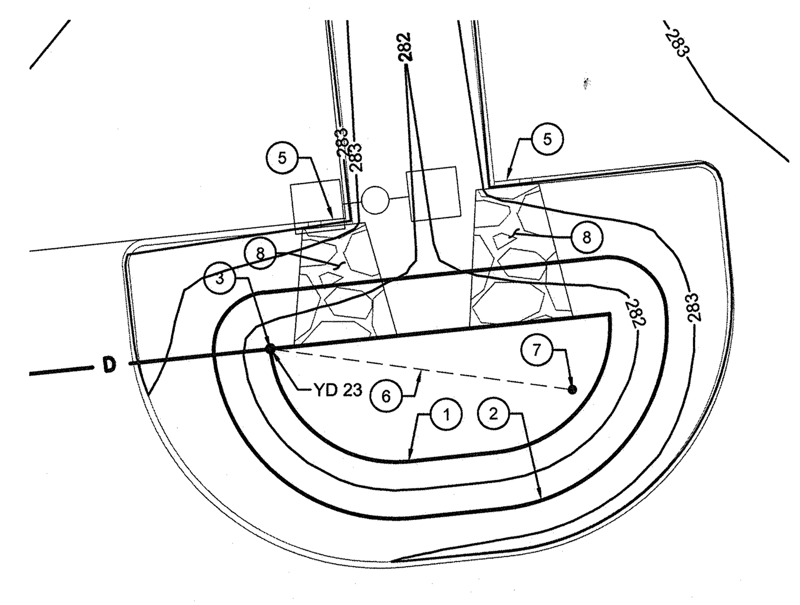
Project Civil Plans



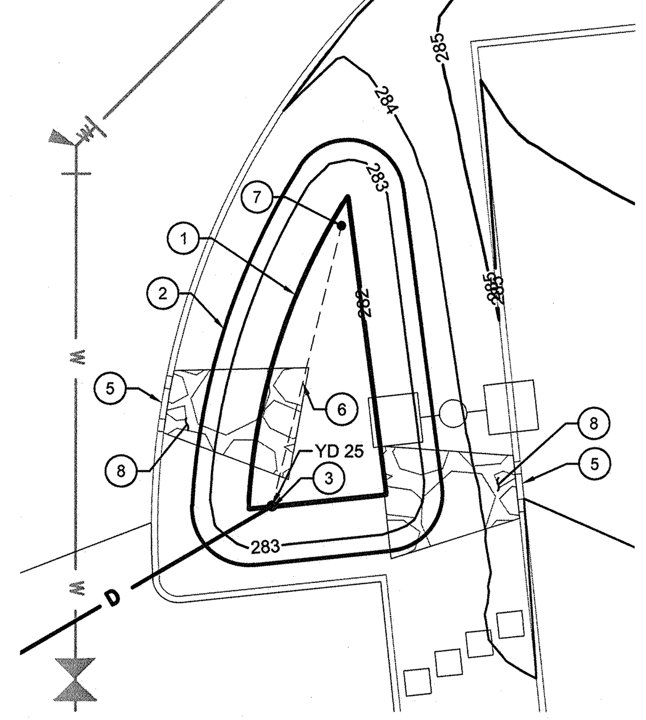
1 BIORETENTION CELL 1
SCALE: 1"=10'



2 BIORETENTION CELL 2
SCALE: 1"=10'



3 BIORETENTION CELL 3
SCALE: 1"=10'



4 BIORETENTION CELL 4
SCALE: 1"=10'

KEYNOTES

1. BOTTOM OF BIORETENTION CELL.
2. TOP OF BIORETENTION CELL.
3. OVERFLOW STRUCTURE. REFER TO SHEET C4.1.
4. END SECTION INLET.
5. CURB CUT INLET.
6. UNDERDRAIN PER BIORETENTION CELL DETAIL.
7. CLEANOUT. RIM SHALL MATCH BOTTOM OF BIORETENTION CELL. (6/C4.4)
8. RIP RAP PAD SHALL CONSIST OF 6" STREAMBED COBBLES PER WSDOT STANDARD SPECIFICATION 9-03.11(2). THICKNESS OF PAD SHALL BE 8" (MIN). LAYOUT AS SHOWN ON DRAWINGS.

BIORETENTION CELL REQUIREMENTS:

INSPECTION #1 - TESC AND GRADING

1. BIORETENTION AREAS SHALL NOT BE USED AS SEDIMENT CONTROL FACILITIES AND SHALL BE PROTECTED FROM SILTATION AND COMPACTION DURING CONSTRUCTION. ALL DRAINAGE SHOULD BE DIRECTED AWAY FROM BIORETENTION AREAS AFTER INITIAL ROUGH GRADING; BLOCK CELL INLETS WITH TEMPORARY CONCRETE OR SAND BAGS DURING CONSTRUCTION. IF SITE CONSTRAINTS REQUIRE BIORETENTION AREAS TO BE USED FOR SEDIMENT CONTROL, INITIALLY EXCAVATE TO 6" ABOVE FINAL GRADE, AND WHEN OTHER EARTH DISTURBING WORK IS DONE THEN EXCAVATE DOWN TO FINAL GRADE AND INSTALL THE BIORETENTION FACILITIES AS DESIGNED.
2. TESC IS CORRECTLY INSTALLED.
3. ROUGH GRADING (VERIFY CONSTRUCTION STAKING) AND BIORETENTION DIMENSIONS ARE TO PLAN.

INSPECTION #2 - BIORETENTION SOIL MIX (BSM) AND BIORETENTION

1. PRIOR TO INSPECTION, APPLICANT MUST SUBMIT SOIL TEST VERIFICATION (LAB REPORT WITHIN PAST 30 DAYS) TO PW INSPECTOR PRIOR TO SOIL INSTALLATION. SOIL TEST VERIFICATION SHOULD INCLUDE INFILTRATION RATE (MUST MATCH DESIGN INFILTRATION RATE), SIEVE ANALYSIS (LESS THAN 5% FINES), AND ORGANIC MATTER CONTENT (4-8% BY DRY WEIGHT).
2. SUBGRADE SOIL IS FREE OF CONSTRUCTION RUNOFF FINES. IF SEDIMENT HAS ENTERED THE BIORETENTION AREA, REMOVE ENOUGH SUBGRADE SOIL TO REMOVE THE FINES AND REPLACE WITH BSM.
3. OVERFLOWS AND UNDER-DRAINS ARE AT PROPER LOCATIONS AND ELEVATIONS.
4. EXCAVATED CELL SUBGRADE IS NOT OVER-SATURATED, AND BSM IS NOT SATURATED WHEN PLACED.
5. WASHED ROCK BACKFILL FOR UNDERDRAINS IS FREE OF FINES. IF FINES ARE PRESENT, REMOVE TOP 6 INCHES OF BACKFILL AND REPLACE.

INSPECTION #3 - BSM PLACEMENT AND PRE-PLANTING

1. VERIFY THE BSM SOIL DELIVERED MEETS SOIL TEST VERIFICATION (LAB REPORT FROM INSPECTION #2) WITH A TRUCKLOAD TICKET OR OTHER DOCUMENTATION.
2. BSM DEPTH AND CELL SIDE SLOPES ARE PER PLAN.
3. VERIFY PLACEMENT & PLANTS PRIOR TO PLANT INSTALLATION. PLANTS SHALL NOT BE INSTALLED NEXT TO WATER METERS.
4. IF PLANTING WILL BE MORE THAN 30 DAYS OUT; MULCH MUST BE PLACED IMMEDIATELY AFTER BSM PLACEMENT (PREVENTS WEED ESTABLISHMENT).

INSPECTION #4 - POST PLANTING AND MULCH

1. PLANT QUANTITIES ARE PER PLAN.
2. MULCH & COARSE COMPOST TYPE AND DEPTH (2-3 INCHES). VERIFY ESC IS ADEQUATE, AND NO SEDIMENT HAS ACCUMULATED ON THE MULCH.
3. FINISHED CELL ELEVATION (INCLUDING MULCH) IS BELOW SIDEWALKS, CURBS, DRIVEWAYS, AND OTHER PAVEMENT PER PLAN.
4. NO EXCESSIVE WEED OR OTHER INVASIVE PLANT ESTABLISHMENT.
5. ALL PIPES, CULVERTS, CONVEYANCE SYSTEMS, FLOW CONTROL STRUCTURES, INLET SPILLWAYS (2-3' DROP) AND OUTLET OVERFLOWS ARE FREE AND CLEAR OF DEBRIS.
6. TEMPORARY WATERING PLAN IS IN PLACE (EITHER ON-SITE IRRIGATION OR OTHER PLAN).

INSPECTION #5 - FINAL (STARTS MAINTENANCE BOND PERIOD)

1. FINAL GRADE PER PLAN, INCLUDING LETTER OF APPROVAL FROM DESIGN ENGINEER FOR FINAL SURVEY OF CELL VOLUME AND CONTRIBUTING AREA SIZE.
2. BSM IS NOT CLOGGED AND INFILTRATION RATE IS ADEQUATE THROUGH VISUAL ASSESSMENT. NO PONDING FOLLOWING PRECIPITATION EVENTS.
3. REMOVAL OF TESC.
4. INSTALLATION OF ADDITIONAL SOIL WILL BE NEEDED ALONG THE EDGE OF CELLS 1 TO 2 MONTHS AFTER CELL CONSTRUCTION (DUE TO SETTLING).
5. 1 YEAR VERIFICATION WALK THROUGH IS REQUIRED DURING MAINTENANCE BOND PERIOD.
6. DUE TO PLANT SURVIVAL RATE REQUIRED, DEVELOPER/CONTRACTOR MUST MAKE PROVISIONS FOR A WATER TRUCK OR TEMPORARY IRRIGATION FROM EXISTING SERVICE ONSITE FOR THE FIRST 2 YEARS AFTER FINAL.

INSPECTION #6 - END OF MAINTENANCE BOND PERIOD

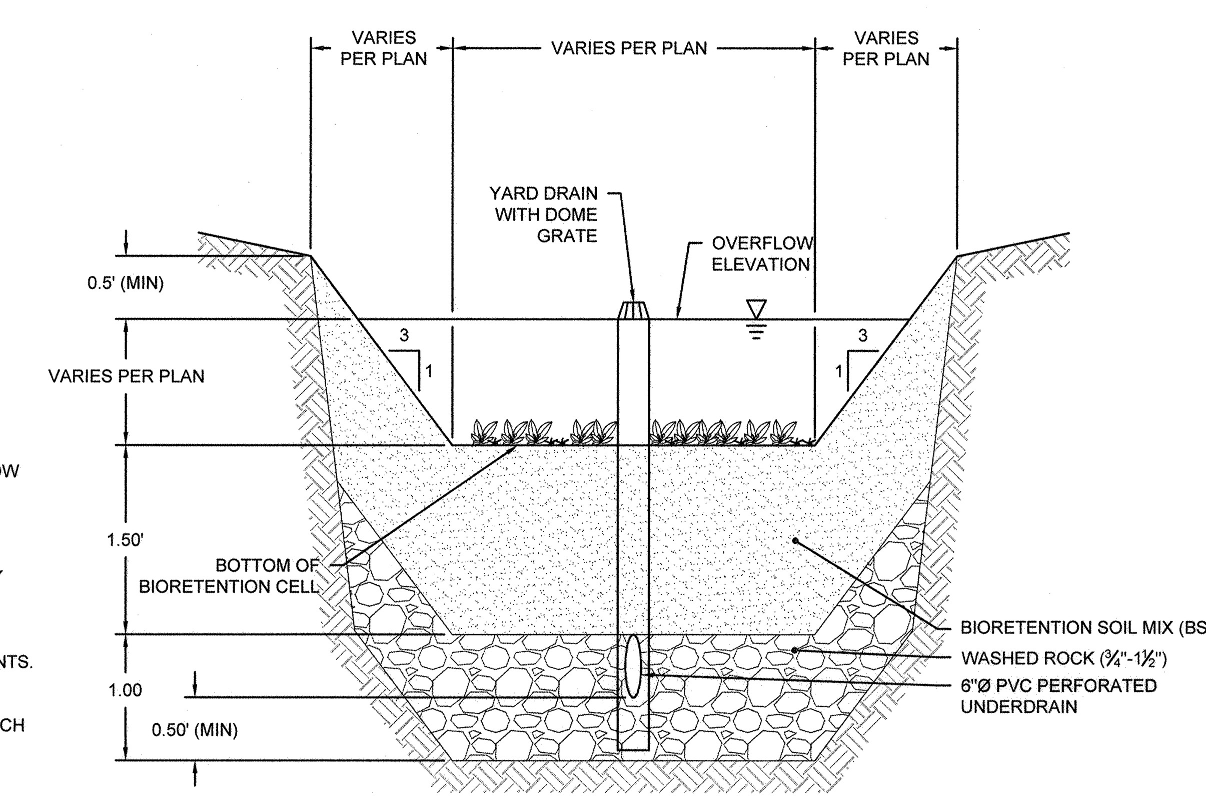
1. NO SEDIMENT ON TOP OF MULCH AND COARSE COMPOST.
2. BSM IS NOT CLOGGED AND INFILTRATION RATE IS ADEQUATE THROUGH VISUAL ASSESSMENT. DRAINS IN 24 TO 48 HOURS.
3. AERIAL PLANT COVER MUST BE AT LEAST 80% WITHIN 2 YEARS AFTER PLANT INSTALLATION.
4. OWNER RESPONSIBLE FOR CONTINUED IRRIGATION, AND PLANT REPLACEMENT IF NEEDED.

BIORETENTION CELL TABLE

CELL No.	MINIMUM BOTTOM AREA (SF)	BOTTOM ELEVATION (FT)	LIVE STORAGE DEPTH (FT)	OVERFLOW ELEVATION (FT)
1	178	280.30	0.5	280.80
2	1010	279.50	1.0	280.50
3	227	281.24	1.0	282.24
4	386	281.95	1.0	282.95

NOTES:

1. OVERFLOW SHALL BE AT LEAST 6" BELOW ANY ADJACENT PAVEMENT AREA.
2. PROVIDE MINIMUM SETBACK OF 5 FEET FROM TO OF BIORETENTION CELL TO BUILDING STRUCTURES AND PROPERTY LINES.
3. REFER TO LANDSCAPE ARCHITECTURE DRAWINGS FOR PLANTING REQUIREMENTS.
4. UNDERDRAIN SHALL BE PVC SLOTTED SUBSURFACE DRAIN PER ASTM D1785 SCH 40 WITH SLOTS FACING UPWARD.



5 BIORETENTION CELL
NOT TO SCALE

N

GRAPHIC SCALE
0 15 30 60
1" = 30 FEET

Know what's **below.** **Call** before you dig.

CITY OF FIRCREST
PUBLIC WORKS DEPARTMENT
ENGINEERING CONSTRUCTION DRAWINGS
APPROVED:
CITY ENGINEER DATE

AHBL
TACOMA · SEATTLE · SPOKANE · TRI-CITIES
2215 North 30th Street, Suite 300 Tacoma, WA 98403
253.383.2422 TEL 253.383.2572 FAX www.ahbl.com WEB
AHBL PROJECT NO.: 2140272.10

DLR Group
Architecture Engineering Planning Interiors

C4.3
73-14167-00
05/29/2015

STORM DRAINAGE NOTES AND DETAILS
WAINWRIGHT INTERMEDIATE SCHOOL
TACOMA PUBLIC SCHOOLS

130 Alameda Ave
Tacoma, WA 98466

BID SET

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Geologic & Monitoring Well Construction Log

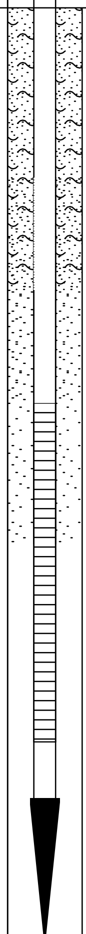
associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	FWI-HA-1/WP	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Elevation (Top of Well Casing): 96 (Project Datum)
Water Level Elevation: Dry
Drilling/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Location: Fircrest, WA
Surface Elevation (ft): 94.2 (Project Datum)
Date Start/Finish: 10/2/18,10/2/18
Hole Diameter (in): 4 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION



WELL CONSTRUCTION

Threaded steel pipe 1.25 inch I.D. with threaded and vented PVC cap -1.8 to 0.6 feet

Bioretention soil mix 0 to 1 foot

Tape over well point screen 0.6 to 1.4 feet

Silica sand 1 to 1.9 feet

Driven into existing sediments 1.9 to 3.3 feet
Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 1.4 to 2.6 feet

Threaded steel pipe 1.25 inches I.D. and drive point 2.6 to 3.3 feet

Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 4.7 feet.

5

DESCRIPTION

Bioretention Soil Mix

Loose, dark brown, moist, medium SAND, some silt, trace gravel; organic rich; massive (SP-SM).

Drain Rock with Bioretention Soil Mix

Loose, brownish gray, slightly moist, rounded GRAVEL (~0.5 inch), some sand, some silt (GP-GM).

Boring terminated at 1.9 feet
Well completed at 3.3 feet on 10/2/18.
Refusal in gravel.
No seepage. Sloughing gravel 1.4 to 1.9 feet.
Steel drive point placed in borehole and hand driven with slide hammer to depth of 3.3 feet.

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	FWI-HA-2	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Fircrest, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/2/18,10/2/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Bioretention Soil Mix					
		S-1		Loose, dark brown, moist, medium SAND, some silt, trace gravel; organic rich; massive (SP-SM).					
		S-2							
				Drain Rock with Bioretention Soil Mix Loose, brownish gray, slightly moist, rounded GRAVEL (~0.5 inch), some sand, some silt (GP-GM).					
				Bottom of exploration boring at 1.6 feet. Refusal in gravel. No seepage. Sloughing gravel 1.4 to 1.6 feet.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	FWI-HA-3	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Fircrest, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/2/18,10/2/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Bioretention Soil Mix					
		S-1		Loose, dark brown, moist, medium SAND, some silt, trace gravel; organic rich; massive (SP-SM).					
		S-2							
				Drain Rock with Bioretention Soil Mix - Loose, brownish gray, slightly moist, rounded GRAVEL (~0.5 inch), some sand, some silt (GP-GM).					
				Bottom of exploration boring at 2.5 feet. Refusal in gravel. No seepage. Sloughing gravel 2.4 to 2.5 feet.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/2/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- FWI			

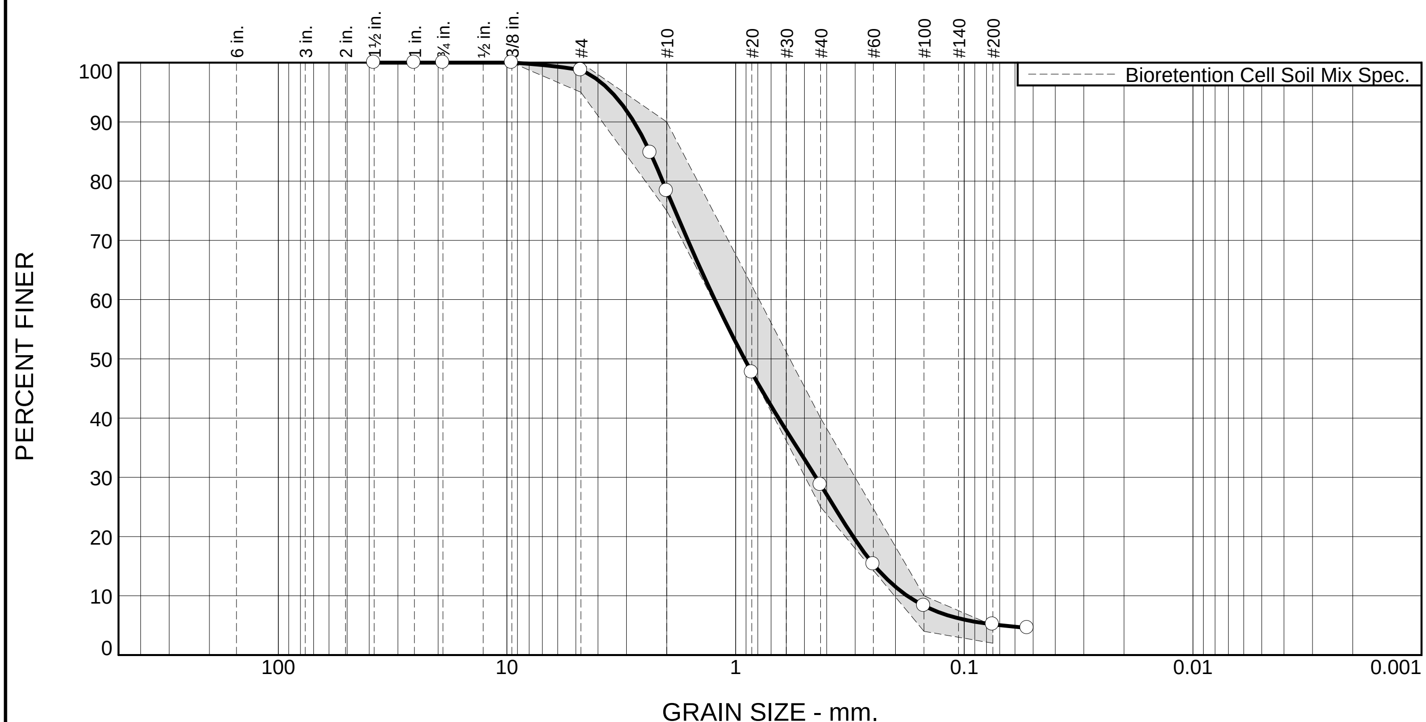
Moisture Content

Sample ID	HA-1 (0.1'-0.5')	HA-2 (0.1'-0.5')	HA-3 (0.1'-0.5')
Wet Weight + Pan	1045.54	1010.73	1032.97
Dry Weight + Pan	993.98	938.71	964.23
Weight of Pan	516.95	422.18	434.66
Weight of Moisture	51.56	72.02	68.74
Dry Weight of Soil	477.03	516.53	529.57
% Moisture	9.8	12.2	11.5

Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	575.92	599.08	602.61
Dry Soil After Burn + Pan	564.55	588.64	585.37
Weight of Pan	357.92	391.93	357.92
Wt. Loss Due to Ignition	11.37	10.44	17.24
Actual Wt. Of Soil After Burr	206.63	196.71	227.45
% Organics	5.2	5.0	7.0

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.2	20.5	49.6	23.5	5.2	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	98.8	95.0 - 100.0	
#8	84.8		
#10	78.3	75.0 - 90.0	
#20	47.7		
#40	28.7	25.0 - 40.0	
#60	15.3		
#100	8.3	4.0 - 10.0	
#200	5.2	2.0 - 5.0	X
#270	4.6		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7831 D_{85}= 2.3741 D_{60}= 1.2336
D_{50}= 0.9154 D_{30}= 0.4454 D_{15}= 0.2458
D_{10}= 0.1777 C_u= 6.94 C_c= 0.91

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/08/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (FWI) Fircrest- Wainwright Intermediate School **Depth:** 0.1'-0.5' **Date Sampled:** 10/02/2018

Sample Number: HA-1

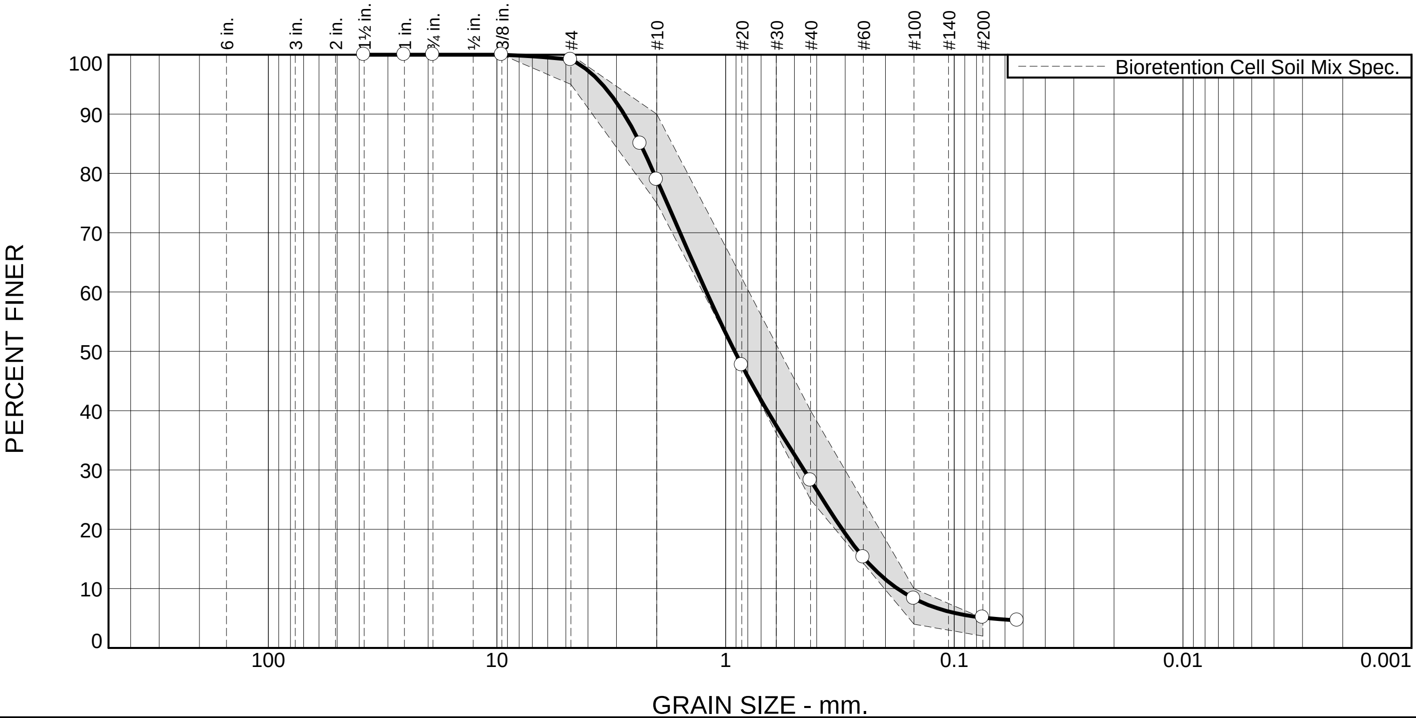
associated earth sciences incorporated

Client: Clear Creek Solutions

Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.8	20.2	50.8	23.1	5.1	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	99.2	95.0 - 100.0	
#8	85.0		
#10	79.0	75.0 - 90.0	
#20	47.7		
#40	28.2	25.0 - 40.0	
#60	15.3		
#100	8.3	4.0 - 10.0	
#200	5.1	2.0 - 5.0	X
#270	4.6		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7791 D_{85}= 2.3597 D_{60}= 1.2132
D_{50}= 0.9128 D_{30}= 0.4541 D_{15}= 0.2463
D_{10}= 0.1771 C_u= 6.85 C_c= 0.96

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/08/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

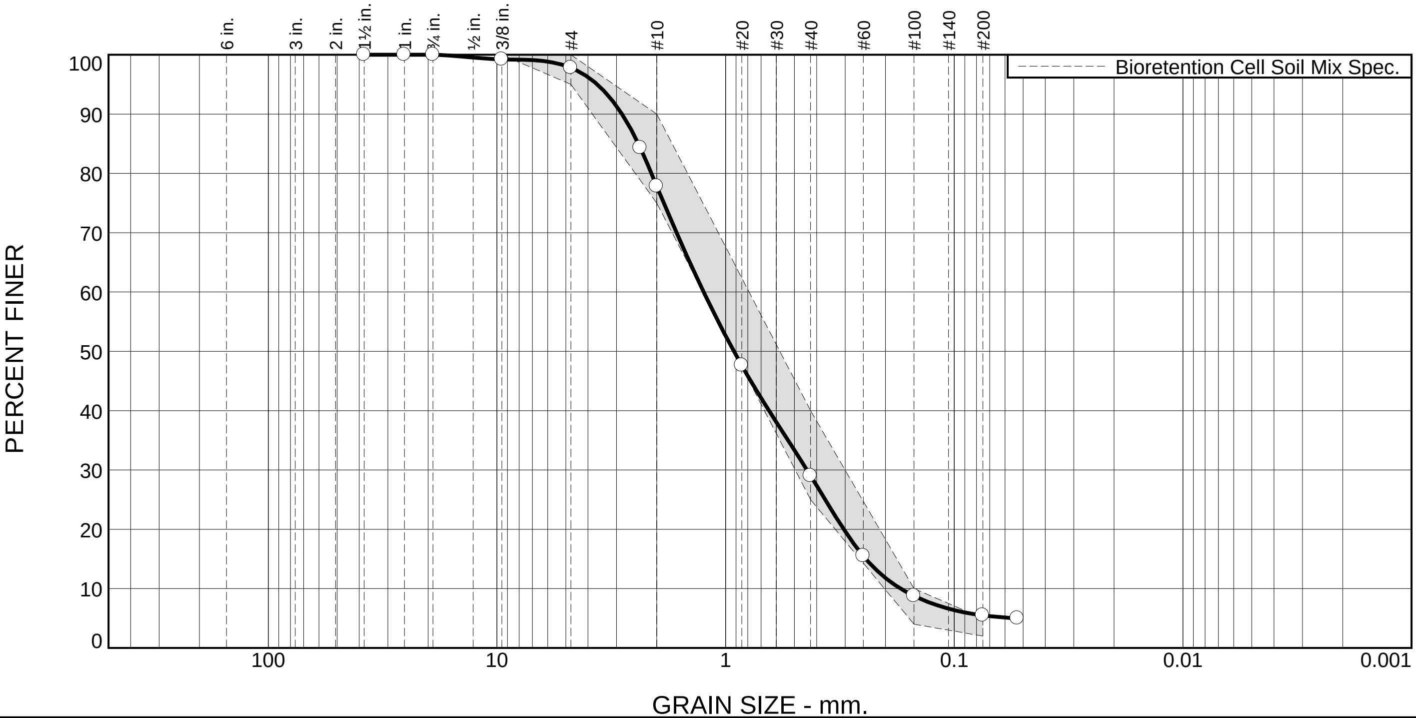
Title:

Source of Sample: (FWI) Fircrest- Wainwright Intermediate School **Depth:** 0.1'-0.5' **Date Sampled:** 10/02/2018
Sample Number: HA-2

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.2	20.0	48.8	23.5	5.5	

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	99.2	100.0	X
#4	97.8	95.0 - 100.0	
#8	84.3		
#10	77.8	75.0 - 90.0	
#20	47.6		
#40	29.0	25.0 - 40.0	
#60	15.5		
#100	8.8	4.0 - 10.0	
#200	5.5	2.0 - 5.0	X
#270	5.0		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.8395 D_{85}= 2.4066 D_{60}= 1.2468
D_{50}= 0.9199 D_{30}= 0.4408 D_{15}= 0.2437
D_{10}= 0.1716 C_u= 7.27 C_c= 0.91

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/08/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (FWI) Fircrest- Wainwright Intermediate School **Depth:** 0.1'-0.5' **Date Sampled:** 10/02
Sample Number: HA-3

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

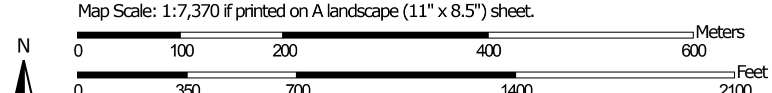
Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)

Map Scale: 1:7,370 if printed on A landscape (11" x 8.5") sheet.



Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at scales ranging from 1:24,000 to 1:124,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: City of Tacoma, Washington
Survey Area Data: Version 2, Dec 5, 2013

Soil Survey Area: Pierce County Area, Washington
Survey Area Data: Version 14, Sep 10, 2018

Your area of interest (AOI) includes more than one soil survey area. These survey areas may have been mapped at different scales, with a different land use in mind, at different times, or at different levels of detail. This may result in map unit symbols, soil properties, and interpretations that do not completely agree across soil survey area boundaries.

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jul 8, 2014—Jul 15, 2014

MAP LEGEND

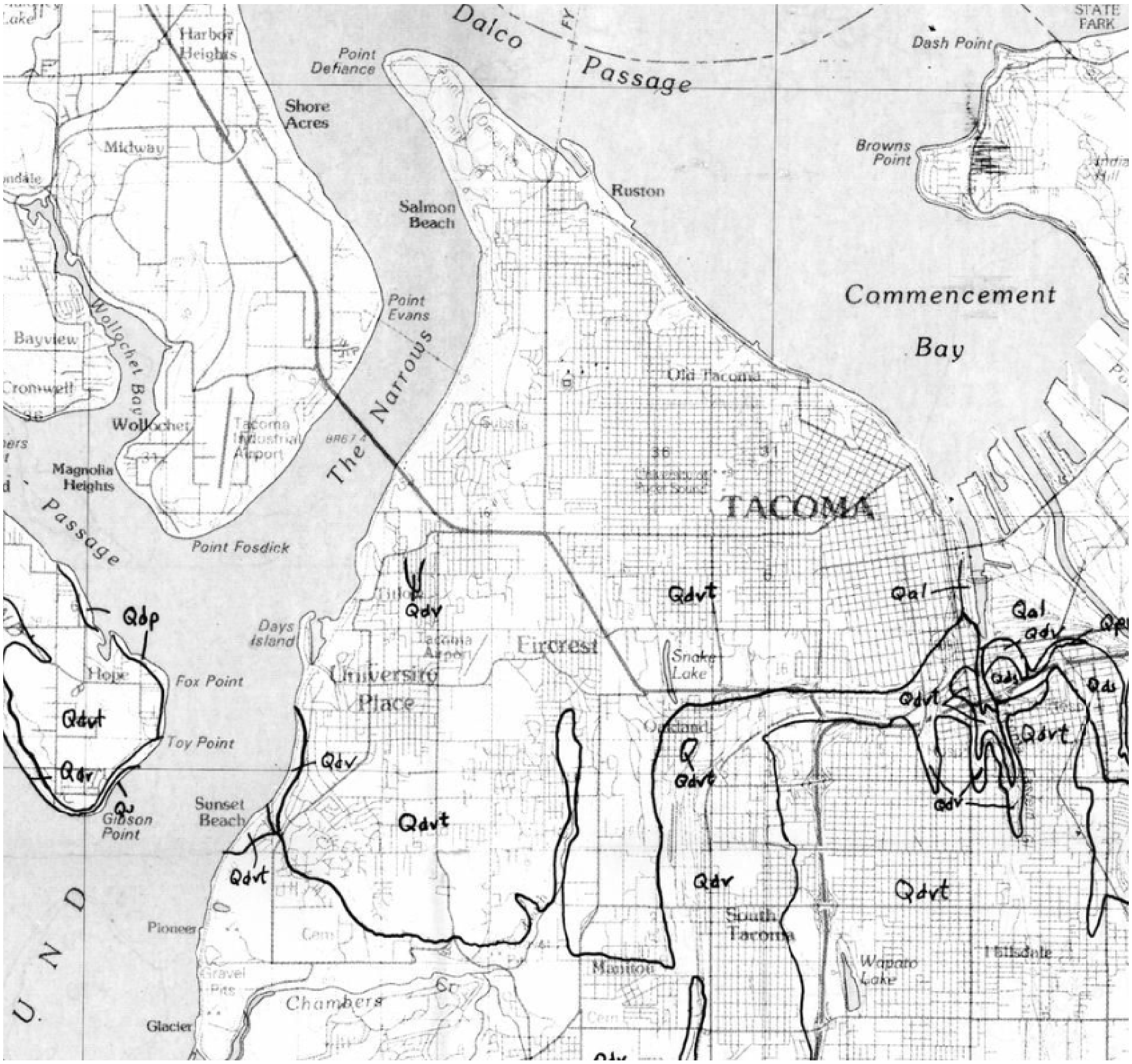
MAP INFORMATION

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

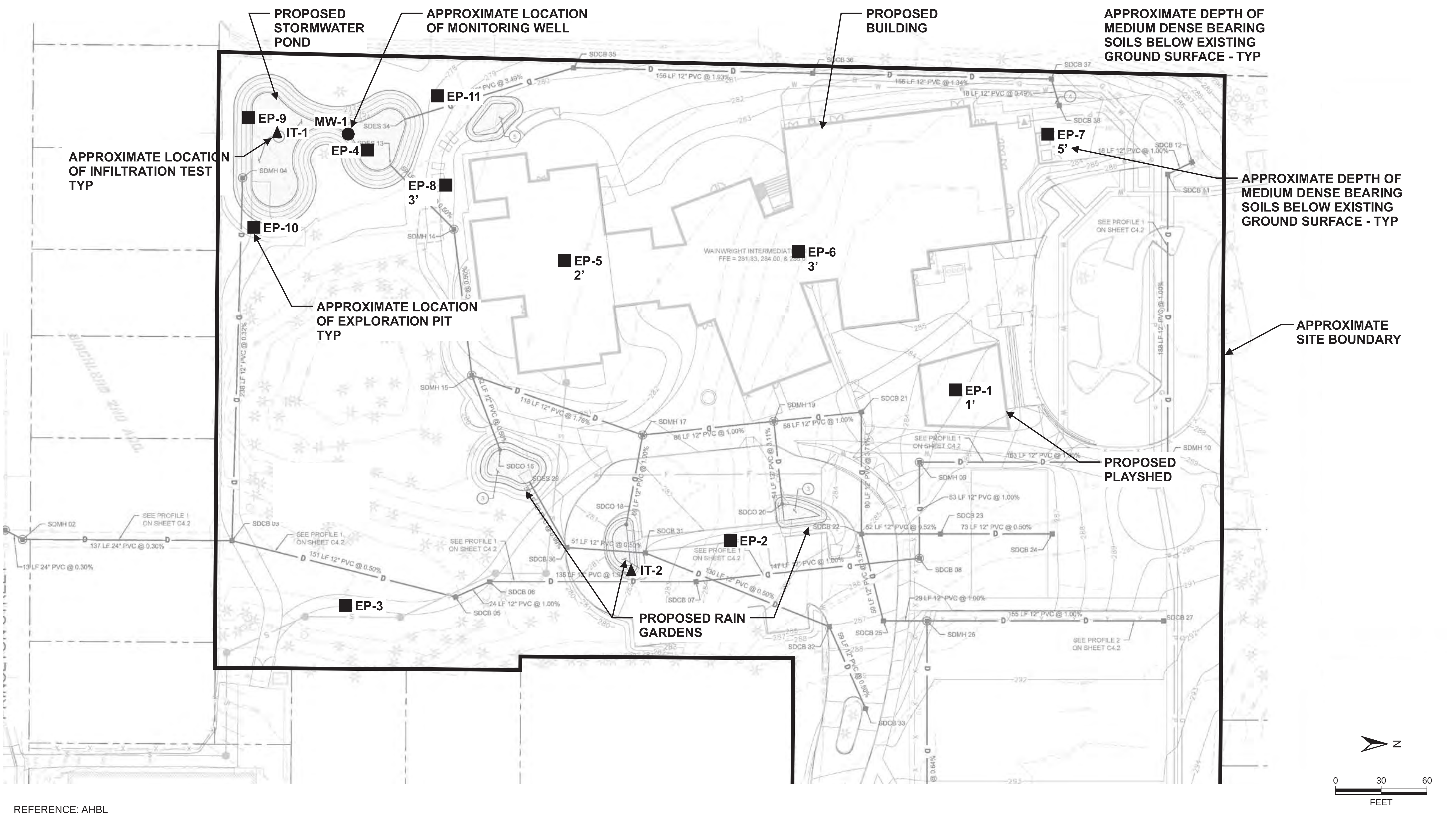
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
NOTCOM	No Digital Data Available	32.7	13.6%
Subtotals for Soil Survey Area		**32.7**	**13.6%**
Totals for Area of Interest		**239.9**	**100.0%**

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1B	Alderwood gravelly sandy loam, 0 to 8 percent slopes	53.7	22.4%
1C	Alderwood gravelly sandy loam, 8 to 15 percent slopes	145.1	60.5%
1D	Alderwood gravelly sandy loam, 15 to 30 percent slopes	8.4	3.5%
Subtotals for Soil Survey Area		**207.2**	**86.4%**
Totals for Area of Interest		**239.9**	**100.0%**



Excerpt from:

Walsh, T. J., 1987, Geologic Map of the south half of the Tacoma quadrangle, Washington, Washington Division of Geology and Earth Resources, Open File Report 87-3, scale 1:100,000.



REFERENCE: AHBL

associated earth sciences incorporated

SITE AND EXPLORATION PLAN

WAINWRIGHT ELEMENTARY SCHOOL RENOVATION
FIRCREST, WASHINGTON

FIGURE 2
DATE 3/15
PROJ. NO. TE140513A

140513 Wainwright Elementary \ 140513 F2 Site and Exploration Plan 3-5-2014.cdr

LOG OF EXPLORATION PIT NO. EP-1

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION
	Gravel - 1 inch
1	**Fill** Medium dense, slightly moist, dark gray brown, silty fine to medium SAND, trace gravel; unsorted (SM).
2	**Vashon Recessional Outwash**
3	Medium dense, dry to slightly moist, light orangish brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
4	Medium dense, dry to slightly moist, brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
5	
6	
7	**Vashon Lodgement Till** Dense, dry, grayish brown, silty fine to medium SAND, some gravel; unsorted (SM).
8	
9	
10	Bottom of exploration pit at depth 9.5 feet No seepage. No caving
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

KCTP3 140513.GPJ November 6, 2014

Wainwright Elementary
Fircrest, WA

Logged by: LBK

Approved by: JMB

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-2

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Vashon Lodgement Till
1	Dense, slightly moist, grayish brown, silty fine to medium SAND, some gravel; unsorted (SP).
2	
3	Becomes very dense.
4	
5	
6	
7	Bottom of exploration pit at depth 6 feet No seepage. No caving
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Wainwright Elementary
Fircrest, WA

Logged by: LBK
Approved by: JMB

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-3

Depth (ft)	DESCRIPTION
	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.
	Grass / Moss / Topsoil
1	Loose, moist, black, silty fine SAND, some gravel, abundant roots and organics (SM).
2	**Vashon Recessional Outwash** Loose, slightly moist, brown, silty fine SAND, some gravel, some roots and organics (SM).
3	Soft, very moist, grayish brown with heavy orange mottling, sandy SILT; massive; sand component chiefly fine sand (ML).
4	
5	
6	Loose to medium dense, moist, brown, gravelly fine to coarse SAND, trace silt; weakly stratified (SW).
7	Medium dense, moist, grayish brown, gravelly fine to medium SAND, some silt; silt stringers; stratified (SP).
8	Medium dense, moist, grayish brown, fine to medium SAND, some gravel, trace silt; discontinuous layers (1 to 4 inches thick) of gray with heavy orange mottling silt (SP/ML).
9	
10	
11	
12	**Weathered Vashon Lodgement Till (?)** Very stiff to hard, slightly moist, grayish brown with orange mottling, sandy SILT, some gravel; unsorted (ML).
13	Medium dense, moist, grayish brown, silty fine to coarse SAND, some gravel; discontinuous layers of gray with heavy orange mottling silt (SM/ML).
14	
15	
16	Bottom of exploration pit at depth 15 feet Slow seepage at 6 feet. Minor caving 0 to 7 feet.
17	
18	
19	
20	

LOG OF EXPLORATION PIT NO. EP-4

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. DESCRIPTION
	Grass / Topsoil
1	Loose, moist, dark brown, silty fine SAND, trace gravel, abundant roots (SM).
	Vashon Recessional Outwash
2	Loose to medium dense, moist, brown, fine to medium SAND, some gravel, some silt, few roots (SM).
3	
4	Medium dense, slightly moist, grayish brown to brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
5	
6	Medium dense, slightly moist, grayish brown to brown, gravelly fine to coarse SAND, trace silt; stratified (SW).
7	
8	Medium dense, slightly moist, grayish brown to brown, fine to coarse SAND, some gravel, trace silt; massive (SW).
9	Increasing gravel.
10	Medium dense, slightly moist, grayish brown to brown, gravelly fine to coarse SAND, trace silt; weakly stratified (SW).
11	
12	
13	Bottom of exploration pit at depth 12 feet No seepage. No caving
14	
15	
16	
17	
18	
19	
20	

Wainwright Elementary
Fircrest, WA

Logged by: LBK

Approved by: JMB

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-5

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Grass / Topsoil Loose, moist, dark brown, silty fine to medium SAND, trace gravel, abundant roots (SM).
1	**Vashon Recessional Outwash**
2	Loose to medium dense, moist, orangish brown, fine to medium SAND, some gravel, some silt; weakly stratified (SP). Becomes medium dense and brown.
3	
4	
5	**Vashon Lodgement Till** Dense, slightly moist, grayish brown, very silty fine to medium SAND, some gravel; unsorted (SM).
6	
7	Bottom of exploration pit at depth 6 feet No seepage. No caving
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Wainwright Elementary
Fircrest, WA

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-6

Depth (ft)

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

DESCRIPTION

Depth (ft)	Description
0–1	**Grass / Topsoil** Loose, moist, dark brown, silty fine to medium SAND, trace gravel, abundant roots (SM).
1–3	**Vashon Recessional Outwash** Loose to medium dense, slightly moist, orangish brown, fine to medium SAND, some gravel, some silt, few roots; weakly stratified (SP).
3–4.5	**Weathered Vashon Lodgement Till** Medium dense to dense, slightly moist, grayish brown with orange mottling, silty fine to medium SAND, some coarse sand, some gravel; unsorted (SM).
4.5–6	**Vashon Lodgement Till** Dense, slightly moist, grayish brown, very silty fine to medium SAND, some gravel, trace cobbles; unsorted (SM).

Bottom of exploration pit at depth 6 feet
No seepage. No caving

Wainwright Elementary
Fircrest, WA

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-7

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION
	Grass / Topsoil
1	Medium dense, moist, dark brown, silty fine to medium SAND, trace gravel, abundant roots (SM).
	Fill / Reworked Vashon Recessional Outwash
2	Medium dense, moist, brown to orangish brown, fine to medium SAND, some gravel, some silt (SP).
3	
4	
5	**Old Topsoil**
	Medium dense, slightly moist, black, silty fine to medium SAND, abundant organics (SM).
6	**Vashon Recessional Outwash**
7	Medium dense, slightly moist, brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
	Vashon Advance Outwash
8	Dense, slightly moist, grayish brown, fine to medium SAND, some coarse sand, some gravel, trace silt; stratified (SP).
9	
10	Dense, slightly moist, grayish brown, fine SAND, trace gravel, trace silt; stratified (SP).
11	
12	Bottom of exploration pit at depth 11 feet No seepage. No caving
13	
14	
15	
16	
17	
18	
19	
20	

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Fircrest, WA

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-8

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. DESCRIPTION
	Grass / Topsoil
	Loose, moist, dark brown, silty fine SAND, abundant roots (SM).
1	**Vashon Recessional Outwash**
2	Medium dense, slightly moist, orangish brown, fine SAND, some silt, trace gravel, abundant roots (SP).
3	Medium dense, slightly moist, brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
4	
5	
6	
7	Medium dense, slightly moist, brown to grayish brown, gravelly fine to coarse SAND, trace silt; stratified (SW).
8	Becoming moist.
9	
10	
11	Bottom of exploration pit at depth 10 feet No seepage. No caving
12	
13	
14	
15	
16	
17	
18	
19	
20	

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Fircrest, WA

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Approved by: JMB

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-9

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION
	Grass / Topsoil Loose, moist, dark brown, silty fine SAND, trace gravel, abundant roots (SM).
1	**Fill**
2	Loose to medium dense, slightly moist, dark brown to brown, silty fine to medium SAND, some gravel, with zones of sandy fine to coarse GRAVEL, some silt, debris (i.e. glass bottles) (SM/GW).
3	**Vashon Recessional Outwash**
4	Medium dense, slightly moist, brown, gravelly fine to coarse SAND, trace silt; weakly stratified (SW).
5	
6	
7	
8	Medium dense, slightly moist, brown, very gravelly fine to coarse SAND, trace silt; stratified; some cemented zones (SW).
9	
10	
11	
12	Bottom of exploration pit at depth 11 feet No seepage. No caving
13	
14	
15	
16	
17	
18	
19	
20	

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Fircrest, WA

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-10

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION
	Grass / Topsoil
1	Loose to medium dense, slightly moist, dark brown, silty fine to medium SAND, trace gravel, abundant roots (SM).
	Vashon Recessional Outwash
2	Medium dense, slightly moist, orangish brown, fine to medium SAND, some gravel, some silt (SP).
3	Medium dense, slightly moist, brown, fine to medium SAND, some gravel, trace silt; weakly stratified (SP).
4	
5	
6	Medium dense, slightly moist, brown, gravelly fine to coarse SAND, trace silt; stratified (SW).
7	
8	
9	
10	Occasional cobbles.
11	
12	
13	Bottom of exploration pit at depth 12 feet No seepage. Minor caving 1 to 3 feet.
14	
15	
16	
17	
18	
19	
20	

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Fircrest, WA

Logged by: LBK
Approved by: JMB

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Project No. TE140513A

10/29/14

LOG OF EXPLORATION PIT NO. EP-11

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION
	Grass / Topsoil
1	Loose, moist, dark brown, silty fine SAND, abundant roots (SM).
	Vashon Recessional Outwash
2	Loose, slightly moist, orangish brown, fine SAND, some silt, trace gravel; massive (SP).
3	
4	Loose to medium dense, slightly moist, brown, fine to medium SAND, trace gravel, trace silt; massive (SP).
5	Medium dense, slightly moist, brown, fine to coarse SAND, some gravel, trace silt; stratified (SW).
6	
7	
8	Becoming gravelly.
9	
10	Medium dense, slightly moist, brown, gravelly fine to coarse SAND, trace silt; stratified (SW).
11	
12	Bottom of exploration pit at depth 11.5 feet No seepage. No caving
13	
14	
15	
16	
17	
18	
19	
20	

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Fircrest, WA

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Approved by: JMB

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Project No. TE140513A

10/29/14

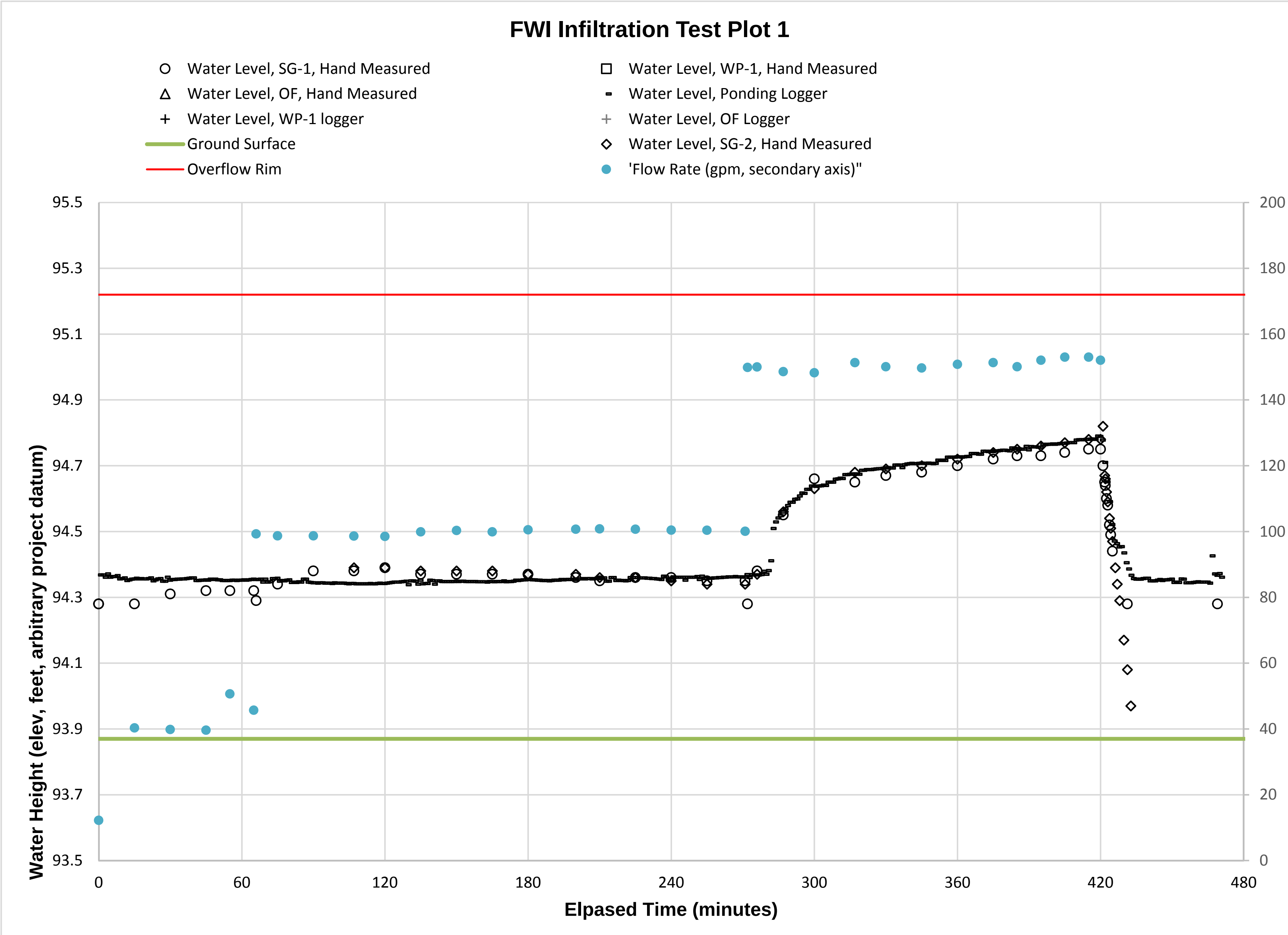
APPENDIX D

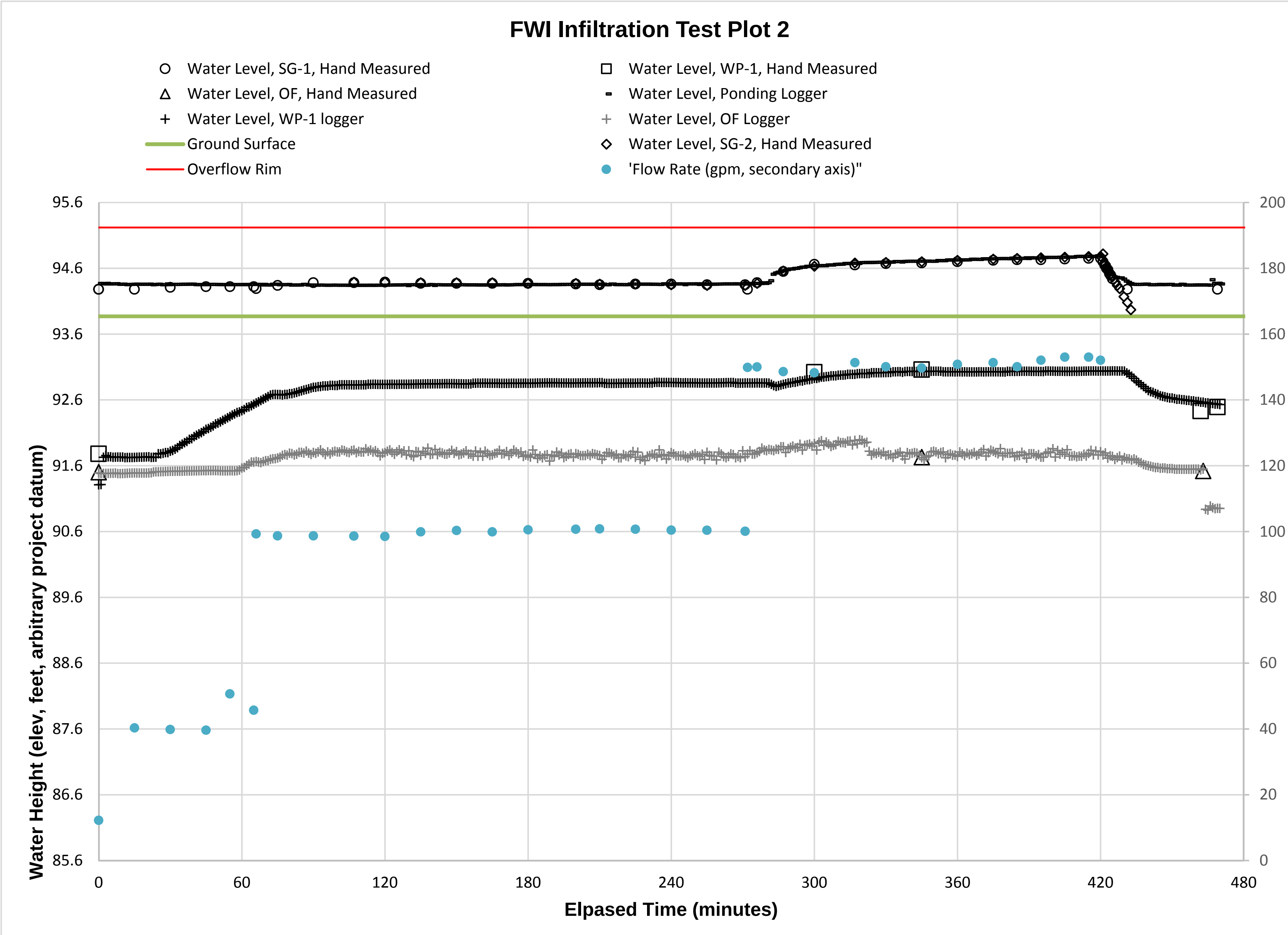
Soil Probe, Level Survey, and Field Infiltration Testing Data

Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5,6,7
Date:	10/25/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	200.0
Test No.:	FWI	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Vashon lodgment till

Time (24-hr)	**Flow Rate (gpm)**	**Stage (feet)**	**Totalizer (gallons)**	**Comments**
8:38			0	
8:45	12.2	0	0	Flow on
9:00	40.3	0	178	Flow observed in underdrain at 09:10
9:15	39.8	0.03	769	
9:30	39.6	0.04	1365	Underdrain: visual estimate of 1-2 gpm flow
9:40	50.6	0.04	1768	
9:50	45.7	0.04	2221	Underdrain: visual estimate 40 gpm flow
9:51	99.3	0.01	2221	
10:00	98.7	0.06	3033	Underdrain: visual estimate 50 gpm flow
10:15	98.7	0.1	4579	Underdrain: visual estimate 100 gpm flow
10:32	98.6	0.1	6290	Installed SG-2 in facility deep point
10:45	98.5	0.11	7491	
11:00	99.9	0.09	9051	
11:15	100.3	0.09	10621	
11:30	99.9	0.09	12011	
11:45	100.5	0.09	13446	
12:05	100.7	0.08	15531	
12:15	100.8	0.07	16681	
12:30	100.7	0.08	18111	
12:45	100.4	0.08	19551	
13:00	100.4	0.07	21027	4.6ft from rim to water in OF cleanout sump in sidewalk.
13:16	100.1	0.07	22651	4.4ft to water behind weir in OF cleanout sump in sidewalk.
13:17	149.9		22651	Swap to FM7
13:21	150.0	0.1	23146	
13:32	148.6	0.27	24777	Weir in OF cleanout sump in sidewalk is backwatered
13:45	148.2	0.38	22651	
14:02	151.3	0.37	29309	
14:15	150.1	0.39	31263	
14:30	149.7	0.4	33481	
14:45	150.8	0.42	36561	
15:00	151.3	0.44	38013	
15:10	150.1	0.45	39519	
15:20	152.1	0.45	41082	
15:30	153.0	0.46	42566	
15:40	153.0	0.47		
15:45	152.1	0.47	44808	Flow off

15:46		0.42		
15:46		0.37		
15:47		0.36		
15:47		0.32		
15:48		0.3		
15:48		0.24		
15:49		0.21		
15:50		0.16		
15:51		0.1		
15:52		0.05		
15:53		dry		


FWI Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, OF, Hand Measured
Water Level, WP-1 logger
Ground Surface
Overflow Rim
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, OF Logger
Water Level, SG-2, Hand Measured
'Flow Rate (gpm, secondary axis)"
Water Height (elev, feet, arbitrary project datum)
95.5
95.3
95.1
94.9
94.7
94.5
94.3
94.1
93.9
93.7
93.5
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elapsed Time (minutes)


FWI Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, OF, Hand Measured
Water Level, WP-1 logger
Ground Surface
Overflow Rim
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, OF Logger
Water Level, SG-2, Hand Measured
'Flow Rate (gpm, secondary axis)"
Water Height (elev, feet, arbitrary project datum)
95.6
94.6
93.6
92.6
91.6
90.6
89.6
88.6
87.6
86.6
85.6
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)

APPENDIX E

Site Photos

Cell FWI, curb cut inlet. Above photo is prior to install of weir. Lower photo is after weir install and during infiltration testing.

Above photo: FWI during infiltration testing. Overflow beehive not visible in vegetation, located in lower left. Lower Photo: overflow structure and staff gauges.

APPENDIX 6

Deliverable Task 4.5, Site M1C, Geotechnical/Soils Assessment Design Data and Current Conditions, 1st Street Low Impact Development Project, Marysville, Washington. Associated Earth Sciences, Inc. 6/14/2019

associated earth sciences incorporated

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site M1C, Geotechnical/Soils Assessment Design Data and Current Conditions, 1st Street Low Impact Development Project, Marysville, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in cell S-1 of the City of Marysville, 1st Street Low Impact Development Project , located in the city of Marysville, Washington (Figure M1C F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 18, 2018, infiltration testing on November 20, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure M1C F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the City of Marysville, 1st Street Low Impact Development Project, located in Marysville, Washington as shown on the attached "Vicinity Map" (Figure M1C F1). The site is bordered by undeveloped City property and Ebey Slough to the south and commercial buildings to the north. Site topography is generally flat. The site is located about 65 feet north of Ebey Slough, a tributary of the Snohomish River system that discharges directly to Puget Sound to the west. Per the Washington State Source Water Assessment Program Mapping Application, the site is not located within a time of travel zone for any Group A water system.

Our specific area of study for this project includes bioretention facility Cell S-1. Cell S-1 is located along the south side of 1st Street, east of Cedar Avenue, referred to as cell M1C for this study. The cell was relocated approximately 100 feet east from predesign plans (Gray & Osborne, Inc. [G&O], 2014) to the 2017 plans (G&O, 2017) and the built condition. The attached "Facility and Exploration Plan" (Figure M1C F2) illustrates the cell area and some of the surrounding site features and utilities from the 2017 plans and the built condition.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Geotechnical Report First and Third Street Retrofit, Marysville, Washington, G&O IPN #13587," Prepared by PanGEO, Inc. for Gray & Osborne, Inc., dated March 4, 2014.
- "Geotechnical Design Recommendations 3rd Street Retrofit," Marysville, Washington, PanGEO, Inc., December 31, 2013.
- "City of Marysville, 1st and 3rd Stormwater Retrofit Project Predesign Report", prepared by Gray & Osborne, Inc., January 2014.
- "City of Marysville, 1st Street Low Impact Development Project," Gray & Osborne, Inc., June 2017 (plan set).

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell M1C consists of a rectangular-shaped bioretention cell with approximately 130 square feet of base area surrounded by bioretention barrier curb set in a concrete sidewalk, as shown on Figure M1C F2, "Facility and Exploration Plan." We understand that the site was developed under the Washington State Department of Ecology (Ecology) 2014 *Stormwater Management Manual for Western Washington* (2014 Ecology Manual) for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 2 inches per hour (in/hr) in the native subgrade. Land use within the drainage basin is primarily roadway, sidewalk, and commercial rooftops and pavement. Per "1st Street Low Impact Development Project, Road and Storm Plan and Profile," Sheet 18 of 25 (G&O, 2017), the facility design includes 2 inches of mulch overlying 18 inches of bioretention soil mix overlying existing native soil.

The facility is designed to infiltrate 100 percent of inflow into the native subgrade. Stormwater enters the facility through one curbcut from 1st Street and four small sidewalk curb notches. If water ponds up on the bioretention soil, the ponded water would discharge into an 8-inch polyvinyl chloride (PVC) overflow riser with an 8-inch Nyloplast dome grate located near the center of the cell, and then into an 8-inch lateral PVC overflow pipe. The rim of the overflow riser was designed to be 6 inches higher than the cell base to create 6 inches of ponding depth. The facility was constructed spring 2018.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facility including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure M1C F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the southwest curb corner of cell S-1 defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: One curbcut from 1st Street and four sidewalk curb notches.
  - The primary curbcut to the facility is a 24-inch curbcut consistent with project plans, which discharges onto a concrete pad approximately 1 foot long by 2 feet wide. Quarry spall splash pads surrounding the concrete pad indicated on plans were not observed.

  - Four small curb notches on the south side of the facility drain runoff from the sidewalk to the facility. The notches are approximately 4 inches wide, are consistent with project plans, and each discharge onto a 1-foot by 2-feet concrete pad.

- Overflow: The overflow consists of an 8-inch PVC overflow riser with an 8-inch Nyloplast dome grate. The rim of this grate was approximately 6.4 to 6.6 inches above the base of the facility. The overflow riser conveys water to an 8-inch lateral overflow pipe that connects to additional bioretention cells in a line to the east, and then ties into existing storm catch basin.

- AESI investigated the loose bioretention soil thickness present in cell M1C using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 2-foot to 4-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.3 to 1.8 feet, and averaged 1.7 feet. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell M1C
Level Survey Data

Location	Elevation (feet, project datum)
Bioretention barrier curb top SW corner	100.00
Bioretention barrier curb top NW corner	100.03
Bioretention barrier curb top NE corner	99.78
Bioretention barrier curb top SE corner	99.71
Curb notch (W)	99.66
Curb notch (center west)	99.57
Curb notch (center east)	99.48
Curb notch (E)	99.38
Curbcut Inlet (W)	98.96
Curbcut Inlet (center)	98.98
Curbcut Inlet (E)	98.95
WP-1 TOC	99.58
WP-2 TOC	99.28
Ponding tube TOC (DL)	98.45
Top/end 8" temporary inlet pipe	99.18
8" PVC overflow rim	98.38

WP: well point; TOC: top of casing; PVC: polyvinyl chloride; DL: datalogger

5.0 SITE SETTING

The text sections below describe our research findings in regard to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- Minard, J.P., 1985, *Geologic Map of the Marysville Quadrangle, Snohomish County, Washington*: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1743, scale 1:24,000.
- Natural Resources Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed January 2019.
- *Soil Survey of Snohomish County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1983.
- Newcomb, R.C., 1952, *Ground-water Resources of Snohomish County, Washington*: U.S. Geological Survey, Water-Supply Paper 1135, scale 1:62,500.

5.1 Regional Topography and Project Grading

The project site is situated at low-lying topography along the Ebey Slough, part of the Snohomish River flats. The Snohomish River and Ebey Slough empty into Possession Sound approximately 2 miles southwest of the project. Elevations on the larger project site range from about 10 to 30 feet.

On a closer scale, the area near cell M1C is relatively level, situated on an outwash plain at about elevation 15 to 20 feet. Cell M1C is located about 65 feet north of Ebey Slough, which is below 10 feet elevation. Relatively level pavement of 1st Street and sidewalks surround the cell. A curb separates the paved surfaces from the cell. A gentle slope rises on the west toward Cedar Avenue and railroad tracks.

The project site was previously undeveloped right-of-way adjacent to a boat storage/marina (since removed). The right-of-way improvements included new pavements, curbs, sidewalks and the bioretention elements. Various utilities are present in the vicinity of the site, including a buried water main. Minor cutting of less than 5 feet were needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to a regional geology map (Minard, 1985), the site vicinity is underlain by Vashon recessional outwash. Recessional outwash sediments in the project area are described on the referenced map to consist of outwash sand with some fine gravel and beds of silt and clay deposited from meltwater streams (Minard, 1985), which is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- Vashon Recessional Outwash (Qvr): This unit is composed of stratified to massive outwash sand with some fine gravel and beds of silt and clay. Recessional outwash in the project area was deposited by glacial meltwater streams during ice retreat (Minard, 1985) and has not been glacially overridden.

Background geotechnical information includes exploration logs B-1 and B-2 within 135 feet and 235 feet, respectively, of cell M1C dated November 25, 2013. Borings B-1 and B-2 reached depths of about 14 feet below current grades, and describe material generally consisting of loose to medium dense, laminated, silty sand to sand with trace to some silt interpreted to be recessional outwash (PanGEO, Inc., 2014), which is consistent with the geologic mapping in the area. Shallow fill soils were encountered to depths of up to 7 feet.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the soil survey (Natural Resources Conservation Service [NRCS], 1983) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Ragnar fine sandy loam (NRCS, 2018). This very deep, well-drained soil is situated on outwash plains and formed in glacial outwash. NRCS describes the permeability as moderately rapid (NRCS, 1983).

As described in the predesign report (G&O, 2014), the pre-developed condition was modeled as 100 percent impervious (roads, flat), consistent with the existing drainage area condition and background geotechnical data.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described by Newcomb (1952). The coastal lowlands often represent hundreds of feet of glacial and alluvial deposits backfilled into ancestral drainage systems. Outwash sands below the local water table carry large quantities of groundwater and alluvial materials in river valleys are good aquifers in the lower Snohomish Valley (Newcomb, 1952).

Within the vicinity of cell M1C, groundwater was encountered within sediments identified as Vashon recessional outwash (PanGEO, Inc., 2014). The shallow aquifer identified is interpreted to be in hydraulic conductivity locally with river valley aquifers of the Snohomish River and Ebey Slough. Limited background groundwater level data was collected at B-1 and B-2; groundwater ranged from approximately 4 to 8 feet below ground surface between November 2013 and January 2014 (PanGEO, Inc., 2014). Hydrographs are included in Appendix C.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and either to refusal in underlying fill (M1C-HA-2 and M1C-HA-3) or into native Vashon recessional outwash (M1C-HA-1). Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI’s offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, “Standard Recommended Practice for Description of Soils.” The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure M1C F2, "Facility and Exploration Plan."

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell M1C were completed on October 18, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring locations are presented on Figure M1C F2. The hand-auger borings encountered a thin layer of fine wood mulch overlying bioretention soil to a depth of 1.6 feet to 1.8 feet, overlying fill. Borings M1C-HA-2 and M1C-HA-3 were terminated on gravel within fill at 1.8 to 1.9 feet. Boring M1C-HA-1 encountered native Vashon recessional outwash below fill from 2.9 to the boring terminal depth of 5.9 feet). Bioretention soil thickness was 1.4 to 1.6 feet in the borings. No seepage or caving was observed.

6.2 Well Points

Well points were installed in M1C-HA-1 (WP-1) and M1C-HA-2 (WP-2). Key well point dimensions are provided in Table 2, below. WP-1 was installed to a depth of 9.4 feet to measure groundwater in the shallow aquifer below the bioretention soil. WP-2 was installed to a depth of 2.2 feet, and screened primarily within the bioretention soil.

Table 2
Summary of Cell M1C
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
M1C-WP-1	M1C-HA-1	11.2	1.25 inch nominal	1.8	9.4
M1C-WP-2	M1C-HA-2	3.6	1.25 inch nominal	1.4	2.2

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). Two samples of material interpreted as representative of the bioretention soil were tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell M1C
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
M1C-HA-1	0.3-0.5	Bioretention Soil	5.6	SAND, trace silt, trace gravel (SP)	3.9	3.1	1.1	Sand
M1C-HA-3	0.2-0.6	Bioretention Soil	6.2	SAND, trace silt, trace gravel (SP)	3.8	3.2	1.1	Sand
MC1C-HA-1	3-3.9	Recessional Outwash	Not tested	SAND, some silt, some gravel (SP-SM)	11.8			Sand to Loamy Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 5.6 and 6.2 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace silt and trace gravel based on ASTM D2487 USCS. The respective fines content as measured on the No. 200 sieve was 3.8 to 3.9 percent within the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 3.1 to 3.2, less than the recommended value of equal to or greater than 4. The coefficient of curvature was 1.1, within the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix contained less than the recommended range of coarse sand and slightly more than the recommended range of fine sand. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell M1C Site Data

Parameter	Recommended Range	Cell M1C
Organic Content (by weight)	5 to 8 percent	5.9 percent by weight
Cu coefficient of uniformity	4 or greater	3.1
Cc coefficient of curvature	1 to 3	1.1
Sieve Size	**Percent Passing**	
3/8" (9.51 mm)	100	100
#4 (4.76 mm)	95 to 100	98.2
#10 (2.0 mm)	75 to 90	92.3
#40 (0.42 mm)	25 to 40	47.3
#100 (0.15 mm)	4 to 10	8.5
#200 (0.074 mm)	2 to 5	3.9

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In cell M1C, a sample of native recessional outwash was sieved. The tested material correlates to a SAND with some silt and some gravel with 11.8 percent by weight of the material passing the No. 200 sieve. A layer of sand fill was observed in the hand-auger borings below the bioretention soil and above the native soil. The sand fill was up to 1.3 feet thick and classified as gravelly SAND, some silt (SP-SM).

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site City water line blow off tap and conveyed to cell M1C with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Ponded water levels within the cell were monitored using a temporary staff gauge (M1C-SG-1) marked in 0.01-foot increments installed adjacent to M1C-WP-1 and within a piezometer ("ponding tube") with a digital water level tape, and with digital pressure transducers for the duration of the test. The water level at the base of the bioretention soil and the shallow groundwater table were monitored in well point M1C-WP-2 and M1C-WP-1, respectively, with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers were compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell M1C is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell M1C

AESI performed infiltration testing on November 20, 2018. Light, intermittent rainfall was noted during testing, and no flow from the inflow pipes was present.

During this test, flow was initially adjusted between about 10 and 35 gpm to fill the cell bottom and stabilize the wetted area, then maintained at about 24 gpm for the duration of test. Inflow to the facility for the infiltration test was directed, through a diffuser, into the cell. The entire cell base was wetted after about 2 hours and a water level of about 0.5 feet was maintained as measured on M1C-SG-1. The wetted pool area was generally stable throughout most of the soaking and testing period covering the entire cell base of approximately 130 square feet. Approximately 10,600 gallons of water were used.

Ponded water in the bioretention cell was monitored in well point M1C-WP-2 with a data logger during the infiltration test and responded rapidly to inflow. Groundwater was not observed within the bioretention soil prior to the start of inflow. The water level in the well point responded to inflow within several minutes, and rose to near ground surface at the well point. AESI interprets this response to indicate that water from the infiltration test infiltrated relatively rapidly through the bioretention soil and then mounded on the native finer-grained recessional outwash. The rate of infiltration was such that the water level in the bioretention soil remained lower than the ponded water in the bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

The shallow groundwater table was monitored in well point M1C-WP-1 using a data logger during the infiltration test and slowly rose during testing. Groundwater was present at about 5.7 feet beneath the bioretention cell prior to the start of inflow and represents the shallow groundwater level in native sediments. The water level in the M1C-WP-1 began to rise after about 40 minutes and rose approximately 2.2 feet (from 5.7 feet below ground surface to 3.5 feet below ground surface) during testing.

After about 7 hours (at 2:40 pm), AESI shut off the flow and monitored the ponded water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 26 minutes. The ponded subsurface water in the bioretention cell also dissipated. However, the shallow groundwater table beneath the facility continued to rise, and was 3.5 feet below the cell ground surface, when the data logger was removed 30 minutes after the end of inflow. This may be due to rising tidal response of Ebey Slough. On the date infiltration testing was done, high tide for Quilceda Creek (near the mouth of Ebey Slough) was measured as approximately 10.8 feet at 2:30 pm, about 6.6 feet higher than low tide at 8:54 am. (https://tidesandcurrents.noaa.gov/gmap3/index.shtml?id=TWC1125).

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated and represents the infiltration rate of the native subgrade.

Table 5
Cell M1C
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling Head Test (in/hr)
M1C (bioretention soil)	130	420	10,644	0.50	greater than native soil infiltration rate	
M1C (subgrade)	Interpreted to be similar to wetted area				17	15

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell M1C was generally consistent with the design shown on the 2017 civil plan sheets (G&O, 2017). Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is consistent with the plans. Site design documents indicate that the ponding level was designed as 6 inches.

- Cell design: Quarry spall splash pads surrounding the concrete pad indicated on plans were not observed.

- Bioretention soil:
  - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.7 feet, plans indicated 1.5 feet.
  - Composition: The soil tested generally within the recommended guidelines for organic content and sand gradation, although the soil mix contained less than the recommended range of coarse sand and slightly more than the recommended range of fine sand. The coefficient of uniformity was below the recommended range.

- Subgrade conditions: The subgrade is interpreted to consist of a sand fill layer (up to 1.3 feet thick) over native Vashon recessional outwash, consistent with previous studies for this project (PanGEO, Inc., 2013 and 2014).

- During infiltration testing, water readily soaked through the bioretention soil mix. Water was observed in the shallow well point (screened at the base of the bioretention soil), demonstrating that water accumulated on the underlying subgrade. The native fine sand is interpreted to have a lower permeability than the overlying bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

- Subgrade infiltration rate: Measured at about 17 in/hr.

- Bioretention soil field infiltration rate:
  - Greater than the measured field rate of 17 in/hr
  - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the native subgrade infiltration rate.

- A shallow groundwater table is present in the location of the M1C facility as measured in M1C-WP-1 and previous studies for this project (PanGEO, Inc., 2014). The groundwater response during testing may have been influenced by the tidal response of Ebey Slough since the water table continued to rise 30 minutes after the end of inflow.

- The effects of shallow groundwater mounding will increase during the wetter winter months, and will reduce the effective infiltration rate by reducing the vertical gradient. The ongoing monitoring data will be reviewed for groundwater and tidal influence on facility infiltration performance.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

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Attachments:	Figure M1C F1:	Vicinity Map
	Figure M1C F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

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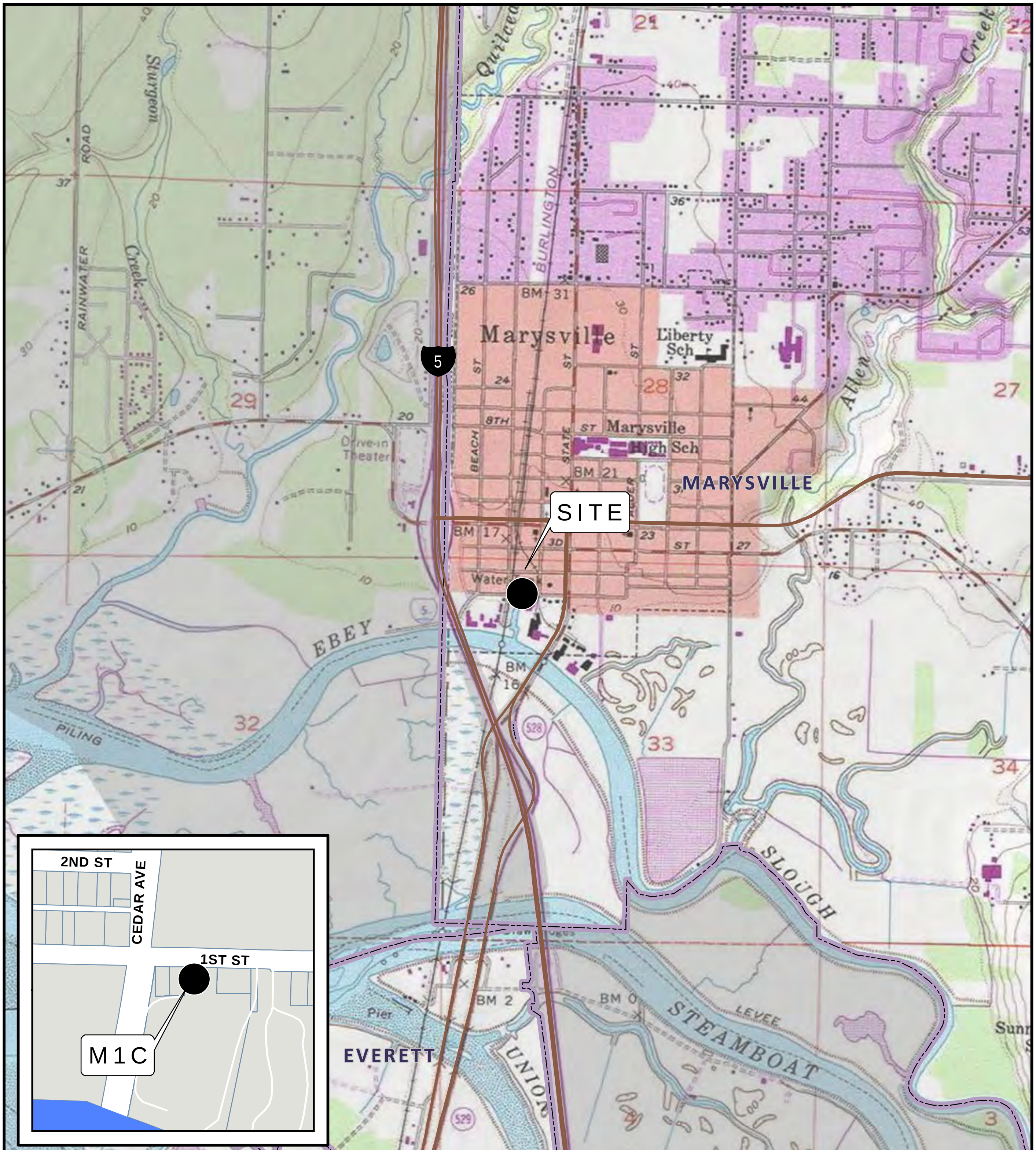

DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NATIONAL GEOGRAPHIC SOCIETY 2013
SNOHOMISH CO: STREETS, CITY LIMITS, PARCELS, 1/18
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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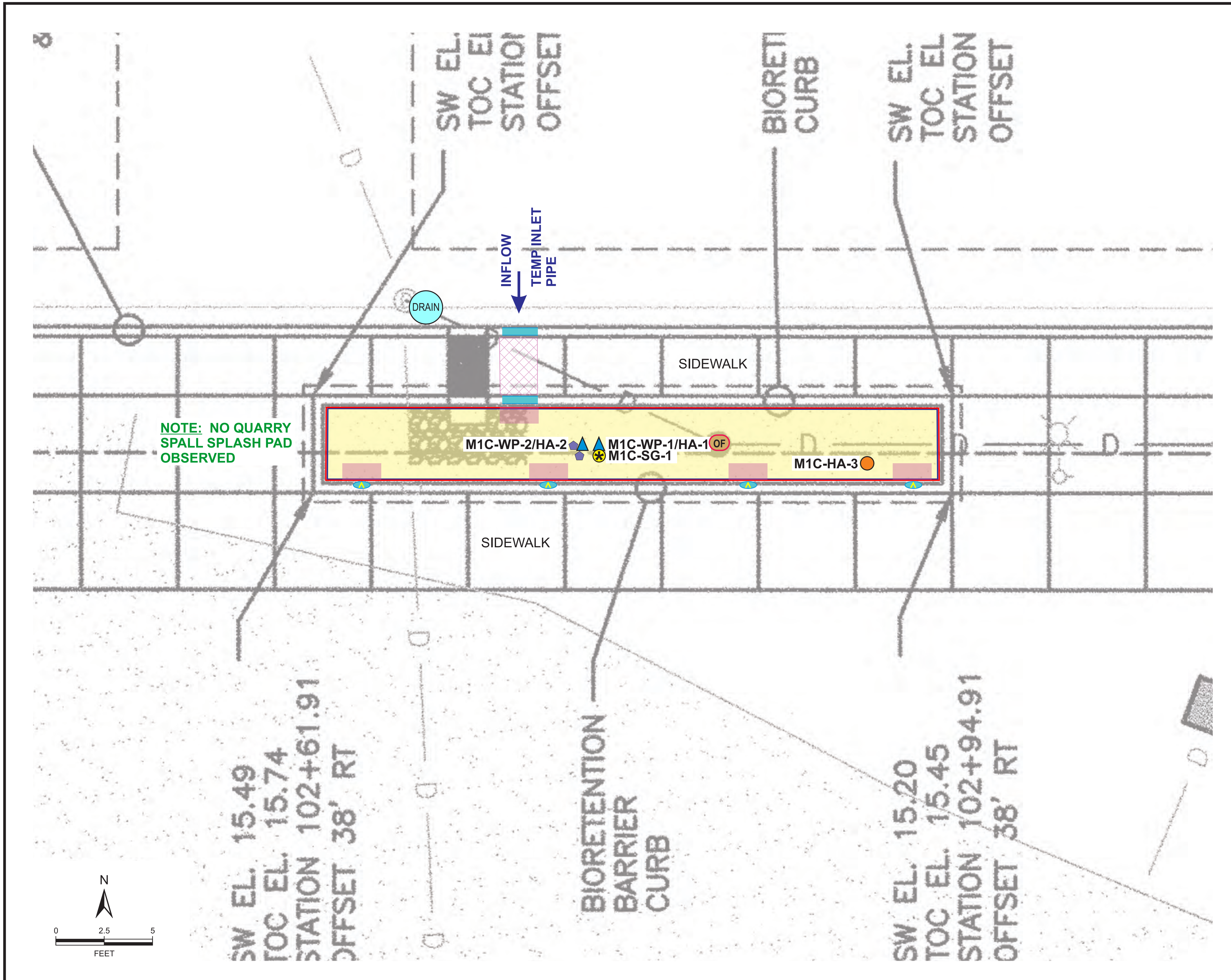
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, M1C SITE
MARYSVILLE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M1C F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_M1C.mxd



150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: M1C F2

LEGEND:

- ● HA — HAND AUGER
- ▲ WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- → INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW - 8" PVC
- PVC PONDING TUBE
- CURB CUT
- CONCRETE SPLASH PAD
- METAL GRATE
- SMALL CURB NOTCH

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: GRAY AND OSBORNE, INC., CITY OF MARYSVILLE, 1ST STREET LOW IMPACT DEVELOPMENT, BIORETENTION PLAN, SHEET 14 OF 25 6/19/17

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

associated earth sciences incorporated

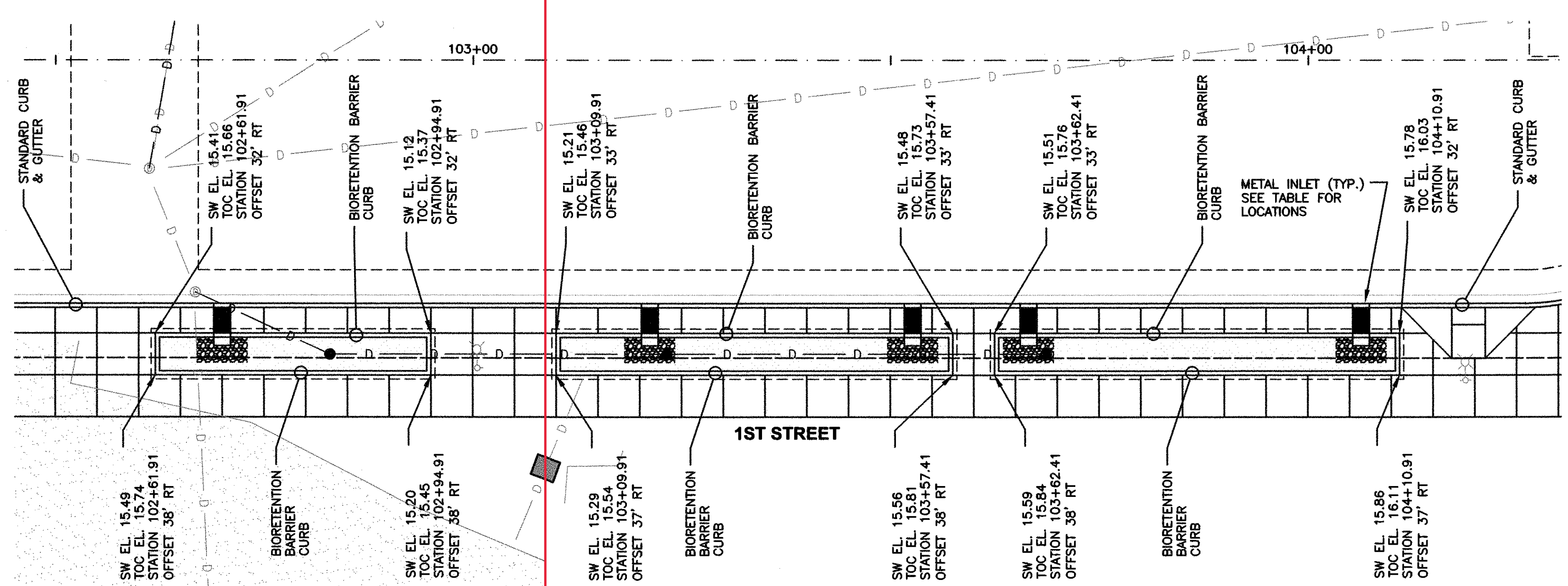
FACILITY AND EXPLORATION PLAN
M1C SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MARYSVILLE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M1C F2

APPENDIX A

Project Civil Plans

SCALE: 1"=20'



BIORETENTION AREA S-1
STATION 102+62 TO STATION 102+95
AREA EL.= 12.4' (±)
OVERFLOW ELEV.= 12.9' (±)

BIORETENTION AREA S-2
STATION 103+10 TO STATION 103+57
AREA EL.= 12.5' (±)
OVERFLOW ELEV.= 13.0' (±)

BIORETENTION AREA S-3
STATION 103+62 TO STATION 104+11
AREA EL.= 12.9' (±)
OVERFLOW ELEV.= 13.4' (±)

METAL INLET LOCATION TABLES

BIORETENTION AREA S-1
102+70.80

SEE NOTE 1

BIORETENTION AREA S-2
103+20.78
103+52.23

SEE NOTE 1

BIORETENTION AREA S-3
103+65.75
104+05.81

SEE NOTE 1

NOTES:

1. SEE BIORETENTION AREA CURB INLET DETAILS, SHEETS 18 – 19.
2. FOR PLAN CLARITY, ONLY EXISTING AND PROPOSED STORM DRAINAGE FACILITIES ARE SHOWN. SEE PLAN AND PROFILE SHEETS FOR ADDITIONAL UTILITY INFORMATION.
3. CONTRACTOR SHALL FURNISH AND INSTALL A 2' WIDE X 1' DEEP QUARRY SPALL SLASH PAD AROUND THE CONC PAD. SEE DETAILS, SHEETS 18 – 19.

Gray & Osborne, Inc.
CONSULTING ENGINEERS
3710 168TH STREET NE, BLDG. B, SUITE 210
ARLINGTON, WA 98223 • (360) 454-5490

DATE: JUNE 2017
SCALE: NOTED
DRAWN: C.J.B.
CHECKED: S.A.C.
APPROVED: K.W.B.

No.	REVISION	DATE	APPD

STACEY ANN CLEAR — STATE OF WASHINGTON — 38311 — REGISTERED PROFESSIONAL ENGINEER

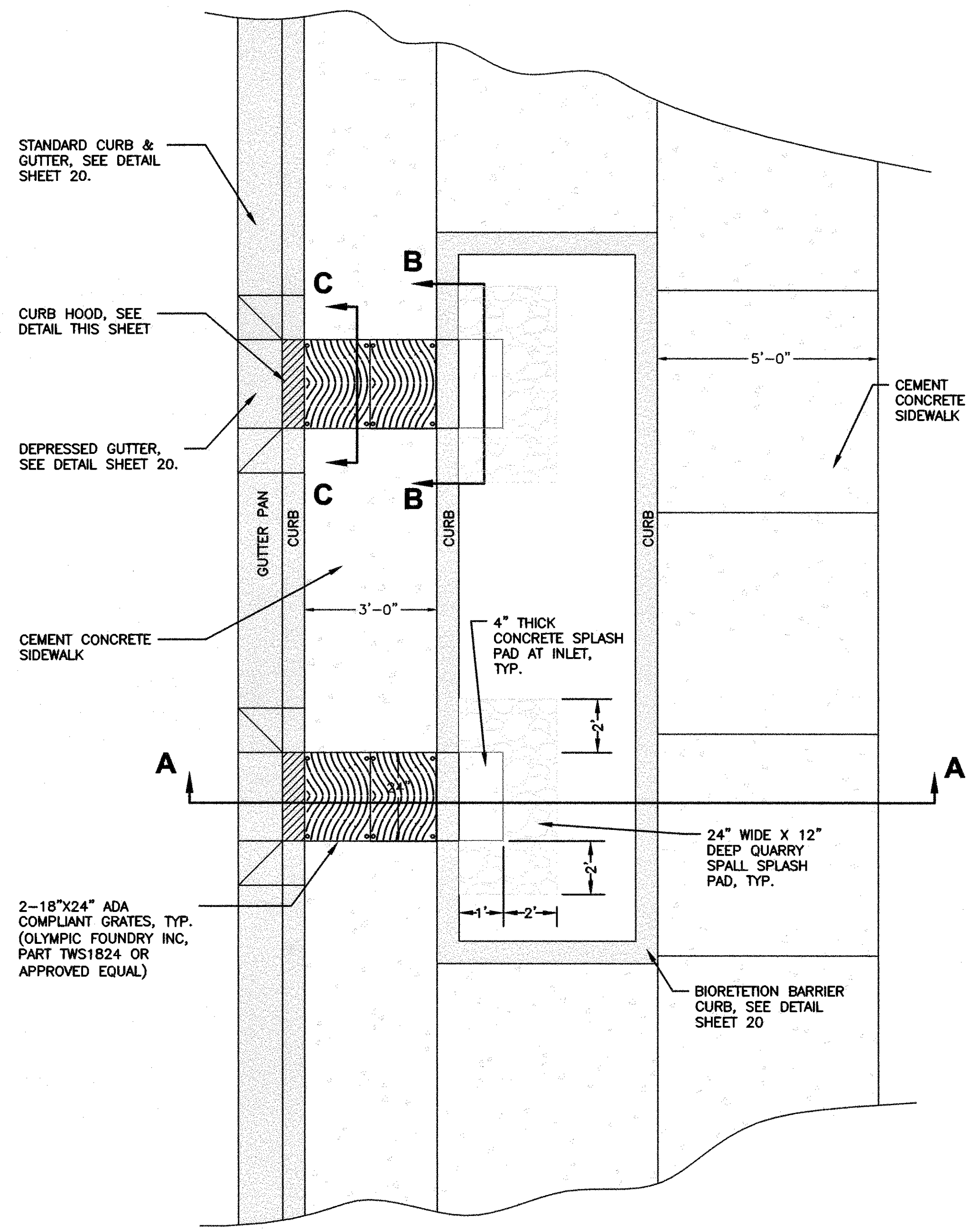
KEVIN W. BROWN — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER — 6/16/17

CITY OF MARYSVILLE
SNOHOMISH COUNTY WASHINGTON
1ST STREET LOW IMPACT DEVELOPMENT PROJECT
BIORETENTION PLAN

SHEET: 14
OF: 25

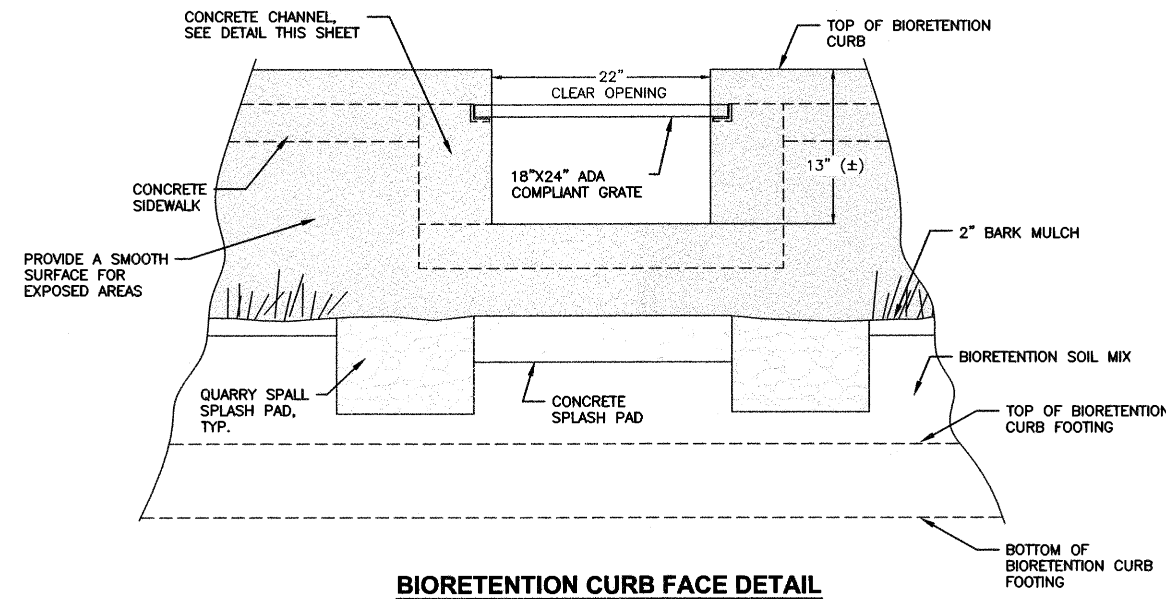
JOB NO.: 13587.00
DWG: RETENTION PLANS

M:\MARYSVILLE\13587 3rd St Retrofit\Planset_1st Street Plans\G-Sheets\Retention Plans.dwg, 6/16/2017 2:35 PM, KEVIN BROWN



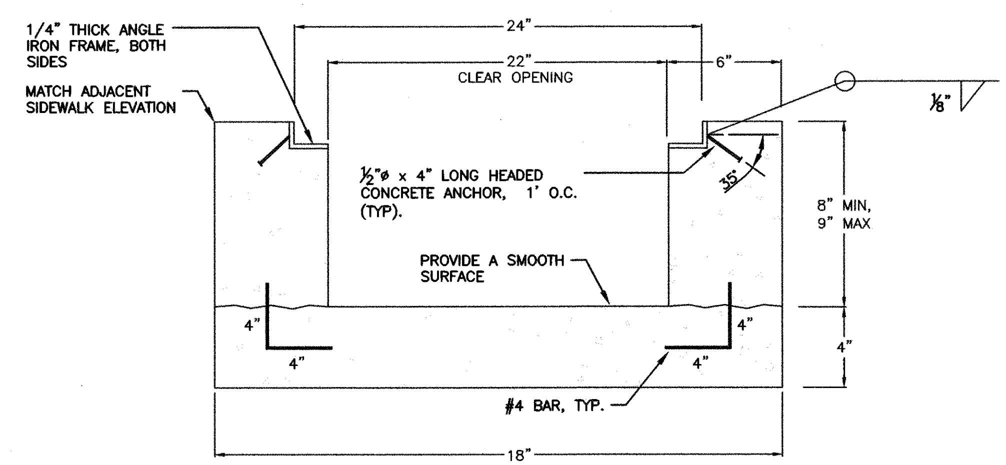
TYPICAL BIORETENTION AREA PLAN VIEW (SOUTH SIDE)

NTS



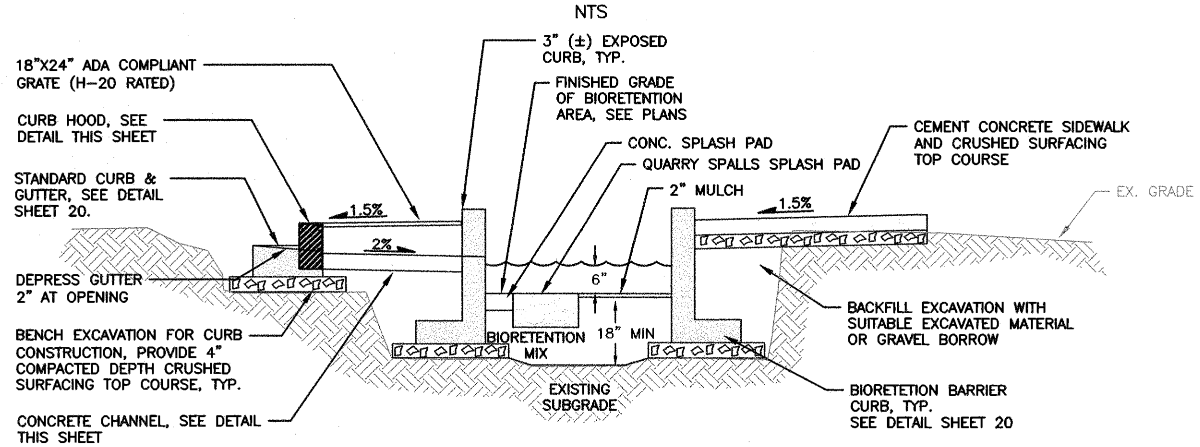
BIORETENTION CURB FACE DETAIL
SECTION B-B

NTS



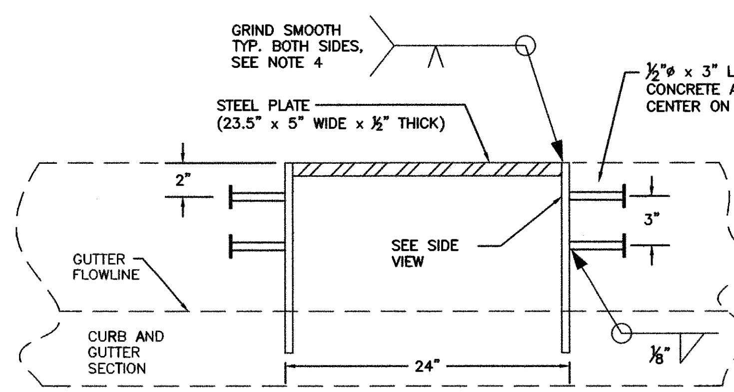
CONCRETE CHANNEL DETAIL
SECTION C-C

NTS



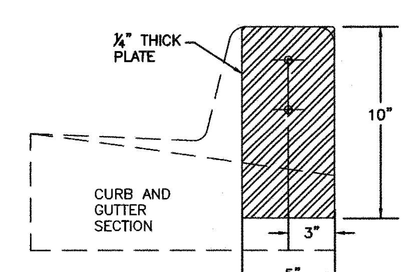
TYPICAL BIORETENTION AREA CROSS
SECTION A-A

NTS



CURB HOOD (FRONT VIEW)

NTS



CURB HOOD (SIDE VIEW)

NTS

CURB HOOD NOTES

1. HEADED CONCRETE ANCHORS SHALL MEET THE REQUIREMENTS OF ASTM A-108.
2. ALL PLATES SHALL MEET THE REQUIREMENTS OF ASTM A-36
3. ENTIRE ASSEMBLY SHALL BE HOT-DIP GALVANIZED IN ACCORDANCE WITH ASTM A-123.
4. SINGLE BEVEL GROOVE WELD.

CURB HOOD DETAIL

NTS

Gray & Osborne, Inc.
CONSULTING ENGINEERS
3710 168TH STREET NE, BLDG. B, SUITE 210
ARLINGTON, WA 98223 • (360) 454-5490

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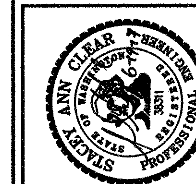
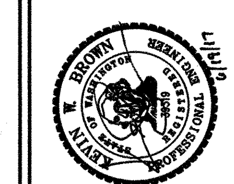
No.	REVISION	DATE	APPD





CITY OF MARYSVILLE
SNOHOMISH COUNTY WASHINGTON
1ST STREET LOW IMPACT DEVELOPMENT PROJECT
DETAILS

SHEET: 18
OF: 25

JOB NO.: 13587.00
DWG:DETAILS

M:\MARYSVILLE\13587 3rd St Retrofit\Planset_1st Street Plans\G-Sheets\Details.dwg, 6/16/2017 2:35 PM, KEVIN BROWN

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	M1C-HA-1/WP	1 of 2

Project Name: Bioretention Hydrologic Performance Study
Elevation (Top of Well Casing): 99.6 (Project Datum)
Water Level Elevation: Dry
Drilling/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Location: Marysville, WA
Surface Elevation (ft): 97.8 (Project Datum)
Date Start/Finish: 10/18/18,10/18/18
Hole Diameter (in): 4 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Fine wood mulch 0 to 0.2 feet				**Fine Wood Mulch**
		Bioretention soil mix 0.2 to 1.6 feet				**Bioretention Soil Mix** Loose, moist, dark brown, fine to medium SAND, trace silt, trace gravel; organic rich; massive (SP).
		Threaded steel pipe 1.25-inch I.D. with threaded vented PVC cap -1.8 to 6.5 feet				
		Bentonite chips 1.6 to 3.6 feet				**Fill** Loose, moist, brown, gravelly, fine to medium SAND, some silt; massive (SP-SM).
						Vashon Recessional Outwash Medium dense, moist, oxidized reddish brown, fine SAND, some silt, some gravel (SP-SM).
		Excavated Recessional Outwash sands 3.6 to 5.9 feet				Becomes very moist, less oxidized, and silt decreases. Occasional wood fragments observed
5						

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
150387H007	M1C-HA-1/WP	2 of 2

Project Name	Bioretention Hydrologic Performance Study	Location	Marysville, WA
Elevation (Top of Well Casing)	99.6 (Project Datum)	Surface Elevation (ft)	97.8 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/18/18,10/18/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Driven into existing sediments 5.9 to 9.8 feet				Boring terminated at 5.9 feet Well completed at 9.8 feet on 10/18/18. Refusal on gravel. No seepage. No caving. Steel drive point placed in borehole and hand driven with slide hammer to depth of 9.8 feet.
		Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 6.5 to 9.1 feet				
		Threaded steel pipe 1.25-inch I.D. and drive point 9.1 to 9.8 feet				
10		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 11.2 feet.				

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

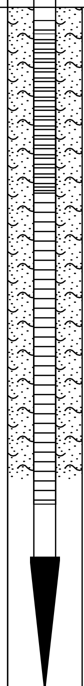
Logged by: ADY
Approved by: JHS

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	M1C-HA-2/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Marysville, WA
Elevation (Top of Well Casing)	99.3 (Project Datum)	Surface Elevation (ft)	97.9 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/18/18,10/18/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		 Fine wood mulch 0 to 0.2 feet				**Fine Wood Mulch**
		Threaded steel pipe 1.25-inch I.D. wtih threaded PVC cap -1.4 to 0.2 feet Tape over well point screen 0.2 to 0.7 feet Bioretention soil mix 0.2 to 1.8 feet				**Bioretention Soil Mix** Loose, moist, dark brown, fine to medium SAND, trace silt, trace gravel; organic rich; massive (SP).
		Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 0.7 to 1.9				
						At 1.7 feet: Fill - Loose, moist, brown, gravelly, fine to medium SAND, some silt; massive (SP-SM).
						Boring terminated at 1.8 feet Well completed at 2.6 feet on 10/18/18. Refusal on gravel. No seepage. No caving. Steel drive point placed in borehole and driven with slide hammer to depth of 2.6 feet.
		Threaded steel pipe 1.25-inch I.D. and drive point 1.9 to 2.6 feet				
		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 3.6 feet.				
5						

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)

Logged by: ADY

Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	M1C-HA-3	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Marysville, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/18/18,10/18/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Fine Wood Mulch					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, fine to medium SAND, trace silt, trace gravel; organic rich; massive (SP).					
		S-2		**At 1.8 feet: Fill** Loose, moist, brown, gravelly, fine to medium SAND, some silt; massive (SP-SM). Bottom of exploration boring at 1.9 feet. Refusal on gravel. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/18/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- M1C			

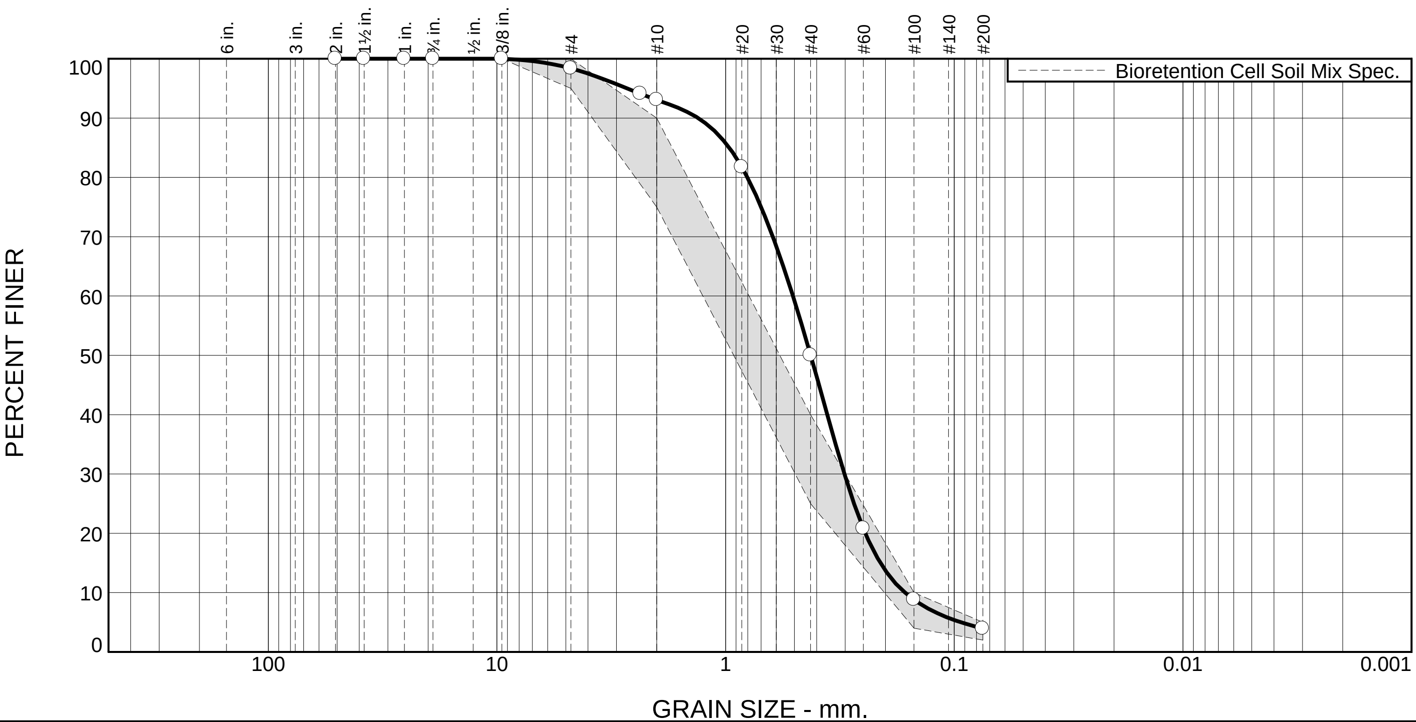
Moisture Content

Sample ID	HA-1 (0.3'-0.5')	HA-3 (0.2'-0.6')
Wet Weight + Pan	963.55	925.72
Dry Weight + Pan	887.34	847.94
Weight of Pan	536.16	421.73
Weight of Moisture	76.21	77.78
Dry Weight of Soil	351.18	426.21
% Moisture	17.8	15.4

Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	599.89	573.01
Dry Soil After Burn + Pan	588.21	559.60
Weight of Pan	391.92	357.93
Wt. Loss Due to Ignition	11.68	13.41
Actual Wt. Of Soil After Burr	196.29	201.67
% Organics	5.6	6.2

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.6	5.3	43.1	46.1	3.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	98.4	95.0 - 100.0	
#8	94.1		
#10	93.1	75.0 - 90.0	X
#20	81.8		
#40	50.0	25.0 - 40.0	X
#60	20.8		
#100	8.8	4.0 - 10.0	
#200	3.9	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 1.3181 D_{85}= 0.9641 D_{60}= 0.5077
D_{50}= 0.4247 D_{30}= 0.3021 D_{15}= 0.2104
D_{10}= 0.1641 C_u= 3.09 C_c= 1.10

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/19/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

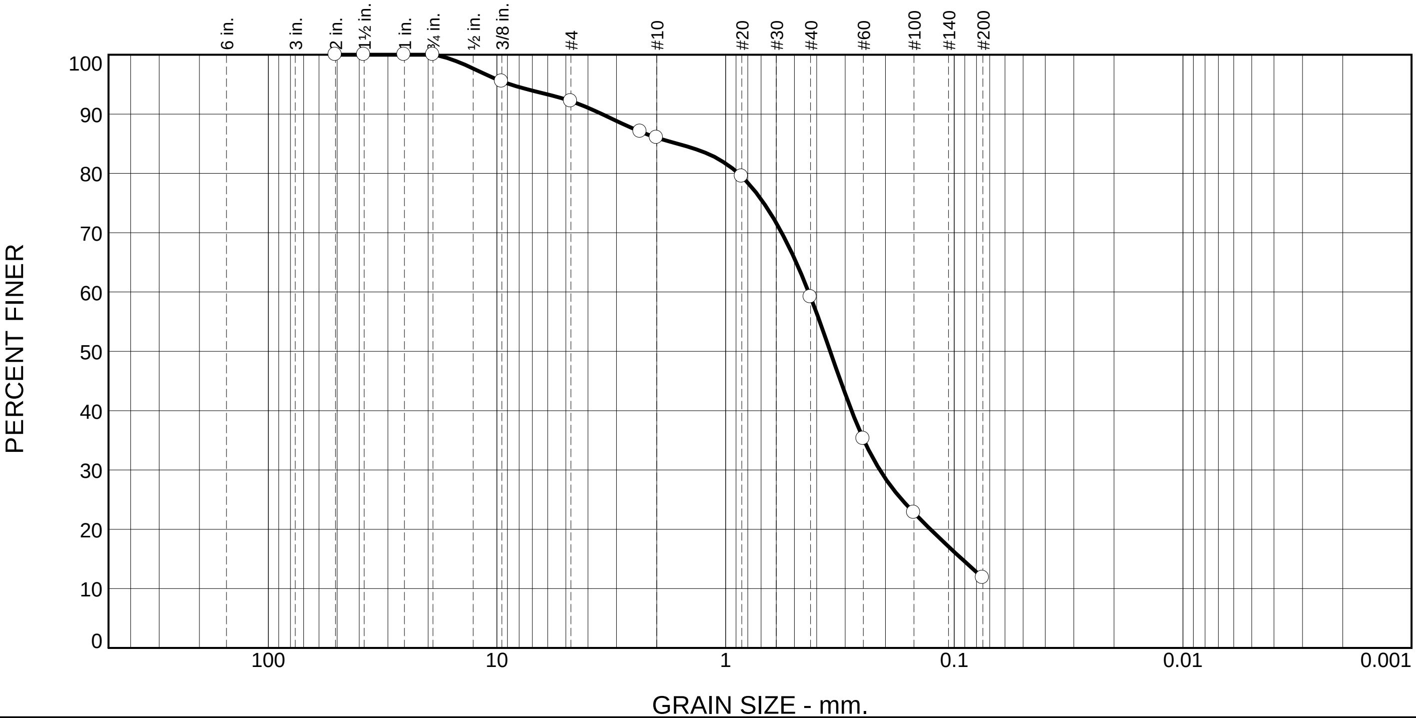
Source of Sample: (M1C) Marysville- 1st Street LID **Depth:** 0.3'-0.5' **Date Sampled:** 10/18/2018
Sample Number: HA-1

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	7.8	6.2	26.8	47.4	11.8	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	95.5		
#4	92.2		
#8	87.0		
#10	86.0		
#20	79.5		
#40	59.2		
#60	35.2		
#100	22.8		
#200	11.8		

* (no specification provided)

Material Description

SAND, some silt, some gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 3.4746 D_{85}= 1.6260 D_{60}= 0.4335
D_{50}= 0.3489 D_{30}= 0.2117 D_{15}= 0.0926
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 10/19/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

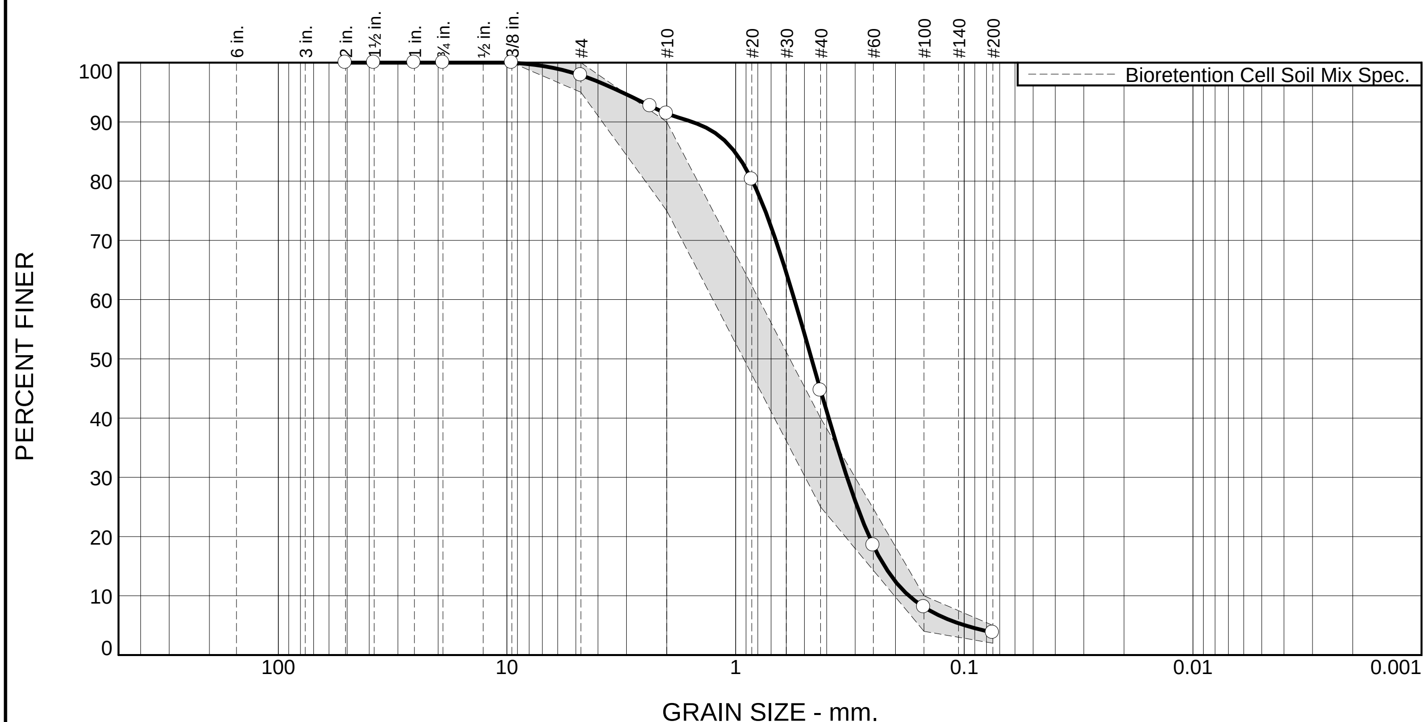
Source of Sample: (M1C) Marysville- 1st Street LID **Depth:** 3'-3.9' **Date Sampled:** 10/19/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.1	6.5	46.7	40.9	3.8	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.9	95.0 - 100.0	
#8	92.7		
#10	91.4	75.0 - 90.0	X
#20	80.3		
#40	44.7	25.0 - 40.0	X
#60	18.5		
#100	8.1	4.0 - 10.0	
#200	3.8	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

$D_{90}=$ 1.5479 $D_{85}=$ 1.0107 $D_{60}=$ 0.5532
$D_{50}=$ 0.4655 $D_{30}=$ 0.3256 $D_{15}=$ 0.2231
$D_{10}=$ 0.1746 $C_u=$ 3.17 $C_c=$ 1.10

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/19/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (M1C) Marysville- 1st Street LID **Depth:** 0.2'-0.6' **Date Sampled:** 10/18/2018
Sample Number: HA-3

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

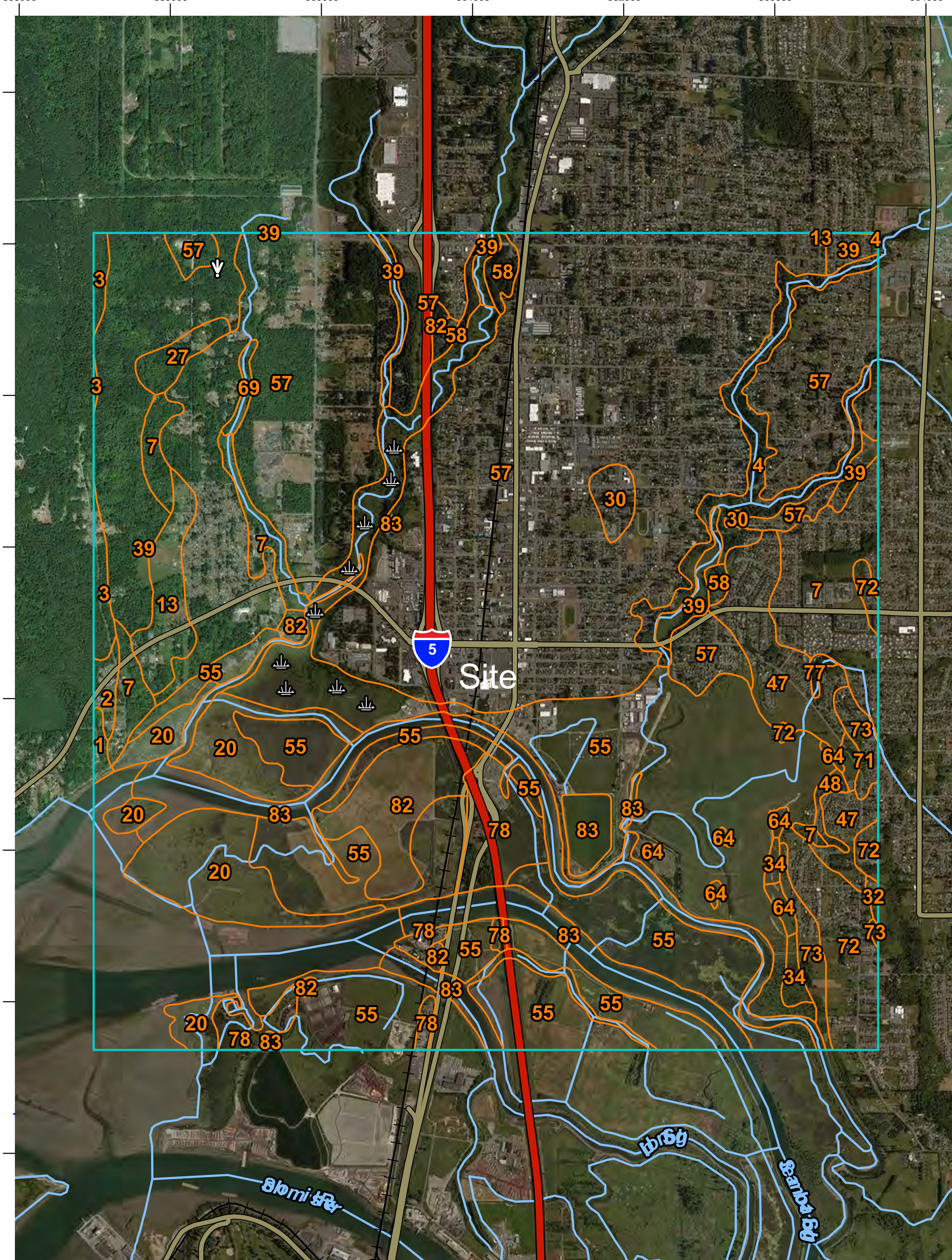
Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)

Site Unit: Qvrm: Vashon Recessional Outwash, Marysville Member

Source:
Geologic map of the Marysville quadrangle, Snohomish County, Washington
Author(s): Minard, J.P.
Publishing Organization: U.S. Geological Survey
Series and Number: Miscellaneous Field Studies Map MF-1743
Publication Date: 1985
Map Scale: 1:24,000



Map Scale: 1:40,200 if printed on A portrait (8.5" x 11") sheet.

N

Meters: 0, 500, 1000, 2000, 3000

Feet: 0, 1500, 3000, 6000, 9000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1	Alderwood gravelly sandy loam, 0 to 8 percent slopes	10.0	0.1%
2	Alderwood gravelly sandy loam, 8 to 15 percent slopes	17.5	0.3%
3	Alderwood gravelly sandy loam, 15 to 30 percent slopes	39.3	0.6%
4	Alderwood-Everett gravelly sandy loams, 25 to 70 percent slopes	133.3	1.9%
7	Bellingham silty clay loam	276.3	4.0%
13	Custer fine sandy loam	79.6	1.1%
20	Fluvaquents, tidal	296.5	4.3%
27	Kitsap silt loam, 0 to 8 percent slopes	31.0	0.4%
30	Lynnwood loamy sand, 0 to 3 percent slopes	30.3	0.4%
32	McKenna gravelly silt loam, 0 to 8 percent slopes	4.3	0.1%
34	Mukilteo muck	18.8	0.3%
39	Norma loam	367.5	5.3%
47	Pastik silt loam, 0 to 8 percent slopes	169.0	2.4%
48	Pastik silt loam, 8 to 25 percent slopes	11.2	0.2%
55	Puget silty clay loam	1,511.0	21.8%
57	Ragnar fine sandy loam, 0 to 8 percent slopes	2,616.5	37.7%
58	Ragnar fine sandy loam, 8 to 15 percent slopes	44.5	0.6%
64	Snohomish silt loam	22.2	0.3%
69	Terric Medisaprists, nearly level	11.0	0.2%
71	Tokul silt loam, 8 to 15 percent slopes	8.8	0.1%
72	Tokul gravelly medial loam, 0 to 8 percent slopes	143.4	2.1%
73	Tokul gravelly medial loam, 8 to 15 percent slopes	61.8	0.9%
77	Tokul-Winston gravelly loams, 25 to 65 percent slopes	5.3	0.1%
78	Urban land	138.2	2.0%
82	Xerorthents, nearly level	150.5	2.2%

Legend:

B-1 Approx. Borehole Location (PanGEO)

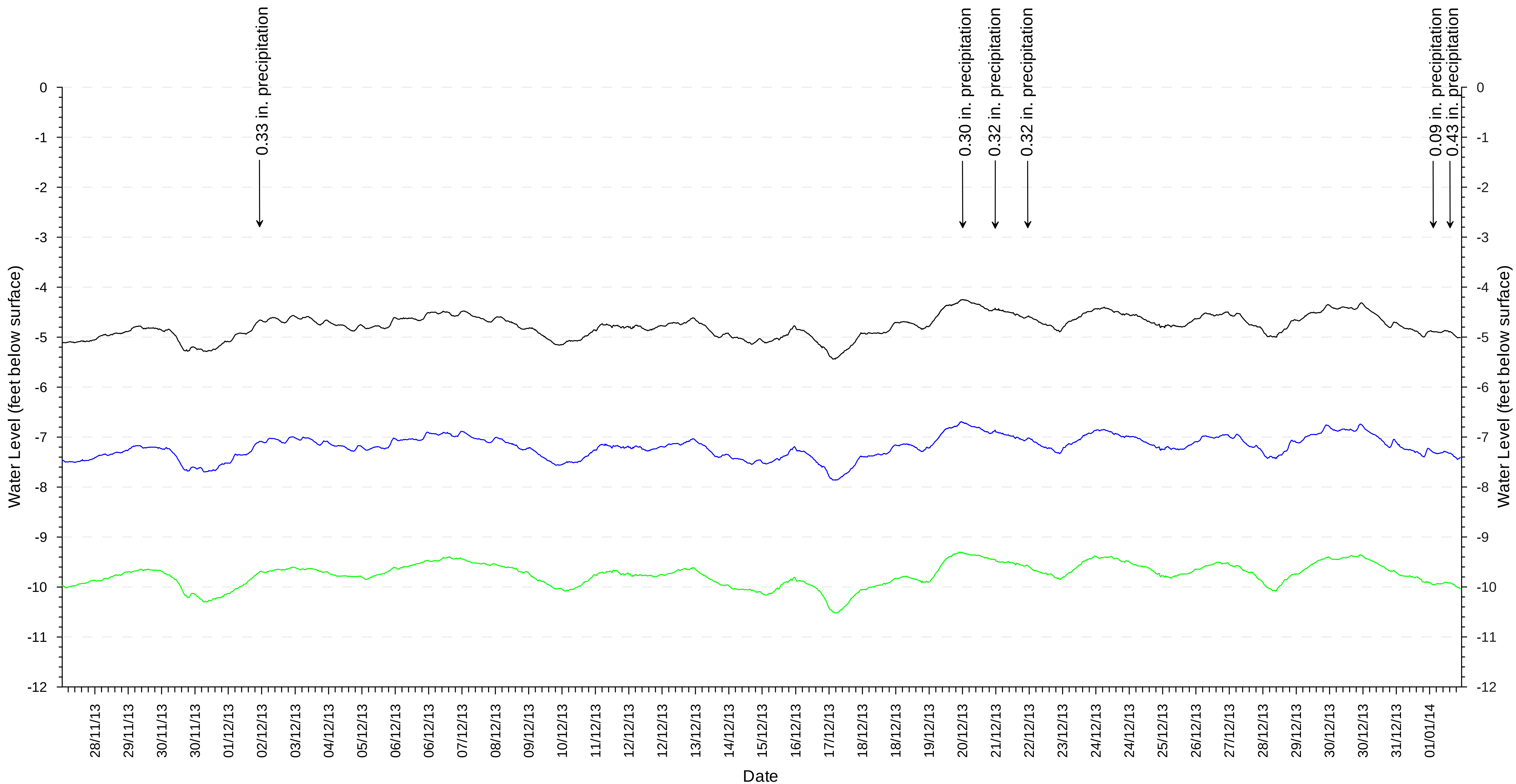
Core #1 Approx. Pavement Core Location (City of Marysville)

Approx. Scale
1" = 60'

Note: Base map modified from Aerial Map provided by City of Marysville.

PanGEO INCORPORATED	1st & 3rd Streets Retrofit Marysville, WA	SITE AND EXPLORATION PLAN 1ST STREET BETWEEN CEDAR AVENUE AND STATE AVENUE	
		Project No. 13-239	Figure No. 2A

file.grf w/ file.dat 1/30/14 (11:29) TEA2



Legend:

- B-1 Water Depth (feet)
- B-2 Water Depth (feet)
- B-4 Water Depth (feet)

Note: Monitoring well in B-7 was dry after drilling.
Rainfall data from Stanwood.

PanGEO INCORPORATED

1st & 3rd Streets Retrofit
Marysville, Washington

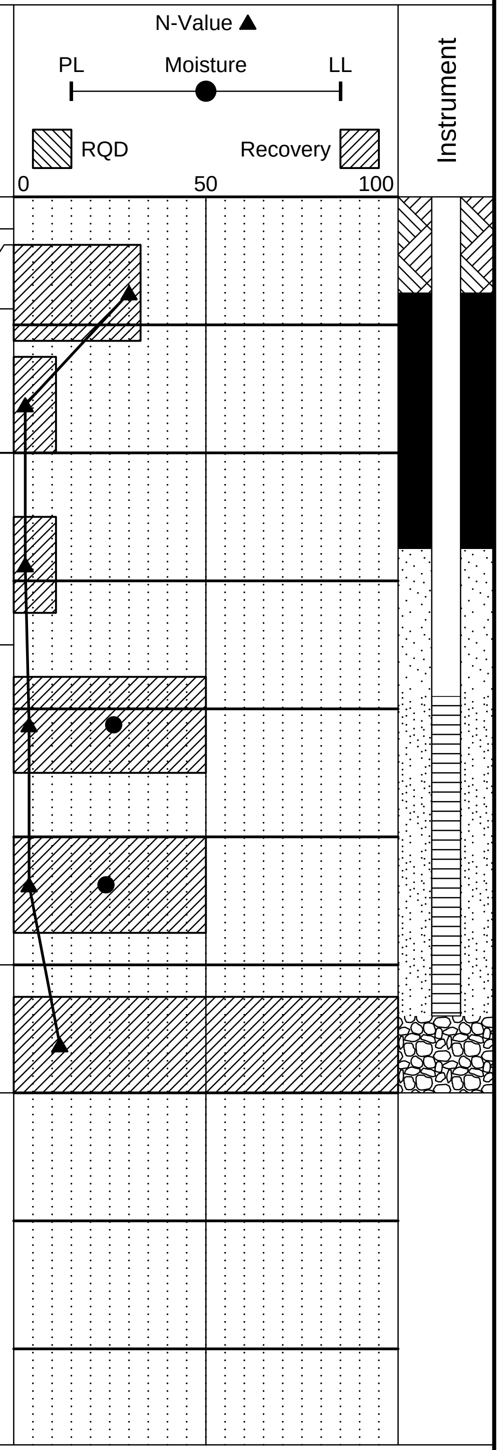
SUMMARY GROUNDWATER LEVEL BETWEEN NOVEMBER 27, 2013 AND JANUARY 8, 2014

Project No.	Figure No.
13-239	3

Pump Test Results 11-8-13.grf 2/3/14 (9:07) SHE

Project:	1st & 3rd Street Retrofit	Surface Elevation:	
Job Number:	13-239	Top of Casing Elev.:	
Location:	1st and 3rd Streets, Marysville, WA	Drilling Method:	HSA
Coordinates:	Northing: , Easting:	Sampling Method:	SPT

Depth, (ft)	Sample No.	Sample Type	Blows / 6 in.	Other Tests	Symbol	MATERIAL DESCRIPTION
0						6 inches Asphalt.
						3 inches chip seal or similar.
	S-1		27 20 10			Approximately 12 inches of sand and gravel (Road Base).
2	S-2		4 2 1			Loose, brown, silty, fine to coarse SAND with gravel: moist, sub-angular gravel. (Fill).
4	S-3		1 1 2			Very loose, brown, fine to coarse SAND with silt: moist, abundant red cedar debris, non-plastic, poorly graded.
8	S-4		1 1 3	GS		Loose, brown-gray, fine to medium SAND with some silt: wet, poorly graded, non-plastic, laminated. (Recessional Outwash).
10	S-5		2 1 3	GS		Becoming fine to coarse SAND, some silt.
12	S-6		3 5 7			Loose to medium dense, brown gray, silty, fine to medium SAND: wet, poorly graded, non-plastic, rapid dilatancy, homogeneous, laminated. (Recessional Outwash).
14						Boring terminated at about 14 feet below the surface. Groundwater was measured at about 7.6 feet below the surface on November 26, 2013.
16						
18						



Completion Depth:	14.0ft
Date Borehole Started:	11/25/13
Date Borehole Completed:	11/25/13
Logged By:	S. Evans
Drilling Company:	Bore Tec Drilling

Remarks: Groundwater measured in well installation on 11/26/13 at 12:31. Well was then developed by pumping with a down-hole pump until return water was nearly clear, about 5 minutes. Data logger installed in well following development. Logging was programed to begin at 12:00 noon, 11/27/13.

PanGEO INCORPORATED

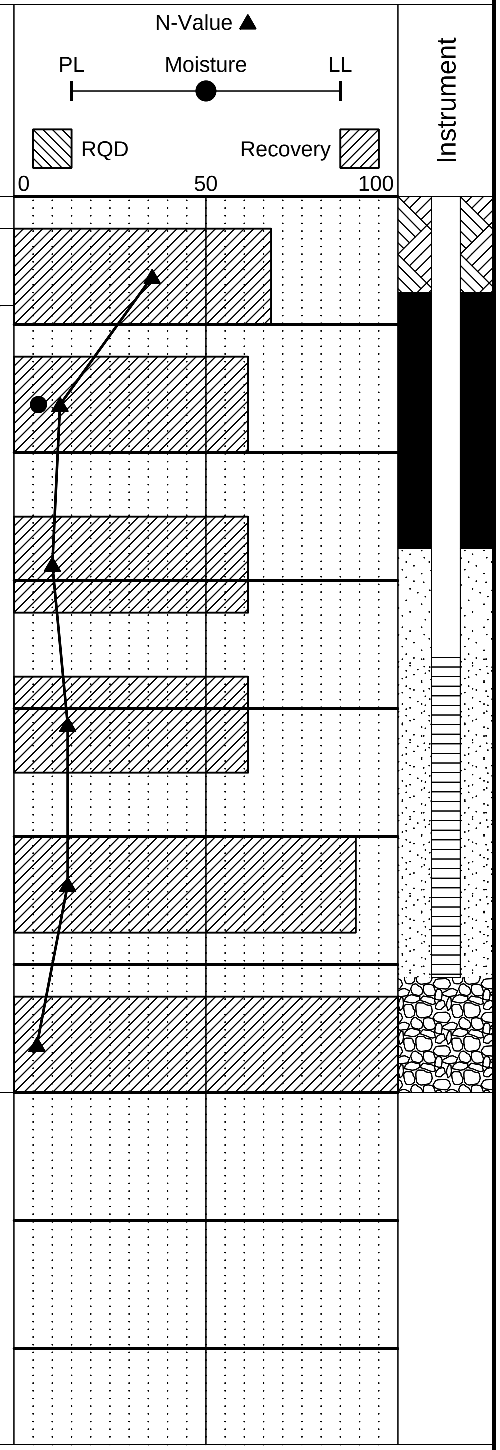
LOG OF TEST BORING B-1

Figure A-2

The stratification lines represent approximate boundaries. The transition may be gradual.

Project:	1st & 3rd Street Retrofit	Surface Elevation:	
Job Number:	13-239	Top of Casing Elev.:	
Location:	1st and 3rd Streets, Marysville, WA	Drilling Method:	HSA
Coordinates:	Northing: , Easting:	Sampling Method:	SPT

Depth, (ft)	Sample No.	Sample Type	Blows / 6 in.	Other Tests	Symbol	MATERIAL DESCRIPTION
0						6 inches of Asphalt.
	S-1		18 24 12			16 inches of Ballast/Base sand and gravel. Dense, brown and white, gravelly, fine to coarse SAND: moist some silt, layered, sub-rounded to sub-angular (Road Base).
2	S-2		5 6 6	GS		Medium dense, brown to gray, fine to medium SAND: moist becoming wet, trace to some silt, well and poorly graded, non-plastic fines, occasional organic material or woody debris, homogeneous, laminated. (Recessional Outwash).
4						
	S-3		4 5 5			Becoming wet.
6						
8	S-4		5 7 7			Some woody debris, occasional gravel.
10	S-5		4 7 7			Becoming fine to medium.
12	S-6		2 2 4			Laminated with one brown silt laminae.
14						Boring terminated at about 14 feet below the surface. Groundwater was measured at about 5.3 feet below the surface on November 26, 2013.
16						
18						



Completion Depth:	14.0ft
Date Borehole Started:	11/25/13
Date Borehole Completed:	11/25/13
Logged By:	S. Evans
Drilling Company:	Bore Tec Drilling

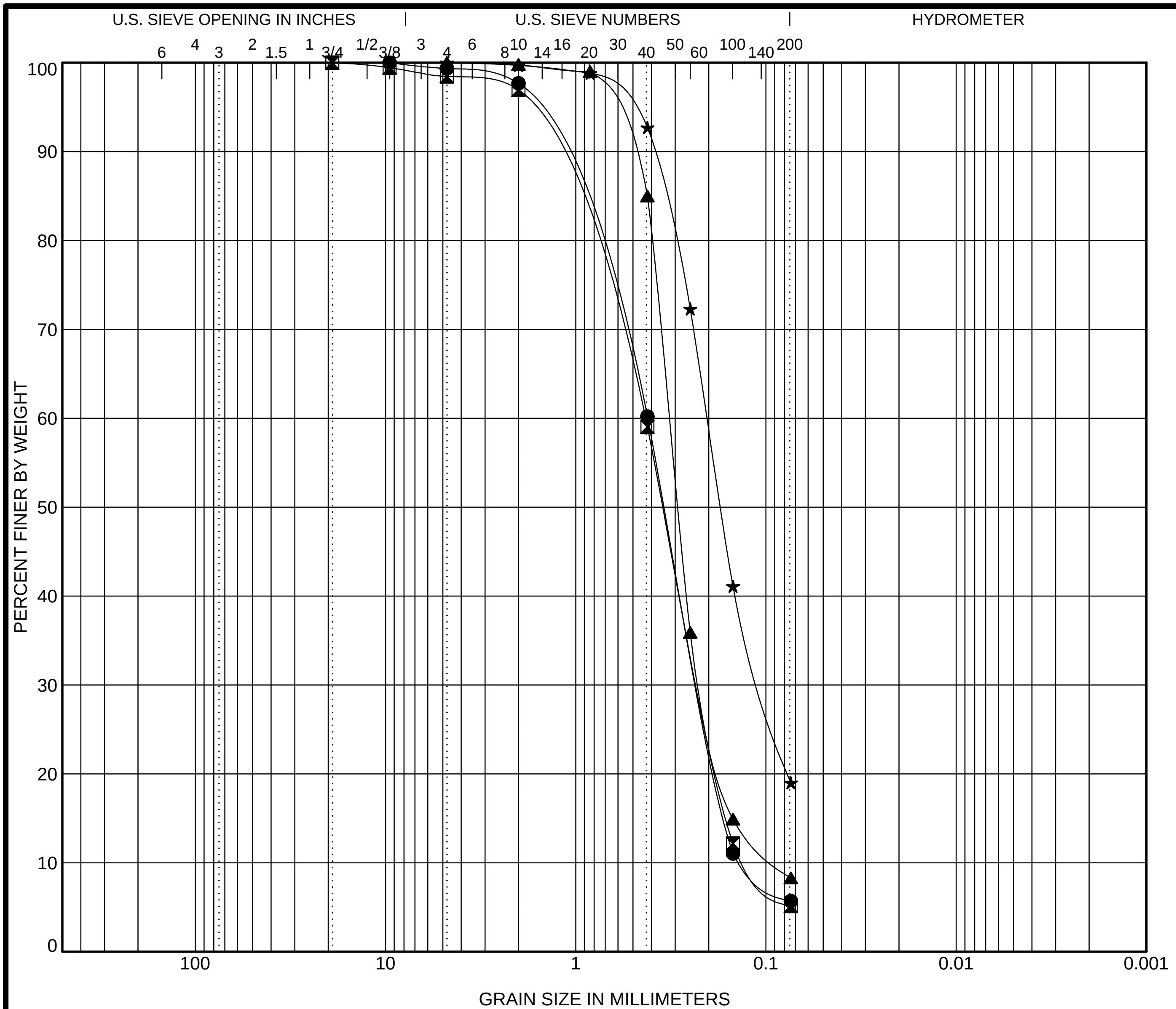
Remarks: Groundwater measured in well installation on 11/26/13 at 12:52. Well was then developed by pumping with a down-hole pump until return water was nearly clear, about 5 minutes. Data logger and barometric pressure logger installed in well following development. Logging was programed to begin at 12:00 noon, 11/27/13.

PanGEO INCORPORATED

LOG OF TEST BORING B-2

Figure A-3

The stratification lines represent approximate boundaries. The transition may be gradual.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	LL	PL	PI	Cc	Cu
●	**B-1**	**@ 7.5 ft.**	**Browm-gray, fine to medium SAND, some silt**				**0.91**	**3.22**
⧗	**B-1**	**@ 10.0 ft.**	**Brown-gray, fine to coarse SAND, some silt**				**0.93**	**3.64**
▲	**B-2**	**@ 2.5 ft.**	**Brown-gray, fine to medium SAND, some silt**				**1.64**	**3.64**
★	**B-3**	**@ 2.5 ft.**	**Dark gray-yellowish brown, silty fine SAND**					

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**B-1**	**7.5**	**9.52**	**0.418**	**0.222**	**0.13**	**0.7**	**93.5**	**5.8**	
⧗	**B-1**	**10.0**	**19.05**	**0.437**	**0.221**	**0.12**	**1.6**	**93.2**	**5.3**	
▲	**B-2**	**2.5**	**4.76**	**0.322**	**0.216**	**0.089**	**0.0**	**91.6**	**8.4**	
★	**B-3**	**2.5**	**4.76**	**0.204**	**0.105**		**0.0**	**80.6**	**19.4**	

PanGEO INCORPORATED
Phone: 206.262.0370

GRAIN SIZE DISTRIBUTION

Project: 1st & 3rd Street Retrofit
Job Number: 13-239
Location: 1st and 3rd Streets, Marysville, WA

Figure B-1

APPENDIX D

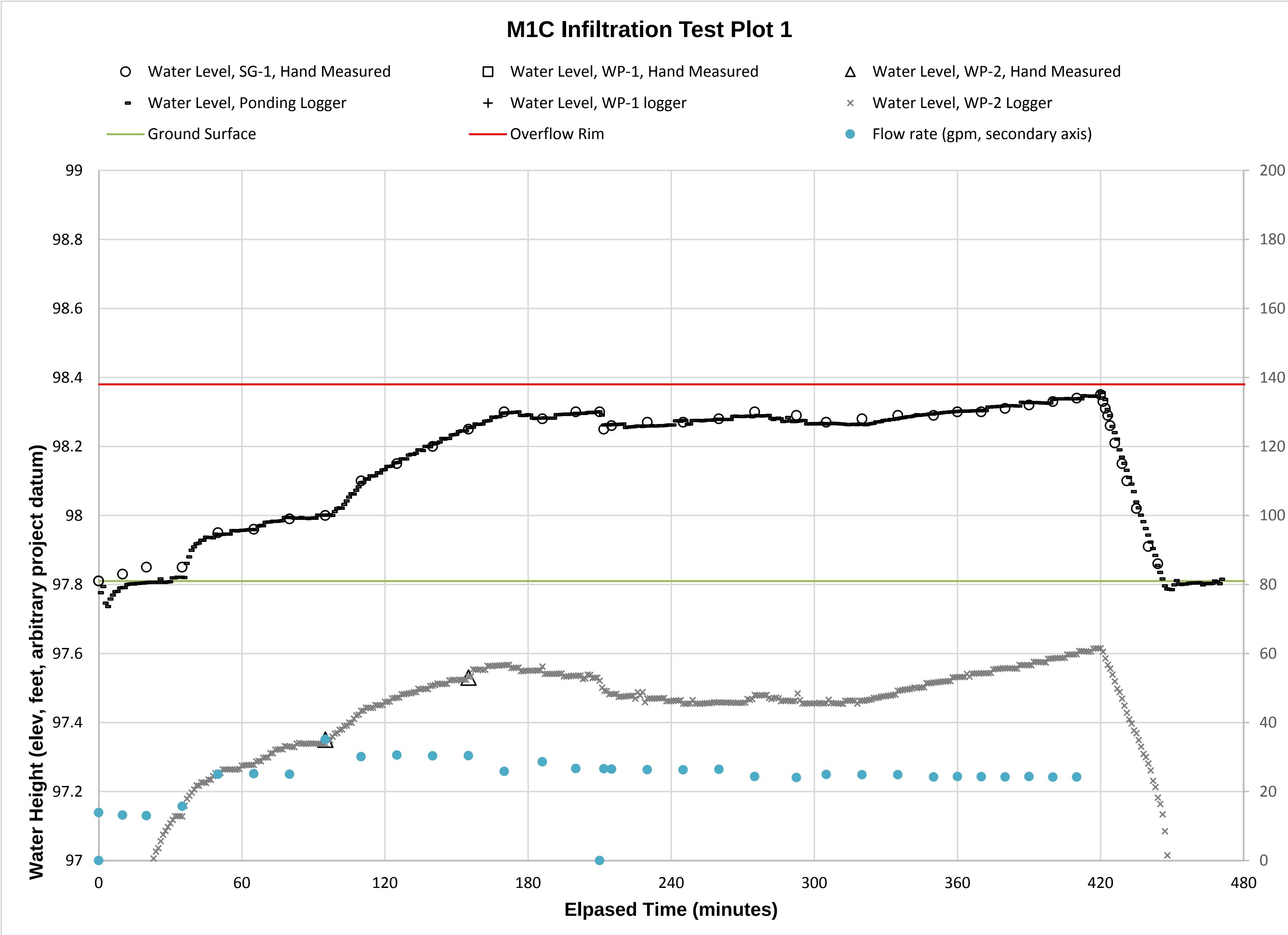
Field Infiltration Testing Data

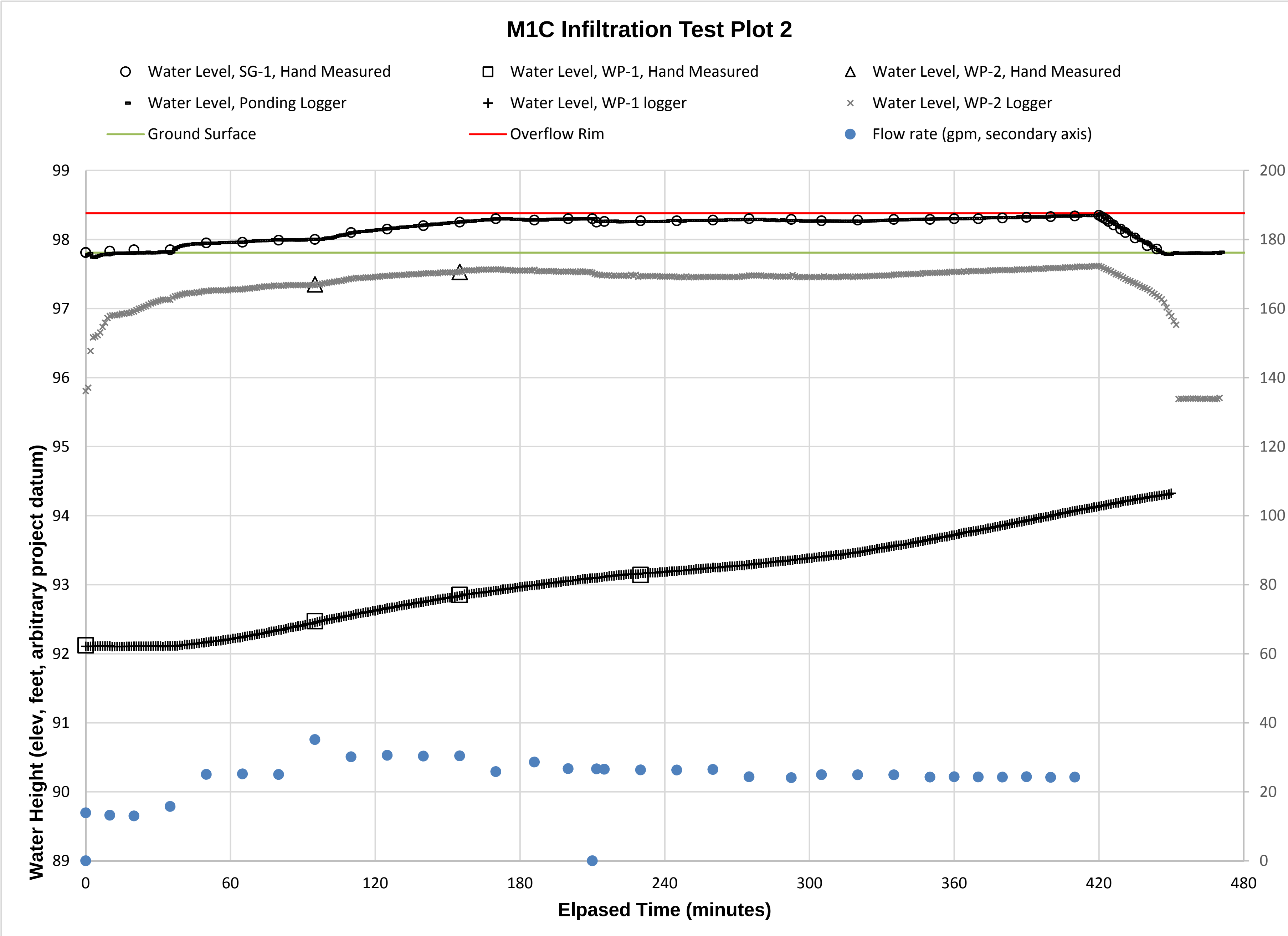
Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5
Date:	11/20/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	130.0
Test No.:	M1C	**Test Depth (feet):**	NA
Performed By:	ADY, KRB	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
7:36				
7:40	13.89	0	0	Flow on
7:50	13.17	0.02	135.9	
8:00	13	0.04	262	
8:15	15.72	0.04	460	
8:30	25.01	0.14	830	
8:45	25.17	0.15	1210	
9:00	25	0.18	1590	
9:15	35.11	0.19	1962	
9:30	30.11	0.29	2474	
9:45	30.56	0.34	2925	
10:00	30.33	0.39	3406	
10:15	30.39	0.44	3837	
10:30	25.83	0.49	4306	
10:46	28.61	0.47	4725	
11:00	26.67	0.49	5122	Approx 0.5 gpm leaking through pipe joint into overflow
11:10	0	0.49		Flow off, flow meter calibration check.
11:11	26.61	0.44		Flow resumed.
11:15	26.5	0.45	5519	
11:30	26.33	0.46	5900	
11:45	26.29	0.46	6296	
12:00	26.44	0.47	6691	
12:15	24.33	0.49	7106	At 12:15, reduced flow rate from 26.4 to 24.3
12:32	24.06	0.48	7523	
12:45	24.94	0.46	7843	Water level meter not reading well point water levels - likely low salinity water
13:00	24.89	0.47	8200	
13:15	24.89	0.48	8583	
13:30	24.22	0.48	8943	
13:40	24.33	0.49	9185	
13:50	24.28	0.49	9437	
14:00	24.22	0.5	9675	
14:10	24.33	0.51	9913	
14:20	24.17	0.52	10177	
14:30	24.22	0.53	10408	14:39: observed flow overtop overflow grate, <0.5 gpm entered grate for approx 1 minute.
14:40	0	0.54	10644	Flow off
14:41		0.52		
14:42		0.5		
14:43		0.48		

14:44		0.45		
14:46		0.4		
14:49		0.34		
14:51		0.29		
14:55		0.21		
15:00		0.1		
15:02		0.08		
15:04		0.05		
15:07		dry		
15:10				
15:20				

	Average Infiltration Rate (in/hr) during last hour of inflow:	17.4
	Average Infiltration Rate (in/hr) during falling head:	14.7


M1C Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, WP-2, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Water Level, WP-2 Logger
Ground Surface
Overflow Rim
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
99
98.8
98.6
98.4
98.2
98
97.8
97.6
97.4
97.2
97
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)


M1C Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, WP-2, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Water Level, WP-2 Logger
Ground Surface
Overflow Rim
Flow rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
Elpased Time (minutes)
99
98
97
96
95
94
93
92
91
90
89
0
60
120
180
240
300
360
420
480
200
180
160
140
120
100
80
60
40
20
0

APPENDIX E

Site Photos

Above photo: Cell M1C, overview of cell.

Lower photo: Cell M1C, note surface water in top of photo, tidally influenced.

Above photo: M1C primary inlet.
Lower Photo: close up of overflow structure.

APPENDIX 7

Deliverable Task 4.5, Site M3Q, Geotechnical/Soils Assessment Design Data and Current Conditions, 3rd Street Low Impact Development, Marysville, Washington. Associated Earth Sciences, Inc. 6/14/2019

associated earth sciences incorporated

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site M3Q, Geotechnical/Soils Assessment Design Data and Current Conditions, 3rd Street Low Impact Development, Marysville, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in bioretention cell #2 at the intersection of Quinn Avenue and 3rd Street, north side of the city of Marysville, 3rd Street Low Impact Development and Roadway Improvement Project, located in the city of Marysville, Washington (Figure M3Q F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 4, 2018, infiltration testing on October 30, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure M3Q F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the City of Marysville, 3rd Street Low Impact Development and Roadway Improvement Project, located in Marysville, Washington as shown on the attached "Vicinity Map" (Figure M3Q F1). The site is bordered by roadways and sidewalks along a residential street with small areas of grass. Site topography is generally flat. The site is located approximately ½ mile north of Ebey Slough, a tributary of the Snohomish River system that discharges directly to Puget Sound.

Per the Washington State Source Water Assessment Program Mapping Application, the site is not located within a time of travel zone for any Group A water system.

Our specific area of study for this project includes bioretention facility cell #2 located on the northeast corner of the intersection of Quinn Avenue and 3rd Street, on the east side of Quinn Avenue, referred to as cell M3Q for this study. The attached "Facility and Exploration Plan" (Figure M3Q F2) illustrates the cell area and some of the surrounding site features and utilities.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Geotechnical Report First and Third Street Retrofit," Marysville, Washington, PanGEO, Inc., March 4, 2014.
- "Geotechnical Design Recommendations 3rd Street Retrofit," Marysville, Washington, PanGEO, Inc., December 31, 2013.
- "City of Marysville, 1st and 3rd Stormwater Retrofit Project Predesign Report," prepared by Gray & Osborne, Inc., January 2014.
- City of Marysville, 3rd Street Low Impact Development and Roadway Improvement Project," prepared by Gray & Osborne, Inc., August 2016 (plan set).

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell M3Q consists of an approximately square-shaped bioretention cell with approximately 200 square feet of base area surrounded by bioretention barrier curb set in a concrete sidewalk, as shown on Figure M3Q F2, "Facility and Exploration Plan." We understand that the site was developed under the Washington State Department of Ecology (Ecology) 2014 *Stormwater Management Manual for Western Washington* (2014 Ecology Manual) for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 2 inches per hour (in/hr) in the native subgrade. Land use within the drainage basin is primarily residential roadway and sidewalk with some residential lawn and rooftops. Per "3rd Street Low Impact Development Project, Road and Storm Plan and Profile," Sheet 18 of 25 (Gray & Osborne, Inc. [G&O], August 2016), the facility design includes 2 inches of mulch overlying 18 inches of bioretention soil mix overlying existing subgrade (native soil).

The facility is designed to infiltrate 100 percent of inflow into the subgrade. Stormwater is designed to enter the facility through one curbcut located on Quinn Avenue and 4-inch sidewalk curb notches placed on 10-foot centers. If water ponds up on the bioretention soil, the ponded water would discharge into an 8-inch polyvinyl chloride (PVC) overflow riser with an 8-inch Nyloplast dome grate located near the south-center of the cell, and then into an 8-inch lateral PVC overflow pipe. The rim of the overflow riser was designed to be 12 inches higher than the cell base to create 12 inches of ponding depth. The facility was constructed during fall 2016.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facility including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure M3Q F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the light utility box cover defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: One curb cut from Quinn Avenue and no sidewalk curb notches.
  - The only inlet to the facility is a 12-inch curbcut consistent with project plans (with a 2-inch depressed gutter allowing flow into the cell), which discharges onto a concrete pad approximately 1 foot long by 2 feet wide. Quarry spall splash pads surrounding the concrete pad indicated on plans were not observed.

  - Small curb notches (4-inch width on 10-foot centers) are called out in the design; however, no curb notches were installed along the sidewalk side of facility. Instead, sidewalk runoff flows south and west against the cell barrier curbs to the enter Quinn Avenue road, then flow into the cell street via the curbcut.

- Overflow: The overflow consists of an 8-inch PVC overflow riser (cleanout) with an 8-inch Nyloplast dome grate. The rim of this grate was approximately 0.95 feet above the base of the facility. The overflow riser conveys water to an 8-inch lateral overflow pipe that connects to cell #4 at a new catch basin (CB #9) and then ties into an existing storm catch basin on the west side of Quinn Avenue.

- AESI investigated the loose bioretention soil thickness present in cell M3Q using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 3-foot to 3-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 0.4 feet to 2.0 feet, and averaged 1.0 feet. Probe penetration data is included in Appendix D to this document.

- The observed cell base area, of 200 square feet, was similar to the design of about 208 square feet. We note that the north curb was placed about approximately a foot south of design.

Table 1
Summary of Cell M3Q
Level Survey Data

Location	Elevation (feet, project datum)
Light utility box cover (center)	100.00
Bioretention barrier curb top NW corner	100.10
Bioretention barrier curb top SW corner	99.83
Bioretention barrier curb top NE corner	100.40
Bioretention barrier curb top SW corner	100.11
Temporary staff gauge	97.80
Curbcut Inlet (center)	99.34
WP-1 TOC	98.74
WP-2 TOC	99.11
Ponding tube TOC (DL)	99.32
Top/end 8" temporary inlet pipe	99.37
8" PVC overflow rim	98.75
Overflow cleanout data logger PVC TOC	98.81

WP: well point; TOC: top of Casing;
PVC: polyvinyl chloride; DL: datalogger;

5.0 SITE SETTING

The text sections below describe our research findings in regard to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under “Project and Site Description.”
- Minard, J.P., 1985, *Geologic Map of the Marysville Quadrangle, Snohomish County, Washington*: U.S. Geological Survey (USGS), Miscellaneous Field Studies Map MF-1743, scale 1:24,000.
- Natural Resources Conservation Service (NRSC), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed January 2019.
- *Soil Survey of Snohomish County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1983.
- Newcomb, R.C., 1952, *Ground-water Resources of Snohomish County, Washington*: U.S. Geological Survey (USGS), Water-Supply Paper 1135, scale 1:62,500.

5.1 Regional Topography and Project Grading

The project site is situated at low-lying topography at the south margin of the Marysville Trough recessional plain, near Ebey Slough, part of the Snohomish River flats. The Snohomish River and Ebey Slough empty into Possession Sound approximately 2 miles southwest of the project. Elevations on the larger project site range from about 20 to 30 feet.

On a closer scale, the area near cell M3Q is relatively level, situated on an outwash plain at about elevation 30 feet. The site is located about ½ mile north of Ebey Slough, which is below 10 feet elevation. Relatively level Quinn Avenue and sidewalks surround the cell on the west, south, and east, and lawn to the north. A curb separates the paved surfaces and lawn from the cell.

Bioretention cell M3Q and the surrounding sidewalk were added to the existing Quinn Avenue and 3rd Street. The right-of-way area previously was grass lawn area and areas with evergreen trees. Various utilities are present in the vicinity of the site, including buried water and sewer mains. Cuts on the order of 5 feet were needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to a regional geology map (Minard, 1985), the site vicinity is underlain by Vashon recessional outwash. Recessional outwash sediments in the project area are described on the referenced map to consist of outwash sand with some fine gravel and beds of silt and clay deposited from meltwater streams (Minard, 1985), which is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- Vashon Recessional Outwash (Qvr): This unit is composed of stratified to massive outwash sand with some fine gravel and beds of silt and clay. Recessional outwash in the project area was deposited by glacial meltwater streams during ice retreat (Minard, 1985) and has not been glacially overridden.

Background geotechnical information includes exploration logs B-5, B-6 and B-7 within 100 feet (B-5) and 450 feet (B-6 and B-7) of cell M3Q dated November 25 and 26, 2013. Borings B-5 to B-7 reached depths of about 14 to 16.5 feet below current grades, and describe material generally consisting of an upper few feet of loose to medium dense, laminated, silty sand and grading to a clean, somewhat coarser sand with trace to some silt and trace gravel interpreted to be recessional outwash (PanGEO, Inc., 2014), which is consistent with the geologic mapping in the area. Shallow fill soils were encountered to depths of up to 1 feet. Groundwater was encountered between 12 (B-5) and 16 feet (B-7) at the time of drilling. Groundwater was not encountered before the terminal depth of 14 feet in B-6.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the soil survey (Natural Resources Conservation Service [NRCS], 1983) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Ragnar fine sandy loam (NRCS, 2018). This very deep, well-drained soil is situated on outwash plains and formed in glacial outwash. NRCS describes the permeability as moderately rapid (NRCS, 1983).

As described in the predesign report (G&O, 2014), the pre-developed condition was modeled as 100 percent impervious (roads, flat), consistent with the existing drainage area condition and background geotechnical data.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described by Newcomb (1952). The coastal lowlands often represent hundreds of feet of glacial and alluvial deposits backfilled into ancestral drainage systems (Newcomb, 1952). Outwash sands below the local water table carry large quantities of groundwater and alluvial materials in river valleys are good aquifers in the lower Snohomish Valley.

Within the vicinity of cell M3Q, groundwater was encountered within sediments identified as Vashon recessional outwash (PanGEO, Inc., 2014). The shallow aquifer identified is interpreted to be in hydraulic conductivity locally with river valley aquifers of the Snohomish River and Ebey Slough to the south/southwest. Groundwater was encountered during drilling in the vicinity of cell M3Q between 12 feet (B-5) and 16 feet (B-7) below grade. Groundwater was not encountered before the terminal depth of 14 feet in B-6 (PanGEO, Inc., 2014).

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and to refusal in the underlying fill (M3Q-HA-3 or into the native Vashon recessional outwash M3Q-HA-1 and M3Q-HA-2). Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure M3Q F2, "Facility and Exploration Plan."

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell M3Q were completed on October 4, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring locations are presented on Figure M3Q-F2. The hand-auger borings, encountered a thin layer of mulch overlying bioretention soil to a depth of 0.8 to 1.1 feet, overlying a mix of backfill and native recessional outwash (M3Q-HA-2 and M3Q-HA-3) and/or native recessional outwash (M3Q-HA-1 and M3Q-HA-2). Bioretention soil thickness was between 0.6 feet to 1.0 feet in each boring. No seepage or caving was observed.

6.2 Well Points

Two well points were installed in cell M3Q, one within M3Q-HA-1 (WP-1) and one driven without a hand-auger exploration (WP-2). Key well point dimensions are provided in Table 2, below. WP-1 was installed to a depth of 6.4 feet to measure groundwater in the shallow aquifer below the bioretention soil. WP-2 was installed to a depth of 1.4 feet, and screened primarily within the bioretention soil.

Table 2
Summary of Cell M3Q
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
M3Q -WP-1	M3Q -HA-1	7.4	1.25 inch nominal	0.8	6.6
M3Q -WP-2	None	2.6	1.25 inch nominal	1.2	1.4

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). Three samples of material interpreted as representative of the bioretention soil was tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell M3Q
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
M3Q-HA-1	0.2-0.5	Bioretention Soil	6.6	SAND, some gravel, trace silt (SP)	4.5	3.4	1.1	Sand
M3Q-HA-2	0.1-0.5	Bioretention Soil	6.0	SAND, trace silt, trace gravel (SP)	4.0	2.9	1.0	Sand
M3Q-HA-3	0.2-0.8	Bioretention Soil	6.4	SAND, some gravel, trace silt (SP)	4.5	3.0	1.0	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 6.0 to 6.6 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace silt and trace to some gravel based on ASTM D2487 USCS. The respective fines content as measured on the No. 200 sieve was 4.0 to 4.5 percent within the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 2.9 to 3.4, below the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 1.0 to 1.1, within the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix met the recommended guidelines for grain size distribution. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell M3Q Site Data

Parameter	Recommended Range	Cell M3Q
Organic Content (by weight)	5 to 8 percent	6.3 percent by weight
Cu coefficient of uniformity	4 or greater	3.1
Cc coefficient of curvature	1 to 3	1.0
Sieve Size	**Percent Passing**	
3/8" (9.51 mm)	100	98.9
#4 (4.76 mm)	95 to 100	94.8
#10 (2.0 mm)	75 to 90	87.2
#40 (0.42 mm)	25 to 40	35.8
#100 (0.15 mm)	4 to 10	6.5
#200 (0.074 mm)	2 to 5	4.3

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In cell M3Q, the native material is recessional outwash, visually classified as a SAND with trace silt (SP).

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facility was discontinued, and the water level was monitored as it dropped. This constitutes the "falling head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell M3Q with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts and discharged through a flow diffuser. Ponded water levels within the cell were monitored using a temporary staff gauge (M3Q-SG-1) marked in 0.01-foot increments installed adjacent the overflow riser and within a piezometer ("ponding tube") with a digital water level tape, and with digital pressure transducers for the duration of the test. The water level at the base of the bioretention soil and deeper in the subsurface were monitored in well point M3Q-WP-2 and M3Q-WP-1, respectively, with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell M3Q is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell M3Q

AESI performed infiltration testing on October 30, 2018. No rainfall was noted during testing; however, a minor leak in the test hoses on the sidewalk contributed less than 0.1 gpm inflow entering via curbcut.

During this test, flow was initially adjusted between about 10 and 65 gpm to fill the cell bottom and stabilize the wetted area, then maintained at about 32 gpm for the duration of test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. The entire cell base was wetted after about 50 minutes and a water level of about 0.9 feet was maintained as measured on M3Q-SG-1. The wetted pool area was generally stable through most of the soaking and testing period covering an area of about 200 square feet. Approximately 15,400 gallons of water were used.

Ponded water in the bioretention cell was monitored in well point M3Q-WP-2 with a data logger during the infiltration test and responded rapidly to inflow. Groundwater was not observed within the bioretention soil prior to the start of inflow. The water level in the well point responded to inflow within several minutes, and rose to near ground surface at the well point. AESI interprets this response to indicate that water from the infiltration test infiltrated relatively rapidly through the bioretention soil and then mounded on the native finer-grained recessional outwash. The shallow subsurface ponded water level mirrored the surface water ponding level.

Groundwater was monitored in the well point M3Q-WP-1 using a data logger during the infiltration test and responded to inflow. Groundwater was not measured beneath the bioretention cell prior to the start of inflow (to the bottom depth of well point M3Q-WP-1 of 7 feet), however a shallow groundwater aquifer is expected to exist in the native sediments at a depth of about 12 to 16 feet. The water level in well point M3Q-WP-1 responded to inflow after about 50 minutes, and rose about 3.4 feet (from greater than 7 feet below ground surface to 3.6 feet below ground surface) during testing. AESI interprets this response to indicate that water from the infiltration test infiltrated relatively rapidly through the bioretention soil and native sediments, then mounded on the shallow groundwater present beneath the facility.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the base of the facility and the ponded subsurface water in the bioretention cell infiltrated over the course of approximately 40 minutes. The groundwater mound immediately decreased after test inflow ended and was about 6.2 feet below the ground surface 50 minutes after inflow ended.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the native subgrade.

Table 5
Cell M3Q
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
M3Q (bioretention soil)	200	420	15,420	0.92	greater than native soil infiltration rate	
M3Q (subgrade)	interpreted to be similar to wetted area				15	14

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell M3Q was generally consistent with the design shown on the civil plan sheets. Observations on site design, shallow soil, and groundwater conditions are discussed below.

- The overflow is generally consistent with the plans. Site design documents indicate that the ponding level was designed as 12 inches, the overflow rim was observed to be 11.4 inches above the ground surface.

- Cell Design: The curbed area was slightly smaller than plans (G&O, 2016). The sidewalk curb notches were not installed, however sidewalk runoff flows into the curbcut.

- Bioretention soil:
  - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.0-foot; less than plans which indicated 1.5 feet.
  - Composition: The soil tested in generally the recommended guidelines for organic content and sand gradation. The coefficient of uniformity was below the recommended range.

- Subgrade conditions: The subgrade is interpreted to consist of Vashon recessional outwash, as documented by previous studies for this project (PanGEO, Inc., 2013 and 2014).

- During infiltration testing, water readily soaked through the bioretention soil mix. Water was observed in the shallow well point (screened at the base of the bioretention soil), demonstrating that water accumulated on the underlying subgrade. The native fine sand is interpreted to have a lower permeability than the overlying bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

- Subgrade infiltration rate: Measured at about 15 in/hr.

- Bioretention soil field infiltration rate:
    - Greater than the measured field rate of 15 in/hr.
    - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the native subgrade infiltration rate.

- Shallow groundwater is expected to be present in the location of the M3Q facility as measured in M3Q-WP-1 during testing and previous studies for this project (PanGEO, Inc., 2014). AESI interprets that the infiltration test water soaked readily through the bioretention soil and native subgrade, and mounded on the underlying shallow water table, then dissipated both laterally and vertically as shallow groundwater flow. During testing, the lag time in response to start of inflow and stop of inflow was approximately 50 minutes.

- The effects of shallow groundwater mounding will increase during the wetter winter months, and if significantly mounded, could reduce the effective infiltration rate by reducing the vertical gradient. The ongoing monitoring data will be reviewed for groundwater influence.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

Suzanne S. Cook, L.G.
Senior Project Geologist

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall

6/14/19

Anton D. Ypma
Staff Geologist

Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure M3Q F1:	Vicinity Map
	Figure M3Q F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

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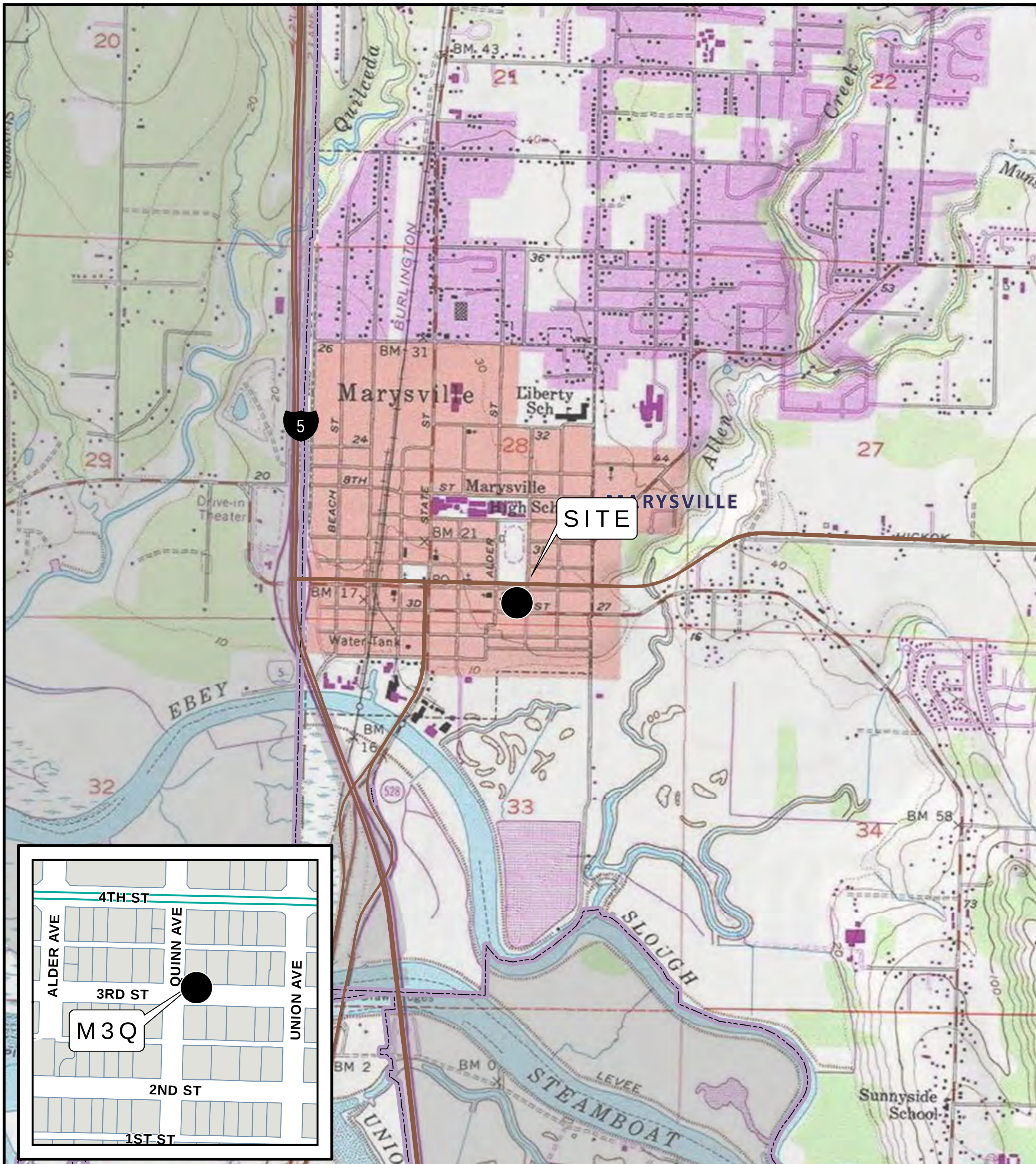
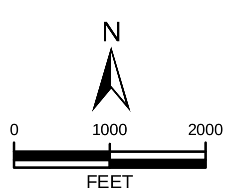


DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NATIONAL GEOGRAPHIC SOCIETY 2013
SNOHOMISH CO: STREETS, CITY LIMITS, PARCELS, 1/18
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE



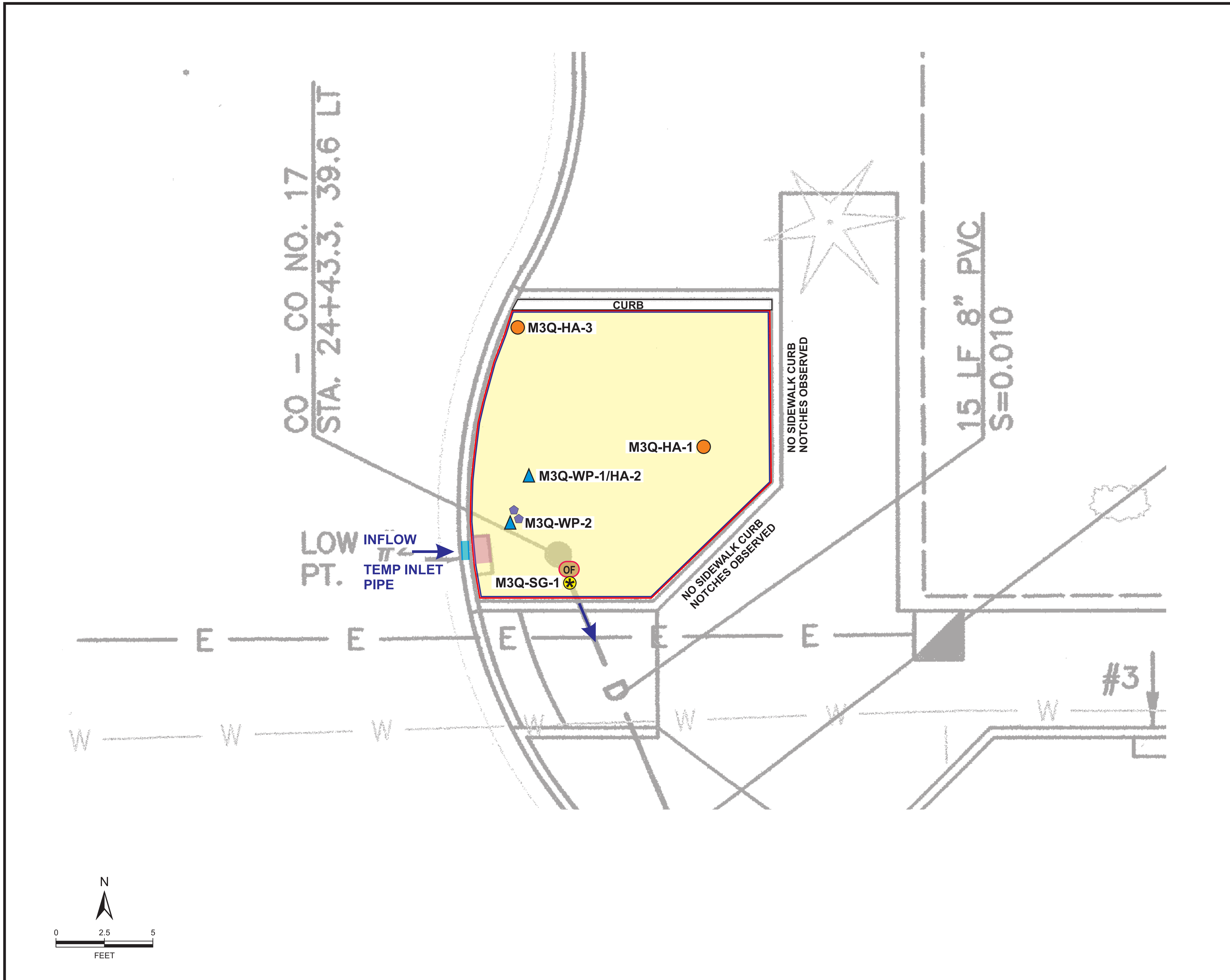
NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, M3Q SITE
MARYSVILLE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M3Q F1



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
OF	OVERFLOW - 8" PVC
	PVC PONDING TUBE
	CURB CUT
	CONCRETE SPLASH PAD

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: GRAY AND OSBORNE, INC., CITY OF MARYSVILLE 3RD STREET LOW IMPACT DEVELOPMENT AND ROADWAY IMPROVEMENT PROJECT, STORMWATER PLAN AND PROFILE, SHEET 21 OF 68, 8/12/16

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN
M3Q SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MARYSVILLE, WASHINGTON

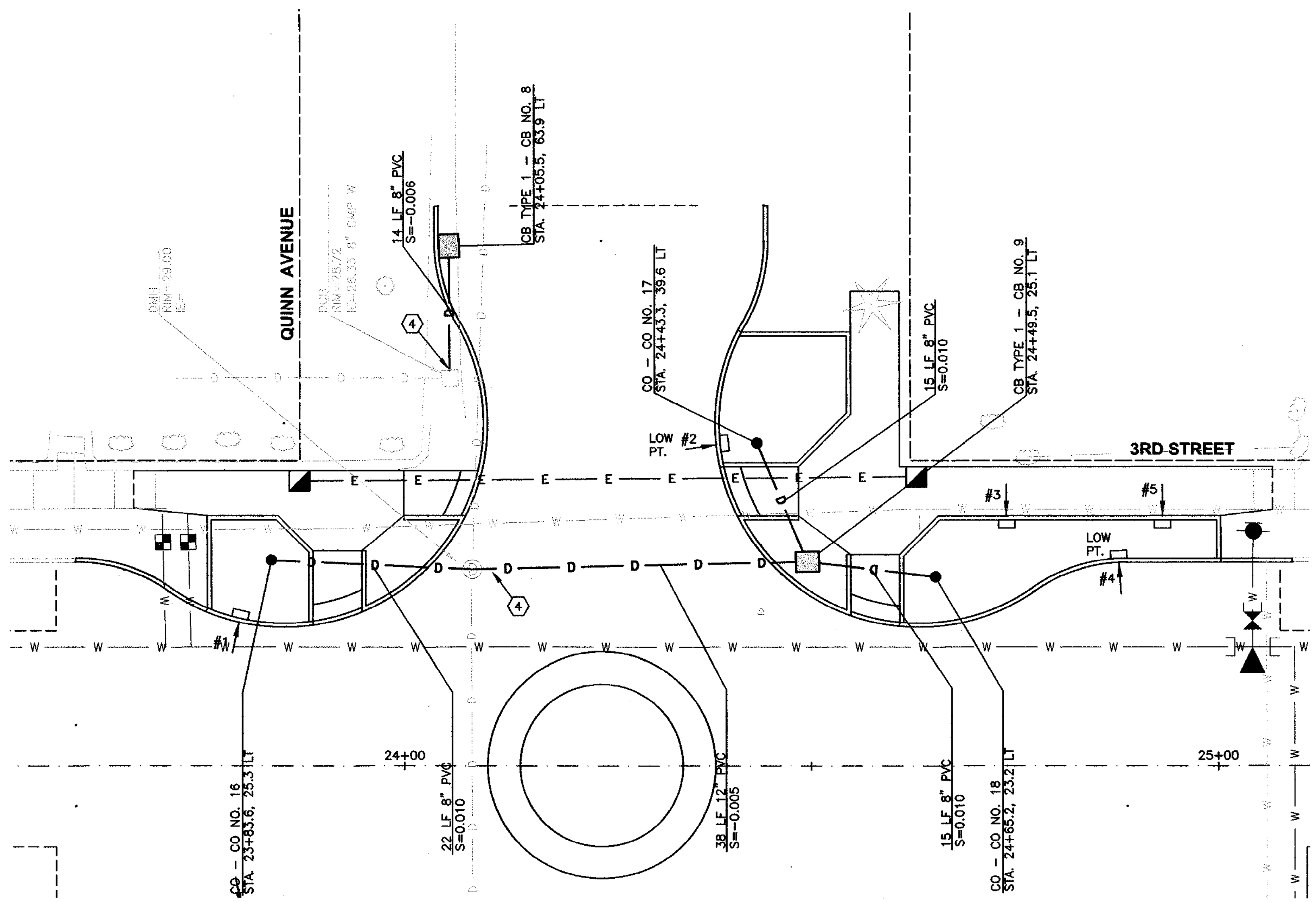
PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M3Q F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: M3Q F2

APPENDIX A

Project Civil Plans

QUINN AVENUE/3RD STREET INTERSECTION - NORTH SIDE



10' 5' 0 10' 20'
SCALE: 1"=10'

N

CURB CUT TABLE

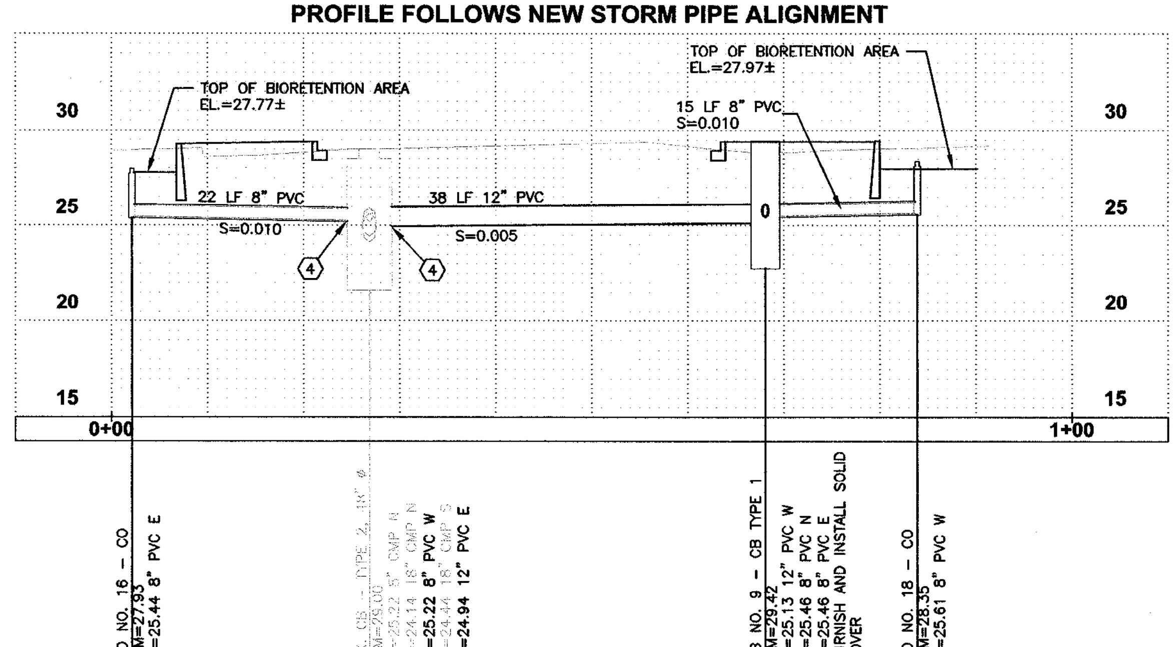
NUMBER	STATION	OFFSET	FLOWLINE ELEVATION (±)	SIDEWALK ELEVATION (±)
1	23+79.63	17.63 LT	28.60	---
2	24+38.32	39.49 LT	28.66	---
3	24+73.94	30.72 LT	---	29.62
4	24+87.86	24.98 LT	28.80	---
5	24+93.14	30.72 LT	---	29.53

SEE CURB CUT DETAIL, SHEET 27

BIORETENTION & STORM DRAINAGE NOTES

1. CAUTION: POTENTIAL UTILITY CONFLICT. CONTRACTOR TO FIELD VERIFY (POTHOLE) EXACT LOCATION AND DEPTH OF EXISTING UTILITY. SEE ORDER OF WORK IN THE SPECIFICATIONS.
2. CONTRACTOR SHALL POTHOLE EXISTING STORM PIPE TO VERIFY EXACT PIPE MATERIAL, LOCATION AND DEPTH PRIOR TO INSTALLING AND CONNECTING NEW CATCH BASIN.
3. CONTRACTOR SHALL PROTECT EXISTING UTILITY POLE, CURB AND/OR, SIDEWALK DURING CONSTRUCTION.
4. CONTRACTOR SHALL CONNECT NEW STORM PIPE TO EXISTING CATCH BASIN (CORE DRILL IF KNOCKOUT IS NOT PRESENT). SEE DETAIL SHEET 31.
5. EXISTING UTILITY TO BE REMOVED/RELOCATED BY OTHERS. CONTRACTOR TO COORDINATE. SEE GENERAL NOTE 2, SHEET 2.

PROFILE FOLLOWS NEW STORM PIPE ALIGNMENT



Gray & Osborne, Inc.
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ARLINGTON, WA 98223 • (360) 454-5490

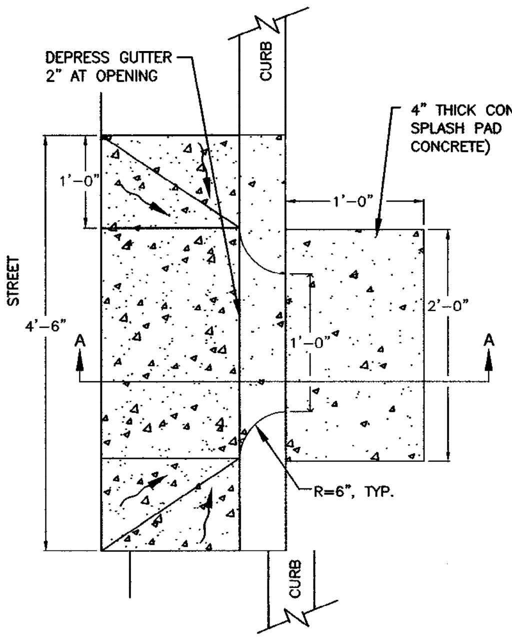
DATE: AUG 2016
SCALE: NOTED
DRAWN: A.A.J.
CHECKED: K.W.B.
APPROVED: S.A.C.

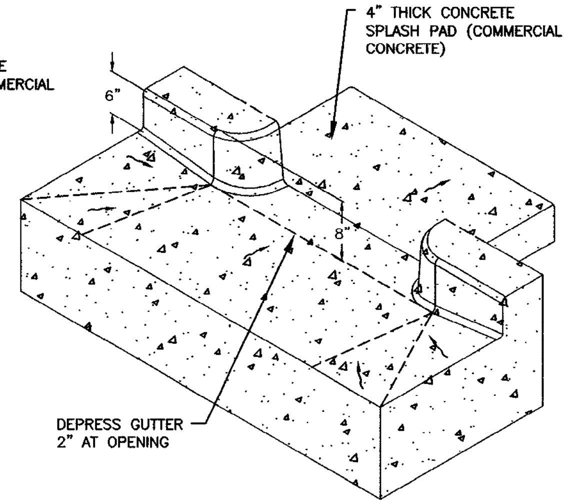
No.	REVISION	DATE	APP'D

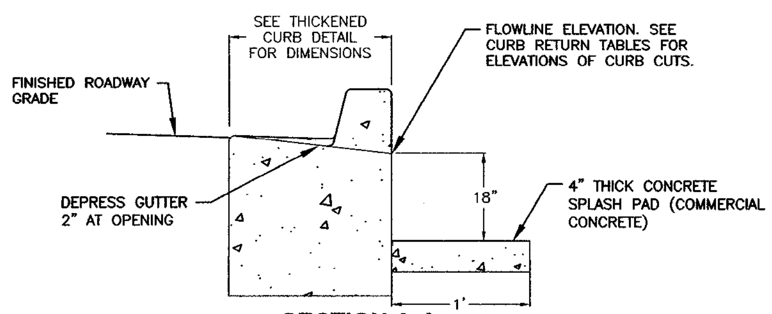
STACEY ANN CLEAR — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER
KEVIN W. BROWN — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER

CITY OF MARYSVILLE
SNOHOMISH COUNTY WASHINGTON
3RD STREET LOW IMPACT DEVELOPMENT AND ROADWAY IMPROVEMENT PROJECT
STORMWATER PLAN AND PROFILE

SHEET: 21
OF: 68
JOB NO.: 13587.00
DWG:INTER



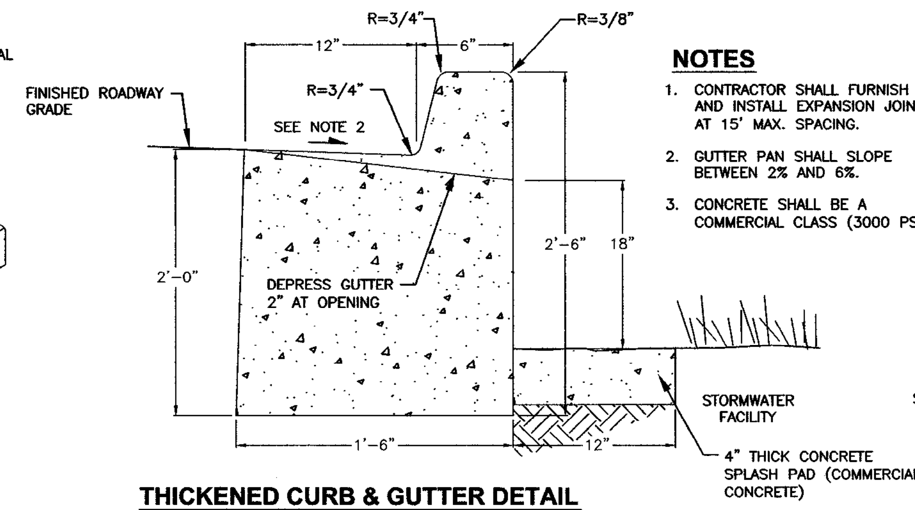




SECTION A-A

BIORETENTION AREA CURB INLET DETAIL

NTS

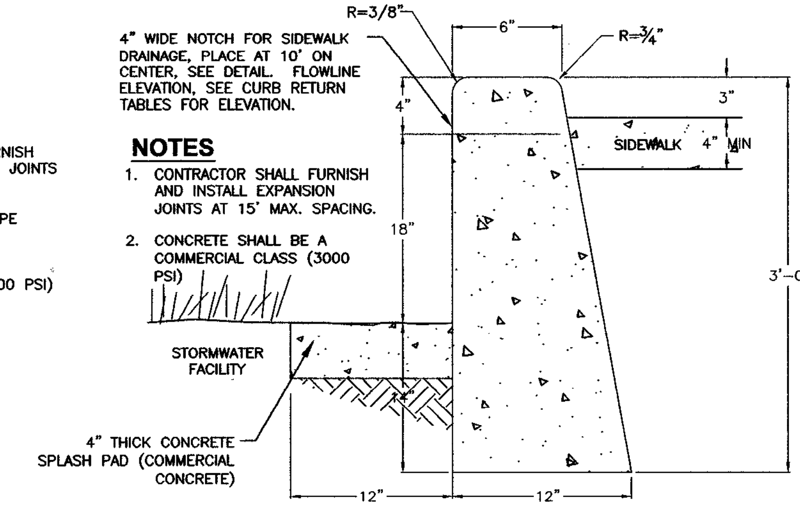


NOTES

1. CONTRACTOR SHALL FURNISH AND INSTALL EXPANSION JOINTS AT 15' MAX. SPACING.
2. GUTTER PAN SHALL SLOPE BETWEEN 2% AND 6%.
3. CONCRETE SHALL BE A COMMERCIAL CLASS (3000 PSI)

THICKENED CURB & GUTTER DETAIL

NTS

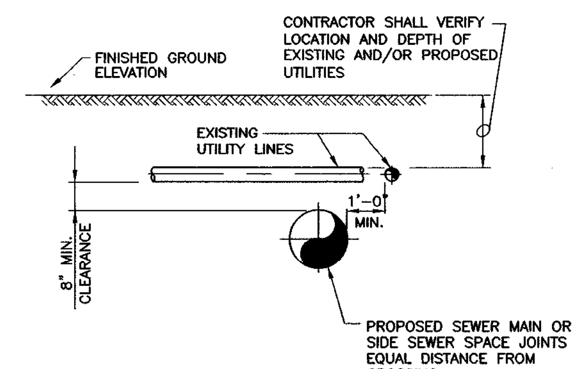


NOTES

1. CONTRACTOR SHALL FURNISH AND INSTALL EXPANSION JOINTS AT 15' MAX. SPACING.
2. CONCRETE SHALL BE A COMMERCIAL CLASS (3000 PSI)

BIORETENTION BARRIER CURB DETAIL

NTS

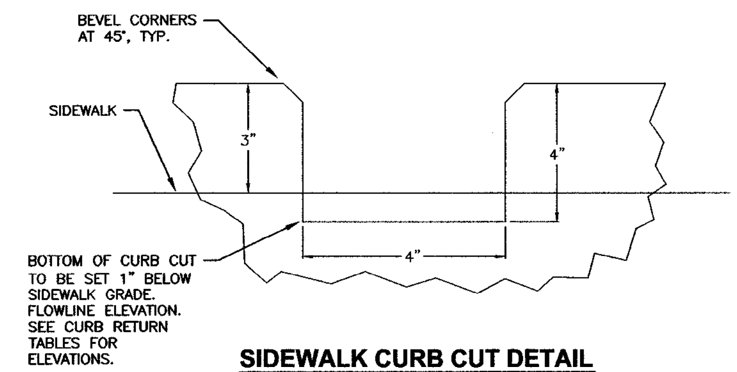


NOTES:

1. ALL SEWER SHALL HAVE A MINIMUM CLEARANCE OF 18" UNDER WATER LINES. MINIMUM CLEARANCE FOR OTHER UTILITIES SHALL BE 8".
2. BACKFILL ANY CROSSING WITH LESS THAN 18" CLEARANCE WITH CDF.

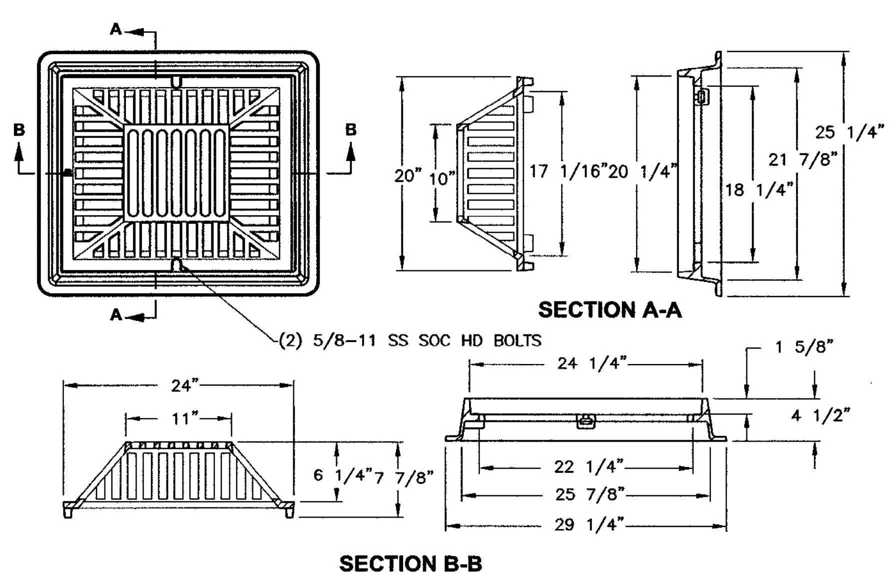
TYPICAL UTILITY CROSSING

NTS



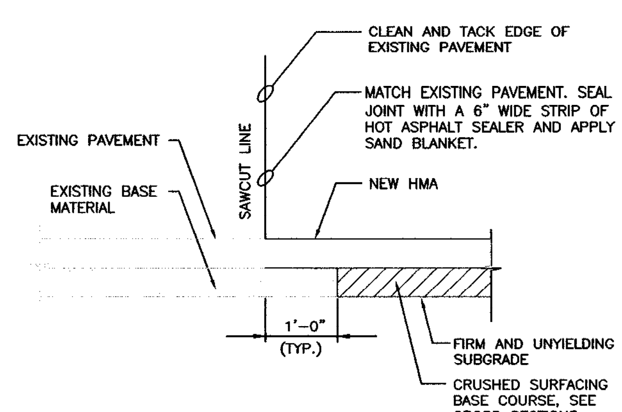
SIDEWALK CURB CUT DETAIL

NTS



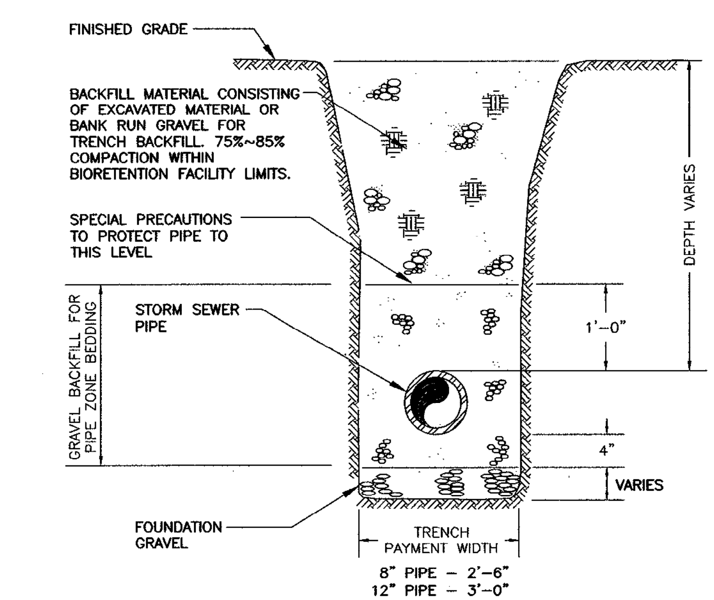
BEEHIVE FRAME AND GRATE DETAIL

NTS



BUTT JOINT DETAIL

NTS



STORM DRAIN PIPE TYPICAL TRENCH SECTION

NTS

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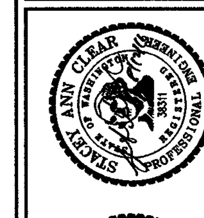
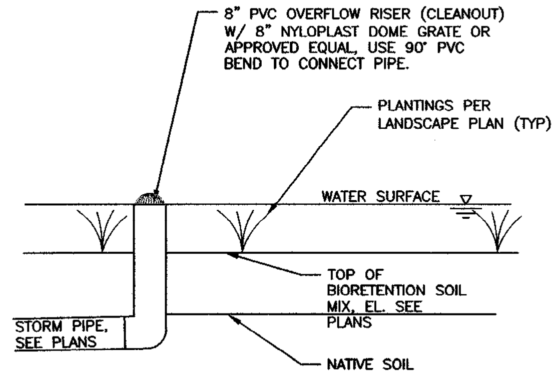
DATE:	AUG 2016
SCALE:	NOTED
DRAWN:	A.A.J.
CHECKED:	K.W.B.
APPROVED:	S.A.C.

No.	REVISION	DATE	APPD



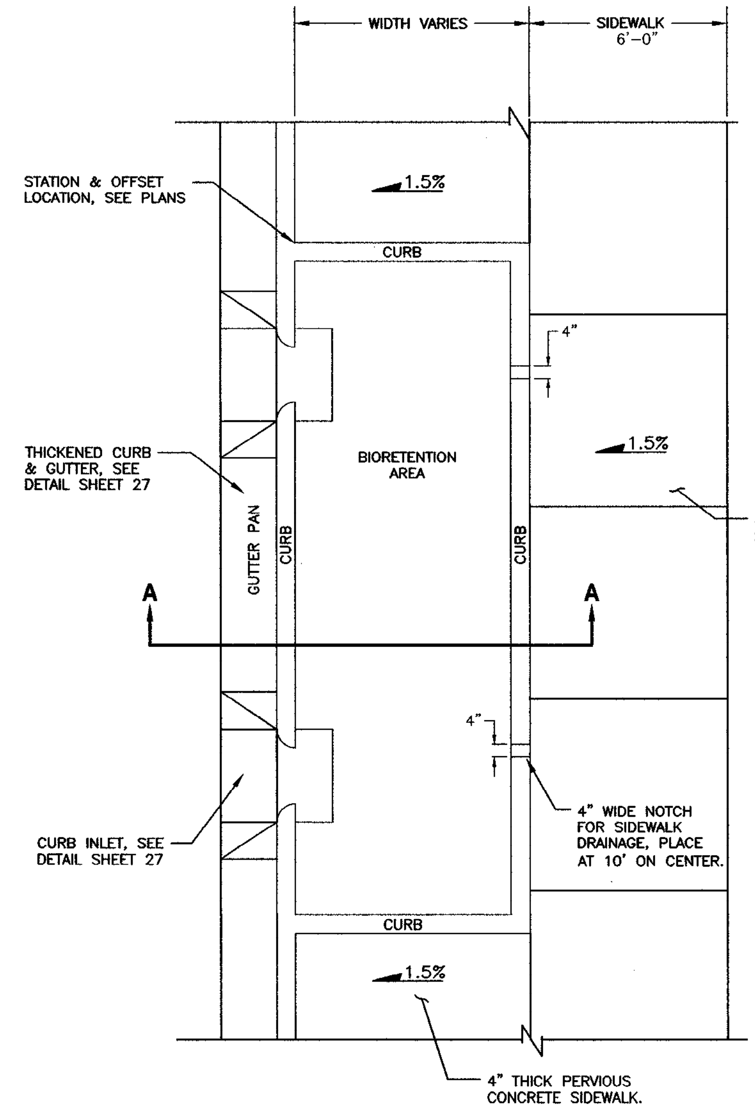
CITY OF MARYSVILLE
SNOHOMISH COUNTY WASHINGTON
3RD STREET LOW IMPACT DEVELOPMENT AND ROADWAY IMPROVEMENT PROJECT
STORM DETAILS

SHEET: 27
OF: 68
JOB NO.: 13587.00
DWG: DETAILS

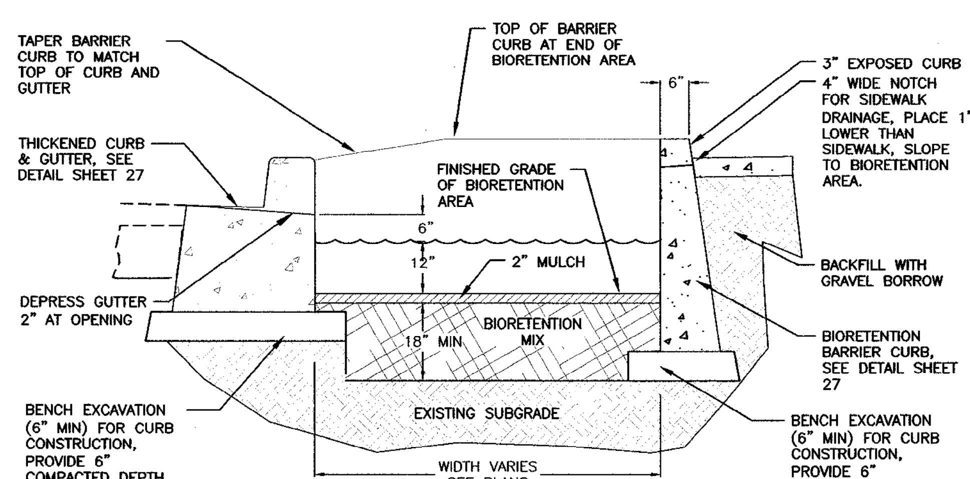


BIORETENTION AREA CLEANOUT DETAIL

NTS



PLAN VIEW



CROSS SECTION A-A

BIORETENTION AREA DETAIL (ADJACENT TO CURB & GUTTER)

NTS

GENERAL LOW IMPACT DEVELOPMENT FACILITY NOTES

1. ALL LOW IMPACT DEVELOPMENT (LID) AREAS (BIORETENTION AND PERMEABLE PAVEMENT) SHALL BE FULLY PROTECTED FROM SEDIMENT INTRUSION BY SILT FENCE OR CONSTRUCTION FENCING. THE CONTRIBUTING DRAINAGE AREA SHALL BE STABILIZED PRIOR TO DIRECTING WATER TO THE AREA.
2. LID AREAS SHALL REMAIN OUTSIDE THE LIMIT OF DISTURBANCE DURING CONSTRUCTION TO PREVENT SOIL COMPACTION BY HEAVY EQUIPMENT. THE AREAS SHALL BE CLEARLY MARKED. TO PREVENT SOIL COMPACTION, HEAVY VEHICULAR AND FOOT TRAFFIC SHALL BE KEPT OUT OF LID AREAS DURING AND IMMEDIATELY AFTER CONSTRUCTION.
3. DURING CONSTRUCTION, CARE SHALL BE TAKEN TO AVOID TRACKING SEDIMENTS ONTO ANY LID SURFACE TO AVOID CLOGGING.
4. STORE MATERIALS IN A PROTECTED AREA TO KEEP THEM FREE FROM MUD, DIRT, AND OTHER FOREIGN MATERIALS.
5. ANY AREA OF THE SITE INTENDED ULTIMATELY TO BE AN LID FACILITY SHALL GENERALLY NOT BE USED AS THE SITE OF A TEMPORARY SEDIMENT BASIN. WHERE LOCATING A SEDIMENT BASIN ON AN AREA INTENDED FOR AN LID FACILITY IS UNAVOIDABLE, THE INVERT OF THE SEDIMENT BASIN MUST BE A MINIMUM OF 2 FEET ABOVE THE FINAL DESIGN ELEVATION OF THE BOTTOM OF THE BIORETENTION SOIL MIX OR AGGREGATE RESERVOIR COURSE. ALL SEDIMENT DEPOSITS IN THE EXCAVATED AREA SHALL BE CAREFULLY REMOVED PRIOR TO INSTALLING THE SUBBASE, BASE AND SURFACE MATERIALS.

LOW IMPACT DEVELOPMENT FACILITY CONSTRUCTION SEQUENCE:

1. CONSTRUCTION OF THE LID FACILITIES SHALL ONLY BEGIN AFTER THE ENTIRE CONTRIBUTING DRAINAGE AREA HAS BEEN STABILIZED. THE SITE SHALL BE CHECKED FOR EXISTING UTILITIES PRIOR TO ANY EXCAVATION. THE CONTRACTOR SHALL NOT INSTALL THE SYSTEM IN RAIN OR SNOW, NOR INSTALL FROZEN BEDDING MATERIALS.
2. INSTALL TEMPORARY EROSION AND SEDIMENT CONTROLS TO DIVERT STORMWATER AWAY FROM THE LID FACILITY AREA UNTIL IT IS COMPLETED. SPECIAL PROTECTION MEASURES SUCH AS EROSION CONTROL FABRICS MAY BE NEEDED TO PROTECT VULNERABLE SIDE SLOPES FROM EROSION DURING THE EXCAVATION PROCESS. THE PROPOSED LID FACILITY AREA MUST BE KEPT FREE FROM SEDIMENT DURING THE ENTIRE CONSTRUCTION PROCESS. CONSTRUCTION MATERIALS THAT ARE CONTAMINATED BY SEDIMENTS MUST BE REMOVED AND REPLACED WITH CLEAN MATERIALS.
3. WHERE POSSIBLE, EXCAVATORS OR BACKHOES SHALL WORK FROM THE SIDES TO EXCAVATE THE BIORETENTION SOIL MIX OR RESERVOIR AGGREGATE LAYER TO THE DESIGN DEPTH AND DIMENSIONS SHOWN ON THE PLANS. FOR MICRO-SCALE AND SMALL-SCALE PAVEMENT APPLICATIONS, EXCAVATING EQUIPMENT SHALL HAVE ARMS WITH ADEQUATE EXTENSION SO THEY DO NOT HAVE TO WORK INSIDE THE FOOTPRINT OF THE LID FACILITY AREA (TO AVOID COMPACTION). CONTRACTORS CAN UTILIZE A CELL CONSTRUCTION APPROACH, WHEREBY THE PROPOSED PERMEABLE PAVEMENT AREA IS SPLIT INTO 500 TO 1000 SQ. FT. TEMPORARY CELLS WITH A 10 TO 15 FOOT EARTH BRIDGE IN BETWEEN, SO THAT CELLS CAN BE EXCAVATED FROM THE SIDE. EXCAVATED MATERIAL SHALL BE PLACED AWAY FROM THE OPEN EXCAVATION SO AS TO NOT JEOPARDIZE THE STABILITY OF THE SIDE WALLS. AS ANOTHER ALTERNATIVE, 6" OF MATERIAL MAY BE LEFT ABOVE THE SUBGRADE DURING OTHER WORK AND REMOVED JUST PRIOR TO PLACING THE FINAL LID MATERIAL (BIORETENTION SOIL MIX/AGGREGATE COURSE).
4. THE NATIVE SOILS ALONG THE BOTTOM AND SIDES OF THE LID FACILITY SHALL BE SCARIFIED OR TILLED TO A DEPTH OF 3 TO 4 INCHES PRIOR TO THE PLACEMENT OF THE BOTTOM SOIL OR AGGREGATE LAYER OF THE LID FACILITY.
5. IF FILTER FABRIC IS SHOWN ON THE PLANS (TO PREVENT AGGREGATE FROM SINKING INTO NATIVE SOIL), IT SHALL BE INSTALLED ON THE BOTTOM AND THE SIDES OF THE PAVEMENT SECTION. FILTER FABRIC STRIPS SHALL OVERLAP DOWN-SLOPE BY A MINIMUM OF 2 FEET, AND BE SECURED A MINIMUM OF 4 FEET BEYOND THE EDGE OF THE EXCAVATION. WHERE THE FILTER LAYER EXTENDS BEYOND THE EDGE OF THE PAVEMENT (TO CONVEY RUNOFF TO THE RESERVOIR LAYER), INSTALL AN ADDITIONAL LAYER OF FILTER FABRIC 1 FOOT BELOW THE SURFACE TO PREVENT SEDIMENTS FROM ENTERING INTO THE RESERVOIR LAYER. EXCESS FILTER FABRIC SHALL NOT BE TRIMMED UNTIL THE SITE IS FULLY STABILIZED.
6. PAVING AND BIORETENTION MATERIALS SHALL BE INSTALLED IN ACCORDANCE WITH THE SPECIFICATIONS.

Gray & Osborne, Inc.
CONSULTING ENGINEERS
3710 168TH STREET NE, BLDG. B, SUITE 210
ARLINGTON, WA 98223 • (360) 454-5490

DATE: AUG 2016
SCALE: NOTED
DRAWN: A.A.J.
CHECKED: K.W.B.
APPROVED: S.A.C.

No.	REVISION	DATE	APP'D

STACEY ANN CLEAR — STATE OF WASHINGTON — PROFESSIONAL ENGINEER
KEVIN W. BROWN — STATE OF WASHINGTON — PROFESSIONAL ENGINEER

CITY OF MARYSVILLE
SNOHOMISH COUNTY WASHINGTON
3RD STREET LOW IMPACT DEVELOPMENT AND ROADWAY IMPROVEMENT PROJECT
STORM DETAILS

SHEET: 28
OF: 68
JOB NO.: 13587.00
DWG: DETAILS

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	M3Q-HA-1/WP	1 of 2

Project Name: Bioretention Hydrologic Performance Study
Location: Marysville, WA
Elevation (Top of Well Casing): 98.7 (Project Datum)
Surface Elevation (ft): 97.9 (Project Datum)
Water Level Elevation: Dry
Date Start/Finish: 10/4/18,10/4/18
Drilling/Equipment: Hand Auger
Hole Diameter (in): 4 inches
Hammer Weight/Drop: N/A

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Coarse mulch 0 to 0.1 feet				**Coarse Mulch**
		Bioretention soil mix 0.1 to 1.5 feet				**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some gravel, trace silt; organic rich; massive (SP).
		Threaded steel pipe 1.25-inch I.D. with threaded, vented PVC cap -0.8 to 3.9 feet				**Vashon Recessional Outwash** Loose, slightly moist, brown, fine to medium SAND, trace silt; stratified (SP).
		Bentonite chips 1.2 to 3.2 feet				
		Vashon Recessional Outwash 1.1 to 6.7 feet				Layer (0.25 to 0.5 inch thick) of brown silt to sandy silt at 4.5 feet.
5		Stainless steel jacket over				

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

NWWELL- B 150387H007M3Q.GPJ BORING.GDT 2/19/19

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	M3Q-HA-1/WP	2 of 2

Project Name: Bioretention Hydrologic Performance Study
Elevation (Top of Well Casing): 98.7 (Project Datum)
Water Level Elevation: Dry
Drilling/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Location: Marysville, WA
Surface Elevation (ft): 97.9 (Project Datum)
Date Start/Finish: 10/4/18,10/4/18
Hole Diameter (in): 4 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		stainless steel #60 gauze, welded to perforated steel pipe 3.9 to 6.3 feet				Grades to grayish brown at 5.5 ft.
		Threaded steel pipe 1.25-inch I.D. and drive point 6.3 to 6.9 feet				
		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 7.4 feet.				Boring terminated at 6.7 feet Well completed at 6.9 feet on 10/4/18. Refusal on gravel. No seepage. No caving. Steel drive point placed in borehole and hand driven with slide hammer to 6.9 feet.
10						

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	M3Q-HA-2	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Marysville, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A
Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/4/18,10/4/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Coarse Mulch					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some gravel, trace silt; organic rich; massive (SP).					
				At 0.9 feet: Mix of Wall Backfill and Native Sand - Medium dense, slightly moist, gray, angular coarse SAND, fine gravel (GP) and brown fine to medium SAND to sandy, SILT (SP/SP-ML).					
				Vashon Recessional Outwash - Loose, slightly moist, brown, fine to medium SAND, trace silt; stratified (SP). Bottom of exploration boring at 1.2 feet. No seepage. No caving.					
5									

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	M3Q-HA-3	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Marysville, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/4/18,10/4/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Coarse Mulch					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some gravel, trace silt; organic rich; massive (SP).					
				Mix of Wall Backfill and Native Sand Loose, slightly moist, gray, angular GRAVEL (GP), and brown, fine to medium SAND, trace to some silt (SP/SP-SM); concrete debris present.					
				Bottom of exploration boring at 1 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

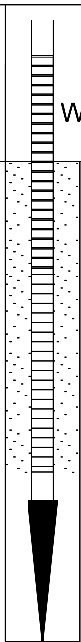
AESIBOR 150387H007M3Q.GPJ February 19, 2019

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	M3Q-WP-2	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Marysville, WA
Elevation (Top of Well Casing)	99.1 (Project Datum)	Surface Elevation (ft)	97.9 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/19/18,10/19/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		 Threaded steel pipe with threaded, vented PVC cap 1.25-inch I.D. -1.2 to -0.9 feet Tape over well point screen -0.9 to 0.4 feet Existing sediments 0 to 1.7 feet Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 0.4 to 1.1 feet Threaded steel pipe 1.25-inch I.D. and drive point 1.1 to 1.7 feet Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 2.6 feet.				Boring terminated at 0 feet Well completed at 1.7 feet on 10/19/18. Well point only. No exploration was completed. Stel drive point hand drien with slide hammer to depth of 1.7 feet. No exploration; well point driven into existing sediments.
5						

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture	**Logged by:** ADY
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()	**Approved by:** JHS
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)	

associated earth sciences incorporated

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/4/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- M3Q			

Moisture Content

Sample ID	HA-2 (0.2'-0.5')	HA-1 (0.2'-0.8')	HA-3 (0.1'-0.5')
Wet Weight + Pan	1024.38	957.44	1006.98
Dry Weight + Pan	946.10	912.32	922.80
Weight of Pan	517.21	449.60	470.00
Weight of Moisture	78.28	45.12	84.18
Dry Weight of Soil	428.89	462.72	452.80
% Moisture	15.4	8.9	15.7

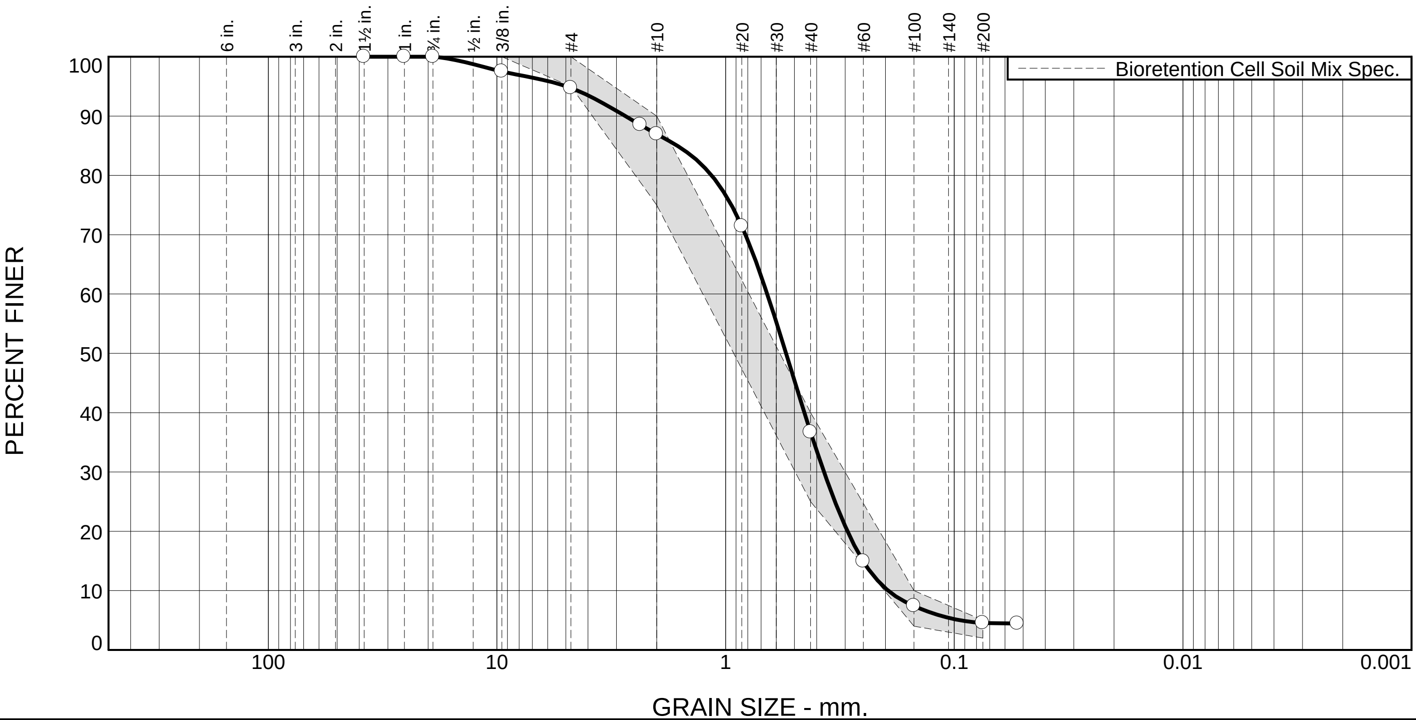
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	398.50	576.62	594.36
Dry Soil After Burn + Pan	388.44	562.58	582.14
Weight of Pan	247.07	357.93	391.93
Wt. Loss Due to Ignition	10.06	14.04	12.22
Actual Wt. Of Soil After Burr	141.37	204.65	190.21
% Organics	6.6	6.4	6.0

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.3	7.8	50.2	32.2	4.5	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	97.5	100.0	X
#4	94.7	95.0 - 100.0	X
#8	88.5		
#10	86.9	75.0 - 90.0	
#20	71.4		
#40	36.7	25.0 - 40.0	
#60	14.9		
#100	7.4	4.0 - 10.0	
#200	4.5	2.0 - 5.0	
#270	4.5		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some gravel, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7447 D_{85}= 1.6280 D_{60}= 0.6578
D_{50}= 0.5443 D_{30}= 0.3713 D_{15}= 0.2506
D_{10}= 0.1947 C_u= 3.38 C_c= 1.08

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/04/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

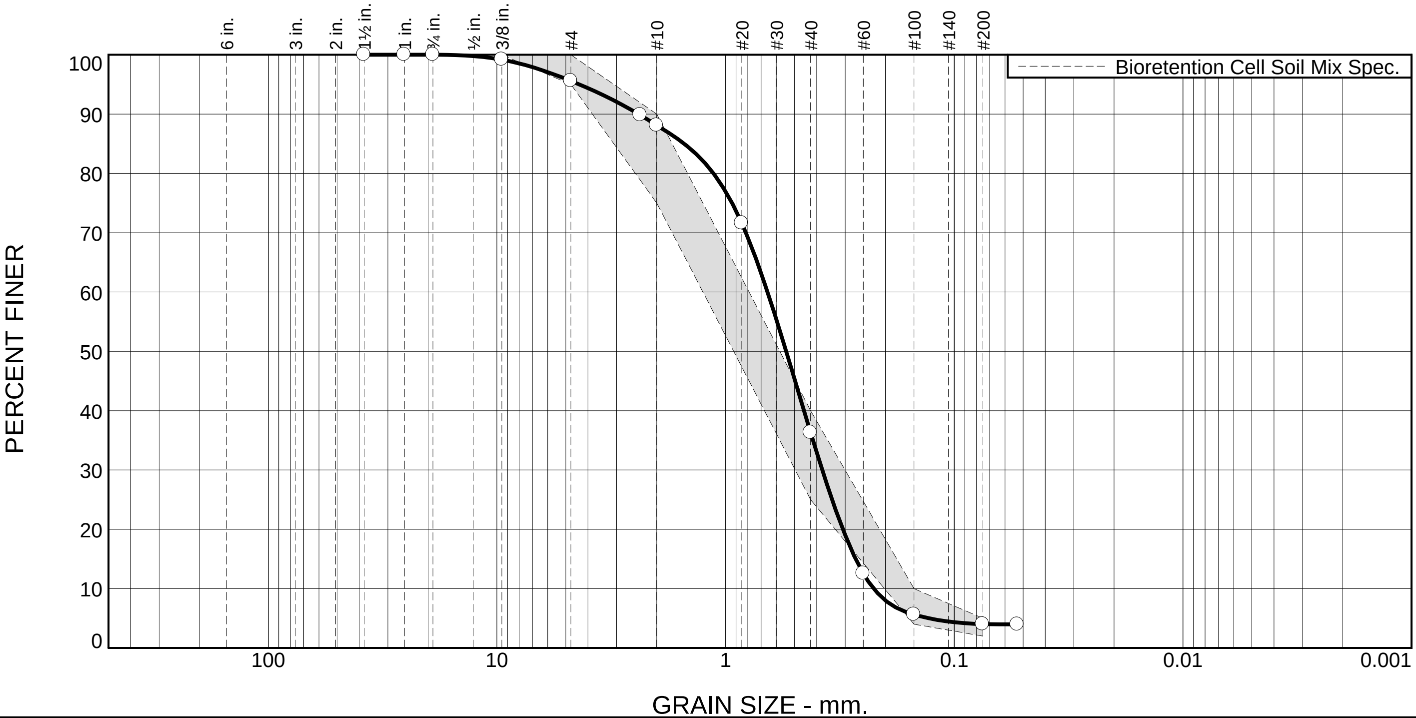
Source of Sample: (M3Q) Marysville- 3rd Street LID **Depth:** 0.2'-0.5' **Date Sampled:** 10/04/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.4	7.5	51.8	32.3	4.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	99.2	100.0	X
#4	95.6	95.0 - 100.0	
#8	89.8		
#10	88.1	75.0 - 90.0	
#20	71.6		
#40	36.3	25.0 - 40.0	
#60	12.6		
#100	5.6	4.0 - 10.0	
#200	4.0	2.0 - 5.0	
#270	4.0		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.4034 D_{85}= 1.5172 D_{60}= 0.6557
D_{50}= 0.5435 D_{30}= 0.3778 D_{15}= 0.2701
D_{10}= 0.2253 C_u= 2.91 C_c= 0.97

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/04/2018 **Date Tested:** 10/29/2018

Tested By: BN

Checked By: JHS

Title:

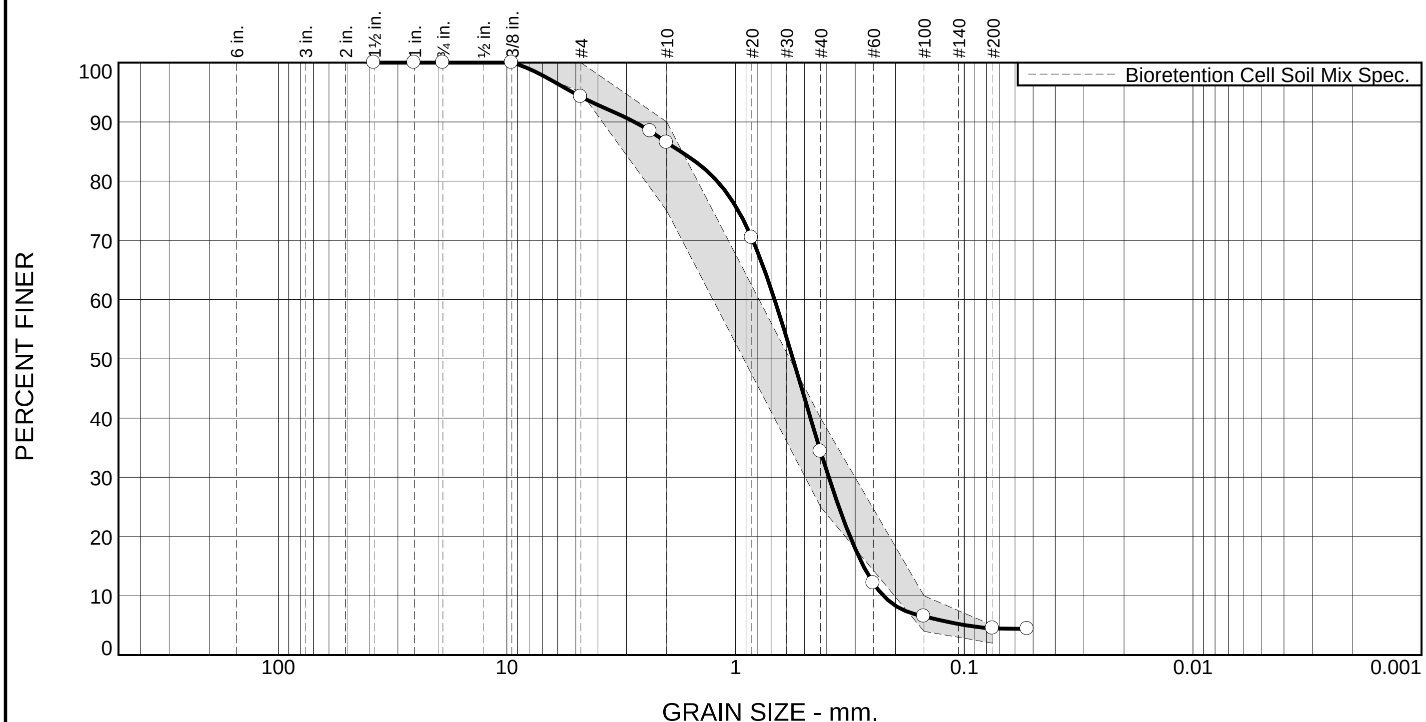
Source of Sample: (M3Q) Marysville- 3rd Street LID **Depth:** 0.1'-0.5'
Sample Number: HA-2 **Date Sampled:** 10/04/2018

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.8	7.7	52.1	29.9	4.5	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	94.2	95.0 - 100.0	X
#8	88.4		
#10	86.5	75.0 - 90.0	
#20	70.4		
#40	34.4	25.0 - 40.0	
#60	12.2		
#100	6.5	4.0 - 10.0	
#200	4.5	2.0 - 5.0	
#270	4.4		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some gravel, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 2.7737 D_{85}= 1.7389 D_{60}= 0.6755
D_{50}= 0.5616 D_{30}= 0.3912 D_{15}= 0.2759
D_{10}= 0.2257 C_u= 2.99 C_c= 1.00

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/04/2018 **Date Tested:** 10/29/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (M3Q) Marysville- 3rd Street LID **Depth:** 0.2'-0.8' **Date Sampled:** 10/04/2018

Sample Number: HA-3

associated earth sciences incorporated

Client: Clear Creek Solutions

Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)

Site Unit: Qvrm: Vashon Recessional Outwash, Marysville Member

Source:
Geologic map of the Marysville quadrangle, Snohomish County, Washington
Author(s): Minard, J.P.
Publishing Organization: U.S. Geological Survey
Series and Number: Miscellaneous Field Studies Map MF-1743
Publication Date: 1985
Map Scale: 1:24,000

Map Scale: 1:40,200 if printed on A portrait (8.5" x 11") sheet.

Meters: 0, 500, 1000, 2000, 3000

Feet: 0, 1500, 3000, 6000, 9000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1	Alderwood gravelly sandy loam, 0 to 8 percent slopes	10.0	0.1%
2	Alderwood gravelly sandy loam, 8 to 15 percent slopes	17.5	0.3%
3	Alderwood gravelly sandy loam, 15 to 30 percent slopes	39.3	0.6%
4	Alderwood-Everett gravelly sandy loams, 25 to 70 percent slopes	133.3	1.9%
7	Bellingham silty clay loam	276.3	4.0%
13	Custer fine sandy loam	79.6	1.1%
20	Fluvaquents, tidal	296.5	4.3%
27	Kitsap silt loam, 0 to 8 percent slopes	31.0	0.4%
30	Lynnwood loamy sand, 0 to 3 percent slopes	30.3	0.4%
32	McKenna gravelly silt loam, 0 to 8 percent slopes	4.3	0.1%
34	Mukilteo muck	18.8	0.3%
39	Norma loam	367.5	5.3%
47	Pastik silt loam, 0 to 8 percent slopes	169.0	2.4%
48	Pastik silt loam, 8 to 25 percent slopes	11.2	0.2%
55	Puget silty clay loam	1,511.0	21.8%
57	Ragnar fine sandy loam, 0 to 8 percent slopes	2,616.5	37.7%
58	Ragnar fine sandy loam, 8 to 15 percent slopes	44.5	0.6%
64	Snohomish silt loam	22.2	0.3%
69	Terric Medisaprists, nearly level	11.0	0.2%
71	Tokul silt loam, 8 to 15 percent slopes	8.8	0.1%
72	Tokul gravelly medial loam, 0 to 8 percent slopes	143.4	2.1%
73	Tokul gravelly medial loam, 8 to 15 percent slopes	61.8	0.9%
77	Tokul-Winston gravelly loams, 25 to 65 percent slopes	5.3	0.1%
78	Urban land	138.2	2.0%
82	Xerorthents, nearly level	150.5	2.2%

Note: Base map modified from Aerial Map provided by City of Marysville.

Legend:

B-1 Approx. Borehole Location (PanGEO)

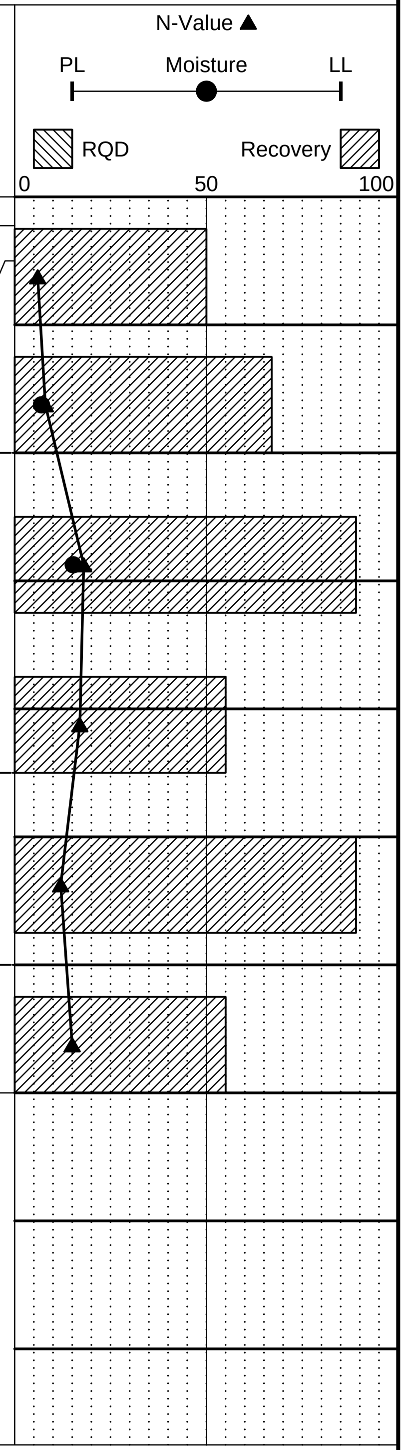
Core #3 Approx. Pavement Core Location (City of Marysville)

PanGEO INCORPORATED	1st and 3rd Streets Retrofit Marysville, WA	SITE AND EXPLORATION PLAN 3RD STREET BETWEEN COLUMBIA AVENUE AND 47TH AVENUE NE
		Project No. 13-239 / Figure No. 2B

file.grf w/ file.dat 1/30/14 (11:33) TEA2

Project:	1st & 3rd Street Retrofit	Surface Elevation:	
Job Number:	13-239	Top of Casing Elev.:	
Location:	1st and 3rd Streets, Marysville, WA	Drilling Method:	HSA
Coordinates:	Northing: , Easting:	Sampling Method:	SPT

Depth, (ft)	Sample No.	Sample Type	Blows / 6 in.	Other Tests	MATERIAL DESCRIPTION
0					5 inches of ASPHALT in two layers.
					6 inches of base. Medium dense, brown gray, silty, fine to coarse SAND with some gravel.
	S-1	SPT	4, 4, 2		Loose, red brown to brown, fine SAND: moist, poorly graded, some silt, non-plastic fines, laminated with occasional rusty laminae, scattered charcoal organics. (Recessional Outwash).
2					
	S-2	SPT	2, 3, 5	GS	
4					Medium dense, light gray, silty, fine to coarse SAND: moist, well graded, homogeneous, laminated with occasional rusty laminae, occasional fine gravel.
6	S-3	SPT	7, 9, 9	GS	
8	S-4	SPT	6, 9, 8		Grading to interbedded, light brown gray, silty, fine to medium SAND and fine to coarse SAND beds, laminated with occasional rusty laminae.
					Medium dense, light brown, SILT with fine sand interbeds: very moist, non-plastic, laminated and fine bedded.
10	S-5	SPT	4, 5, 7		
12					<medium dense, brown gray, fine to medium SAND with silt: wet, poorly graded, occasional fine to coarse sand interbed, homogeneous, laminated.
	S-6	SPT	6, 7, 8		
14					Boring terminated at about 14 feet below the surface. Groundwater was estimated based on the soil sample moisture on November 26, 2013.
16					
18					



Completion Depth:	14.0ft
Date Borehole Started:	11/26/13
Date Borehole Completed:	11/26/13
Logged By:	S. Evans
Drilling Company:	Bore Tec Drilling

Remarks: Groundwater observed in sample S-6 during drilling.

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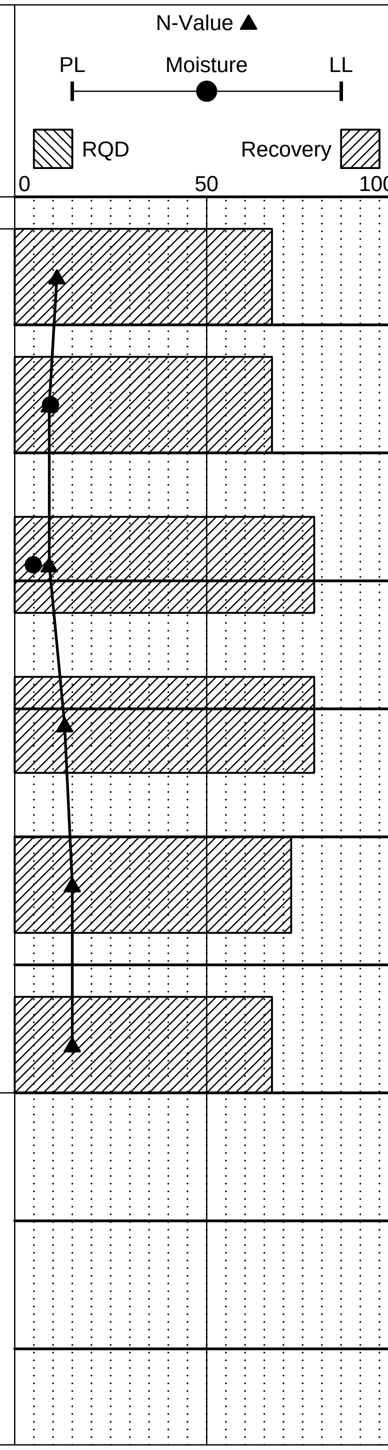
LOG OF TEST BORING B-5

Figure A-6

The stratification lines represent approximate boundaries. The transition may be gradual.

Project:	1st & 3rd Street Retrofit	Surface Elevation:	
Job Number:	13-239	Top of Casing Elev.:	
Location:	1st and 3rd Streets, Marysville, WA	Drilling Method:	HSA
Coordinates:	Northing: , Easting:	Sampling Method:	SPT

Depth, (ft)	Sample No.	Sample Type	Blows / 6 in.	Other Tests	Symbol	MATERIAL DESCRIPTION
0						6 inches of Asphalt, thin road base (<2 inches).
1	S-1	SPT	6, 6, 5			Loose to medium dense, yellow brown, silty, fine SAND to fine to medium SAND with silt: moist, poorly graded, non-plastic fines, trace gravel and organics at top, homogeneous, laminated. (Recessional Outwash).
3	S-2	SPT	4, 5, 4	GS		Grading to silty, fine to medium SAND, light brown gray.
5.5	S-3	SPT	2, 5, 4	GS		Grading to light gray, fine to medium SAND, some silt, occasional rusty laminae, finer and coarser beds.
8	S-4	SPT	4, 5, 8			Interbedded fine to coarse SAND, silty fine SAND and fine to medium SAND with silt, rusty laminae, finer beds brown, coarser are gray.
10.5	S-5	SPT	7, 7, 8			Homogeneous, fine to medium SAND, moist, trace silt, occasional rusty laminae.
13	S-6	SPT	6, 7, 8			Light gray, fine to medium SAND, moist, some silt, laminated to massive.
14						Boring terminated at about 14 feet below the surface. Groundwater was not observed during drilling.



Completion Depth:	14.0ft
Date Borehole Started:	11/25/13
Date Borehole Completed:	11/25/13
Logged By:	S. Evans
Drilling Company:	Bore Tec Drilling

Remarks: Groundwater not observed in SPT samples.

PanGEO INCORPORATED

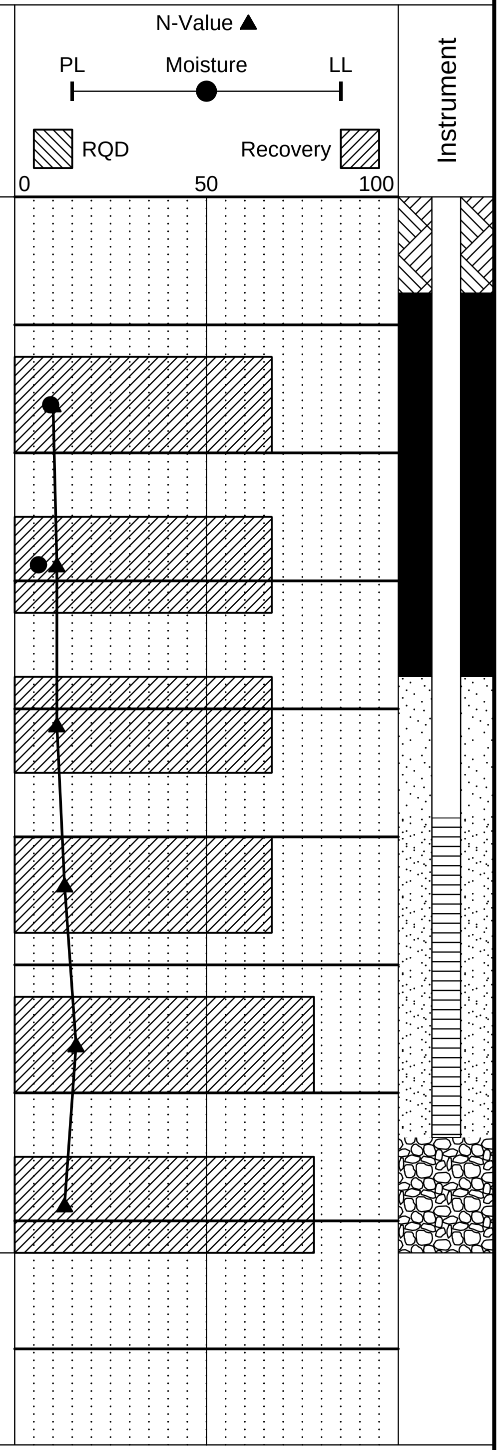
LOG OF TEST BORING B-6

Figure A-7

The stratification lines represent approximate boundaries. The transition may be gradual.

Project:	1st & 3rd Street Retrofit	Surface Elevation:	
Job Number:	13-239	Top of Casing Elev.:	
Location:	1st and 3rd Streets, Marysville, WA	Drilling Method:	HSA
Coordinates:	Northing: , Easting:	Sampling Method:	SPT

Depth, (ft)	Sample No.	Sample Type	Blows / 6 in.	Other Tests	MATERIAL DESCRIPTION
0					Medium dense, light gray, fine to medium SAND: moist, some silt, poorly graded, homogeneous, massive to laminated, occasional orange pockets. (Recessional Outwash).
2.5–4	S-1	SPT	3 5 5	GS	Occasional organics.
5–6.5	S-2	SPT	5 5 6	GS	Trace to some silt.
7.5–9	S-3	SPT	5 5 6		
10–11.5	S-4	SPT	4 6 7		Laminated with occasional brown laminae.
12.5–14	S-5	SPT	5 8 8		Grading to light gray, fine SAND with silt.
15–16.5	S-6	SPT	5 6 7		Grading to fine to medium SAND with silt.
16.5					Boring terminated at about 16.5 feet below the surface. Groundwater was estimated based on the soil sample moisture on November 26, 2013.



Completion Depth:	16.5ft
Date Borehole Started:	11/25/13
Date Borehole Completed:	11/25/13
Logged By:	S. Evans
Drilling Company:	Bore Tec Drilling

Remarks: Well dry when measured on 11/26/13. Groundwater estimated from SPT sample S-6 from 15 to 16.5 feet.

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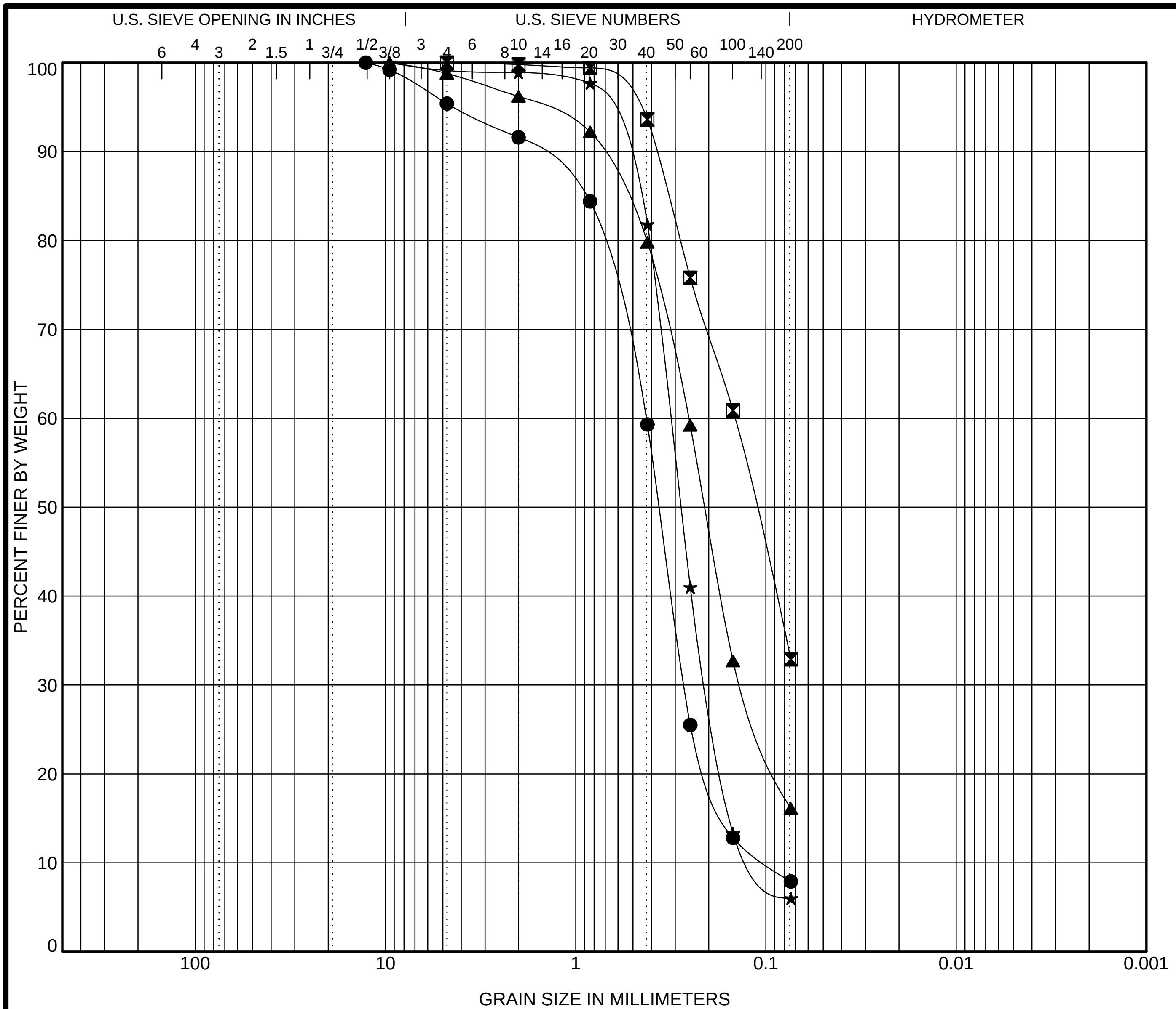
LOG OF TEST BORING B-7

Figure A-8

The stratification lines represent approximate boundaries. The transition may be gradual.



<table>
<tr><td rowspan="2">COBBLES</td><td colspan="2">GRAVEL</td><td colspan="3">SAND</td><td rowspan="2">SILT OR CLAY</td></tr>
<tr><td>coarse</td><td>fine</td><td>coarse</td><td>medium</td><td>fine</td></tr>
</table>

Specimen Identification		Classification	LL	PL	PI	Cc	Cu
● B-5	@ 2.5 ft.	**Red brown-brown, fine SAND, some silt**				1.68	4.29
⧗ B-5	@ 5.0 ft.	**Light gray, silty fine to medium SAND**					
▲ B-6	@ 2.5 ft.	**Yellow brown, silty fine to medium SAND**					
★ B-6	@ 5.0 ft.	**Light gray, fine to medium SAND, some silt**				1.20	2.93

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● B-5	2.5	12.7	0.428	0.268	0.1	4.6	87.4	8.0	
⧗ B-5	5.0	4.76	0.146			0.0	66.6	33.4	
▲ B-6	2.5	9.52	0.255	0.133		1.2	82.4	16.4	
★ B-6	5.0	9.52	0.318	0.204	0.109	0.9	93.0	6.1	

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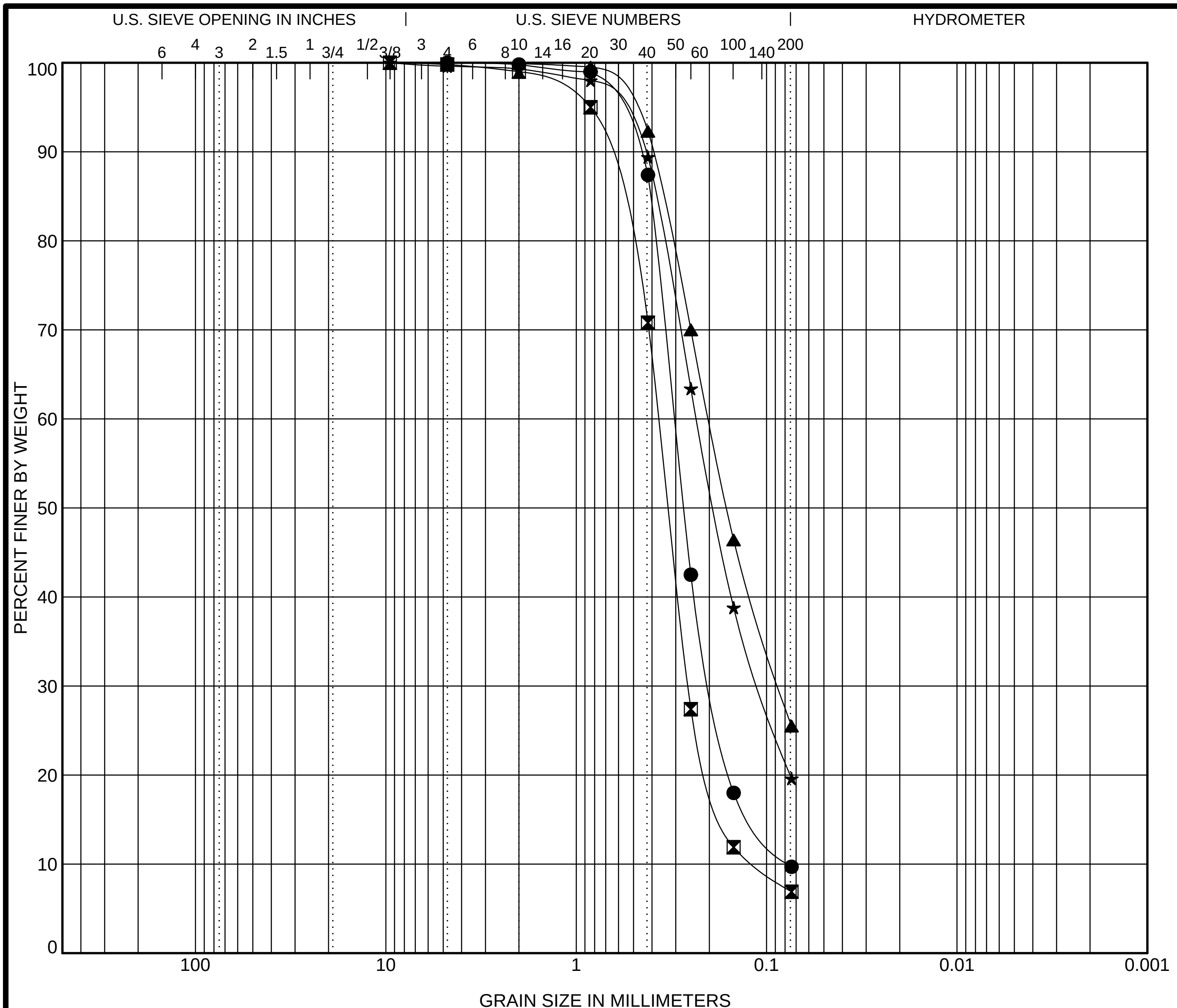
GRAIN SIZE DISTRIBUTION

Project: 1st & 3rd Street Retrofit
Job Number: 13-239
Location: 1st and 3rd Streets, Marysville, WA

Figure B-3



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	LL	PL	PI	Cc	Cu
●	B-7	@ 2.5 ft.	**Light gray, fine to medium SAND, some silt**				1.59	4.03
⊠	B-7	@ 5.0 ft.	**Light gray, fine to medium SAND, trace to some silt**				1.58	3.23
▲	B-8	@ 2.5 ft.	**Red brown, silty fine SAND**					
★	B-8	@ 5.0 ft.	**Light brown-gray, silty fine SAND**					

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	B-7	2.5	4.76	0.306	0.192	0.076	0.0	90.1	9.9	
⊠	B-7	5.0	9.52	0.369	0.258	0.114	0.2	92.8	7.0	
▲	B-8	2.5	4.76	0.201	0.086		0.0	74.1	25.9	
★	B-8	5.0	9.52	0.233	0.108		0.4	79.6	20.0	

GRAIN SIZE DISTRIBUTION

PanGEO INCORPORATED
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Project: 1st & 3rd Street Retrofit
Job Number: 13-239
Location: 1st and 3rd Streets, Marysville, WA

Figure B-4

APPENDIX D

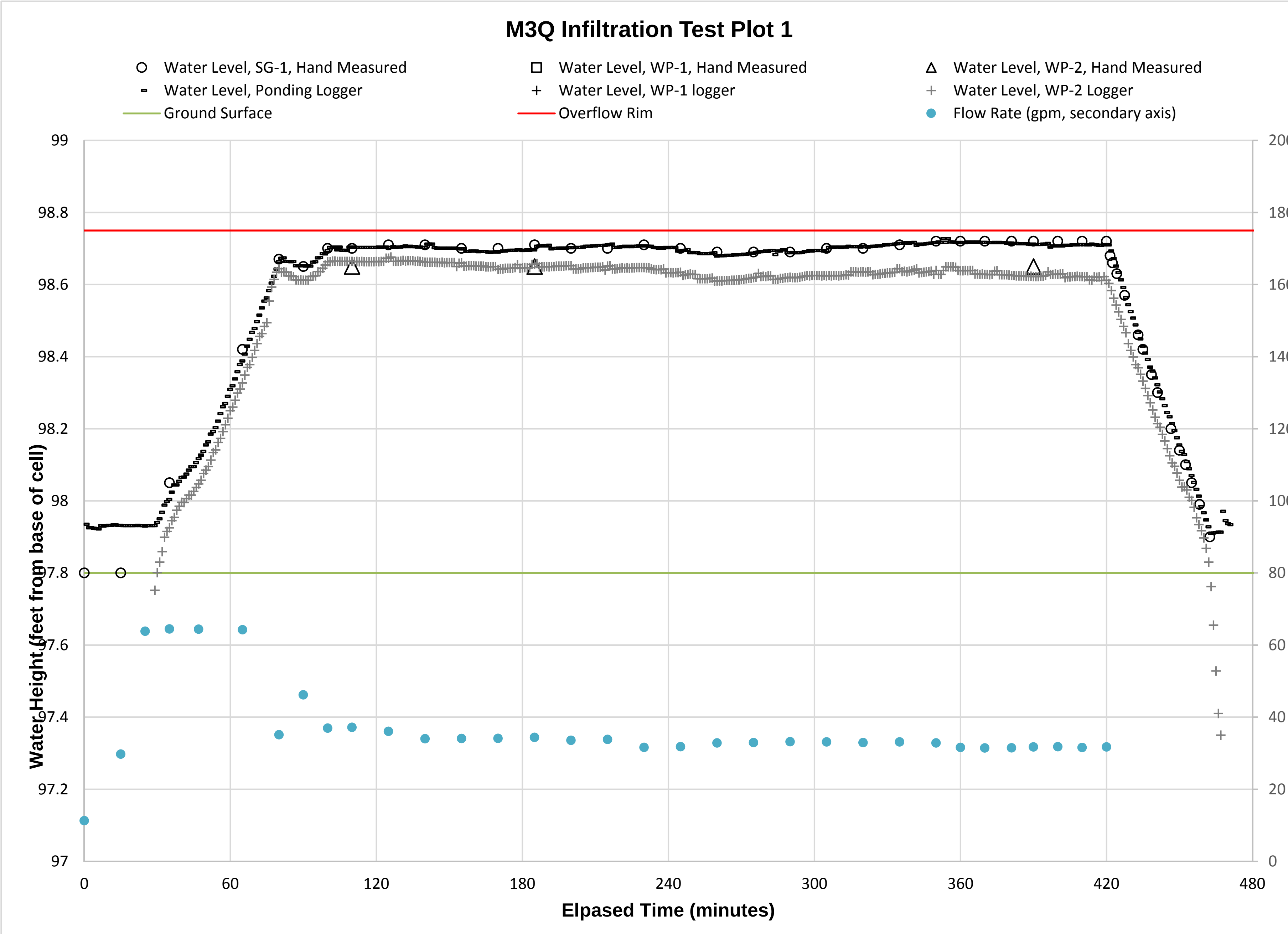
Soil Probe, Level Survey, and Field Infiltration Testing Data

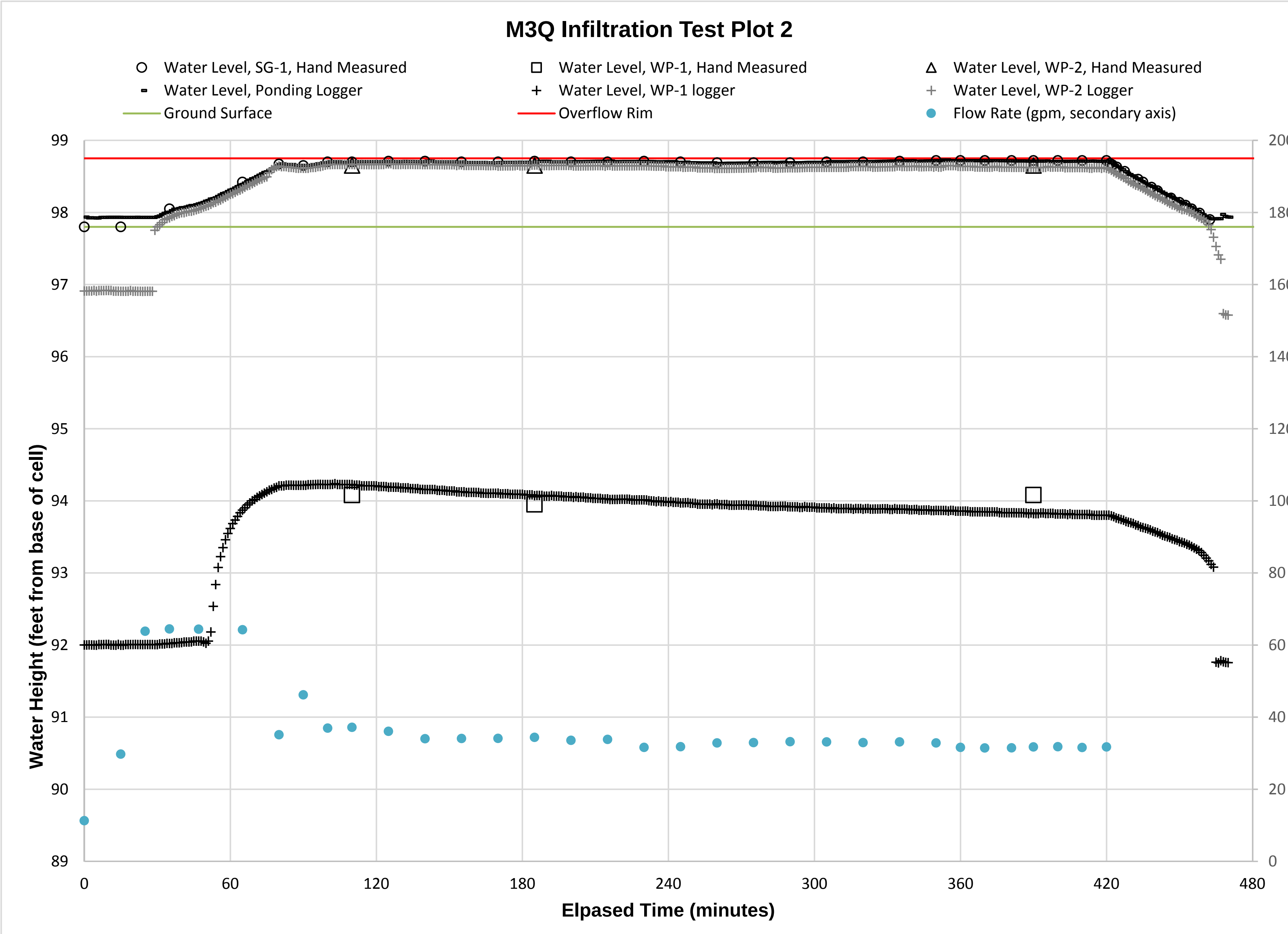
Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5
Date:	10/30/2018	**Base Area (sq.ft.):**	200
Weather:	overcast, 60's	**Ponded Area(sq.ft.):**	200.0
Test No.:	M3Q	**Test Depth (feet):**	NA
Performed By:	ADY	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
9:10	11.28	0	0	Flow on
9:25	29.72	0	187	Water pooling on East, South sides
9:35	63.83		464	
9:45	64.44	0.25	1062	
9:57	64.39	33	1840	Base fully wetted
10:15	64.22	0.62	3001	
10:30	35.11	0.87	3961	
10:40	46.17	0.85	4341	
10:50	36.94	0.9	4769	
11:00	37.17	0.9	5159	
11:15	36.06	0.91	5694	
11:30	34	0.91	6267	
11:45	34.06	0.9	6737	
12:00	34.11	0.9	7246	
12:15	34.39	0.91	7784	
12:30	33.56	0.9	8283	
12:45	33.83	0.9	8778	
13:00	31.61	0.91	9283	
13:15	31.78	0.9	9750	
13:30	32.83	0.89	10243	
13:45	32.94	0.89	10738	
14:00	33.17	0.89	11216	
14:15	33.11	0.9	11712	
14:30	32.94	0.9	12240	
14:45	33.11	0.91	12704	
15:00	32.83	0.92	13214	
15:10	31.61	0.92	13513	
15:20	31.44	0.92	13851	
15:31	31.46	0.92	14200	
15:40	31.72	0.92	14454	
15:50	31.78	0.92	14781	
16:00	31.56	0.92	15098	
16:10	31.72	0.92	15420	Flow off
16:11		0.88		
16:12		0.86		
16:14		0.83		
16:17		0.77		
16:23		0.66		
16:25		0.62		
16:28		0.55		
16:31		0.5		
16:36		0.4		
16:40		0.34		
16:42		0.3		
16:45		0.25		

16:48		0.19		
16:52		0.1		

	Average Infiltration Rate (in/hr) during last hour of inflow:	15.3
	Average Infiltration Rate (in/hr) during falling head:	13.7


M3Q Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, WP-2, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Water Level, WP-2 Logger
Ground Surface
Overflow Rim
Flow Rate (gpm, secondary axis)
Water Height (feet from base of cell)
Elpased Time (minutes)
99
98.8
98.6
98.4
98.2
98
97.8
97.6
97.4
97.2
97
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480



M3Q Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, Ponding Logger
Ground Surface
Water Level, WP-1, Hand Measured
Water Level, WP-1 logger
Overflow Rim
Water Level, WP-2, Hand Measured
Water Level, WP-2 Logger
Flow Rate (gpm, secondary axis)
Water Height (feet from base of cell)
99
98
97
96
95
94
93
92
91
90
89
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)

APPENDIX E

Site Photos

Cell M3Q overview. In above photo, the curbcut weir has not been installed. Lower photo is after weir install and during infiltration testing.

Above photo: Cell M3Q inlet modified for monitoring and nearby well points and ponding station.
Lower Photo: close up of overflow structure during infiltration testing.

APPENDIX 8

Deliverable Task 4.5, Site MPP, Geotechnical/Soils Assessment Design Data and Current Conditions, Monroe Park Place Middle School, Monroe, Washington. Associated Earth Sciences, Inc. 6/14/2019

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site MPP, Geotechnical/Soils Assessment Design Data and Current Conditions, Monroe Park Place Middle School, Monroe, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Cell #6 of the Monroe Park Place Middle School Project, located in the city of Monroe, Washington (Figure MPP F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously-documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 10, 2018, infiltration testing on November 8, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure MPP F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Monroe Park Place Middle School Project, located in Monroe, Washington as shown on the attached "Vicinity Map" (Figure MPP F1). The Monroe Park Place Middle School is located on a 21-acre parcel. The site is bordered by West Main Street to the north, mixed-use residential and business and associated parking to the west and east and vacant, wooded area to the south. Site topography slopes gently toward the southeast with a vertical relief of less than

10 feet (60 feet near the northwest corner and 56 feet along the west side with a low of 54 feet). The site is located about 1,000 feet north of the Skykomish River, which flows to the southwest in the vicinity of the site. An abandoned channel of the river is immediately south of the site. No on-site surface water features are present.

Our specific area of study for this project includes bioretention facility cell #6 located on the southeast portion of campus referred to as cell MPP for this study. The attached "Facility and Exploration Plan" (Figure MPP F2) illustrates the cell area and some of the surrounding site features and utilities.

Details of the bioretention facility design and basis for design were presented in the following documents:

- Associated Earth Sciences, Inc., 2015, Subsurface Exploration, Geologic Hazard, and Preliminary Geotechnical Engineering Report, Park Place Middle School, Monroe, Washington: Prepared for Monroe Public Schools, July 31, 2015.
- Associated Earth Sciences, Inc., 2016, In-situ Infiltration Testing and Design Infiltration Rate Recommendations, Park Place Middle School, Monroe, Washington: Prepared for Monroe Public Schools, January 22, 2016.
- Harmsen & Associates, Inc., 2016, Stormwater Site Plan for Park Place Middle School, Monroe, Washington, February 4, 2016 (Drainage report).
- Integrus Architecture, Monroe School District Park Place Middle School, Plan Set, June 6, 2016 (plan set).
- Associated Earth Sciences, Inc., 2017, Park Place Middle School, Project No. 150324E011, Selected Field Reports, June 2017.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell MPP consists of an approximately rectangular-shaped bioretention cell with approximately 684 square feet of base area, as shown on Figure MPP F2, "Facility and Exploration Plan." We understand that the site was developed under the 2005 Washington State Department of Ecology (Ecology) *Stormwater Management Manual for Western Washington* (2005 Ecology Manual) as adopted by the City of Monroe for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 2 inches per hour (in/hr) for the bioretention soil; the native subgrade infiltration rate exceeded the bioretention soil rate. As described in the drainage report, land use within the drainage basin is primarily roads and walkways (0.29 acres) and lawn/landscaping (0.19 acres). Per plan sheet C302, "Monroe School District Park Place Middle School" (Integrus Architecture, June 6, 2016), the facility design includes 18 inches of bioretention soil mix overlying approximately 6 inches of "A33" sand (washed fine- to medium-grained sand) overlying native subgrade.

The facility is designed to infiltrate 100 percent of inflow into the subgrade. Stormwater enters the facility through one inlet curbcut on the north end. No overflow structure was installed in cell MPP.

The inlet to cell MPP and the pond rim was designed to be 1.5 feet above the cell base to create 1.5 feet of ponding depth. If water ponds up and fills the cell, the ponded water would flow into the parking lot to the north. The facility was constructed during Summer 2017.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility on Figure MPP F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the top of curb at the northeast corner of the track (west of cell MPP defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: One inflow consisting of a curb cut to cell MPP was observed on the north end of the cell.
    - Inflow to the facility via a curb cut, allows sheet flow from the parking lot to discharge onto a quarry spall energy dissipation pad approximately 4 to 5 feet wide and 18 feet long.

- Overflow: No overflow structure for cell MPP was observed. The approximate low of the rim of the cell to the south was measured to be 3.6 feet above the cell base and 1.8 feet above the cell inlet. If ponded water filled the cell, overflow would flow into the parking lot to the north before overtopping the cell rim to the south, west, or east.

- AESI investigated the loose bioretention soil thickness present in cell MPP using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 4-foot to 5-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.4 feet to 2.5 feet, and averaged 1.9 feet. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell MPP
Level Survey Data

Location	Elevation (feet, project datum)
Top of curb, northeast corner of track, west of cell	100
MPP-WP-1 TOC	98.82
Ground surface at MPP-WP-1 and temporary staff gauge MPP-SG-1	96.17
Ponding tube TOC (DL)	99.05
Temporary inlet pipe top/end	98.21
Curbcut, inside lip, low	97.99
Cell rim low, south of cell	99.82

WP: well point; TOC: top of Casing; DL: datalogger;

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- Dragovich, J. et al., 2011, *Geologic Map of the Monroe 7.5' Quadrangle, King and Snohomish Counties, Washington*, Washington Department of Natural Resources (DNR), scale 1:24,000.
- Natural Resources Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed December 2018.
- *Soil Survey of Snohomish County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1983.
- Newcomb, R.C., 1952, Ground-water Resources of Snohomish County, Washington: U.S. Geological Survey (USGS).
- Thomas, B.E., Wilkinson, J.M., and Embrey, S.S., 1997, The Ground-water System and Groundwater Quality in Western Snohomish County, Washington: U.S. Geological Survey USGS), U.S. Department of the Interior.

5.1 Regional Topography and Project Grading

The site and vicinity are on the south edge of the city of Monroe, within a broad river valley flat near the confluence of the Skykomish and Snoqualmie rivers. Topographic features in the vicinity of the site were formed by glacial and post-glacial processes. Elevations on the larger project site range from about 54 to 60 feet. The site is located about a 1,000 feet north of the Skykomish River, and is about 15 to 20 feet higher in elevation than the river. An abandoned channel of the river is immediately south of the site. No on-site surface water features are present.

On a closer scale, the area near cell MPP is relatively flat, situated on an alluvial plain at about elevation 59 to 60 feet. Level parking and access road areas are to the north, lawn and an athletic track are to the west and lawn is to the east and south. A curb separates the paved surfaces from the cell and the track.

The project site was previously developed as Park Place Middle School which was demolished, to allow for the construction of the new Park Place Middle School. Minor cutting (about 4 to 5 feet) was needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the geology map (Dragovich et al., 2011), the site vicinity is underlain by Deltaic Outwash of the Vashon Stade of the Fraser Glaciation. The interpretation of the sediments encountered at the subject site during our geotechnical and infiltration studies (AESI, 2015 and 2016) is not in general agreement with the regional geologic map, and is not consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project. Sediments interpreted to be representative of Skykomish River alluvium were encountered directly below the topsoil and/or fill at the locations of all explorations done during our geotechnical and infiltration studies (AESI, 2015 and 2016). The Skykomish River alluvium was deposited by the Skykomish River system. The alluvial sediments generally consisted of two facies: levee deposits which were deposited during river flooding and coarse grained alluvium which was deposited within stream channels.

- <u>Alluvium - Levee Deposits</u>: Sediments interpreted to be levee deposits were encountered in all explorations to depths between 3 to 6 feet. These sediments generally consisted of soft to medium stiff, moist, tannish brown to brown, fine sandy silt with varying amounts of organics. The levee deposits form in a low-energy environment at the edges of channels where the floodwater velocity decreases.

- <u>Alluvium - Coarse-Grained</u>: Sediments interpreted to be coarse-grained alluvium extended below the levee deposits to the bottom of all explorations at a maximum depth of 21.5 feet. The channel alluvium generally consisted of medium dense to dense, moist, fine to coarse sand and gravel with cobbles and trace silt. These sediments were deposited by the Skykomish River System in a high-energy environment.

Infiltration tests were conducted as part of design. Infiltration tests IT-5 and IT-7 were located near cell MPP (bioretention cell #6) with field infiltration rates of 12 and 75 inches per hour, respectively. Subsurface information from the bioretention cell during construction (Appendix C, June 2017 field reports) indicate that the cell was 'over-excavated' (deepened) in some areas to remove levee deposits (silt and silty fine sand) and expose the better-draining channel deposits (sandy gravel).

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the soil survey (Natural Resources Conservation Service [NRCS], 1983) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Sultan Silt Loam, which formed in alluvium on 0- to 2-percent slopes. NRCS describes the permeability as moderately slow (NRCS, 1983).

As described in the drainage report (Harmsen & Associates. Inc., 2016), the pre-developed condition was modeled as Type C soils, consistent with mapped soil and background geotechnical data that shows the upper alluvium levee deposits consist of sandy silt.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in Newcomb (1952) and Thomas et al. (1997). Thomas et al, (1997) identifies an alluvial aquifer within the Skykomish River alluvium and notes the Skykomish alluvium deposits are among the most areally extensive in the area of study.

According to our geotechnical and infiltration studies at the site (AESI, 2015 and 2016), groundwater is present at shallow depths beneath the site within the coarse-grained alluvial deposits. Groundwater seepage was encountered in our explorations from previous studies (AESI, 2015 and 2016) below depths of approximately 14 to 21 feet. Exploration EB-3 is within 100 feet of cell MPP and encountered groundwater seepage below depths of approximately 18 feet.

Groundwater measurements were taken from the three groundwater monitoring wells installed June 30, 2015 (AESI, 2015). Groundwater ranged from approximately 48 to 49 feet below ground surface in December 2015 (AESI, 2016), or within about 6 to 7 feet below the top of bioretention soil layer (planned elevation of 54.9 feet). Hydrographs are included in Appendix C.

The shallow unconfined groundwater encountered in the on-site monitoring wells is part of the regional aquifer contained within the alluvial deposits present in the Skykomish/Snoqualmie River deposits. Groundwater flow direction is typically toward the river, except during river flood stage when groundwater flow direction is affected by river stage.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and into underlying sand fill. Two of the borings were also advanced into native material underlying the fill (MPP-HA-1 and MPP-HA-2). Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure MPP F2, "Facility and Exploration Plan."

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell MPP were completed on October 10, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring locations are presented on Figure MPP F2. The hand-auger borings encountered a thin layer of shredded wood overlying bioretention soil to a depth of 1.6 to 1.7 feet, overlying a thin layer of sand fill, and native alluvium sediment (MPP-HA-1 and MPP-HA-2). Hand-auger MPP-HA-3 was terminated in the sand fill layer at 2 feet. Bioretention soil thickness was 1.5 to 1.6 feet in each boring. No seepage or caving was observed.

6.2 Well Points

One well point was installed in MPP-HA-1 (WP-1) a depth of 2.5 feet, and screened primarily within the bioretention soil and imported sand layer. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell MPP
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
MPP-WP-1	MPP-HA-1	5.1	1.25 inch nominal	2.6	2.5

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). Two samples of material interpreted as representative of the bioretention soil were tested for grain-size distribution. The data are summarized in Table 3.

Table 3
Summary of Cell MPP
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
MPP-HA-1	0.1-0.5	Bioretention Soil	10.1	SAND, trace silt, trace gravel (SW)	4.2	6.2	1.0	Sand
MPP-HA-2	0.1-0.5	Bioretention Soil	9.9	SAND, trace silt, trace gravel (SW)	2.9	6.0	1.0	Sand
MPP-HA-3	1.0-1.6	Bioretention Soil	--	SAND, trace silt, trace gravel (SP)	2.9	5.1	1.1	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture; *No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 9.9 to 10.1 percent by weight, slightly higher than the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace silt and trace gravel based on ASTM D2487 USCS. The respective fines content as measured on the No. 200 sieve was 2.9 to 4.2 percent, within the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 5.1 to 6.2, meeting the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 1.0 to 1.1, within the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix contained slightly more than the recommended range of coarse sand. The tested bioretention soil was a poorly- to well-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell MPP Site Data

Parameter	Recommended Range	Cell MPP
Organic Content (by weight)	5 to 8 percent	10.0 percent by weight
Cu coefficient of uniformity	4 or greater	5.8
Cc coefficient of curvature	1 to 3	1.1
Sieve Size	**Percent Passing**	
3/8” (9.51 mm)	100	100
#4 (4.76 mm)	95 to 100	97.6
#10 (2.0 mm)	75 to 90	72.5
#40 (0.42 mm)	25 to 40	20.1
#100 (0.15 mm)	4 to 10	5.8
#200 (0.074 mm)	2 to 5	3.3

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In cell MPP, AESI observed excavation of cell MPP during construction and conducted hand-auger borings within the cell as part of the current study. A thin layer of imported sand, 0.2 to 0.9 feet thick, classified as SAND, trace silt (SP), was observed overlying native material consisting of alluvium, classified as a sandy GRAVEL with trace silt (GP). Grain-size testing from a nearby infiltration test at the time of design (AESI, 2016) is included in Appendix C.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a “soaking period,” to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the “constant-head” phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the “falling-head” portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell MPP with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Ponded water levels within the cell were monitored using a temporary staff gauge (MPP-SG-1) marked in 0.01-foot increments installed adjacent MPP-WP-1, and within a piezometer (“ponding tube”) with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell MPP is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell MPP

AESI performed infiltration testing on November 8, 2018. No rainfall was noted during testing, and no flow from the inflow pipes was present.

During this test, flow was initially adjusted between about 50 and 100 gpm to fill the cell bottom and stabilize the wetted area, then maintained at about 30 gpm for the duration of the test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. The entire cell base was wetted after about 100 minutes and a water level between 1.0 and 1.2 feet was maintained at the staff gauge after about 170 minutes (MPP-SG-1, Figure MPP F2). The wetted pool area had been generally stable through most of the soaking and testing period covering an area of about 800 square feet. Approximately 18,000 gallons of water were used.

Ponded water in the bioretention cell was monitored in well point MPP-WP-1 using a data logger during the infiltration test and responded to inflow. Groundwater was observed within the bioretention soil prior to the start of inflow to the bottom depth of MPP-WP-1 (2.5 feet). The water level in the well point is interpreted to have responded to inflow within several minutes. The first about 70 minutes of water level data was not recovered. The water level in MPP-WP-1 rose approximately 3.5 feet above the base of the well point to 1.0 feet above ground surface during the course of testing. AESI interprets this response to indicate that water from the infiltration test infiltrated rapidly through the bioretention soil and then mounded then mounded on the native alluvial sediments. The shallow subsurface ponded water level mirrored the surface water ponding level.

After about 7 hours, AESI shut off the flow and monitored water level as it fell. AESI observed that the pooled water in the base of the facility and the groundwater level in well point MPP-WP-1 dropped about 0.3 feet after 60 minutes.

Water was still ponded in the base of the facility about 0.9 feet and groundwater still mounded in well point MPP-WP-1 about 0.7 feet above the ground surface 60 minutes after inflow was stopped.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the native subgrade.

Table 5
Cell MPP
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
MPP (bioretention soil)	800	420	18,065	1.2	greater than native soil infiltration rate	
MPP (subgrade)	interpreted to be similar to wetted area				3	3

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell MPP was generally consistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- No overflow was designed or observed. Site design documents indicate that the ponding level was designed as 1.5 feet.

- Bioretention soil:
    - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.9 feet thick, slightly thicker than as indicated on the plans (1.5 feet).
    - Composition: The soil tested in generally the recommended guidelines for sand gradation. The organic content was higher than recommended with an average of 10 percent.

- Subgrade conditions: The subgrade is interpreted to consist of a thin layer of imported sand fill overlying native alluvium sediments as documented during construction and design reports (AESI, 2015, 2016).

- During infiltration testing, water readily soaked through the bioretention soil mix. Water was observed in the shallow well point (screened at the base of the bioretention soil), demonstrating that water accumulated on the underlying subgrade. The native alluvium is interpreted to have a lower permeability than the overlying bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

- Subgrade infiltration rate: Measured at about 3 in/hr. This is lower than the infiltration testing conducted as part of design (infiltration rates of 12 and 75 inches per hour).

- Bioretention soil field infiltration rate:
    - Greater than the measured field rate of at about 3 in/hr.
    - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the native subgrade infiltration rate.

- Groundwater is expected to be present seasonally at shallow depths in the location of the MPP facility below the bottom of well point MPP-WP-1 since it was encountered in several explorations onsite (AESI, 2015 and 2016) and seasonal groundwater monitoring indicates high of about 6 feet below top of bioretention soil surface. Peak groundwater occurred for a few days during peak river stage during the groundwater level monitoring period of record.

- The effects of shallow groundwater mounding will increase during the wetter winter months, and will reduce the effective infiltration rate by reducing the vertical gradient. The ongoing monitoring data will be reviewed for groundwater influence.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

State of Washington
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2335
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Principal Geologist/Hydrogeologist

Attachments:	Figure MPP F1:	Vicinity Map
	Figure MPP F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

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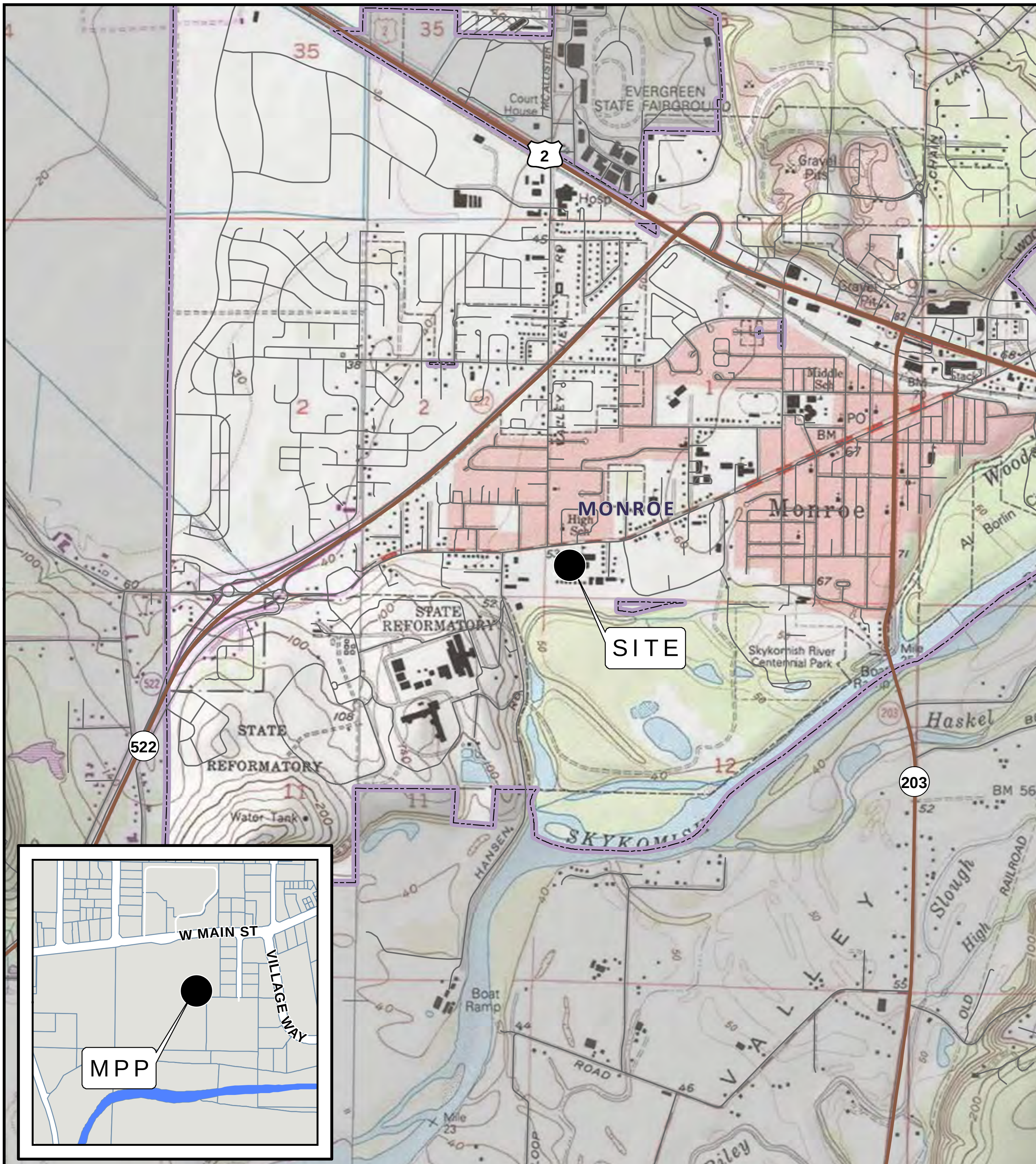

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FEET

DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NATIONAL GEOGRAPHIC SOCIETY 2013
SNOHOMISH CO: STREETS, CITY LIMITS, PARCELS, 1/18
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

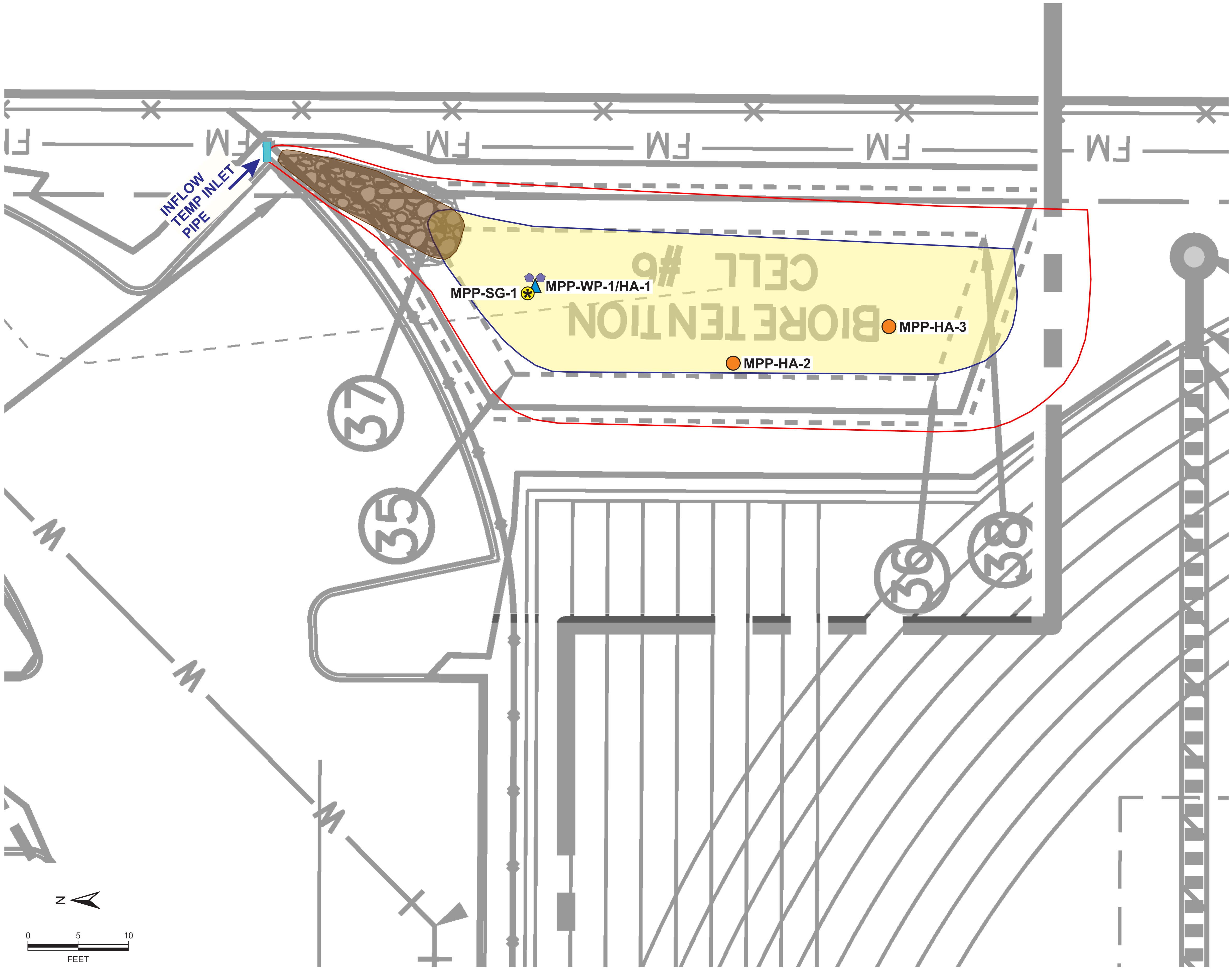
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, MPP SITE
MONROE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	MPP F1

Document Path: G:\GIS_Projects\aV15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_MPP.mxd



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
	PVC PONDING TUBE
	CURB CUT
	ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: INTEGRUS ARCHITECTURE, MONROE SCHOOL DISTRICT, PARK PLACE MIDDLE SCHOOL, STORM DRAINAGE PLAN, SHEETS C300 AND C301, 6/6/16

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN
MPP SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MONROE, WASHINGTON

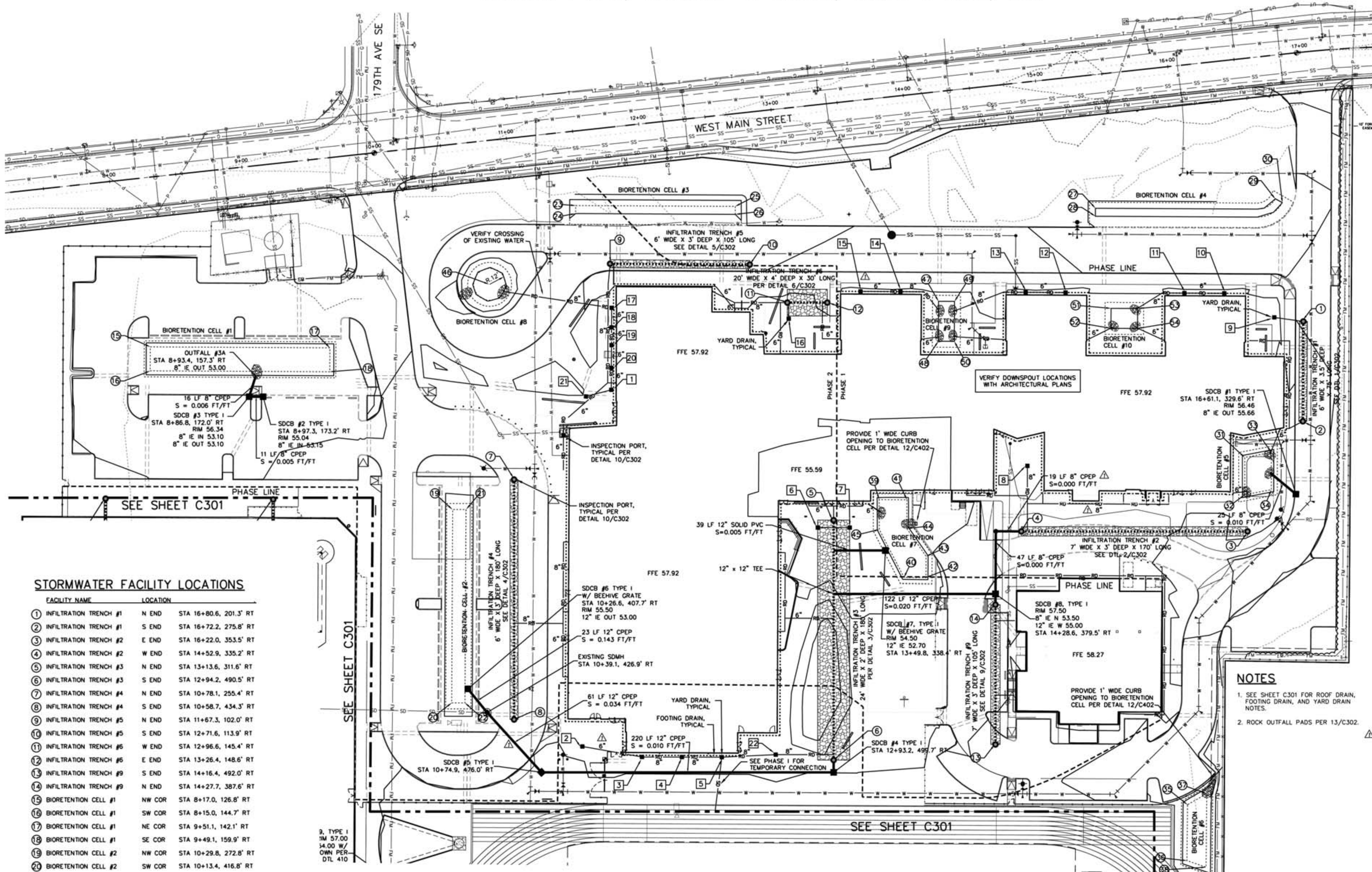
PROJ NO.	DATE:	FIGURE:
150387H007	3/19	MPP F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: MPP F2

APPENDIX A

Project Civil Plans

SECTION 1 & 2, TOWNSHIP 27 NORTH, RANGE 6 EAST, W.M.



STORMWATER FACILITY LOCATIONS

	FACILITY NAME	LOCATION	
1	INFILTRATION TRENCH #1	N END	STA 16+80.6, 201.3' RT
2	INFILTRATION TRENCH #1	S END	STA 16+72.2, 275.8' RT
3	INFILTRATION TRENCH #2	E END	STA 16+22.0, 353.5' RT
4	INFILTRATION TRENCH #2	W END	STA 14+52.9, 335.2' RT
5	INFILTRATION TRENCH #3	N END	STA 13+13.6, 311.6' RT
6	INFILTRATION TRENCH #3	S END	STA 12+94.2, 490.5' RT
7	INFILTRATION TRENCH #4	N END	STA 10+78.1, 255.4' RT
8	INFILTRATION TRENCH #4	S END	STA 10+58.7, 434.3' RT
9	INFILTRATION TRENCH #5	N END	STA 11+67.3, 102.0' RT
10	INFILTRATION TRENCH #5	S END	STA 12+71.6, 113.9' RT
11	INFILTRATION TRENCH #6	W END	STA 12+96.6, 145.4' RT
12	INFILTRATION TRENCH #6	E END	STA 13+26.4, 148.6' RT
13	INFILTRATION TRENCH #9	S END	STA 14+16.4, 492.0' RT
14	INFILTRATION TRENCH #9	N END	STA 14+27.7, 387.6' RT
15	BIORETENTION CELL #1	NW COR	STA 8+17.0, 126.8' RT
16	BIORETENTION CELL #1	SW COR	STA 8+15.0, 144.7' RT
17	BIORETENTION CELL #1	NE COR	STA 9+51.1, 142.1' RT
18	BIORETENTION CELL #1	SE COR	STA 9+49.1, 159.9' RT
19	BIORETENTION CELL #2	NW COR	STA 10+29.8, 272.8' RT
20	BIORETENTION CELL #2	SW COR	STA 10+13.4, 416.8' RT
21	BIORETENTION CELL #2	NE COR	STA 10+39.7, 273.8' RT
22	BIORETENTION CELL #2	SE COR	STA 10+23.3, 417.9' RT
23	BIORETENTION CELL #3	NW COR	STA 11+46.3, 55.7' RT
24	BIORETENTION CELL #3	SW COR	STA 11+45.6, 61.7' RT
25	BIORETENTION CELL #3	NE COR	STA 12+65.5, 69.3' RT
26	BIORETENTION CELL #3	SE COR	STA 12+64.9, 75.3' RT
27	BIORETENTION CELL #4	NW COR	STA 15+34.5, 99.9' RT
28	BIORETENTION CELL #4	SW COR	STA 15+33.8, 105.8' RT
29	BIORETENTION CELL #4	NE COR	STA 16+69.6, 107.5' RT
30	BIORETENTION CELL #4	SE COR	STA 16+74.5, 110.8' RT
31	BIORETENTION CELL #5	NW COR	STA 16+25.8, 298.1' RT
32	BIORETENTION CELL #5	SW COR	STA 16+22.8, 325.9' RT
33	BIORETENTION CELL #5	NE COR	STA 16+46.1, 296.4' RT
34	BIORETENTION CELL #5	SE COR	STA 16+43.1, 324.3' RT
35	BIORETENTION CELL #6	NW COR	STA 15+55.0, 552.5' RT
36	BIORETENTION CELL #6	SW COR	STA 15+50.0, 594.2' RT

	FACILITY NAME	LOCATION	
37	BIORETENTION CELL #6	NE COR	STA 15+70.3, 545.8' RT
38	BIORETENTION CELL #6	SE COR	STA 15+63.8, 600.7' RT
39	BIORETENTION CELL #7	NW COR	STA 13+49.3, 300.0' RT
40	BIORETENTION CELL #7	SW COR	STA 13+61.5, 360.0' RT
41	BIORETENTION CELL #7	NE COR	STA 13+70.0, 302.3' RT
42	BIORETENTION CELL #7	SE COR	STA 13+77.9, 362.0' RT
43	BIORETENTION CELL #7	CORNER	STA 13+79.7, 346.1' RT
44	BIORETENTION CELL #7	CORNER	STA 13+67.6, 323.8' RT
45	BIORETENTION CELL #7	CORNER	STA 13+46.9, 322.3' RT
46	BIORETENTION CELL #8	CENTER	STA 10+75.6, 107.6' RT
47	BIORETENTION CELL #9	NW COR	STA 14+09.7, 156.7' RT
48	BIORETENTION CELL #9	SW COR	STA 14+06.3, 186.5' RT

	FACILITY NAME	LOCATION	
49	BIORETENTION CELL #9	NE COR	STA 14+21.6, 158.0' RT
50	BIORETENTION CELL #9	SE COR	STA 14+18.2, 187.8' RT
51	BIORETENTION CELL #10	NW COR	STA 15+38.0, 175.9' RT
52	BIORETENTION CELL #10	SW COR	STA 15+36.3, 190.8' RT
53	BIORETENTION CELL #10	NE COR	STA 15+57.9, 178.1' RT
54	BIORETENTION CELL #10	SE COR	STA 15+56.2, 193.1' RT

STORM DRAINAGE PLAN

SCALE: 1" = 30'

YARD DRAIN LOCATIONS

	FACILITY NAME	LOCATION	RIM	DISCHARGE
1	YARD DRAIN	STA 11+58.0, 196.2' RT	57.40	BIORETENTION CELL #8
2	YARD DRAIN	STA 11+07.5, 460.0' RT	57.20	INFILTRATION TRENCH #3
3	YARD DRAIN	STA 11+51.2, 472.7' RT	57.50	INFILTRATION TRENCH #3
4	YARD DRAIN	STA 11+81.0, 475.9' RT	57.50	INFILTRATION TRENCH #3
5	YARD DRAIN	STA 12+10.9, 479.3' RT	57.50	INFILTRATION TRENCH #3
6	YARD DRAIN	STA 13+01.1, 315.8' RT	55.10	INFILTRATION TRENCH #3
7	YARD DRAIN	STA 13+25.0, 318.5' RT	55.10	INFILTRATION TRENCH #3
8	YARD DRAIN	STA 14+62.8, 286.7' RT	57.50	INFILTRATION TRENCH #2
9	YARD DRAIN	STA 16+59.3, 195.9' RT	57.20	INFILTRATION TRENCH #1
10	YARD DRAIN	STA 16+23.9, 173.8' RT	57.30	BIORETENTION CELL #10
11	YARD DRAIN	STA 15+94.1, 170.4' RT	57.30	BIORETENTION CELL #10

	FACILITY NAME	LOCATION	RIM	DISCHARGE
12	YARD DRAIN	STA 15+05.3, 160.4' RT	57.30	BIORETENTION CELL #9
13	YARD DRAIN	STA 14+75.5, 157.0' RT	57.30	BIORETENTION CELL #9
14	YARD DRAIN	STA 13+82.0, 146.3' RT	57.30	INFILTRATION TRENCH #9
15	YARD DRAIN	STA 13+52.2, 142.9' RT	57.30	INFILTRATION TRENCH #9
16	YARD DRAIN	STA 12+96.5, 156.5' RT	57.20	INFILTRATION TRENCH #6
17	YARD DRAIN	STA 11+64.9, 135.0' RT	57.40	BIORETENTION CELL #8
18	YARD DRAIN	STA 11+63.2, 149.6' RT	57.40	BIORETENTION CELL #8
19	YARD DRAIN	STA 11+61.8, 162.9' RT	57.40	BIORETENTION CELL #8
20	YARD DRAIN	STA 11+59.8, 179.8' RT	57.40	BIORETENTION CELL #8
21	YARD DRAIN	STA 11+38.6, 199.2' RT	57.40	BIORETENTION CELL #8
22	YARD DRAIN	STA 12+51.3, 481.7' RT	57.40	INFILTRATION TRENCH #3

NOTES

1. SEE SHEET C301 FOR ROOF DRAIN, FOOTING DRAIN, AND YARD DRAIN NOTES.
2. ROCK OUTFALL PADS PER 13/C302.

1" = 30'

0 15 30 60

VERTICAL DATUM
NAVD 88
ESTABLISHED BY GPS

BENCHMARK #1:
FOUND MONUMENT 3" BRASSIE WITH "X" ON 4"x4" CONC. MONUMENT INTX OF W. MAIN ST & 179th AVE SE
ELEV: 57.24'

BENCHMARK #2:
FOUND 4x4 CONC. MONUMENT W/BRASS DISK & PUNCH,DOWN 0.7' ON C/L W. MAIN ST.
ELEV: 60.40'

LEGEND

- FOUND MONUMENT IN CASE
- FOUND PLAT MONUMENT
- BASKETBALL HOOP
- GATE POST
- CATCH BASIN
- TURN ARROW
- WATER VALVE
- FINISHED FLOOR ELEVATION
- GAS VALVE
- IRRIGATION CONTROL VALVE
- LUMINAIRE
- POLE & LUMINAIRE
- YARD POLE
- CULVERT END
- TRANSFORMER PAD
- POWER VAULT
- FLAGPOLE
- STORM DRAIN MANHOLE
- SIGN POST
- SEWER MANHOLE
- CEDAR TREE
- DECIDUOUS TREE
- FIR TREE
- FRUIT TREE
- TELEPHONE PEDESTAL
- TELEPHONE GAS CANISTER
- JUNCTION BOX
- MANHOLE (UNKNOWN)
- POWER POLE W/ U.G. FEED
- POWER POLE
- GUY ANCHOR
- FIRE HYDRANT
- BOLLARD
- WATER METER
- WATER VAULT
- GROUND SHOT
- FENCE LINE
- GAS LINE
- POWER LINE
- UNDERGROUND POWER
- SEWER LINE
- STORM DRAIN LINE
- TELEPHONE LINE
- UNDERGROUND TELEPHONE
- WATER LINE
- INSPECTION PORT PER DETAIL 10/C302

Know what's below. Call before you dig.

CONFORM SET

integrus ARCHITECTURE

DAVID W. HARMSEN STATE OF WASHINGTON 33745 REGISTERED PROFESSIONAL ENGINEER 6/6/16

THIS DRAWING HAS BEEN UPDATED TO INCORPORATE CHANGES MADE TO THE BID DOCUMENTS BY ADDENDA. IT IS ISSUED FOR THE CONVENIENCE OF THE CONTRACTOR AND DOES NOT REPLACE THE CONTRACT DOCUMENTS AS ENUMERATED IN THE CONTRACT.

Monroe School District
Park Place Middle School
1408 W Main St, Monroe, WA 98272

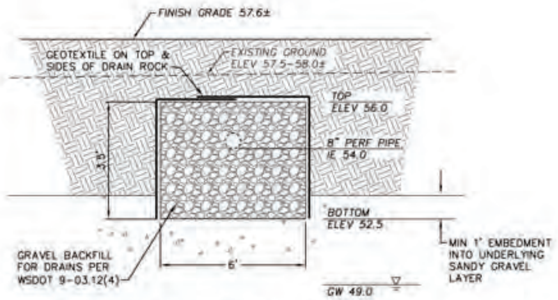
Date:	6.6.2016
Job No.:	21004.00
Drawn By:	AWK
Checked by:	DWH

Revisions

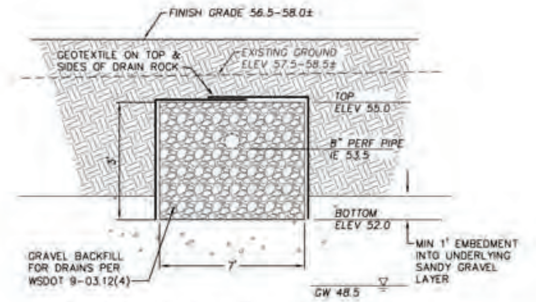
#	Date	Description
1	3-28-16	ADDENDUM #1

STORM DRAINAGE PLAN

C300



(1) INFILTRATION TRENCH #1
SCALE: NONE



(2) INFILTRATION TRENCH #2
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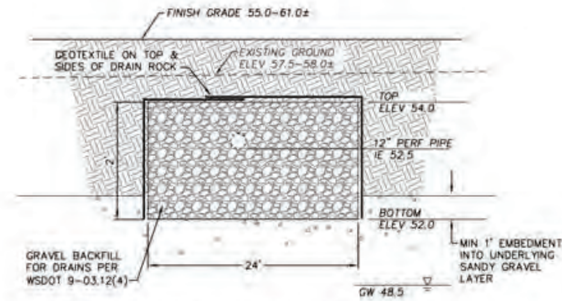
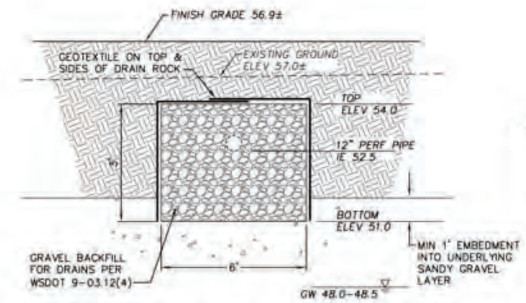


(3) INFILTRATION TRENCH #3
SCALE: NONE

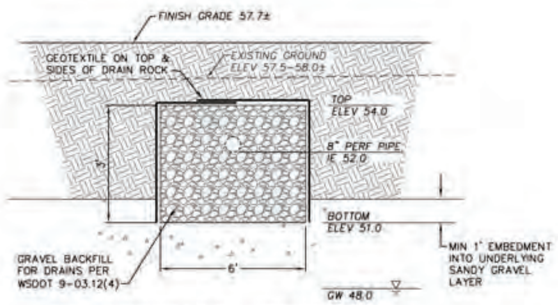


(4) INFILTRATION TRENCH #4
SCALE: NONE

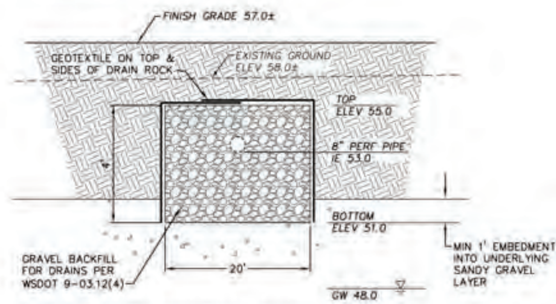
VERTICAL DATUM
NAVD 88
ESTABLISHED BY GPS

INFILTRATION NOTE:

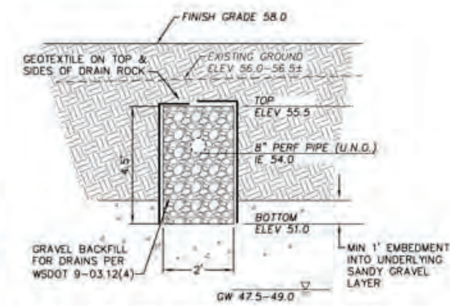
TO ENSURE PROPER FUNCTIONING OF THE BIO-RETENTION AND INFILTRATION TRENCH AREAS IT IS ABSOLUTELY NECESSARY TO AVOID COMPACTION OF THE UNDERLYING SOILS DURING CONSTRUCTION AND SEDIMENT TRANSPORT INTO THE EXCAVATION DURING CONSTRUCTION. NO HEAVY EQUIPMENT SHALL RUN ACROSS THE BASE OF THE POROUS PAVING AREAS TO PREVENT ANY DAMAGE TO THE UNDERLYING SOILS DURING CONSTRUCTION ACTIVITIES. GEOTECHNICAL ENGINEER SHALL INSPECT AND APPROVE THE SUBGRADE SOILS OF INFILTRATION TRENCHES AND THE EMBEDMENT INTO NATIVE SOILS.



(5) INFILTRATION TRENCH #5
SCALE: NONE



(6) INFILTRATION TRENCH #6
SCALE: NONE



(7) INFILTRATION TRENCHES 7A&B
SCALE: NONE

BIO-RETENTION CELL SOIL MIX SPECIFICATIONS

SHOULD HAVE A TESTED LONG TERM DESIGN INFILTRATION RATE OF 2"/HR MINIMUM.

MINERAL AGGREGATE

PERCENT FINES: A RANGE OF 2 TO 4 PERCENT PASSING THE #200 SIEVE IS IDEAL AND FINES SHOULD NOT BE ABOVE 5 PERCENT FOR A PROPER FUNCTIONING SPECIFICATION ACCORDING TO ASTM D422.

AGGREGATE GRADATION

THE AGGREGATE PORTION OF THE BSM SHOULD BE WELL-GRADED. ACCORDING TO ASTM D 2487-98 (CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (UNIFIED SOIL CLASSIFICATION SYSTEM)). WELL-GRADED SAND SHOULD HAVE THE FOLLOWING GRADATION COEFFICIENTS:

- COEFFICIENT OF UNIFORMITY (CU = D60/D10) EQUAL TO OR GREATER THAN 4, AND
- COEFFICIENT OF CURVE (CC = (D30)2/D60 X D10) GREATER THAN OR EQUAL TO 1 AND LESS THAN OR EQUAL TO 3.

TABLE 7.4.1 PROVIDES A GRADATION GUIDELINE FOR THE AGGREGATE COMPONENT OF A BIORETENTION SOIL MIX SPECIFICATION IN WESTERN WASHINGTON (HINMAN, ROBERTSON, 2007). THE SAND GRADATION BELOW IS OFTEN SUPPLIED AS A WELL- GRADED UTILITY OR SCREENED. WITH COMPOST THIS BLEND PROVIDES ENOUGH FINES FOR ADEQUATE WATER RETENTION, HYDRAULIC CONDUCTIVITY WITHIN RECOMMENDED RANGE (SEE BELOW), POLLUTANT REMOVAL CAPABILITY, AND PLANT GROWTH CHARACTERISTICS FOR MEETING DESIGN GUIDELINES AND OBJECTIVES.

TABLE 7.4.1

GENERAL GUIDELINE FOR MINERAL AGGREGATE GRADATION	
SIEVE SIZE	PERCENT PASSING
3/8"	100
#4	95–100
#10	75–90
#40	25–40
#100	4–10
#200	2–5

WHERE EXISTING SOILS MEET THE ABOVE AGGREGATE GRADATION, THOSE SOILS MAY BE AMENDED RATHER THAN IMPORTING MINERAL AGGREGATE.

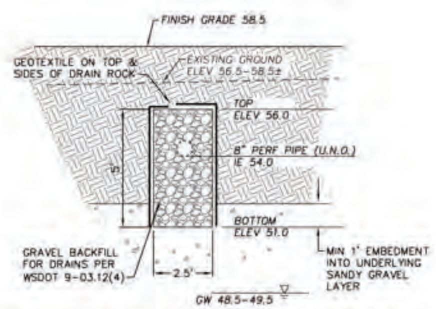
COMPOST TO AGGREGATE RATIO, ORGANIC MATTER CONTENT, CATION EXCHANGE CAPACITY

- COMPOST TO AGGREGATE RATIO: 60–65 PERCENT MINERAL AGGREGATE, 35 – 40 PERCENT COMPOST.
- ORGANIC MATTER CONTENT: 5 – 8 PERCENT BY WEIGHT.
- CATION EXCHANGE CAPACITY (CEC) MUST BE ≥ 5 MILLIEQUIVALENTS/100 G DRY SOIL NOTE: SOIL MIXES MEETING THE ABOVE SPECIFICATIONS DO NOT HAVE TO BE TESTED FOR CEC. THEY WILL READILY MEET THE MINIMUM CEC.

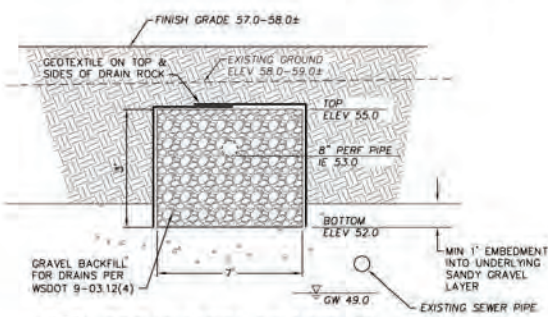
COMPOST

TO ENSURE THAT THE BSM WILL SUPPORT HEALTHY PLANT GROWTH AND ROOT DEVELOPMENT, CONTRIBUTE TO BIOFILTRATION OF POLLUTANTS, AND NOT RESTRICT INFILTRATION WHEN USED IN THE PROPORTIONS CITED HEREIN, THE FOLLOWING COMPOST STANDARDS ARE REQUIRED.

- MEETS THE DEFINITION OF "COMPOSTED MATERIALS" IN WAC 173-350-220 (INCLUDING CONTAMINANT LEVELS AND OTHER STANDARDS), AVAILABLE ONLINE AT HTTP://WWW.ECY.WA.GOV/PROGRAMS/SWFA/ORGANICS/SOIL.HTML
- PRODUCED AT A COMPOSTING FACILITY PERMITTED BY THE WA DEPARTMENT OF ECOLOGY. A CURRENT LIST OF PERMITTED FACILITIES IS AVAILABLE AT HTTP://WWW.ECY.WA.GOV/PROGRAMS/SWFA/COMPOST/
- THE COMPOST PRODUCT MUST ORIGINATE A MINIMUM OF 65 PERCENT BY VOLUME FROM RECYCLED PLANT WASTE AS DEFINED IN WAC 173-350-100 AS "TYPE I FEEDSTOCKS." A MAXIMUM OF 35 PERCENT BY VOLUME OF OTHER APPROVED ORGANIC WASTE AS DEFINED IN WAC 173-350-100 AS "TYPE III", INCLUDING POSTCONSUMER FOOD WASTE, BUT NOT INCLUDING BIOSOLIDS,
- MAY BE SUBSTITUTED FOR RECYCLED PLANT WASTE. TYPE II AND IV FEEDSTOCKS SHALL NOT BE USED FOR THE COMPOST GOING INTO BIORETENTION FACILITIES OR RAIN GARDENS.
- STABLE (LOW OXYGEN USE AND CO2 GENERATION) AND MATURE (CAPABLE OF SUPPORTING PLANT GROWTH) BY TESTS SHOWN BELOW. THIS IS CRITICAL TO PLANT SUCCESS IN A BIORETENTION SOIL MIXES.
- MOISTURE CONTENT RANGE: NO VISIBLE FREE WATER OR DUST PRODUCED WHEN HANDLING THE MATERIAL.
- TESTED IN ACCORDANCE WITH THE U.S. COMPOSTING COUNCIL "TESTING METHODS FOR THE EXAMINATION OF COMPOST AND COMPOSTING" (TMECC), AS ESTABLISHED IN THE COMPOSTING COUNCIL'S "SEAL OF TESTING ASSURANCE" (STA) PROGRAM. MOST WASHINGTON COMPOST FACILITIES NOW USE THESE TESTS.
- SCREENED TO THE SIZE GRADATIONS FOR FINE COMPOST UNDER TMECC TEST METHOD 02.02-B (GRADATIONS ARE SHOWN IN THE SPECIFICATION IN AN APPENDIX OF THE LOW IMPACT DEVELOPMENT TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND)
- PH BETWEEN 6.0 AND 8.5 (TMECC 04.11-A). IF THE PH FALLS OUTSIDE OF THE ACCEPTABLE RANGE, IT MAY BE MODIFIED WITH LIME TO INCREASE THE PH OR IRON SULFATE PLUS SULFUR TO LOWER THE PH. THE LIME OR IRON SULFATE MUST BE MIXED UNIFORMLY INTO THE SOIL PRIOR TO USE IN THE BIORETENTION AREA.
- MANUFACTURED INERT CONTENT LESS THAT 1% BY WEIGHT (TMECC 03.08-A)
- MINIMUM ORGANIC MATTER CONTENT OF 40% (TMECC 05.07-A)
- SOLUBLE SALT CONTENT LESS THAN 4.0 MMHOS/CM (TMECC 04.10-A)
- MATURITY GREATER THAN 80% (TMECC 05.05-A "GERMINATION AND VIGOR")
- STABILITY OF 7 OR BELOW (TMECC 05.08-B "CARBON DIOXIDE EVOLUTION RATE")
- CARBON TO NITROGEN RATIO (TMECC 04.01 "TOTAL CARBON" AND 04.02D "TOTAL KJELDAHL NITROGEN") OF LESS THAN 25:1. THE C:N RATIO MAY BE UP TO 35:1 FOR PLANTINGS COMPOSED ENTIRELY OF PUGET SOUND LOWLAND NATIVE SPECIES AND UP TO 40:1 FOR COARSE COMPOST TO BE USED AS A SURFACE MULCH (NOT IN A SOIL MIX).



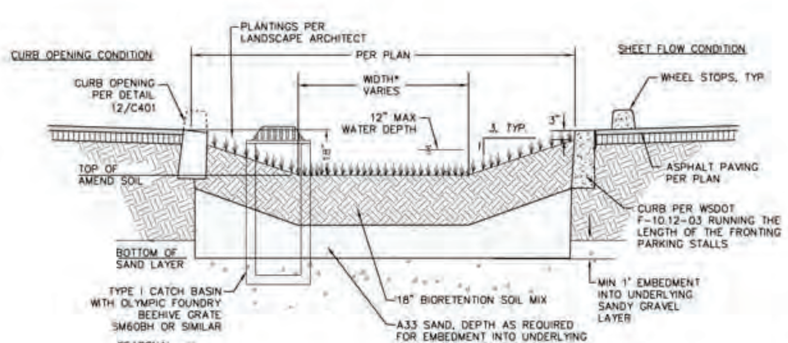
(8) INFILTRATION TRENCHES 8A&B
SCALE: NONE



(9) INFILTRATION TRENCH #9
SCALE: NONE

BIO-RETENTION CELL CONSTRUCTION NOTES

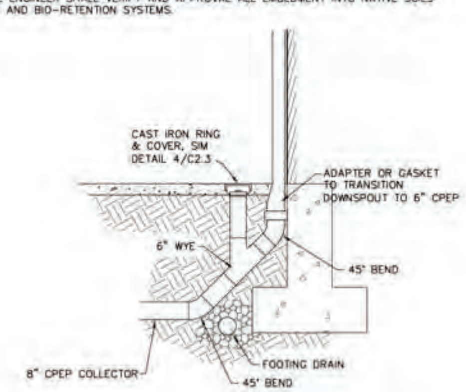
1. THE BIO-RETENTION CELL SHALL BE OVEREXCAVATED TO ELEVATIONS SHOWN ON GRADING SECTIONS AND FILLED WITH 18" DEPTH OF COMPOST AMENDED SOIL.
2. MINIMUM COMPACTION OF SIDEWALLS AND BASE OF BIO-RETENTION CELL IS ESSENTIAL. KEEP ALL MACHINERY OUTSIDE OF CELL AREA UNDER DIRECTION OF GEOTECHNICAL ENGINEER.
3. SUB-GRADES SHALL BE SCARIFIED, CLEARED OF ALL WEEDS, ROCKS, AND DEBRIS, AND ROUGH GRADED. TOPSOIL SHALL BE ROTOTILLED INTO SUB-GRADE TO A MIN DEPTH OF 8".
4. IF COMPACTION OCCURS IN BOTTOM OF FACILITY DURING EXCAVATION, RIP A MINIMUM OF 12" AND TILL 2 TO 3 INCHES OF AND INTO BASE BEFORE BACKFILLING WITH COMPOST AMENDED SOILS.
5. EXCAVATION FOR THE BIO-RETENTION CELL WILL NOT BE ALLOWED DURING WET WEATHER OR SATURATED SOIL CONDITIONS.
6. SOIL MIXING SHALL OCCUR OUTSIDE/ADJACENT TO THE CELL AREA AND THEN PLACED IN BOTTOM OF CELL.
7. ON-SITE SOIL MIXING SHALL NOT BE PERFORMED IF SOILS ARE SATURATED.
8. FINAL GRADING TO BE ACCOMPLISHED BY HAND.
9. PLANT BOTTOM AND SIDES OF CELL PER LANDSCAPE PLAN.
10. TO PROTECT THE BIORETENTION CELL FROM SEDIMENT LOADING DURING CONSTRUCTION THE INSTALLATION OF THE BIO-RETENTION SOIL AND PLANTINGS SHALL NOT OCCUR UNTIL THE TRIBUTARY AREA DRAINING TO THE CELL HAS BEEN STABILIZED.
DO NOT ROUTE VEHICULAR TRAFFIC THROUGH BIO-RETENTION AREAS AFTER SUBGRADE IS ESTABLISHED.
11. GEOTECHNICAL ENGINEER SHALL VERIFY AND APPROVAL ALL EMBEDMENT INTO NATIVE SOILS FOR INFILTRATION AND BIO-RETENTION SYSTEMS.



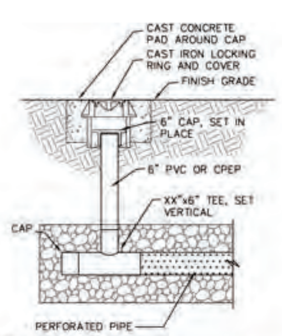
BIORETENTION CELL #	BOTTOM AREA	WIDTH	TOP OF AMEND SOIL	BOTTOM OF SAND LAYER	SEASONAL HIGH GW
1	2,430	18'	53.0	50.0	47.5
2	1,450	10'	55.0	51.0	48.5
3	720	6'	56.0	52.0	48.0
4	840	6'	56.0	53.0	48.5
5*	560	N/A	55.4	54.0	49.0
6	684	N/A	54.9	53.0	49.0
7	1080	N/A	53.5	52.0	48.5
8	450	N/A	53.8	50.0–51.0	47.5
9	360	12'	56.0	53.0	48.5
10	300	15'	56.0	52.0	48.5

* PARKING ALTERNATE C-1: SEE DETAIL 1/C400 FOR INCREASING SIZE OF BIORETENTION CELL #5

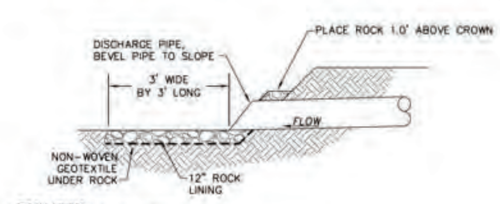
(11) TYPICAL BIORETENTION CELL DETAIL
SCALE: NONE



(12) DOWNSPOUT CONNECTION & CLEANOUT DETAIL
SCALE: NONE



(10) INSPECTION PORT DETAIL
SCALE: NONE



ROCK LINING
QUARRY SPALLS PER WSDOT 9-13.6

(13) CULVERT OUTFALL PAD DETAIL
SCALE: NONE

integrus ARCHITECTURE

DAVID W. HARMSEN, STATE OF WASHINGTON, 33745, REGISTERED PROFESSIONAL ENGINEER, 6/6/16

THIS DRAWING HAS BEEN UPDATED TO INCORPORATE CHANGES MADE TO THE BID DOCUMENTS BY ADDENDA. IT IS ISSUED FOR THE CONVENIENCE OF THE CONTRACTOR AND DOES NOT REPLACE THE CONTRACT DOCUMENTS AS ENUMERATED IN THE CONTRACT.

Monroe School District
Park Place Middle School
1408 W Main St, Monroe, WA 98272

Date:	6.6.2016
Job No.:	21004.00
Drawn By:	AWK
Checked by:	DWH

Revisions

#	Date	Description
1	3-28-16	ADDENDUM #1

STORM DRAINAGE DETAILS

C302

811 Know what's below. Call before you dig.

CONFORM SET

associated earth sciences incorporated

911 Fifth Avenue
Kirkland, Washington 98033
Phone: 425-827-7701
Fax: 425- 827-5424
www.aesgeo.com

FIELD REPORT

Date	Project Name		Project No.
6/12/2017	Park Place Middle School		150324E011
Location		**Municipality**	**Weather**
1408 West Main Street		Monroe	Overcast
Permit No.	**DPD No.**		**Report No.**
			88
Engineer/Architect			
Integrus Architecture			
Client/Owner			
Monroe Public Schools			
General Contractor/Superintendent			
Cornerstone/Eric Scott			
Grading Contractor/Superintendent			
Continental Dirt/Tim			

TO: Monroe Public Schools/Cornerstone
200 East Fremont Street
Monroe, WA 98272

ATTN: John Mannix

AS REQUESTED BY: Client

THE FOLLOWING WAS NOTED:

Associated Earth Sciences, Inc. (AESI) was on site from 10:25 to 14:45 to monitor the construction/widening of Bioretention Cell #6. The cell location and details are shown on sheets C300 (Storm Drainage Plan) and C302 (Storm Drainage Details) of the site plan set, prepared by Integrus Architecture, dated June 6, 2016 (Figures 1 and 2). Bioretention Cell #6 had previously been partially excavated, but the original excavation did not cover the full footprint area as designed. The original excavation was approximately 5' deep in the center and had a flat base about 8' wide in the east-west direction. The purpose of the day's work was to widen the cell to the design length and width, shape the sidewalls, and clear the bottom of the excavation in preparation for installation of C33 sand and bioretention soil as shown on the plan detail. Continental Dirt (Tim) provided survey control for the location and base elevation of the cell. The surveyed ground surface elevation was 56.7' (feet) at the northwest corner of the cell, 57.8' at the southwest corner, and 59.0' at the southeast corner.

Bioretention Cell Construction Summary

Bioretention Cell #6 was widened and shaped using a larger track-mounted excavator (Komatsu PC200 C-135) and a smaller track-mounted excavator (CAT 304E2 CR). The excavated material was stockpiled at the north end of the cell. The cell had a flat base at an elevation of 52.5', with sidewalls sloping up to the ground surface. An area covering the northern ~5' of the cell base was lowered by an additional 0.5' to remove a lens of silty sand (see geologic summary and Photo 2 below), resulting in a base elevation of 52.0' at the north end of the cell. The elevation of the cell base was checked throughout the excavation using a laser survey level and measuring rod. The flat base of the cell was approximately 8.5' wide and 45' long. The overall cell footprint was approximately 24' wide (east-west), 42' long on the west side, and 60' long on the east side. The cell was designed to have 3:1 slopes, but the actual slopes were steeper due to the cell depth, existing base width, and available lateral area. Slopes ranged from approximately 23° to 30 ° on the west side, 16° to 30° on the south side, 21° to 35° on the east side, and 27° to 42° on the north side. The dimensions of the cell were consistent with the plan details shown on sheet C302 (Figure 2).

Geologic Summary

The material exposed by the cell generally consisted of overbank deposits (as described below) overlying native sand and gravel. The flat central part of the cell was dug approximately 1' into the native sand and gravel, as specified on the plan detail (Figure 2). Geologic samples were collected from the base of the cell at the locations indicated on Figure 1 and transported to AESI for further visual classification and testing, as necessary. The contact between the overbank deposits and alluvial deposits was not sharply defined in the sidewalls.

Overbank deposits: Medium dense moist brown SILT (ML), trace gravel, trace root fragments, roots in place observed while excavating the slope on the southeast corner of the cell

Copies To: ____________ Field Rep: Katherine Beeler, L.G.

Date Mailed: JUL 07 2017 Principal / PM: Kurt Merriman, P.E.

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

To:	Monroe PS/Cornerstone	Project Name:	Park Place Middle School
Date:	6/12/2017	Project No.:	150324E011
Permit No.		DPD No.	

Sample 1: Medium dense moist grayish brown fine to medium sandy GRAVEL (GW), trace coarse sand, trace silt, trace cobble (Alluvial deposits)

Sample 2: Medium dense moist grayish brown fine to medium very sandy GRAVEL (GW), trace coarse sand, trace silt, trace cobble (Alluvial deposits)

Sample 3: Medium dense moist grayish brown fine to medium sandy GRAVEL (GW), trace coarse sand, some silt, trace cobble, iron oxide staining (Alluvial deposits). Small area of medium dense moist gray fine to medium SAND (SW) at the edge of the flat base west of the Sample 3 location.

An area of silty sand was encountered at the north end of the cell base. The cell was excavated an additional ~0.5' to remove the material, described here:
Medium dense moist grayish brown silty fine to medium SAND (SM) to sandy SILT (ML), mottled with iron oxide staining in some areas

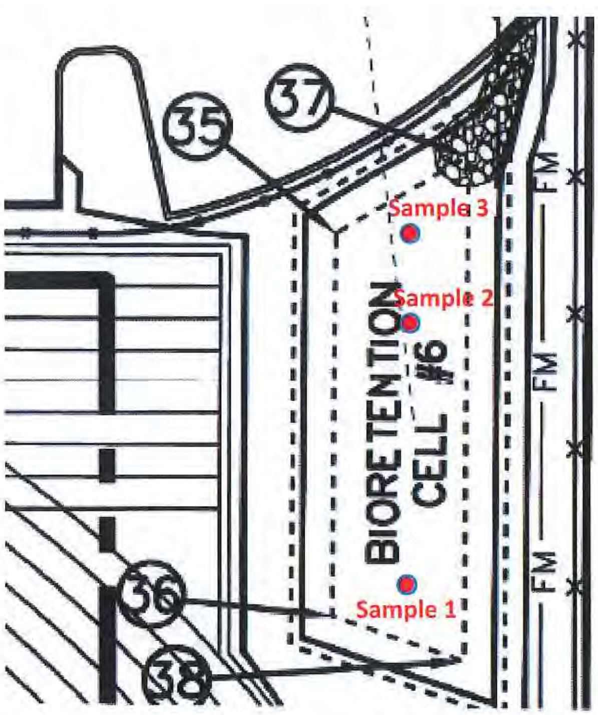
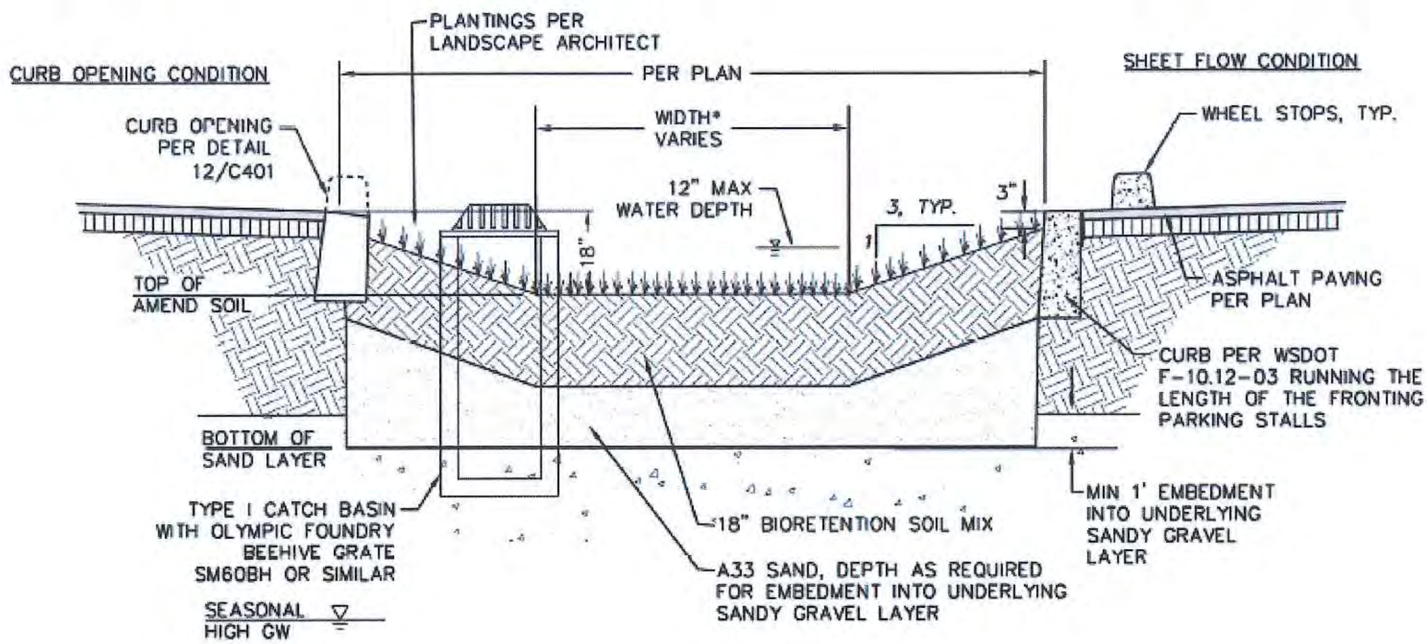


Figure 1: Site plan and sample locations for Bioretention Cell #6, modified from sheet C300, Integrus Architecture (2016).

Copies To:		Field Rep:	Katherine Beeler, L.G.
Date Mailed:		Principal / PM:	Kurt Merriman, P.E.

AESI FIELD REPORT

To: Monroe PS/Cornerstone
Date: 6/12/2017
Permit No.
Project Name: Park Place Middle School
Project No.: 150324E011
DPD No.



BIORETENTION CELL #	BOTTOM AREA	WIDTH	TOP OF AMEND SOIL	BOTTOM OF SAND LAYER	SEASONAL HIGH GW
1	2,430	18'	53.0	50.0	47.5
2	1,450	10'	55.0	51.0	48.5
3	720	6'	56.0	52.0	48.0
4	840	6'	56.0	53.0	48.5
5*	560	N/A	55.4	54.0	49.0
6	684	N/A	54.9	53.0	49.0
7	1080	N/A	53.5	52.0	48.5
8	450	N/A	53.8	50.0–51.0	47.5
9	360	12'	56.0	53.0	48.5
10	300	15'	56.0	52.0	48.5

* PARKING ALTERNATE C-1:
SEE DETAIL 1/C400 FOR INCREASING SIZE OF BIORETENTION CELL #5

11 *TYPICAL BIORETENTION CELL DETAIL*

SCALE: *NONE*

Figure 2: Plan detail for bioretention cells, from sheet C302, Integrus Architecture (2016).

Copies To:
Date Mailed:
Field Rep: Katherine Beeler, L.G.
Principal / PM: Kurt Merriman, P.E.

AESI FIELD REPORT

To:	Monroe PS/Cornerstone	Project Name:	Park Place Middle School
Date:	6/12/2017	Project No.:	150324E011
Permit No.		DPD No.	

Photo 1 (left)**:** Excavation of Bioretention Cell #6 in progress.

Photo 2 (right)**:** Area excavated an additional ~0.5' at the north end of the cell.

Photo 3 (left)**:** Bioretention Cell #6 viewed from the north.

Photo 4 (right)**:** Bioretention Cell #6 viewed from the south.

Copies To:		Field Rep:	Katherine Beeler, L.G.
Date Mailed:		Principal / PM:	Kurt Merriman, P.E.

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

FIELD REPORT

associated earth sciences incorporated

911 Fifth Avenue
Kirkland, Washington 98033
Phone: 425-827-7701
Fax: 425- 827-5424
www.aesgeo.com

Date	Project Name		Project No.
6/13/17	Park Place Middle School		150324E011
Location		Municipality	Weather
1408 West Main Street		Monroe	Rain, 50s
Permit No.	DPD No.		Report No.
			89
Engineer/Architect Harmsen and Associates/ Integrus Architecture			
Client/Owner Monroe School District			
General Contractor/Superintendent Cornerstone/Eric Scott			
Grading Contractor/Superintendent Continental Dirt/Tim			

TO: Monroe Public Schools / Cornerstone
200 East Fremont Street
Monroe, WA 98272

ATTN: John Mannix

AS REQUESTED BY: Client

THE FOLLOWING WAS NOTED:
AESI was on site at the Park Place Middle School site part time to observed the excavated condition of bioretention cell #6 (BR6), following excavation activities on 6/12/2017 (FR# 88).

We arrived on the site at 06:40 and observed that although it rained overnight, there was no inflow into the pond and the surficial sediments appeared damp but not saturated. We observed that in general sand and gravel were exposed on the bottom of BR6, however, an area near the north end of BR6 was visibly silty – described as a tan/light brown to gray fine sandy silt/silty fine sand.

We discussed this with Tim (Continental Dirt), who said he could work on it immediately. We observed the removal of approximately 6 inches of silty material, which graded into gray, fine to medium sand for a few inches, which was underlain by sandy gravel/gravelly sand, trace to some silt. In total, an area about 6 feet wide (east to west) by 5 feet long (north to south) by 5 to 6 inches deep was removed and placed in the existing stockpile immediately north of BR6. The photos below show the conditions before and after the excavation.


Left: Looking south at bioretention cell #6 subgrade. Right: Close-up of ridge of in-place silty material.

Copies To:
Date Mailed: JUL 07 2017

Field Rep: Stan Thompson, L.G., L.Hg.
Principal / PM: Kurt D. Merriman P.E.

(This document is considered a draft until signed and approved by an AESI Principal or Project Manager)


Left: BR6 viewing west; removal of silty sediments under way. Right: finished product after silty sediment removal.

Additional observations:

We observed the following constructed bioretention cells: BR9, BR10, BR5.

Bioretention Cell #9

BR9 has been receiving roof water since it was installed earlier this year. Although the contractor placed a row of sand bags around BR9 to prevent surface water flow into the facility, there are several breaches of the sand bag line, which have caused blow-outs of the bioretention mix, and silty sand plumes on the surface of the bioretention mix out into the facility. See photos.

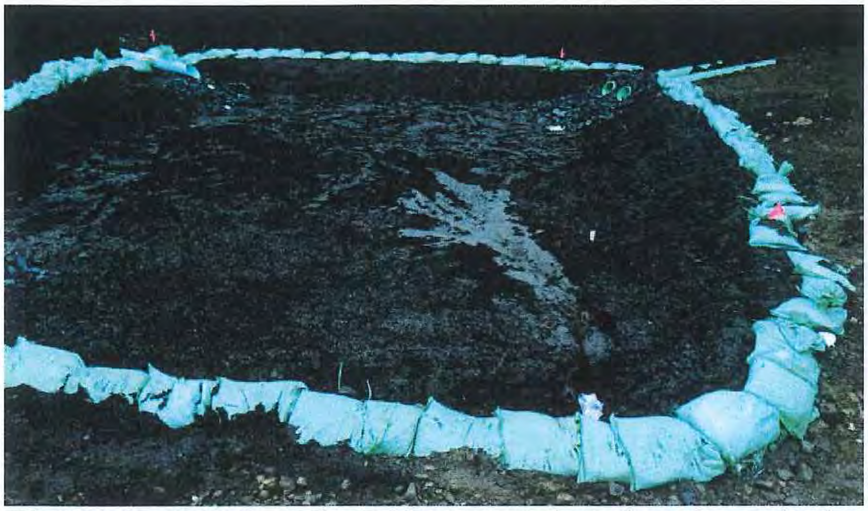

Left: BR9 showing native material on the bioretention mix surface. Right: Close up of a blow out and the resultant plume/delta on the bioretention mix.

Copies To:		Field Rep:	Stan Thompson, L.G., L.Hg.
Date Mailed:		Principal/PM:	Kurt Merriman P.E.

(This document is considered a draft until signed and approved by an AESI Principal or Project Manager)

Bioretention Cell #10

The surface of BR#10 is in approximately the same condition as that of BR9. There are a few breaches of the sand bag line where surface soils have flowed out with surface water onto the surface of the bioretention mix. See photos.



Left: BR10 showing surface soils which have migrated onto the surface. Right: Close-up of breach in the northwest corner of BR10.

Bioretention Cell #5

BR5 has seen fewer storm events than BR9 or BR10. The surface appears in good shape, with only minor detritus (plastic water bottles, etc.) on the surface. See photo.

BR5, viewing north.

associated earth sciences incorporated

FIELD REPORT

911 Fifth Avenue
Kirkland, Washington 98033
Phone: 425-827-7701
Fax: 425- 827-5424
www.aesgeo.com

Date	Project Name		Project No.
6/16/17	Park Place Middle School		150324E011
Location		Municipality	Weather
1408 West Main Street		Monroe	Overcast, 50s
Permit No.	DPD No.		Report No.
			93
Engineer/Architect Harmsen and Associates/ Integrus Architecture			
Client/Owner Monroe School District			
General Contractor/Superintendent Cornerstone/Eric Scott			
Grading Contractor/Superintendent Continental Dirt/Tim			

TO: **Monroe Public Schools / Cornerstone**
200 East Fremont Street
Monroe, WA 98272

ATTN: **John Mannix**

AS REQUESTED BY: **Client**

THE FOLLOWING WAS NOTED:
AESI was on site at the Park Place Middle School site part time to observed the completed condition of bioretention cell #6 (BR6), following the installation of the C33 sand and bioretention soil, and to observe the other completed bioretention cells (BR5, BR9 and BR10).

Bioretention Cell #6
The top of the berm around BR6 is approximately 4 to 6 inches above surrounding grade. Additionally, it appears that there is no water directed toward BR6 at this time. The irrigation has been installed within BR6. Photos show the current condition.

Copies To: ______
Date Mailed: JUL 07 2017

Field Rep: Stan Thompson, L.G., L.Hg.
Principal / PM: Kurt D. Merriman P.E.

(This document is considered a draft until signed and approved by an AESI Principal or Project Manager)

associated earth sciences incorporated

FIELD REPORT

911 Fifth Avenue
Kirkland, Washington 98033
Phone: 425-827-7701
Fax: 425- 827-5424
www.aesgeo.com

Date	Project Name			Project No. /Task
6/29/2017	Park Place Middle School			150324011
Location			Municipality	Weather
1408 West Main Street			Monroe	Sun 70's
Permit No.		SDCI Permit No.		Report No.
				95
Engineer/Architect				
Harmsen and Associates/ Integrus Architecture				
Client/Owner				
Monroe Public Schools				
General Contractor/Superintendent				
Cornerstone/ Eric Scott				
Grading Contractor/Superintendent				
Continental/ Tim				

TO: Monroe Public School
200 East Freemont Street
Monroe, WA 98272

ATTN: John Mannix

AS REQUESTED BY: Client

THE FOLLOWING WAS NOTED:

Storm:

AESI was on site today to examine and photograph the finished bio retention cells and connecting storm systems. Bio retention cells 5, 6, 9, and 10 were examined and photographed. The connecting storm systems to infiltration trenches 1 and 2 were also examined no area drains are connected to 1 and 2. All area drains have been plugged and the catch basin east of cell 5 has also been plugged. The baseball softball field infiltration trench at the north and south ends were also photographed. The photo of the northwest baseball softball field infiltration trench shows exposed drain rock. The earthwork contractor notes: Filter fabric will be placed over the drain rock and anchored to protect the exposed drain rock this afternoon.

Portion of cell # 7 used for temporary storm retention

Plugged area drain to infiltration trench #1

Copies To:

Field Rep: Jon Stevenson

Date Mailed: JUL 07 2017

Principal / PM: Kurt D Merriman P.E.

v. 5.17

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

AESI FIELD REPORT

To:		Project Name:	Park Place MS
Date:	6/29/2017	Project No.:	150324E011
Permit No.		SDCI Permit	

Plugged area drain to cell # 9

Riling at cell # 9

Erosion at cell # 9

Overall cell # 9

Copies To:		Field Rep:	Jon Stevenson
Date Mailed:		Principal / PM:	Kurt D Merriman P.E.

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

AESI FIELD REPORT

To:		Project Name:	Park Place MS
Date:	6/29/2017	Project No.:	150324E011
Permit No.		SDCI Permit	


SW ballfield infiltration trench


NW ballfield infiltration trench to be covered today


Overall cell # 5


Plugged catch basin to cell # 5


Area drain plugged to cell # 10


Overall cell # 10

Copies To:		Field Rep:	Jon Stevenson
Date Mailed:		Principal / PM:	Kurt D Merriman P.E.

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

AESI FIELD REPORT

To:		Project Name:	Park Place MS
Date:	6/29/2017	Project No.:	150324E011
Permit No.		SDCI Permit	

Entry point cell 6 not complete

Irrigation trench to be backfilled cell # 6

Copies To:		Field Rep:	Jon Stevenson
Date Mailed:		Principal / PM:	Kurt D Merriman P.E.

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

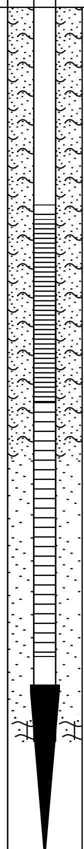
Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	MPP-HA-1/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Monroe, WA
Elevation (Top of Well Casing)	98.8 (Project Datum)	Surface Elevation (ft)	96.2 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/10/18,10/10/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft) | Water Level | WELL CONSTRUCTION | S T | Blows/ 6" | Graphic Symbol | DESCRIPTION



WELL CONSTRUCTION

Shredded wood 0 to 0.1 feet

Threaded steel pipe
1.25-inch I.D. -2.6 to 0.7 feet

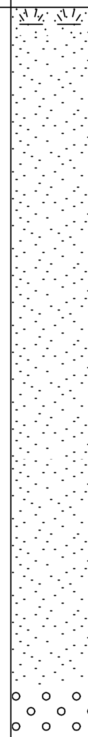
Tape over well point screen
0.7 to 1.4 feet

Bioretention soil mix 0.1 to
1.6 feet

Stainless steel jacket over
stainless steel #60 gauze,
welded to perforated steel
pipe 1.4 to 2.3 feet
Sand fill 1.6 to 2.5 feet

Coarse grained alluvium 2.5
to 2.6 feet
Threaded steel pipe
1.25-inch I.D. and drive point
2.3 to 3 feet

Note: ~4 inches of "dead
space" below bottom of
perforated openings and total
inside depth. Total inside
depth = 5.1 feet.



DESCRIPTION

Shredded Wood

Bioretention Soil Mix

Loose, moist, dark brown, medium SAND, trace gravel, trace silt; organic rich; massive (SP).

Sand Fill

Loose, moist, brown, fine to medium SAND, trace silt; massive (SP).

At 2.5 feet: Coarse Alluvium - Medium dense, brown, sandy GRAVEL, trace silt (GP). No stratification observed in exploration.

Boring terminated at 2.6 feet
Well completed at 2.6 feet on 10/10/18.
Steel drive point placed in borehole and hand driven with slide hammer to depth of 2.6 feet.

5

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture	**Logged by:** ADY
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()	**Approved by:** JHS
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)	

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	MPP-HA-2	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Monroe, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A
Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/10/18,10/10/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Shredded Wood					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace gravel, trace silt; organic rich; massive (SP).					
				Sand Fill Loose, moist, brown, fine to medium SAND, trace silt; massive (SP).					
				At 1.8 feet: Coarse Alluvium - Medium dense, brown, sandy GRAVEL, trace silt (GP). No stratification observed in exploration.					
				Bottom of exploration boring at 1.9 feet.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	MPP-HA-3	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Monroe, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/10/18,10/10/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Shredded Wood					
				Bioretention Soil Mix Loose, moist, dark brown, medium SAND, trace gravel, trace silt; organic rich; massive (SP).					
		S-1							
				Sand Fill Loose, moist, brown, fine to medium SAND, trace silt; massive (SP).					
				Bottom of exploration boring at 2 feet.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

a s s o c i a t e d
earth sciences
i n c o r p o r a t e d

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/10/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- MPP			

Moisture Content

Sample ID	HA-1/WP (0.1'-0.5')	HA-2 (0.1'-0.5')
Wet Weight + Pan	872.09	1019.77
Dry Weight + Pan	756.80	898.62
Weight of Pan	452.01	537.33
Weight of Moisture	115.29	121.15
Dry Weight of Soil	304.79	361.29
% Moisture	27.4	25.1

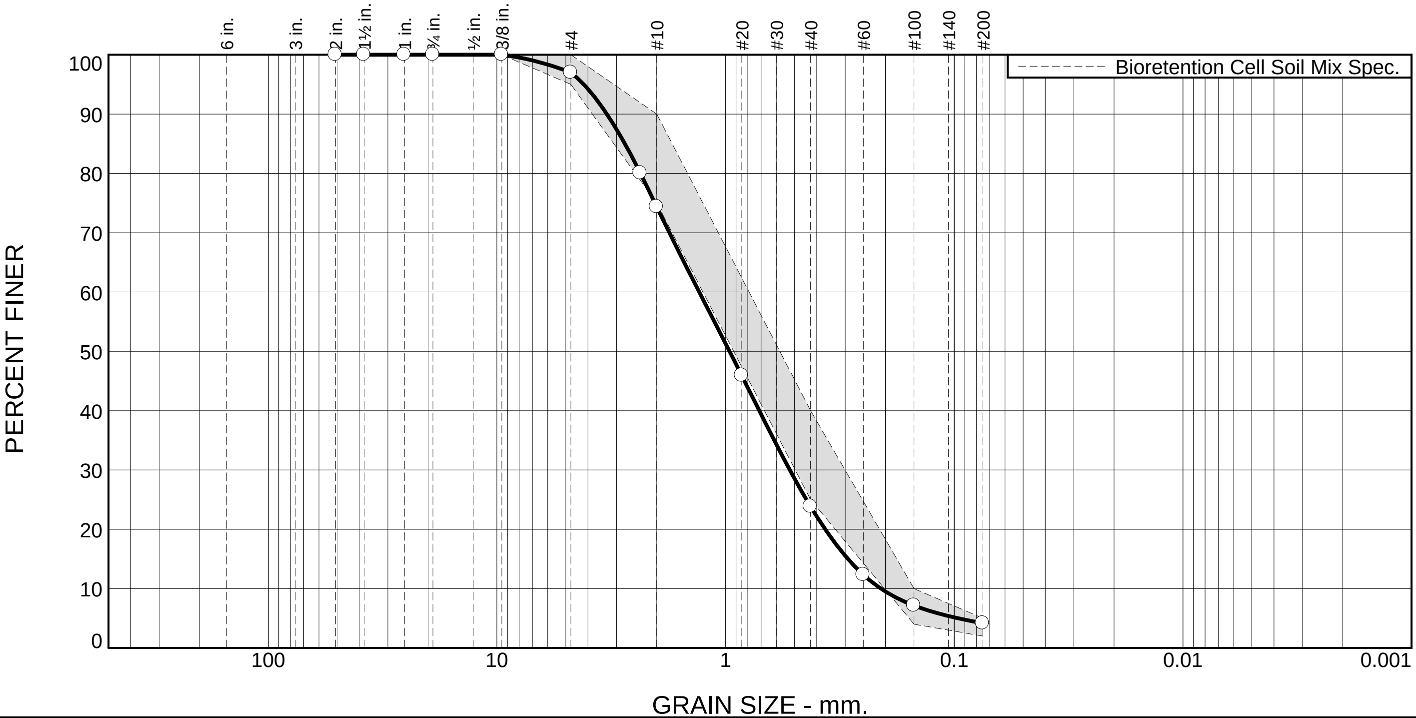
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	568.60	610.72
Dry Soil After Burn + Pan	547.28	589.02
Weight of Pan	357.89	391.91
Wt. Loss Due to Ignition	21.32	21.70
Actual Wt. Of Soil After Burr	189.39	197.11
% Organics	10.1	9.9

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.0	22.7	50.5	19.6	4.2	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.0	95.0 - 100.0	
#8	80.0		
#10	74.3	75.0 - 90.0	X
#20	45.9		
#40	23.8	25.0 - 40.0	X
#60	12.3		
#100	7.1	4.0 - 10.0	
#200	4.2	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= SW **AASHTO (M 145)=**

Coefficients

D_{90}= 3.3054 D_{85}= 2.7577 D_{60}= 1.3045
D_{50}= 0.9616 D_{30}= 0.5241 D_{15}= 0.2918
D_{10}= 0.2095 C_u= 6.23 C_c= 1.01

Remarks

Collected by: ADY
Bioretention soil mix burned first per ASTM D2974 then sieved.

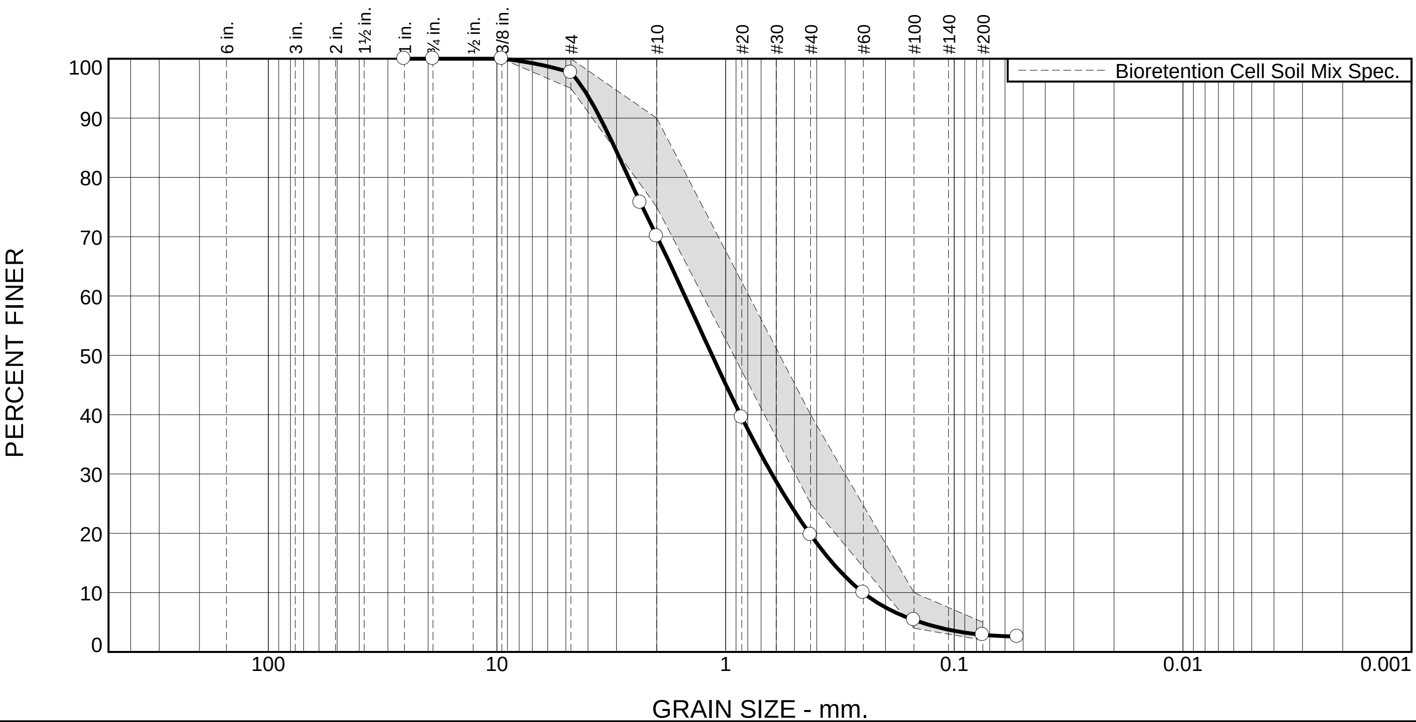
Date Received: **Date Tested:**
Tested By: BN
Checked By: JHS
Title:

Source of Sample: (MPP) Marysville- Park Place Middle School **Depth:** 0.1'-0.5' **Date Sampled:**
Sample Number: HA-1/ WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.3	27.6	50.4	16.8	2.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.7	95.0 - 100.0	
#8	75.8		
#10	70.1	75.0 - 90.0	X
#20	39.5		
#40	19.7	25.0 - 40.0	X
#60	10.0		
#100	5.4	4.0 - 10.0	
#200	2.9	2.0 - 5.0	
#270	2.6		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SW **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.5333 D_{85}= 3.0525 D_{60}= 1.5063
D_{50}= 1.1453 D_{30}= 0.6277 D_{15}= 0.3402
D_{10}= 0.2506 C_u= 6.01 C_c= 1.04

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/12/2018 **Date Tested:** 12/12/2018

Tested By: BN

Checked By: JHS

Title:

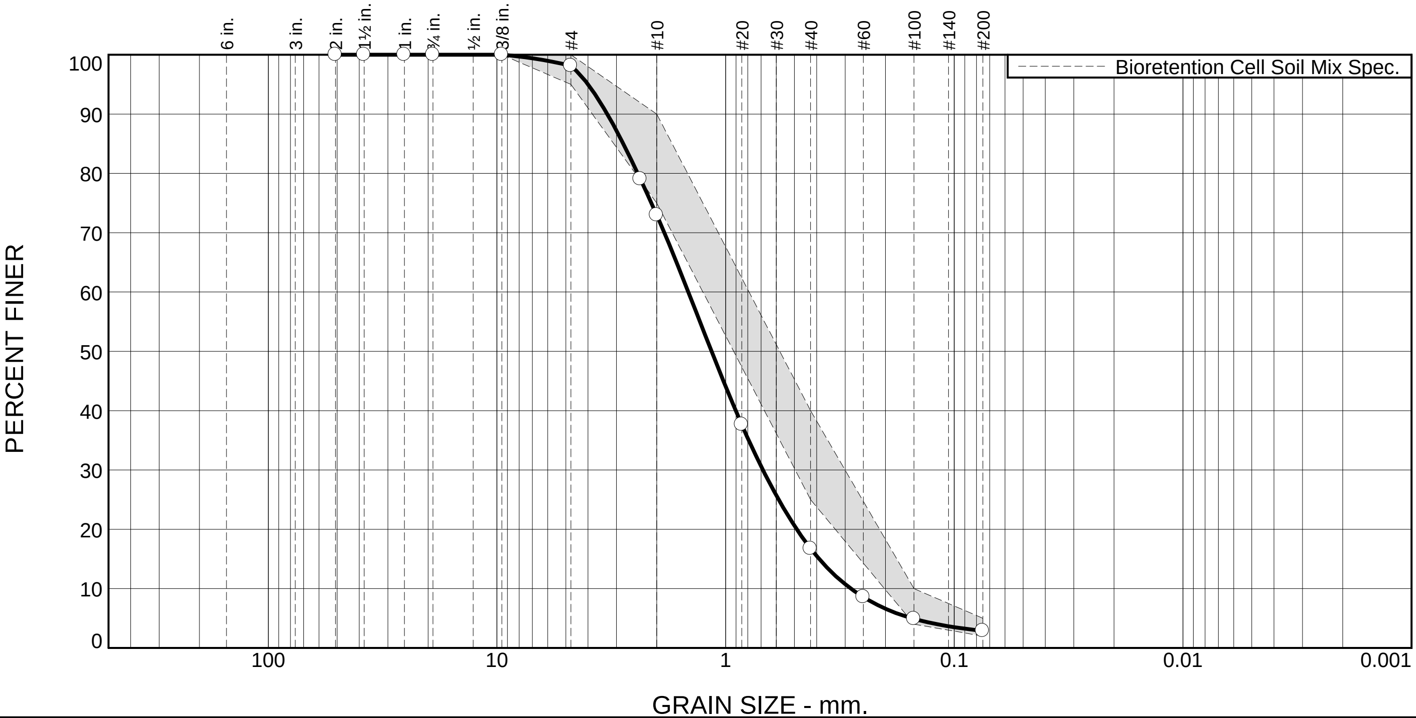
Source of Sample: (MPP) Marysville- Park Place Middle School **Depth:** 0.1'-0.5' **Date Sampled:** 10/10/2018
Sample Number: HA-2

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.9	25.1	56.2	13.9	2.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	98.1	95.0 - 100.0	
#8	79.1		
#10	73.0	75.0 - 90.0	X
#20	37.6		
#40	16.8	25.0 - 40.0	X
#60	8.6		
#100	4.9	4.0 - 10.0	
#200	2.9	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.2911 D_{85}= 2.8037 D_{60}= 1.4556
D_{50}= 1.1517 D_{30}= 0.6868 D_{15}= 0.3899
D_{10}= 0.2832 C_u= 5.14 C_c= 1.14

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: **Date Tested:**

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (MPP) Marysville- Park Place Middle School **Depth:** 1'-1.6' **Date Sampled:**
Sample Number: HA-3

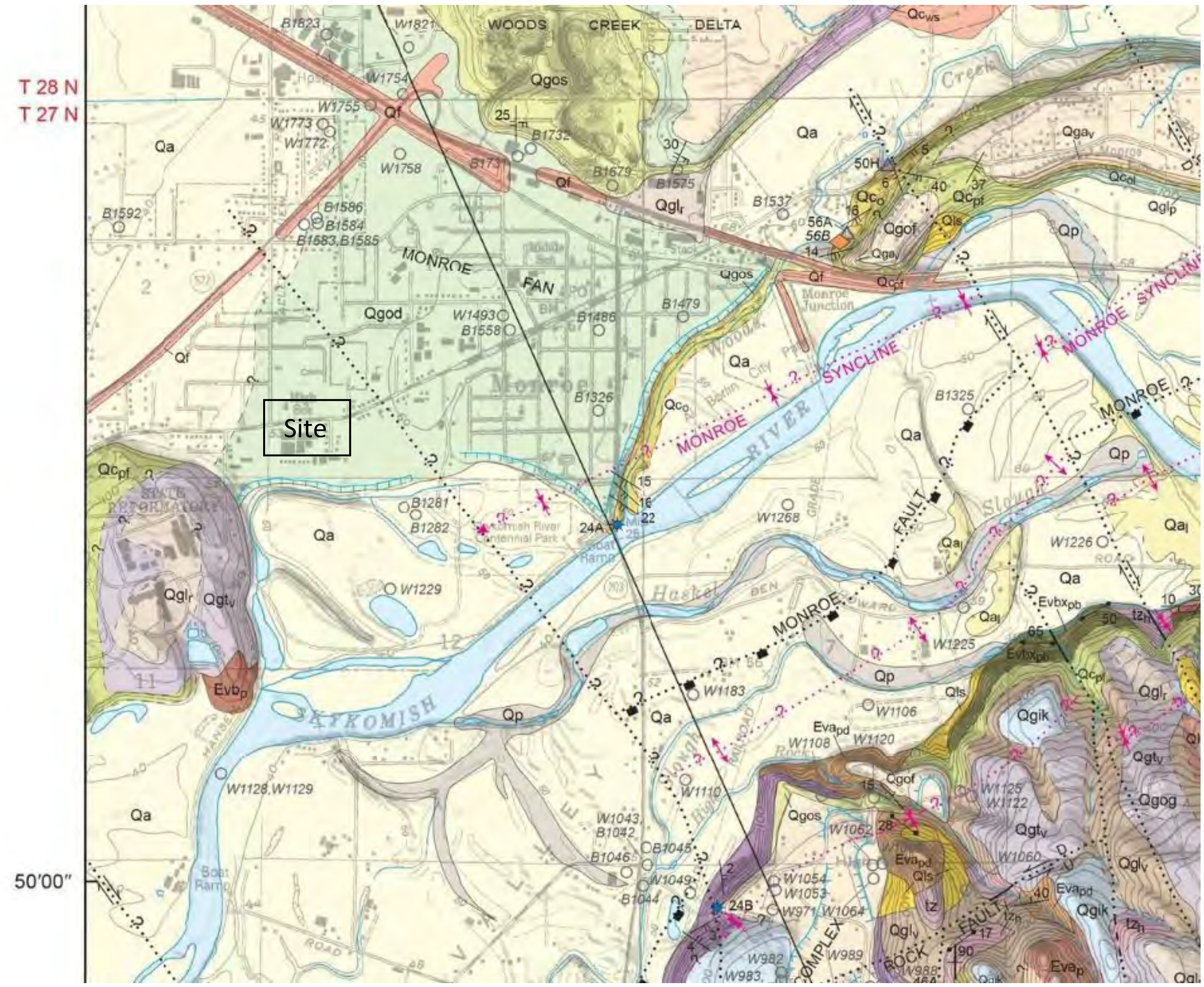
associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

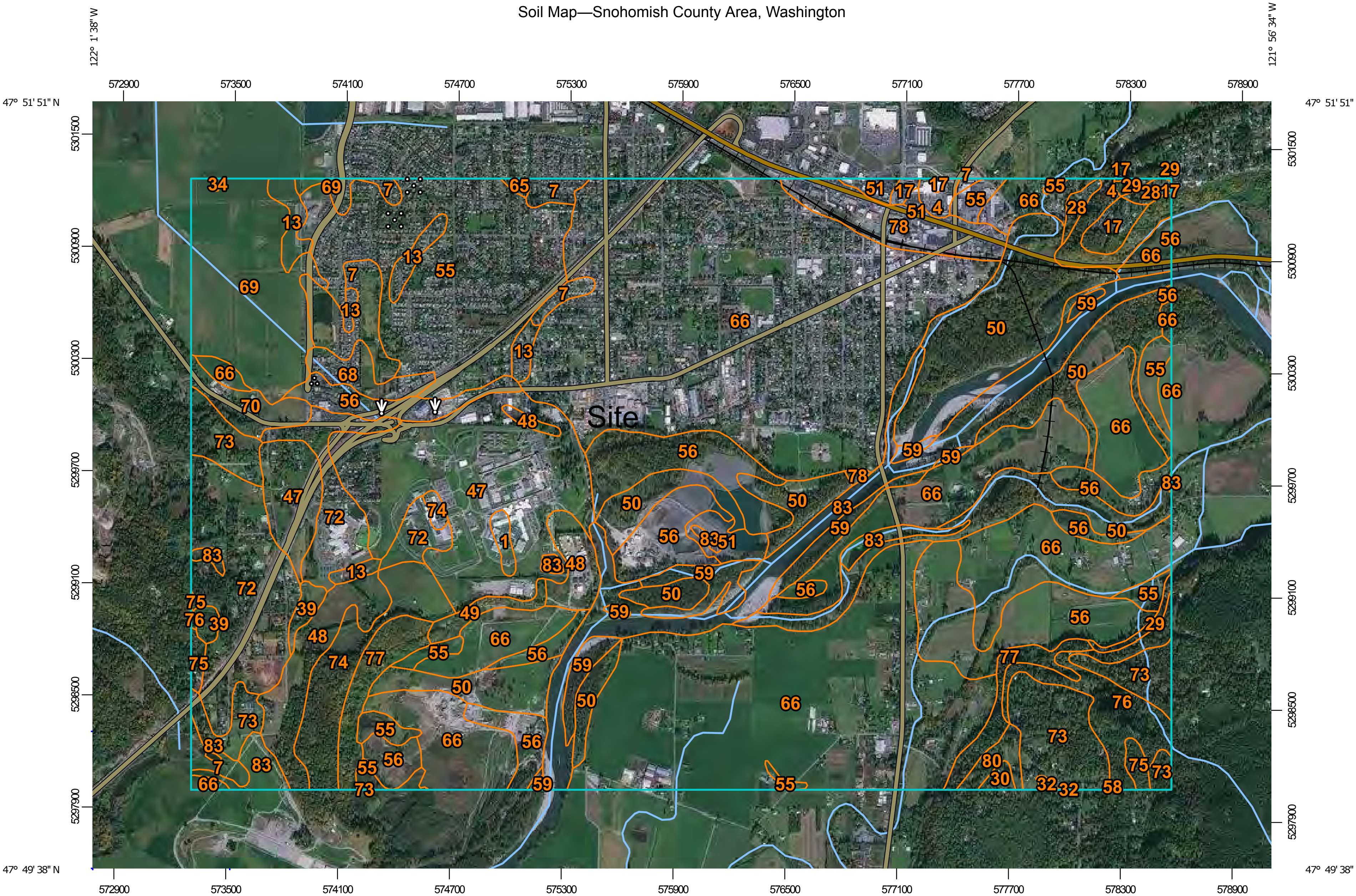
Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Site Unit: Qpod: Deltaic Outwash of the Vashon Stade of the Fraser Glaciation

Source:
Geologic map of the Monroe 7.5-minute quadrangle, King and Snohomish Counties, Washington
Author(s): Dragovich, J.D., Anderson, M.L., Mahan, S.A., Koger, C.J., Saltonstall, J.H., MacDonald, J.H., Jr., Wessel, G.R., Stoker, B.A., Bethel, J.P., Labadie, J.E., Cakir, Recep, Bowman, J.D., and DuFrane, S.A.
Publishing Organization: Washington Division of Geology and Earth Resources
Series and Number: Open File Report 2011-1
Publication Date: 2011
Map Scale: 1:24,000

Soil Map—Snohomish County Area, Washington



Map Scale: 1:28,900 if printed on A landscape (11" x 8.5") sheet.

Meters: 0 400 800 1600 2400

Feet: 0 1000 2000 4000 6000

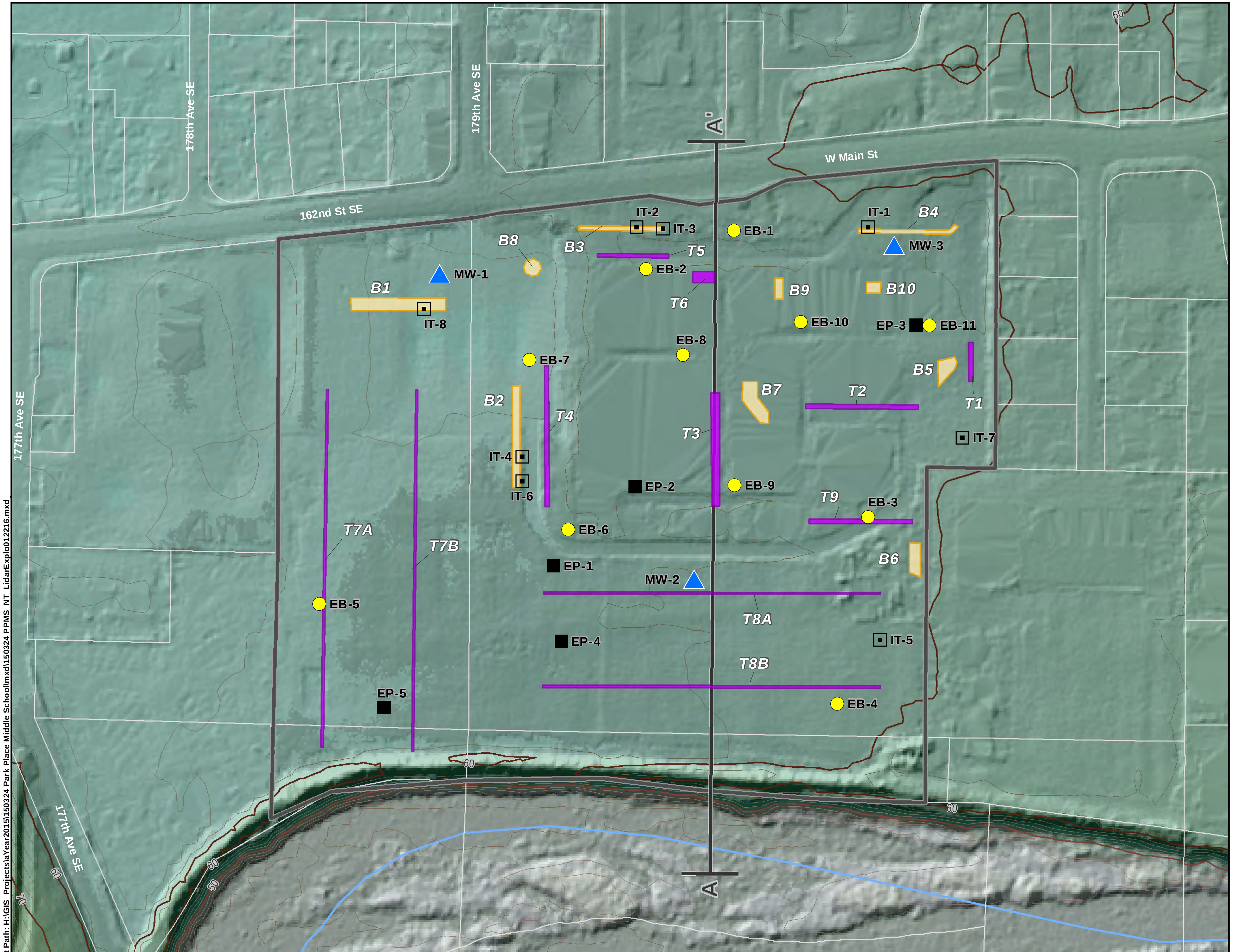
N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1	Alderwood gravelly sandy loam, 0 to 8 percent slopes	6.9	0.2%
4	Alderwood-Everett gravelly sandy loams, 25 to 70 percent slopes	34.3	0.8%
7	Bellingham silty clay loam	70.9	1.7%
13	Custer fine sandy loam	39.2	0.9%
17	Everett very gravelly sandy loam, 0 to 8 percent slopes	19.7	0.5%
28	Kitsap silt loam, 8 to 25 percent slopes	11.0	0.3%
29	Kitsap silt loam, 25 to 50 percent slopes	8.4	0.2%
30	Lynnwood loamy sand, 0 to 3 percent slopes	4.6	0.1%
32	McKenna gravelly silt loam, 0 to 8 percent slopes	1.4	0.0%
34	Mukilteo muck	0.7	0.0%
39	Norma loam	13.1	0.3%
47	Pastik silt loam, 0 to 8 percent slopes	280.2	6.6%
48	Pastik silt loam, 8 to 25 percent slopes	88.7	2.1%
49	Pastik silt loam, 25 to 50 percent slopes	13.8	0.3%
50	Pilchuck loamy sand	391.6	9.2%
51	Pits	24.9	0.6%
55	Puget silty clay loam	318.1	7.5%
56	Puyallup fine sandy loam	331.2	7.8%
58	Ragnar fine sandy loam, 8 to 15 percent slopes	0.3	0.0%
59	Riverwash	62.0	1.5%
65	Sulsavar gravelly loam, 0 to 8 percent slopes	2.3	0.1%
66	Sultan silt loam	1,519.0	35.6%
68	Sumas silt loam	24.2	0.6%
69	Terric Medisaprists, nearly level	158.4	3.7%
70	Tokul silt loam, 2 to 8 percent slopes	27.3	0.6%
72	Tokul gravelly medial loam, 0 to 8 percent slopes	208.4	4.9%

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
73	Tokul gravelly medial loam, 8 to 15 percent slopes	136.6	3.2%
74	Tokul gravelly medial loam, 15 to 30 percent slopes	74.3	1.7%
75	Tokul-Ogarty-Rock outcrop complex, 0 to 25 percent slopes	12.0	0.3%
76	Tokul-Ogarty-Rock outcrop complex, 25 to 65 percent slopes	60.0	1.4%
77	Tokul-Winston gravelly loams, 25 to 65 percent slopes	60.7	1.4%
78	Urban land	60.6	1.4%
80	Winston gravelly loam, 0 to 3 percent slopes	12.8	0.3%
83	Water	190.0	4.5%
Totals for Area of Interest		**4,267.6**	**100.0%**



Document Path: H:\GIS_Projects\aYear2015\150324 Park Place Middle School\mxd\150324 PPMS_NT_LidarExplo012216.mxd

LEGEND:

- EXPLORATION BORING
- EXPLORATION PIT
- INFILTRATION TEST
- MONITORING WELL
- BIORETENTION CELL
- UNDERGROUND INFIL TRENCH
- CROSS SECTION
- PROJECT SITE
- CONTOUR 10 FT
- CONTOUR 2 FT

DATA SOURCES / REFERENCES:
PSLC: LIDAR 2014, GRID CELL SIZE IS 3'.
WA STATE PLANE NORTH, NAD83(HARN) NAVD88, US SURVEY FEET.

SNOHOMISH CO: PARCELS, STREETS

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 70 140
FEET

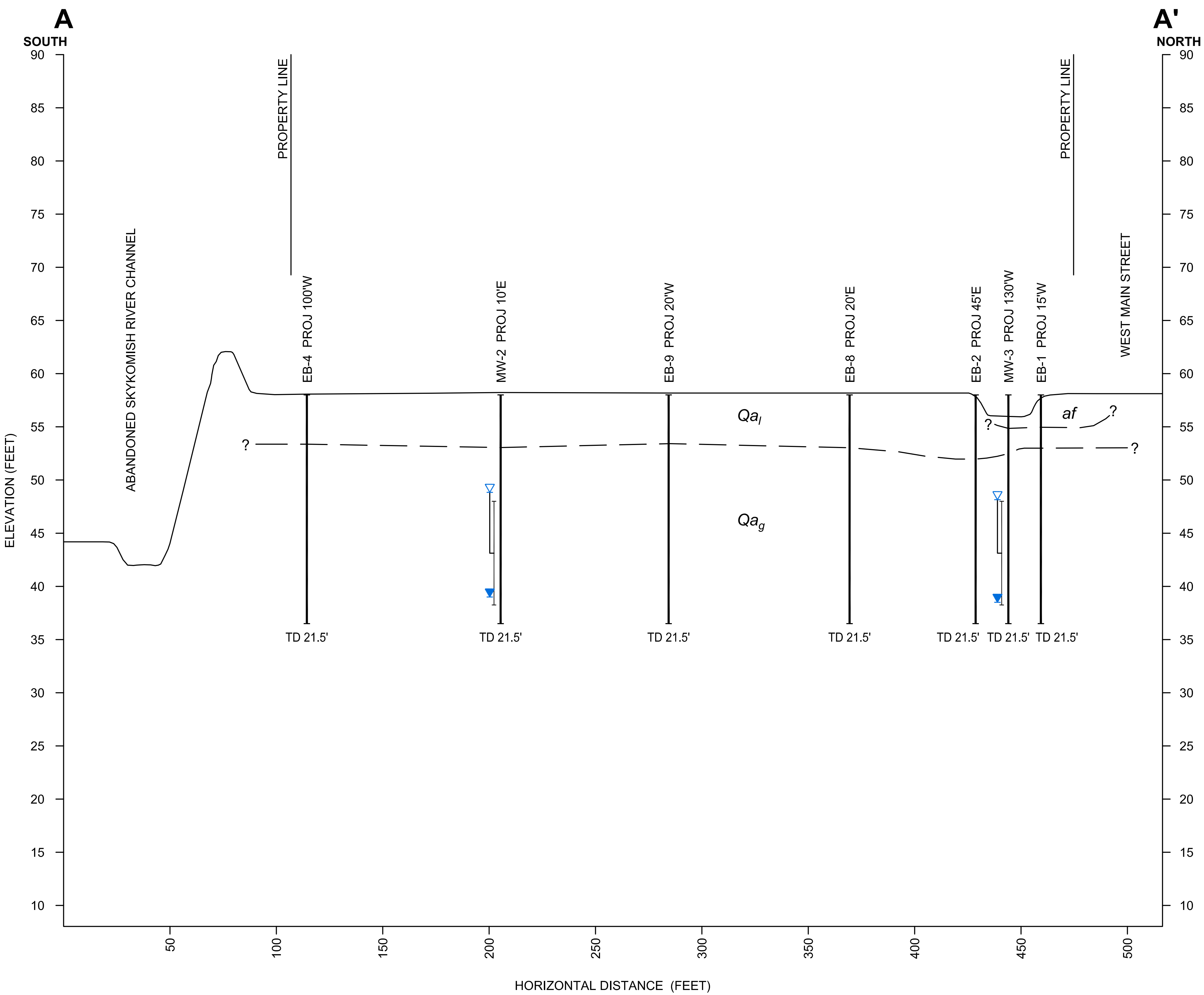
BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

EXPLORATIONS AND LIDAR BASED TOPOGRAPHY

PARK PLACE MIDDLE SCHOOL
MONROE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
KE150324B	1/16	2



LEGEND:

af	FILL
Qa_l	ALLUVIUM - LEVEE DEPOSITS
Qa_g	ALLUVIUM - COARSE GRAINED
	EXPLORATION: BORING (EB) MONITORING WELL (MW)
	WATER LEVEL AT TIME OF DRILLING - 7/1/15
	WATER LEVEL - 12/9/15
	SCREENED INTERVAL
TD	TOTAL DEPTH OF BORING
	GEOLOGIC CONTACT

VERTICAL EXAGGERATION = 5X

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE

NOTE:

1. THE SUBSURFACE CONDITIONS PRESENTED IN THIS GEOLOGIC CROSS-SECTION ARE BASED ON AN INTERPRETATION OF CONDITIONS ENCOUNTERED IN WIDELY SPACED EXPLORATIONS COMPLETED AT THE SUBJECT SITE AND RELEVANT SITE INFORMATION DEVELOPED AND PROVIDED BY OTHERS. THE SUBSURFACE INTERPRETATIONS PRESENTED IN THIS GEOLOGIC CROSS-SECTION SHOULD NOT BE CONSTRUED AS A WARRANTY OF ACTUAL SUBSURFACE CONDITIONS AT THE SITE. OUR EXPERIENCE HAS SHOWN THAT SOIL AND GROUND WATER CONDITIONS CAN VARY SIGNIFICANTLY OVER SMALL DISTANCES.

2. OFFSITE GROUND SURFACE ELEVATIONS DERIVED FROM LIDAR.

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

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SCHEMATIC HYDROGEOLOGIC CROSS-SECTION A - A'

PARK PLACE MIDDLE SCHOOL
MONROE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
KE150324B	1/16	3

150324 Park Place MS \ 150324 GeoSect 1-16.dwg LAYOUT: F3 Sect A-A

Geologic & Monitoring Well Construction Log

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Project Number	Well Number	Sheet
KE150324A	-MW-2	1 of 1

Project Name	Park Place Middle School	Location	Monroe, WA
Elevation (Top of Well Casing)		Surface Elevation (ft)	
Water Level Elevation		Date Start/Finish	6/30/15,6/30/15
Drilling/Equipment	GDI / Tracked	Hole Diameter (in)	8.5 inches
Hammer Weight/Drop	140# / 30"		

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
0		Flush mount locking monument Concrete seal 0 to 1.5 feet				**Grass / Topsoil - 3 inches** **Alluvium - Levee Deposits**
						Medium stiff, moist, tannish brown, sandy SILT; contains trace organics (ML).
		Bentonite seal 1.5 to 8 feet		3 3 4		Driller notes gravelly drill action at 5 feet.
5				14 13 24		**Alluvium - Coarse-Grained** Dense, moist to very moist, gray, SAND, some gravel (SP).
		2-inch I.D. PVC pipe casing: 0 to 10 feet				
10				22 30 22		Dense, moist, brownish gray, gravelly SAND, some silt; contains fractured gravel in sampler tip (SW).
		2-inch I.D. PVC well screen: 0.020-inch slot width, 10 to 19.46 feet				
15		10/20 silica sand 8 to 21.5 feet		50/2"		No recovery. Blow counts overstated due to gravel.
	▼	Slip cap				
20		Well Tag #BIJ 526		12 12 13		Medium dense, wet, dark brown, gravelly SAND / sandy GRAVEL; contains dark-stained sediments (SP/GP).
						Boring terminated at 21.5 feet. Well completed at 19.66 feet on 6/30/15.

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture	**Logged by:** AWR
3" OD Split Spoon Sampler (D & M)	Ring Sample	▽ Water Level ()	**Approved by:** JHS
Grab Sample	Shelby Tube Sample	▼ Water Level at time of drilling (ATD)	

Exploration Log

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Project Number	Exploration Number	Sheet
KE150324A	EB-3	1 of 1

Project Name	Park Place Middle School	Ground Surface Elevation (ft)	
Location	Monroe, WA	Datum	N/A
Driller/Equipment	GDI / Tracked	Date Start/Finish	6/30/15,6/30/15
Hammer Weight/Drop	140# / 30"	Hole Diameter (in)	6 inches

Depth (ft)	Samples	DESCRIPTION	Water Level	Blows/6"	Blows/Foot
		Asphalt - 4 inches			
		Alluvium - Levee Deposits			
	S-1	Medium dense/stiff, moist, brown, silty SAND/sandy SILT (SM-ML).		4 4 12	16
5		**Alluvium - Coarse-Grained**			
	S-2	Dense, dry, tan, gravelly SAND; contains unsorted silty till-like clast in sampler tip (SP). Driller notes gravel at 5.5 feet.		6 18 23	41
10	S-3	Dense, moist, tan, gravelly SAND; contains unsorted silty till-like clasts; blow counts overstated due to gravel (SP).		27 50/4"	50/4"
15	S-4	Dense, moist, dark brown, silty SAND, some gravel; contains unsorted silty till-like clasts; blow count overstated (SP).		50/3"	50/3"
			▼ (ATD)		
20	S-5	Dense, wet, brown, gravelly SAND / sandy GRAVEL; poor recovery (SP/GP).		31 36 20	56
		Bottom of exploration boring at 21.5 feet			

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: AWR
Approved by: JHS

LOG OF EXPLORATION PIT NO. IT-5

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Topsoil / Grass
1	**Alluvium - Levee Deposits**
2	Medium stiff, moist, brown, fine sandy SILT (ML).
3	
4	
5	**Alluvium - Coarse-Grained**
6	Medium dense to dense, moist, tannish gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles (GW).
7	
8	Operator notes very dense digging action at 8.5 feet.
9	Very dense, very moist, tan, fine to coarse sandy GRAVEL; contains cobbles (GW).
10	
11	
12	As above.
13	Bottom of exploration pit at depth 12 feet Minor caving from 6 to 12 feet. Infiltration test completed at 6 feet. Post-test seepage was observed in sidewalls of pit at depths of 6 to 7 feet.
14	
15	
16	
17	
18	
19	
20	

KCTP3 150324B.GPJ December 4, 2015

Park Place Middle School
Monroe, WA

Logged by: AWR

Approved by: CJK

associated earth sciences incorporated

Project No. KE150324B

11/12/15

LOG OF EXPLORATION PIT NO. IT-7

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Asphalt - 5 inches
	Crushed Rock Base Course - 8 inches
1	**Alluvium - Levee Deposits**
2	Medium stiff, moist, tannish brown, fine sandy SILT (ML).
3	**Alluvium - Coarse-Grained**
4	
5	Medium dense to dense, wet, brown, sandy GRAVEL; contains cobbles (GW).
6	
7	
8	
9	
10	
11	Bottom of exploration pit at depth 10 feet Moderate to heavy seepage at 7.5 feet. Slight to heavy caving from 4.5 to 10 feet. Infiltration test completed at 4.5 feet.
12	
13	
14	
15	
16	
17	
18	
19	
20	

KCTP3 150324B.GPJ January 6, 2016

Park Place Middle School
Monroe, WA

associated earth sciences incorporated

Logged by: AWR

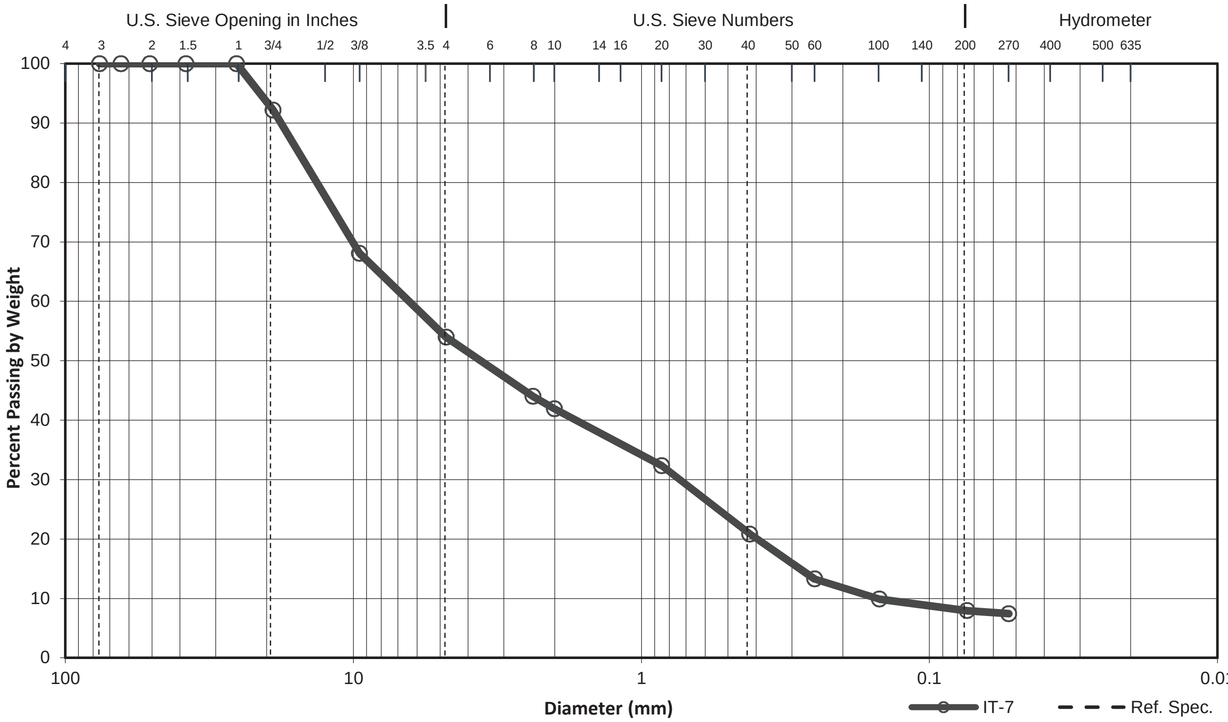
Approved by: CJK

Project No. KE150324B

12/29/15

GRAIN SIZE ANALYSIS - MECHANICAL ASTM D422

Project Name	Project Number	Date Sampled	Date Tested	Tested By
PPMS	KE150524B	12/29/2015	1/13/2016	MS
Sample Source	Sample No.	Depth (ft)	Soil Description	
Onsite	IT-7	4-5	very sandy GRAVEL, some silt (GP-GM)	
Total Sample Dry Wt. (g)	Moisture Content (%)	D_{10} (mm)	Reference Specification	
974.5	8	0.151		



Sieve No.	Diam. (mm)	Cum. Wt. Ret. (g)	% Ret. by Wt.	% Passing by Wt.	% Specs. Pass. by Wt. Min	% Specs. Pass. by Wt. Max
3	76.1		0.0	100.0		
2.5	64		0.0	100.0		
2	50.8		0.0	100.0		
1.5	38.1		0.0	100.0		
1	25.4		0.0	100.0		
3/4	19	75.9	7.8	92.2		
3/8	9.51	310.9	31.9	68.1		
#4	4.76	448.7	46.0	54.0		
#8	2.38	545.7	56.0	44.0		
#10	2	566.2	58.1	41.9		
#20	0.85	659.2	67.6	32.4		
#40	0.42	771.4	79.2	20.8		
#60	0.25	845.1	86.7	13.3		
#100	0.149	878.3	90.1	9.9		
#200	0.074	897.1	92.1	7.9		
#270	0.053	902.0	92.6	7.4		

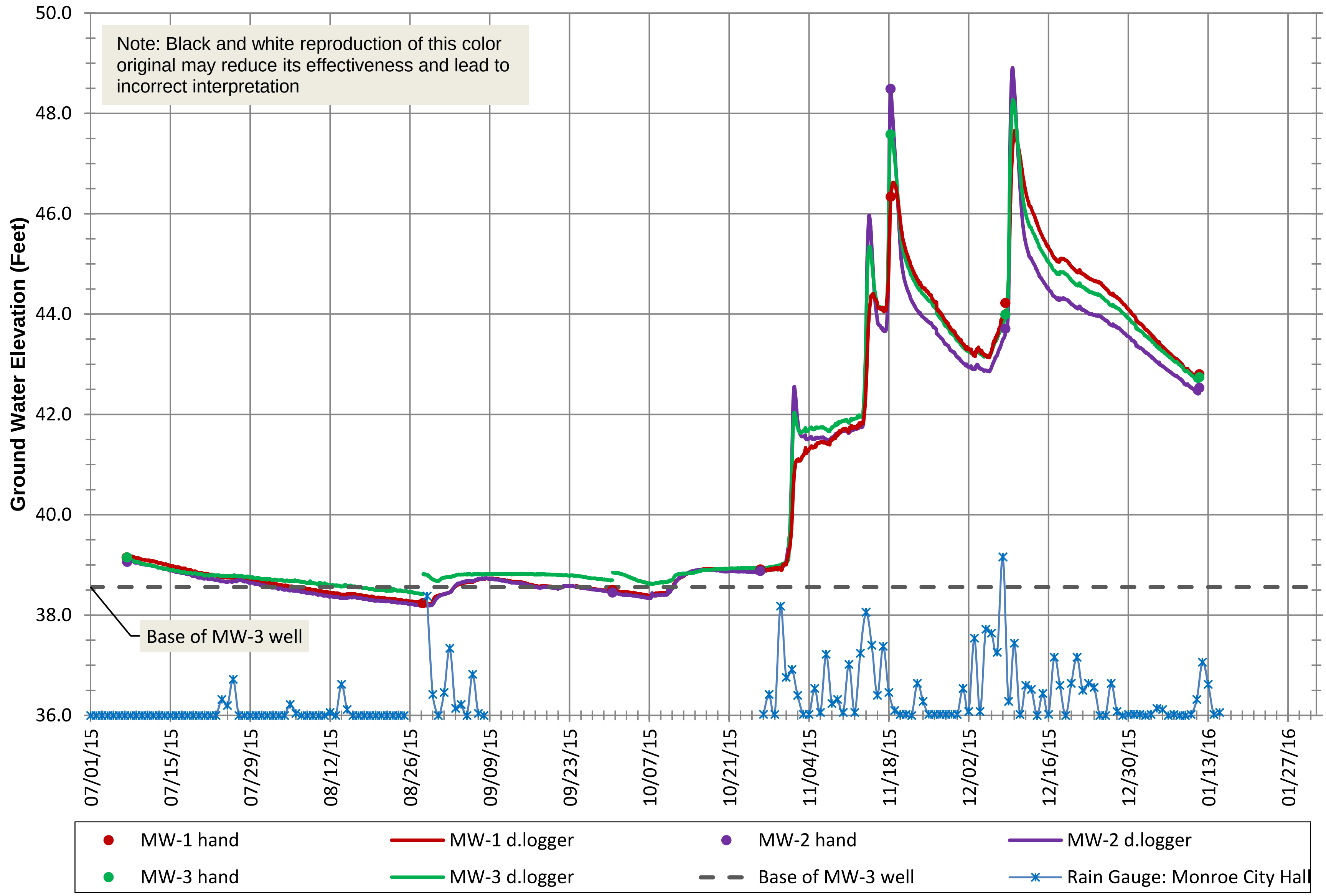
Project Name	Park Place Middles School	**Initial Pit Area (ft^2)**	71-inch-diameter ring
Project Number	KE150324B	**Test Depth (ft)**	6
Date	11.12.12	**Receptor Soils**	sandy GRAVEL
Weather	Pt. Sunny, 60's	**Testing Performed By**	AWR
Test No.	IT-5		
Meter	AESI Low Flow		
Water Source	City of Monroe Hydrant		

Time (24-hr)	Increm. Time (min)	Total (min)	Flow Rate (gpm)	Stage (ft)	Totalizer (gal)	Incremental Infiltration Rate (in/hr)	Notes
9:18:00	0.0	0.0	0	0	0		
9:20:00	2.0	2.0	39.63	0.05	60	120.7	
9:21:00	1.0	3.0	39.63	0.16	97	59.5	
9:22:00	1.0	4.0	39.81	0.30	140	38.5	
9:23:00	1.0	5.0	39.51	0.50	180	-5.7	decrease flow
9:25:00	2.0	7.0	8.01	0.56	203	6.4	
9:28:00	3.0	10.0	7.86	0.58	239	22.7	
9:33:00	5.0	15.0	7.92	0.60	278	24.8	decrease flow
9:37:00	4.0	19.0	5.41	0.60	301	18.9	
9:45:00	8.0	27.0	5.41	0.60	348	18.9	
9:53:00	8.0	35.0	5.41	0.62	394	17.1	decrease flow
10:00:00	7.0	42.0	4.13	0.62	419	14.5	
10:30:00	30.0	72.0	4.21	0.61	545	15.0	
10:45:00	15.0	87.0	3.95	0.61	608	13.8	
11:00:00	15.0	102.0	4.14	0.62	672	14.0	decrease flow
11:15:00	15.0	117.0	3.35	0.61	702	12.2	
11:30:00	15.0	132.0	3.29	0.59	770	12.5	
12:00:00	30.0	162.0	3.21	0.56	866	12.0	increase flow
12:10:00	10.0	172.0	4.04	0.56	899	14.1	
12:27:00	17.0	189.0	3.87	0.60	970	11.9	
12:42:00	15.0	204.0	3.75	0.61	1027	12.6	
13:13:00	31.0	235.0	3.59	0.63	1140	12.1	decrease flow
13:49:00	36.0	271.0	3.36	0.62	1262	12.0	
13:54:00	5.0	276.0	3.38	0.62	1279	11.8	
14:16:00	22.0	298.0	3.52	0.62	1355	12.3	
14:20:00	4.0	302.0	3.5	0.62	1369	12.2	
14:25:00	5.0	307.0	3.5	0.62	1387	12.2	
14:30:00	5.0	312.0	3.48	0.62	1404	12.2	
14:35:00	5.0	317.0	3.52	0.62	1421	12.3	
14:40:00	5.0	322.0	3.48	0.62	1439	12.2	
14:45:00	5.0	327.0	3.36	0.62	1456	11.8	
14:50:00	5.0	332.0	3.38	0.62	1473	11.8	
14:55:00	5.0	337.0	3.36	0.63	1490	10.3	
15:00:00	5.0	342.0	3.35	0.63	1506	11.7	
15:05:00	5.0	347.0	3.36	0.63	1523	11.8	
15:10:00	5.0	352.0	3.43	0.63	1540	12.0	
15:15:00	5.0	357.0	3.48	0.63	1556	12.2	
15:20:00	5.0	362.0	3.48	0.63	1575	12.2	water off at 15:20
15:22:00	2.0	364.0		0.62		3.6	falling head
15:24:00	2.0	366.0		0.59		7.2	
15:26:00	2.0	368.0		0.56		8.4	
15:27:00	1.0	369.0		0.54		9.3	
15:29:00	2.0	371.0		0.52		8.8	
15:30:00	1.0	372.0		0.50		9.4	
15:33:00	3.0	375.0		0.46		9.4	
15:38:00	5.0	380.0		0.39		9.6	
15:43:00	5.0	385.0		0.32		9.7	
15:48:00	5.0	390.0		0.27		9.3	
15:54:00	6.0	396.0		0.19		9.3	end test, remove ring, over ex
Average Infiltration Rate During Last Hour of Constant Head Test:						11.9	
Average infiltration Rate During Falling Head Test:						9.3	

Project Name	Park Place Middles School	**Initial Pit Area (ft^2)**	2.17 x 7
Project Number	KE150324B	**Test Depth (ft)**	4.5
Date	12.29.15	**Receptor Soils**	sandy GRAVEL
Weather	Overcast, 30s	**Testing Performed By**	AWR
Test No.	IT-7		
Meter	AESI 3-30gpm		
Water Source	City of Monroe Hydrant		

Time (24-hr)	Increm. Time (min)	Total (min)	Flow Rate (gpm)*	Stage (ft)	Totalizer (gal)*	Incremental Infiltration Rate (in/hr)	Notes
8:08:00	0.0	0.0	7	0	0		flow on
8:10:00	2.0	2.0	31.4	0.17	44	138.0	
8:11:00	1.0	3.0	31.3	0.33	78	81.0	
8:13:00	2.0	5.0	31.5	0.50	111	139.5	decreased flow
8:14:00	1.0	6.0	6.4	0.56	129	-4.2	
8:18:00	4.0	10.0	8.1	0.42	160	77.8	increased flow
8:23:00	5.0	15.0	10.1	0.48	223	54.9	
8:28:00	5.0	20.0	10.5	0.48	269	66.6	increased flow
8:45:00	17.0	37.0	11.2	0.50	453	70.0	
9:00:00	15.0	52.0	11.1	0.50	626	70.5	
9:15:00	15.0	67.0	11.1	0.50	781	70.5	
9:30:00	15.0	82.0	10.9	0.50	957	69.2	increased flow
9:45:00	15.0	97.0	11.02	0.44	1094	72.8	increased flow
10:00:00	15.0	112.0	13.29	0.58	1318	77.2	decreased flow
10:15:00	15.0	127.0	11.18	0.50	1490	74.8	increased flow
10:30:00	15.0	142.0	11.79	0.50	1668	74.7	
10:45:00	15.0	157.0	11.23	0.46	1831	73.2	increased flow
11:00:00	15.0	172.0	12.15	0.50	2012	75.0	
11:15:00	15.0	187.0	12.25	0.52	2190	76.6	
11:30:00	15.0	202.0	12.25	0.52	2373	77.7	
11:45:00	15.0	217.0	12.25	0.52	2554	77.6	
12:00:00	15.0	232.0	12.20	0.52	2739	77.3	
12:15:00	15.0	247.0	12.15	0.52	2925	77.0	
12:30:00	15.0	262.0	12.20	0.52	3109	77.3	
12:45:00	15.0	277.0	12.20	0.52	3283	77.3	
13:00:00	15.0	292.0	12.82	0.54	3462	80.2	
13:15:00	15.0	307.0	12.72	0.60	3654	77.8	decreased flow
13:30:00	15.0	322.0	11.89	0.54	3841	78.1	
13:45:00	15.0	337.0	11.84	0.54	4008	75.1	
14:00:00	15.0	352.0	11.84	0.54	4184	75.0	
14:15:00	15.0	367.0	11.84	0.52	4364	75.9	
14:30:00	15.0	382.0	11.84	0.50	4543	76.0	
14:45:00	15.0	397.0	11.94	0.50	4723	75.7	
15:00:00	15.0	412.0	11.89	0.48	4904	76.3	
15:15:00	15.0	427.0	11.43	0.46	5083	73.4	Flow off, falling head start
15:16:00	1.0	428.0	0.00	0.38	5083	60.0	
15:17:00	1.0	429.0	0.00	0.29	5083	60.0	
15:18:00	1.0	430.0	0	0.21	5083	60.0	
15:19:00	1.0	431.0	0	0.13	5083	60.0	
15:20:00	1.0	432.0	0	0.08	5083	50.0	
15:21:00	1.0	433.0	0	0.04	5083	45.0	End falling head test
Average Infiltration Rate During Last Hour of Constant Head Test:						75.0	
Average infiltration Rate During Falling Head Test:						54.0	

Ground Water Elevation and Daily Rainfall vs Time
Park Place Middle School



APPENDIX D

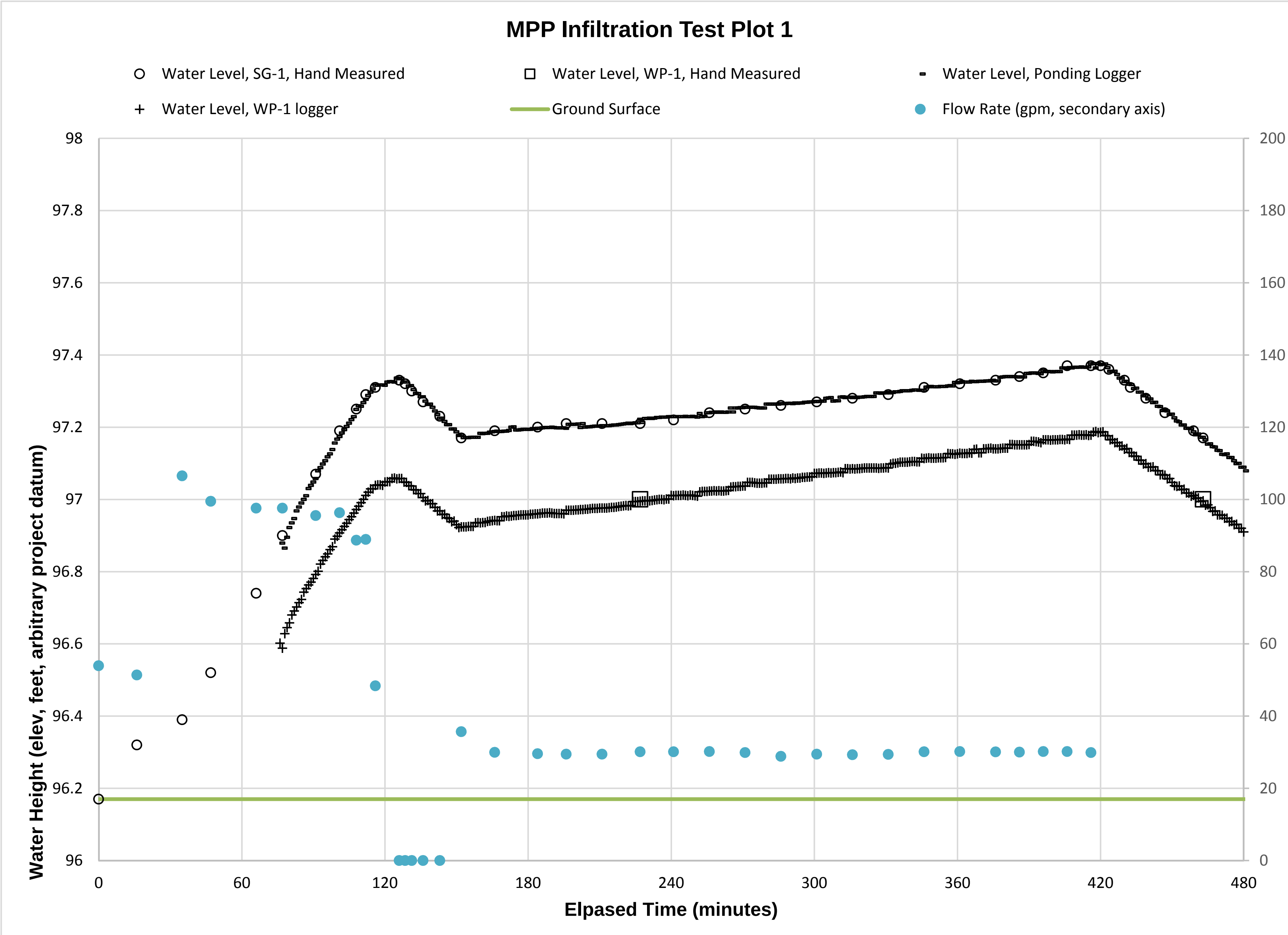
Soil Probe, Level Survey, and Field Infiltration Testing Data

Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5,7
Date:	11/8/2018	**Base Area (sq.ft.):**	NA
Weather:	Overcast, 60's	**Ponded Area(sq.ft.):**	800.0
Test No.:	MPP	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
8:44	53.94	0	0	Flow on
9:00	51.36	0.15	798.16	
9:19	106.5	0.22	1750	
9:31	99.46	0.35	2921	
9:50	97.58	0.57	4806	
10:01	97.58	0.73	5927	logger in WP-1 wet: moved to alternate loca
10:15	95.5	0.9	7240	
10:25	96.3	1.02	8230	Flow reduced to 92 gpm
10:32	88.7	1.08	8797	Flow reduced to 88 gpm
10:36	88.9	1.12	9221	Flow reduced to 80 gpm
10:40	48.37	1.14	9530	flow reduced to 50 gpm
10:50	0	1.16	9981	Flow off, remove FM7
10:52	0	1.15	9981	
10:55	0	1.13	9981	
11:00	0	1.1	9981	
11:07	0	1.06	9981	
11:16	35.67	1	9981	Flow resumed, FM5
11:30	29.94	1.02	10484	
11:48	29.56	1.03	11024	
12:00	29.44	1.04	11364	
12:15	29.44	1.04	11798	
12:31	30.11	1.04	12296	
12:45	30.11	1.05	12706	
13:00	30.17	1.07	13159	
13:15	29.89	1.08	13626	
13:30	28.83	1.09	14067	
13:45	29.44	1.1	14511	
14:00	29.28	1.11	14938	
14:15	29.39	1.12	15396	
14:30	30.11	1.14	15846	
14:45	30.17	1.15	16284	
15:00	30.06	1.16	16729	
15:10	30	1.17	17039	
15:20	30.17	1.18	17331	
15:30	30.17	1.2	17642	
15:40	29.89	1.2	17930	
15:44	0	1.2	18065	Flow off
15:47		1.19		
15:54		1.16		
15:56		1.14		
16:03		1.11		
16:11		1.07		
16:23		1.02		
16:27		1		
16:40		0.93		

16:45		0.91		
16:48				
16:50		0.89		

	Average Infiltration Rate (in/hr) during last hour of inflow:	3.0
	Average Infiltration Rate (in/hr) during falling head:	3.4


MPP Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Ground Surface
Flow Rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
Elpased Time (minutes)
98
97.8
97.6
97.4
97.2
97
96.8
96.6
96.4
96.2
96
0
60
120
180
240
300
360
420
480
200
180
160
140
120
100
80
60
40
20
0

APPENDIX E

Site Photos

Cell MPP overview during infiltration testing.

Above photo: Cell MPP inlet modified for monitoring.
Lower Photo: close up of curb cut inlet prior to weir installation.

APPENDIX 9

Deliverable Task 4.5, Site RSH, Geotechnical/Soils Assessment Design Data and Current Conditions, Renton Sunset Community at Harrington Avenue NE, Renton, Washington. Associated Earth Sciences, Inc. 6/14/2019

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ypma Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site RSH, Geotechnical/Soils Assessment Design Data and Current Conditions, Renton Sunset Community at Harrington Avenue NE, Renton, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Swale E2 of the Sunset Community Low Impact Development Retrofit Green Connection: Harrington Avenue NE Phase II Between NE 8th Place and NE 7th Street Project, located in the City of Renton, Washington (Figure RSH F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously-documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 10, 2018, infiltration testing on November 5, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle-size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure RSH F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Sunset Community Project, located in Renton, Washington as shown on the attached "Vicinity Map" (Figure RSH F1). The Phase II Sunset Community project is located along Harrington Avenue NE, generally between 8th Place and NE 7th Street. The site is generally located in the right-of-way of Harrington Avenue, which runs north to south, and is bordered by Highlands Elementary School on the west, and mixed single-family and multifamily residential homes on the

East. Site topography generally slopes gradually downhill to the southwest. No surface water features are present onsite. Stormwater onsite discharges to Johns Creek and Lake Washington (CH2MHILL, August 2012).

Our specific area of study for this project includes bioretention swale E2 located on the east side of Harrington Avenue, immediately north of the intersection with NE 8th Street, referred to as cell RSH for this study. The attached "Facility and Exploration Plan" (Figure RSH F2) illustrates the cell area and some of the surrounding site features and utilities.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Geotechnical Data and Recommendations Report, Renton Sunset Stormwater Retrofit/LID Project," CH2MHILL, August 2012.
- "Technical Information Report, Green Connections – Harrington Avenue Phase II, NE 8th Place to NE 7th Street – Stormwater Retrofit Project," CH2MHILL, April 2017.
- Sunset Community LID Retrofit Green Connection: Harrington Avenue NE Phase II Between NE 8th Pl and NE 7th St, 100% Submittal," CH2MHILL, May 5, 2017.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell RSH consists of an approximately rectangular-shaped bioretention cell with approximately 64 square feet of base area, as shown on Figure RSH F2, "Facility and Exploration Plan." We understand that the site was developed under the 2009 King County Surface Water Design Manual (KCSWDM) along with the 2010 city of Renton Amendments to King County Surface Water Design Manual for design and construction of stormwater facilities and modeled using WWHM4 with a design infiltration rate of 1.2 inches per hour (in/hr) in the native subgrade. Land use within the drainage basin is primarily roadway. Per detail sheet C-5 (CH2MHILL, 2017), the facility design includes a 2-inch woodchip mulch layer overlying 18 inches of bioretention soil mix overlying a rock-filled trench which is present along one side of the facility base, and native subgrade on the remainder of the facility base. The rock-filled trench is not separated from the overlying bioretention soil mix. The rock-filled trench contains an 8-inch-diameter perforated underdrain pipe bedded in approximately 20 inches of "mineral aggregate type 26," which overlies native soil. The underdrain pipe connects to a "drain basin," which then connects to a storm drain catch basin via an 8-inch pipe with a 1-inch orifice. The 8-inch pipe which allows discharge from the drain basin to the storm drain catch basin is at a higher elevation than the underdrain pipe. The storm drain catch basin discharges to the City stormwater system.

The facility is designed to infiltrate 29 percent of inflow into the subgrade. Stormwater enters the facility through two curbcuts. If water ponds up on the bioretention soil, the ponded water would discharge into a Type I Catch Basin with a beehive grate located near the southern end of the cell, and then into the stormwater system. A 6-inch ponding depth is specified, with a 9-inch overflow depth per detail sheet C-5 (CH2MHILL, 2017). Based on review of historic aerial imagery, the facility was constructed and began receiving runoff after June 2017 and before May 2018.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facility including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure RSH F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the center of the "sewer cleanout" lid in the cell (identified on the "RSH Level Survey Data" map in Appendix D) defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: Two curbcuts are present, with one allowing inflow from the northern end and the other allowing inflow from the side near the southern end, near the overflow beehive grate.
    - The primary inlet (Inlet 1) to the facility is a 1.3-foot-wide curb cut into the northern end of the cell, opposite the overflow. A 3.5-foot by 4-foot gravel/cobble energy dissipater pad was present. We observed sediment deposition across an area of approximately 1 foot by 3 feet of the energy dissipater pad at the time of our October 10, 2018 site visit. The deposited sediment consisted of fine sand and organics at the inlet. At the base of the pad, organic deposits had accumulated to a depth of ½ inch to 2 inches, and extended approximately 3 feet beyond the end of the energy dissipater pad.

    - A second inlet pipe (Inlet 2) to the facility is a 1-foot-wide curbcut. An energy dissipater pad 1.5 to 2.5 feet wide by 5 feet long was present, consisting of rounded gravel and cobbles. Approximately 1 square foot was covered with 1½ inches of sand, with leaves present along the remaining length.

- Overflow: The overflow consists of a Type I Catch Basin with a beehive grate. The rim of this grate was a maximum of 0.3 feet above the facility base, and the southwest corner was inset by less than 0.1 foot into the mulch. AESI observed wood chips accumulated against the sides of the grate on all four sides, interpreted as indicative of the grate receiving flow. AESI notes that the grate is immediately adjacent to the flow dissipater pad from Inlet 2, such that water could flow in the inlet and directly into the overflow grate. The overflow catch basin has two pipes connected to it, one of which is 12-inches in diameter and discharges water from the catch basin to the City storm system. The other pipe is 8-inch polyvinyl chloride (PVC) with a threaded end cap, with an approximately 1-inch orifice, through which water flows into the catch basin from the drain basin.

- Drain Basin: The drain basin consists of an 18-inch pipe, oriented vertically, covered with a circular grated metal lid. The grated metal lid is set approximately 0.6 feet higher than the rim of the beehive overflow grate, such that ponded water should enter the overflow before ponding high enough to directly enter the drain basin through the grated lid. Water enters the drain basin from the 8-inch underdrain pipe, and exits through an 8-inch pipe with 1-inch orifice to the overflow storm drain basin. The underdrain is set approximately 14 inches below the level of the pipe which allows discharge to the overflow. AESI observed one piece of plastic trash floating in the drain basin sump.

- AESI investigated the loose bioretention soil thickness present in cell RSH using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 3-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.5 to 1.9 feet and averaged 1.7 feet. Some areas of compacted soil occurred during the primary inlet. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell RSH
Level Survey Data

Location	Elevation (feet, project datum)
Center of "Sewer Cleanout" lid	100.00
Inlet#1 (N) Green pipe top/end@weir	99.53
Inlet#1 (N) curbcut inside lip, LOW (E)	99.14
Inlet#2 (S) Green pipe top/end@weir	98.96
Inlet#2 (S) curbcut LOW (S)	98.88
WP-1 TOC	101.04
Ponding Tube TOC (Baro)	99.49
Ponding Tube TOC (DL)	99.07
Overflow inner rim @ notch (S)	98.48
Overflow outer rim NW corner, LOW	98.56
UD CO Inner rim @notch (W)	98.72

WP: well point; TOC: top of casing; DL: datalogger; UD CO: underdrain cleanout

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- Mullineaux, D.R., *Geologic Map of the Renton Quadrangle, King County, Washington*, 1965, U.S. Geological Survey (USGS), Geologic Quadrangle Map GQ-405, scale 1:24,000.
- Natural Resource Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed December 2018.
- *Soil Survey of King County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1973.
- Liesch, Bruce A., Price, Charles E., and Walters, Kenneth L., *Geology and Ground-water Resources of Northwestern King County, Washington*, Washington State Division of Water Resources, Water Supply Bulletin No. 20, 1963.

5.1 Regional Topography and Project Grading

The project site is situated on an upland area on the southeast of Lake Washington, a little over 300 feet above the elevation to the lake and about a 1¼ mile northeast of Cedar River, which flows into Lake Washington.

On a closer scale, the area near cell RSH slopes gently down to the south, with elevations in the vicinity of the cell around 308 to 310 feet. Harrington Avenue, sloping down to the south, runs along the west side of the cell. Curbside parking is present to the north of the cell. The multifamily residence east of the cell includes a parking lot which is several feet higher in elevation than the cell. A portion of this parking lot appears to slope gently toward a northern driveway, which slopes down to meet Harrington Avenue north of the cell.

The project site was previously developed as sidewalk area and curbside parking along Harrington Avenue. Minor cutting (about 4 feet) was needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the *Geologic Map of the Renton Quadrangle* (U.S. Geological Survey [USGS] Geologic Quadrangle Map GQ-405), the site vicinity is underlain by recessional stratified drift, specifically identified as outwash at the project site. This is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- <u>Vashon Recessional Stratified Drift, Outwash (Qpa)</u>: Outwash along Cedar River valley: sandy pebble-and-cobble gravel in easternmost terraces, grades to interbedded sand and pebble gravel at Renton, and to sand at northern edge of quadrangle.

Background geotechnical information includes B-12-12, a boring drilled approximately 400 feet from the location of cell RSH. No log was included with the documents received, but the report describes the exploration as encountering ”Soil Unit 1 – Surface Soils” to a depth of 20 feet (CH2MHILL, August 2012). The report indicated that B-12-12 encountered overconsolidated glacial till at 20 feet.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the *Soil Survey of King County Area, Washington* (NRCS, 1973) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of the Ragnar-Indianola Association soils (NRCS, 2018). These soils are formed from the weathering of glacial drift and outwash. NRCS describes the permeability of both Ragnar and Indianola soils as moderately rapid to rapid in the substratum, with slowly permeable silty layers.

As described in the Technical Information Report (CH2MHILL, April 2017), the pre-developed condition was modeled as Type A soils where not impervious, consistent with mapped soil and background geotechnical data.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in Geology and Ground-water Resources of Northwestern King County (Liesch et al., 1963). Liesch et al. (1963) indicates that recessional outwash can be an aquifer where saturated. This unit commons overlies Vashon lodgement till, which is described by Liesch et al. (1963) as typically a confining bed.

On a closer scale, as described in the Technical Information Report (CH2MHILL, April 2017), the storm drain system at the site ultimately discharges to Johns Creek, which flows into Lake Washington. Limited background groundwater level data was collected in geotechnical explorations pits and boreholes; closest to the RSH site, a 6-inch zone of perched groundwater was observed at 12.5 feet, and groundwater was encountered at 15 feet. Several other explorations are described as encountering perched groundwater at depths ranging from 8 to 15.5 feet (CH2MHILL, August 2017). These explorations were generally located north and uphill of the RSH site.

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and underlying subgrade, where encountered. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure RSH F2, "Facility and Exploration Plan." Global Positioning System (GPS) coordinates for the explorations were taken using a hand-held GPS, and are summarized in Appendix B.

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell RSH were completed on October 10, 2018. No rainfall was noted at the time of exploration, however evidence of recent rainfall was observed.

Hand-auger boring number 1 (RSH-HA-1), and hand-auger boring number 2 (RSH-HA-2), which were completed in the base of the cell in the southern portion and near the center, respectively, encountered approximately 1.2 to 1.3 feet of bioretention soil, overlying material interpreted as Vashon recessional outwash to the total depth of up to 3.9 feet. A thin layer (0.3 feet thick) of fill was encountered above the Vashon recessional outwash in RSH-HA-1. Seepage was encountered at 3.7 feet in RSH-HA-1, and from 3.5 to 3.9 feet in RSH-HA-2. RSH-HA-3 encountered bioretention soil mix directly overlying cobbles, interpreted as the buried end of the energy dissipater pad.

6.2 Well Points

A well point was installed in RSH-HA-2 (WP-1). WP-1 was installed to a depth of 4.1 feet to measure groundwater in the shallow aquifer below the bioretention soil. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell RSH
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
RSH-WP	RSH-HA-2/WP	6.7	1.25 inch nominal	2.6	4.1

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology Manual. Two samples of material interpreted as representative of the subgrade were tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell RSH
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
RSH-HA-1	0.2-0.5	Bioretention Soil	4.4	SAND, some silt, trace gravel (SP-SM)	5.2	5.9	0.9	Sand
RSH-HA-1	2-2.5	Recessional outwash		Very sandy SILT, trace gravel (ML)	53.8			Sandy clay to silt loam
RSH-HA-2	0.2-0.5	Bioretention Soil	6.4	SAND, trace silt, trace gravel (SP)	5.7	6.3	0.9	Sand
RSH-HA-2	1.3.-2	Recessional outwash		Very silty SAND, trace gravel (SM)	41.4			Sandy clay to sandy loam

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture; *No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 4.4 and 6.4 percent by weight.

One tested sample meets, and the other does not meet, the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace to some silt and trace gravel based on ASTM D2487 Unified Soil Classification System (USCS). The respective fines content as measured on the No. 200 sieve was 5.2 to 5.7 percent, higher than the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 5.9 to 6.3, meeting the recommended value of equal to or greater than 4. The coefficient of curvature was 0.9, lower than the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix was generally finer-grained with more than the recommended range of silt and fine sand. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell RSH Site Data

Parameter	Recommended Range	Cell RSH
Organic Content (by weight)	5 to 8 percent	5.4 percent by weight
Cu coefficient of uniformity	4 or greater	6.1
Cc coefficient of curvature	1 to 3	0.9
Sieve Size	**Percent Passing**	
3/8” (9.51 mm)	100	100
#4 (4.76 mm)	95 to 100	96.7
#10 (2.0 mm)	75 to 90	79.5
#40 (0.42 mm)	25 to 40	45.9
#100 (0.15 mm)	4 to 10	14
#200 (0.074 mm)	2 to 5	5.5

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

7.2 Subgrade

In RSH-HA-1 and RSH-HA-2, samples of native recessional outwash were sieved, one from a layer that perched groundwater and one from the deeper sandier portion of the augered borehole. The tested material for the perching layer correlates to a sandy SILT, trace gravel with 53.8 percent by weight of the material passing the No. 200 sieve, and the deeper sandier layer correlates to a very silty SAND, trace gravel with 41.4 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the United States Department of Agriculture (USDA) soil texture. The grain-size distributions were normalized to the No. 10 sieve—i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 46.8 to 53.3 percent for the native recessional outwash material.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facility was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell RSHwith fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Water levels were monitored using an existing staff gauge (SG-1) marked in 0.01-foot increments installed adjacent to the well point, a second temporary metal staff gauge (SG-2) marked in 0.01-foot increments installed near overflow grate, within the well point with a digital water level tape, the drain basin (structure connecting the underdrain outflow to the overflow structure) and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell RSH is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell RSH

AESI performed infiltration testing on November 5, 2018. No rainfall was noted during testing, and no flow from the inlets was present.

During this test, flow was initially maintained at between 3 and 10 gpm, until water built up to near the overflow beehive grate. Flow was then stopped briefly, and resumed at approximately 1.5 gpm, where it was maintained for the duration of the test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the energy dissipater from the northern curbcut. After approximately 7 hours, the water level in the wetted area was less than 0.1 feet as measured on SG-1. The wetted pool area had been generally stable for about 4 hours, and had filled in the base of the facility covering an area of about 80 square feet. Approximately 490 gallons of water were used.

Water in the well point and in the drain basin was monitored with a data logger during the infiltration test and responded to inflow. Perched groundwater was present at about 2.7 feet beneath the bioretention cell prior to the start of inflow, and represents the static shallow perched groundwater level. The drain basin water level represents initially stagnant water in the sump, and then water within the underdrain pipe. The water level in the well point and drain basin responded to inflow after about 30 and 50 minutes, respectively, and rose approximately 1.7 feet below ground surface during the course of testing. The water level height is interpreted to be limited by the elevation at which water discharged from the drain basin into the storm drain overflow system.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 30 minutes.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the bioretention soil.

Table 5
Cell RSH
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
RSH (bioretention soil)	80	415	489	0.08	1.8	2.2
RSH (subgrade)	Shallow groundwater mounding response in well point and drain basin				Unknown, underdrained system with shallow groundwater	

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Portions of Cell RSH were inconsistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is inconsistent with the plans. Site design documents indicate that the ponding level was designed as 6 inches (0.5 feet). The rim of the overflow grate is at most 0.3 feet above the cell base, and a portion of it is set below the surrounding mulch. AESI also observed that it is placed immediately adjacent to the energy dissipater from Inlet 2, such that flow could enter the overflow directly.

- Base area is inconsistent with the plans. AESI observed that, with the facility near overflow, approximately 80 square feet of base area was wetted. The Technical Information Report (CH2MHILL, April 2017) indicates a base area of 64.5 square feet.

- Bioretention soil:
  - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.5 to 1.9 feet, averaging 1.7 feet, slightly thicker than the 1.5 feet indicated per plan.
  - Composition: The soil tested in generally the recommended guidelines for organic content, although the soil mix was finer-grained, containing slightly more than the recommended range of fine sand and silt.

- Subgrade conditions: The subgrade is interpreted to consist of fine-grained Vashon recessional outwash sand and silt. Perched groundwater was present.

- Bioretention soil field infiltration rate:
  - Measured at about 2 in/hr.
  - The infiltration rate is lower than typical for bioretention soil; some compaction of the bioretention soil was noted during the soil probing.

- Native subgrade infiltration rate: Interpreted to be less than 2 in/hr; the infiltrated water appeared to be mounding on top of perched groundwater.

- Shallow groundwater is present in the location of the RSH facility as measured in the well point and documented in the hand-auger explorations. AESI interprets that the infiltration test water mounded on the bioretention soil and slows soaked vertically downward and caused a moderate rise in the perched water level. During testing, the lag time in response to start of inflow was approximately 30 minutes.

- The effects of shallow groundwater mounding will increase during the wetter winter months; however, the water level height is interpreted to be limited by the elevation at which water discharged from the drain basin into the storm drain overflow system. The ongoing monitoring data will be reviewed for groundwater influence.

- AESI notes that the drain basin, with a grated metal lid, and which discharges into the storm drain via a pipe with a 1-inch orifice, had a piece of plastic trash floating in it at the time of out site visit. It is possible that a large piece of plastic trash or other debris could block the 1-inch orifice, preventing the underdrain from functioning.

- In our opinion, the facility will experience more frequent bypass overflows due to the low-set overflow, the somewhat compacted bioretention soil and low infiltration rate, and the proximity of the secondary inflow to the overflow.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

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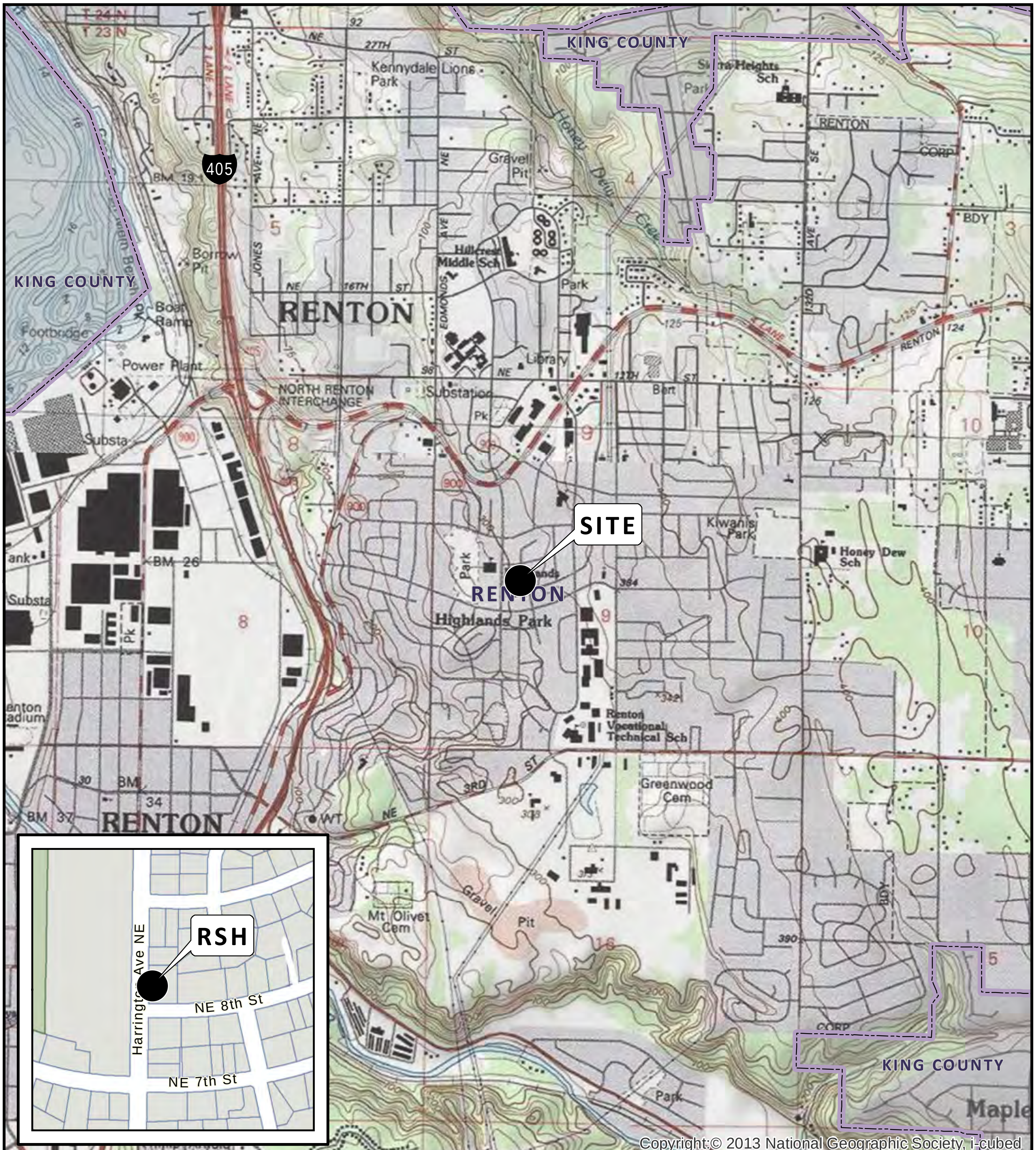
6/14/19

Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure RSH F1:	Vicinity Map
	Figure RSH F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

JHS/ld
150387H007-8
Projects\20150387\KH\WP



DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
KING CO: STREETS, CITY LIMITS 1/18, PARCELS 8/18

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 1000 2000
FEET

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

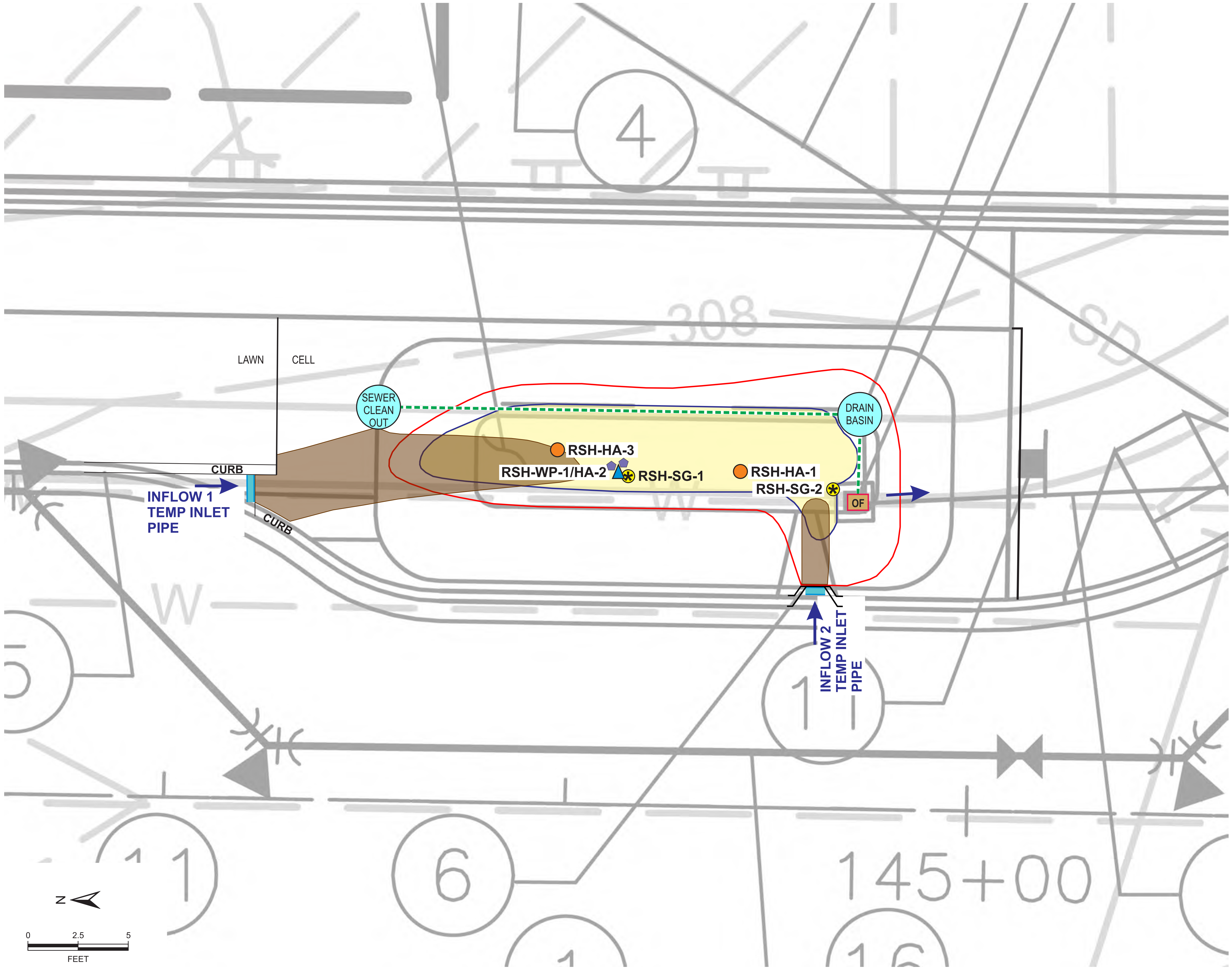
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, RSH SITE
RENTON, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	RSH F1

Document Path: G:\GIS_Projects\aV15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_RSH.mxd



LEGEND:

Symbol	Description
HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
OF	OVERFLOW GRATE - 24" X 18"
	PVC PONDING TUBE
	UNDERDRAIN
	CURB CUT
	ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:

1. BASE MAP REFERENCE: CH2MHILL, HARRINGTON AVENUE NE PHASE II SUNSET COMMUNITY GREEN CONNECTOR, DRW C-2, SHEET 6 OF 24, 5/5/17

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

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN

RSH SITE

BIORETENTION HYDROLOGIC PERFORMANCE

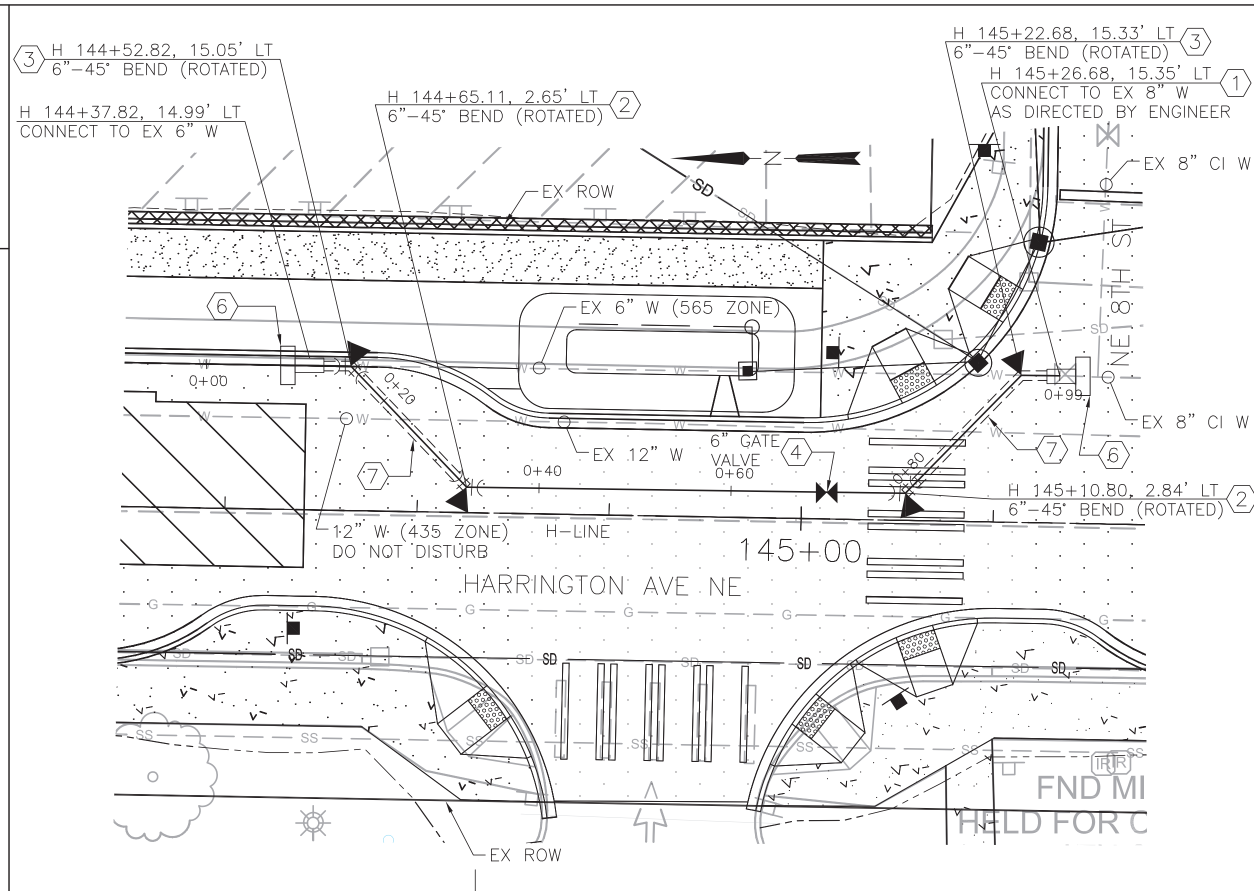
RENTON, WASHINGTON

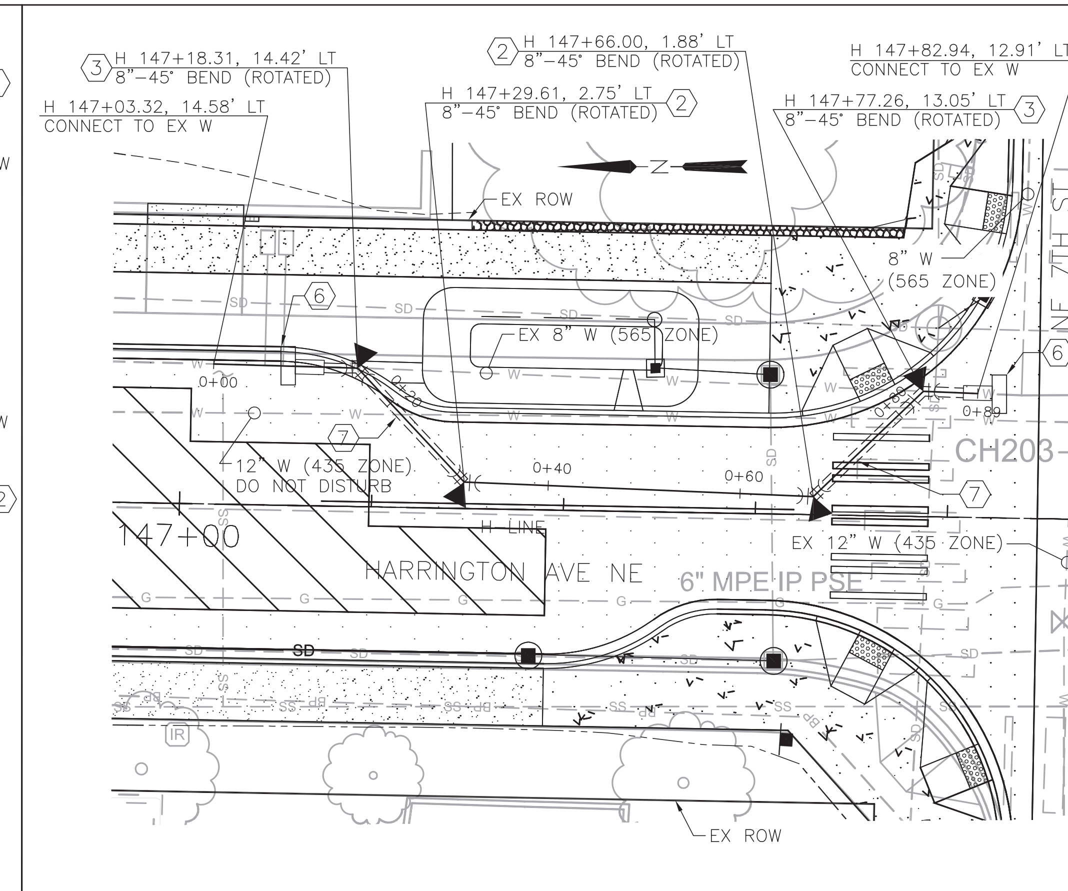
PROJ NO.	DATE:	FIGURE:
150387H007	3/19	RSH F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: RSH F2

APPENDIX A

Project Civil Plans





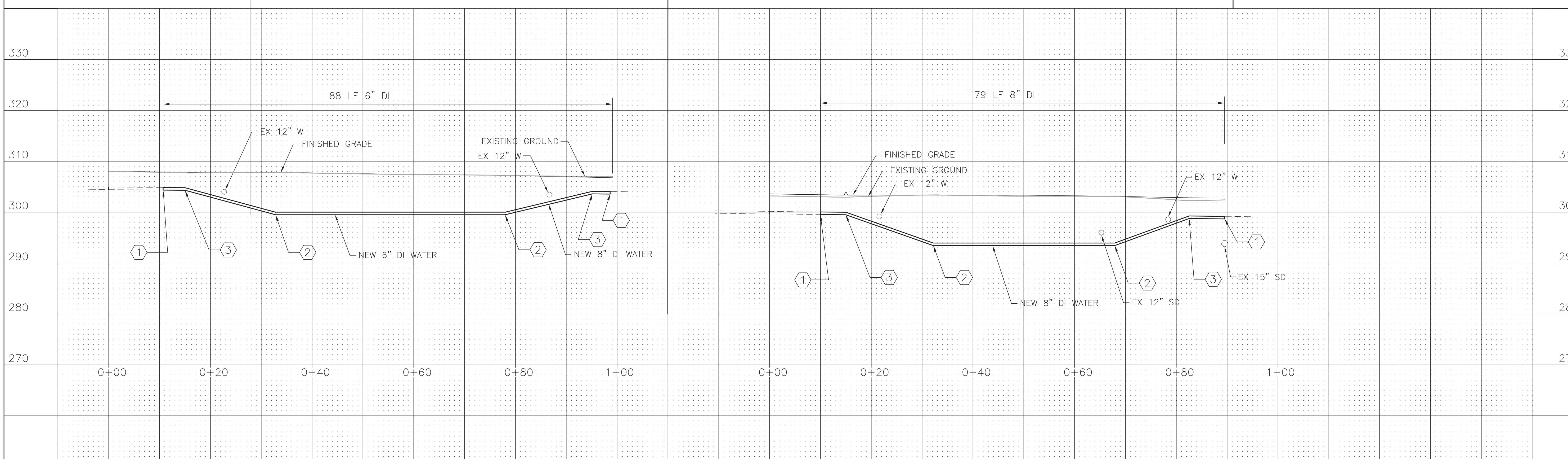
CONSTRUCTION NOTES

1. CONNECT TO EXISTING MAIN WITH DI SLEEVES (MJ X MJ) WITH MEGALUGS
2. INSTALL:
   1 – 45 DEGREE MJ BEND WITH MEGALUGS
   1 – THRUST BLOCK
   PER CITY OF RENTON STANDARD PLAN 330.2
3. INSTALL:
   1 – 45 DEGREE MJ BEND WITH MEGALUGS
   1 – THRUST BLOCK
   PER CITY OF RENTON STANDARD PLAN 330.3, THRUST BLOCK SHALL BE SIZED TO ACCOMMODATE HORIZONTAL AND VERTICAL FORCES. PROVIDE SHACKLE RODS AND TURN BUCKLES IN ACCORDANCE WITH STANDARD PLAN 330.3
4. INSTALL GATE VALVE PER CITY OF RENTON STANDARD PLAN 330.1
5. RECONNECT SERVICE LINE, REPLACE GATE VALVE
6. INSTALL CONCRETE DEAD-MAN BLOCK ON EXISTING WATER MAIN. SEE CITY OF RENTON STANDARD PLAN 330.4.
7. INSTALL 2-3/4" SHACKLE RODS PER CITY ST RENTON STANDARD PLAN 330.5 AND 330.4.

NOTES

1. SEE DRAWINGS C-1 AND C-2 FOR WATER LINE TO BE ABANDONED

10 5 0 10 20
SCALE IN FEET



CH2MHILL

RECOMMENDED FOR APPROVAL
BY ____________
BY ____________

NO.	REVISION	BY	DATE	APPR

SURVEYED: G. BROOKS
DESIGNED: A. ROSHAK
DRAWN: K. LORENTSON
CHECKED: R. CHUNG
APPROVED: D. ATCHISON

SCALE: AS NOTED
ONE INCH AT FULL SCALE IF NOT ONE INCH SCALE ACCORDINGLY

VERTICAL: NAVD 1988
HORIZONTAL: NAD 1983/1991
DATUM

CITY OF RENTON
Planning/Building/Public Works Dept.

HARRINGTON AVENUE NE PHASE II
SUNSET COMMUNITY - GREEN CONNECTION
WATER PLAN

DATE: 05/05/2017
FIELDBOOK:
PAGE:
DRAWING NO: W-2
SHEET: 23 OF 24

100% SUBMITTAL - NOT FOR CONSTRUCTION

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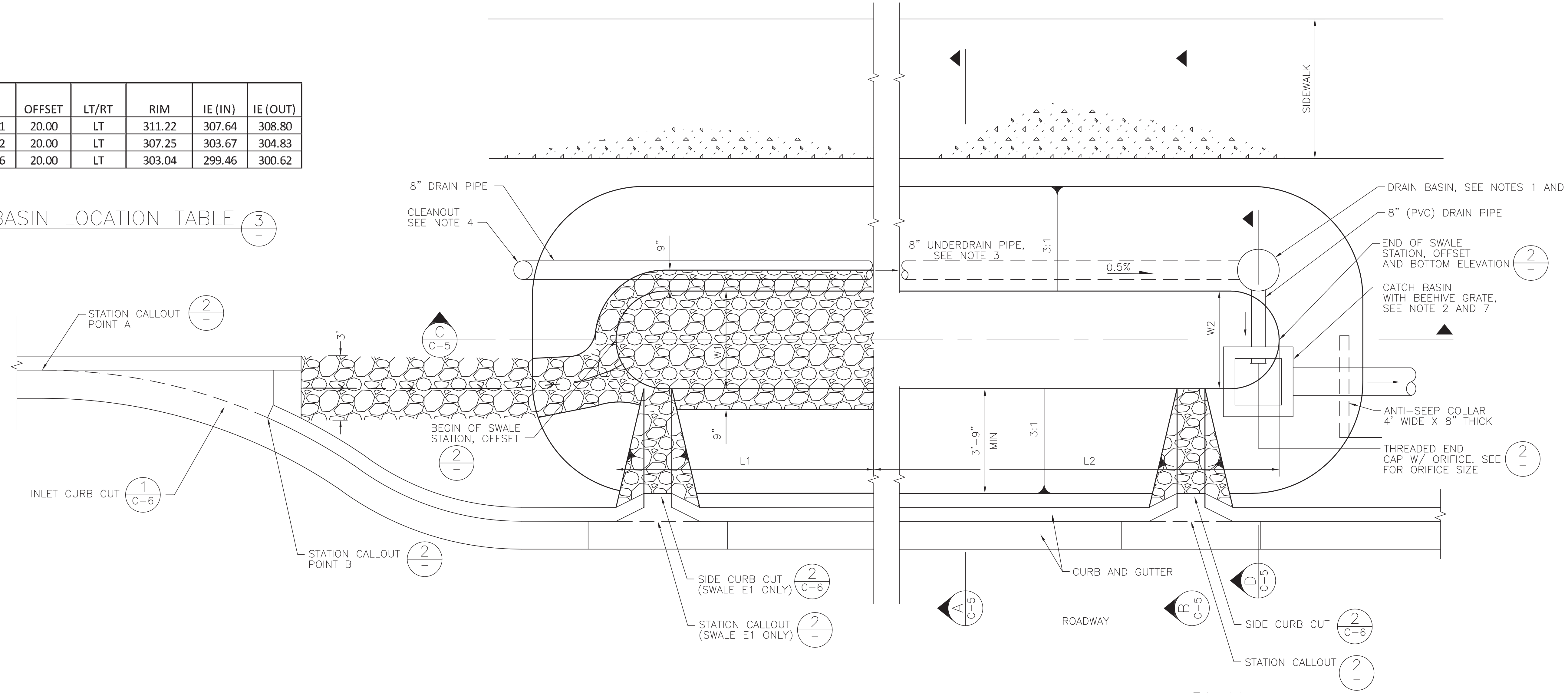
DRAIN BASIN ID	STATION	OFFSET	LT/RT	RIM	IE (IN)	IE (OUT)
2-1	142+50.21	20.00	LT	311.22	307.64	308.80
2-3	144+94.52	20.00	LT	307.25	303.67	304.83
2-5	147+49.26	20.00	LT	303.04	299.46	300.62

DRAIN BASIN LOCATION TABLE 3/–



PLAN

BIORETENTION SWALE DETAIL 1/C-2

SCALE: NTS

	BEGIN OF SWALE			END OF SWALE											
SWALE ID	STATION	OFFSET	LT/RT	STA TO PM	OFFSET	LT/RT	L1	L2	W2	W1	SWALE BOTTOM SLOPE	SWALE BOTTOM ELEVATION	INLET CURB CUT POINT A	INLET CURB CUT POINT B	SIDE CURB CUT
E1	142+16.96	17.00	LT	142+50.96	17.00	LT	8.5	25.5	4.5	2.8	0.50%	310.47	--	--	142+18.46 142+47.46
E2	144+75.27	17.00	LT	144+95.27	17.00	LT	5.0	15.0	4.5	3.6	0.50%	306.50	144+55.6	144+63.68	144+91.77
E3	147+30.01	17.00	LT	147+50.01	17.00	LT	5.0	15.0	4.5	3.2	0.50%	302.29	147+10.3	147+18.40	147+46.51

BIORETENTION SWALE TABLE 2/–

NOTES:

1. FOR L1 AND L2, SEE SECTION C/C-5
2. SWALE BOTTOM ELEVATION AT DOWNSTREAM END

NOTES:

1. DRAIN BASIN SHALL BE 18-INCH NYLOPLAST-ADS DRAIN BASIN WITH 12" SUMP AND 18" DIA. LOCKING COVER PEDESTRIAN H-10 OR APPROVED EQUAL.
2. BEEHIVE GRATE SHALL BE OLYMPIC FOUNDRY FRAME AND GRATE SM60BH OR APPROVED EQUAL.
3. UNDERDRAIN SHALL BE SLOTTED, PVC PIPE SCHEDULE 40. SLOT DIMENSIONS ARE 0.064" WIDE X 1.00" LONG SPACED ALONG PIPE AT 0.3" ON CENTER. FOUR SLOTS PER RADIUS AT 40°, 120°, 240° AND 320°.
4. CLEANOUT SHALL BE PER WSDOT STANDARD PLAN B-85.40-00, 8-INCH SEWER CLEANOUT.
5. FOR W1 AND W2, SEE BIORETENTION SWALE TABLE ON THIS SHEET.
6. ANTI-SEEP COLLAR SHALL BE FORMED WITH CDF.
7. SEE D/C-5 FOR DETAILS.

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CH2MHILL

RECOMMENDED FOR APPROVAL
BY ____________
BY ____________

NO.	REVISION	BY	DATE	APPR

SURVEYED: N/A
DESIGNED: J. STICK
DRAWN: K. LORENTSON
CHECKED: R. CHUNG
APPROVED: D. ATCHISON

SCALE: AS NOTED
ONE INCH AT FULL SCALE IF NOT ONE INCH SCALE ACCORDINGLY

VERTICAL: NAVD 1988 HORIZONTAL: NAD 1983/1991
DATUM

CITY OF RENTON
Planning/Building/Public Works Dept.

HARRINGTON AVENUE NE PHASE II
SUNSET COMMUNITY - GREEN CONNECTION
DETAILS

DATE: 05/05/2017
FIELDBOOK:
PAGE:
DRAWING NO: C-4
SHEET: 8 OF 24

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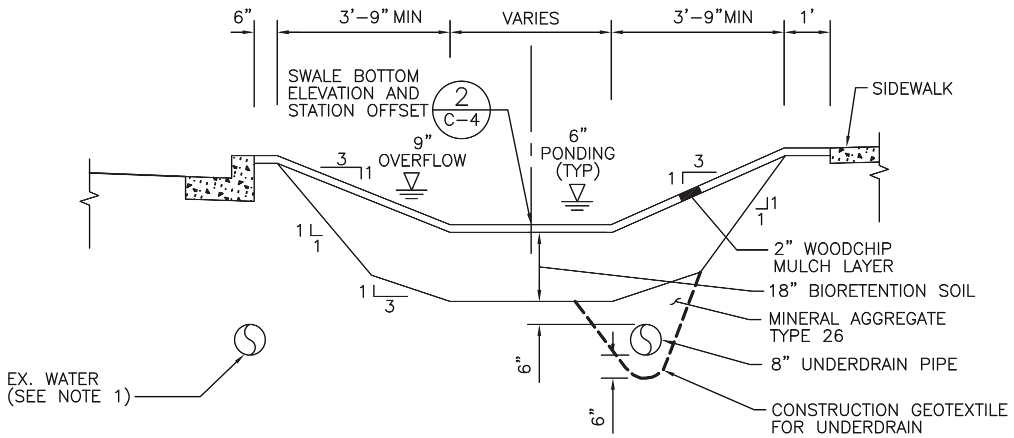
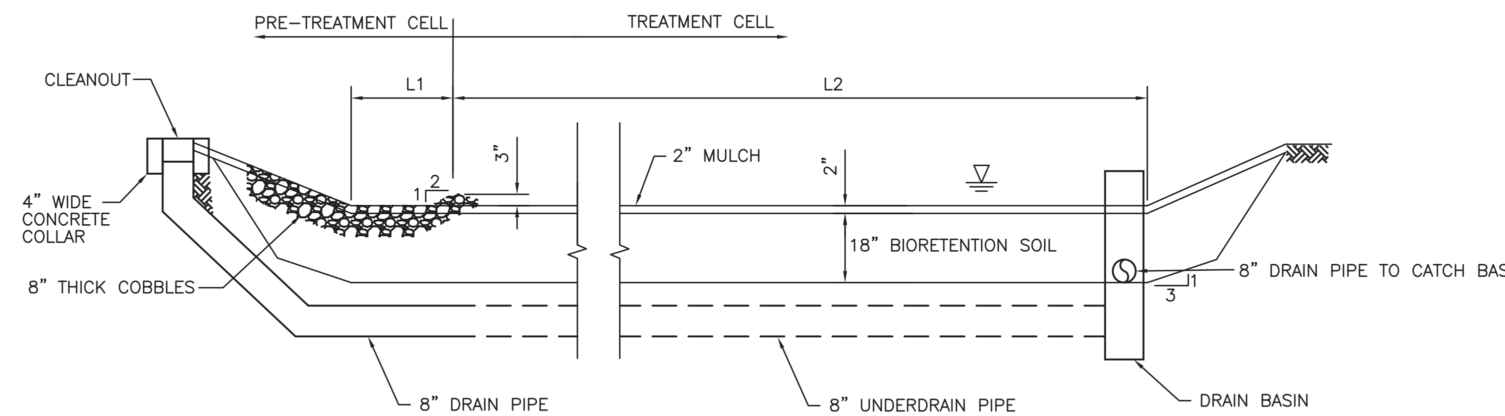


NOTES:

1. CONTRACTOR TO LOCATE AND PROTECT EXISTING WATER LINE.

BIORETENTION SWALE TYPICAL SECTION (A / C-2)

SCALE: NTS

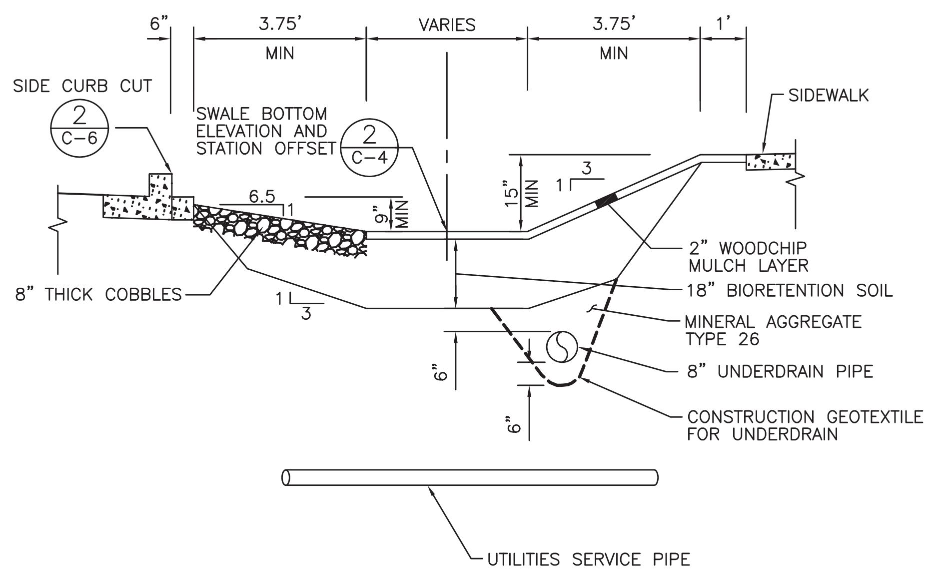


NOTES:

1. FOR L1 AND L2, SEE TABLE (2 / C-4)

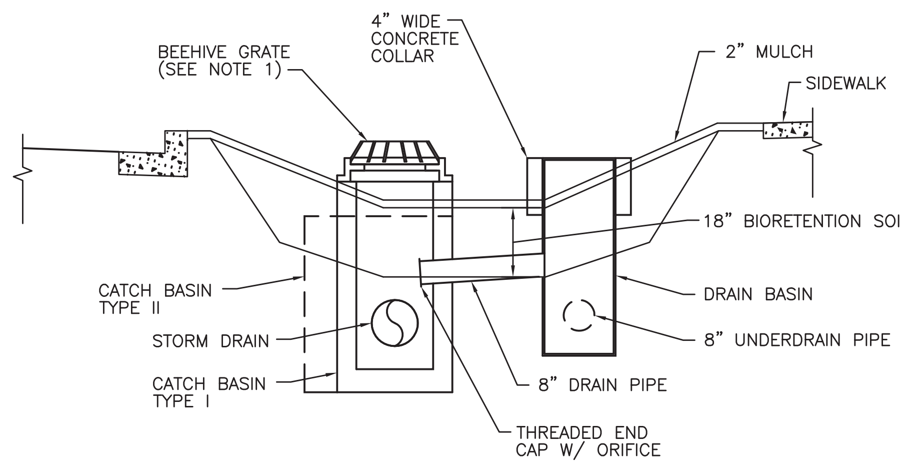
BIORETENTION SWALE TYPICAL LONGITUDINAL SECTION (C / C-2)

SCALE: NTS



BIORETENTION SWALE TYPICAL SECTION AT SIDE CURB CUT (B / C-2)

SCALE: NTS

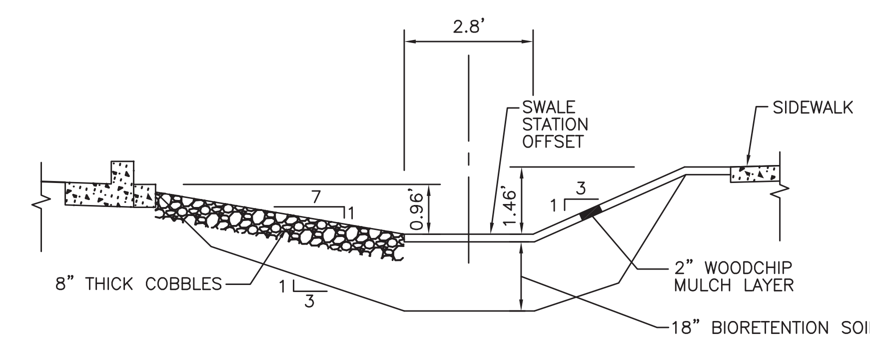


NOTES:

1. STATION CALLOUTS FOR CATCH BASINS AND DRAIN BASIN IN BIORETENTION SWALES ARE TO CENTER OF GRATE.
2. SEE DRAINAGE PROFILES ON SHEET C-3 AND TABLES ON SHEET C-4 FOR DRAINAGE PIPES AND STRUCTURES ELEVATIONS.
3. INSTALL CONCRETE COLLAR TO SECURE THE FRAME AND GRATE OVER THE DRAIN BASIN.

BIORETENTION SWALE TYPICAL SECTION AT CATCH BASIN (D / C-2)

SCALE: NTS



BIORETENTION SWALE E1 SECTION AT SIDE CURB CUT (E / C-2)

SCALE: NTS

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CH2MHILL

RECOMMENDED FOR APPROVAL

BY ____________

BY ____________

NO.	REVISION	BY	DATE	APPR

SURVEYED: N/A
DESIGNED: J. STICK
DRAWN: K. LORENTSON
CHECKED: R. CHUNG
APPROVED: D. ATCHISON

SCALE: AS NOTED

ONE INCH AT FULL SCALE IF NOT ONE INCH SCALE ACCORDINGLY

VERTICAL: NAVD 1988 HORIZONTAL: NAD 1983/1991

DATUM

CITY OF RENTON

Planning/Building/Public Works Dept.

HARRINGTON AVENUE NE PHASE II
SUNSET COMMUNITY - GREEN CONNECTION
DETAILS

DATE: 05/05/2017
FIELDBOOK:
PAGE:
DRAWING NO: C-5
SHEET: 9 OF: 24

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APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	RSH-HA-1	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Renton, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/10/18,10/10/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Fine Mulch and Wood Chips					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, fine SAND, trace to some silt, trace gravel; organic rich; massive (SP/SP-SM).					
		S-2		**Fill** Medium dense,moist, grayish brown, silty, gravelly, fine SAND; massive (SM).					
		S-3		**Vashon Recessional Outwash** Loose to medium dense, moist, light brown, silty, fine SAND to very sandy, SILT, trace gravel; stratified (SM-ML).					
				Becomes very moist, slightly oxidized tan to grayish brown, fine sandy, SILT (ML).					
				Grades to moist, brown, fine SAND, trace to some silt, trace gravel (SP-SM/SP). Difficulty augering 3.2 to 3.7 feet, gravel on side locking auger. Water in base of hole at 3.7 ft.					
				Bottom of exploration boring at 3.7 feet. Apparent seepage at 3/7 feet. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
150387H007	RSH-HA-2/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Renton, WA
Elevation (Top of Well Casing)	101 (Project Datum)	Surface Elevation (ft)	98.4 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/10/18,10/10/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft) | Water Level | WELL CONSTRUCTION | ST | Blows/ 6" | Graphic Symbol | DESCRIPTION

WELL CONSTRUCTION

Coarse mulch 0 to 0.1 feet

Threaded steel pipe 1.25-inch I.D. with threaded, vented PVC cap -2.6 to 1.8 feet

Bioretention soil mix 0.1 to 1.2 feet

Bentonite chips 1.2 to 1.7 feet

Silica sand 1.7 to 3.9 feet

Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 1.8 to 3.9 feet

Threaded steel pipe 1.25-inch I.D. and drive point3.8 to 4.4 feet

Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 6.7 feet.

5

DESCRIPTION

Fine Mulch and Wood Chips

Bioretention Soil Mix

Loose, moist, dark brown, fine SAND, trace to some silt, trace gravel; organic rich; massive (SP/SP-SM).

Vashon Recessional Outwash

Loose to medium dense, moist, brown, very silty, fine SAND, trace gravel (SM); contains sandy, silt interbeds (ML) stratified.

Layer of very moist, tan to grayish brown, sandy, SILT to SILT (ML) from 2.9 to 3.2 feet.

Layer of very moist to wet, brown, silty fine to medium SAND, trace gravel (SM) from 3.2 to 3.9 feet.

Boring terminated at 3.9 feet
Well completed at 4.4 feet on 10/10/18.
Slow seepage 3.5 to 3.9 feet. No caving.
Steel drive point placed in borehole and hand driven with slide hammer to depth of 4.4 feet.

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture	**Logged by:** ADY
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()	**Approved by:** JHS
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)	

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	RSH-HA-3	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Renton, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/10/18,10/10/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Fine Mulch and Organic Deposition					
				Bioretention Soil Mix					
		S-1		Loose, dark brown, moist, fine SAND, trace to some silt, trace gravel; organic rich; massive (SP/SP-SM). Cobbles at 0.5 feet, end of dispersion pad. Interpreted that end of dispersion pad is partially buried in bioretention soil mix					
				Bottom of exploration boring at 0.5 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/10/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- RSH			

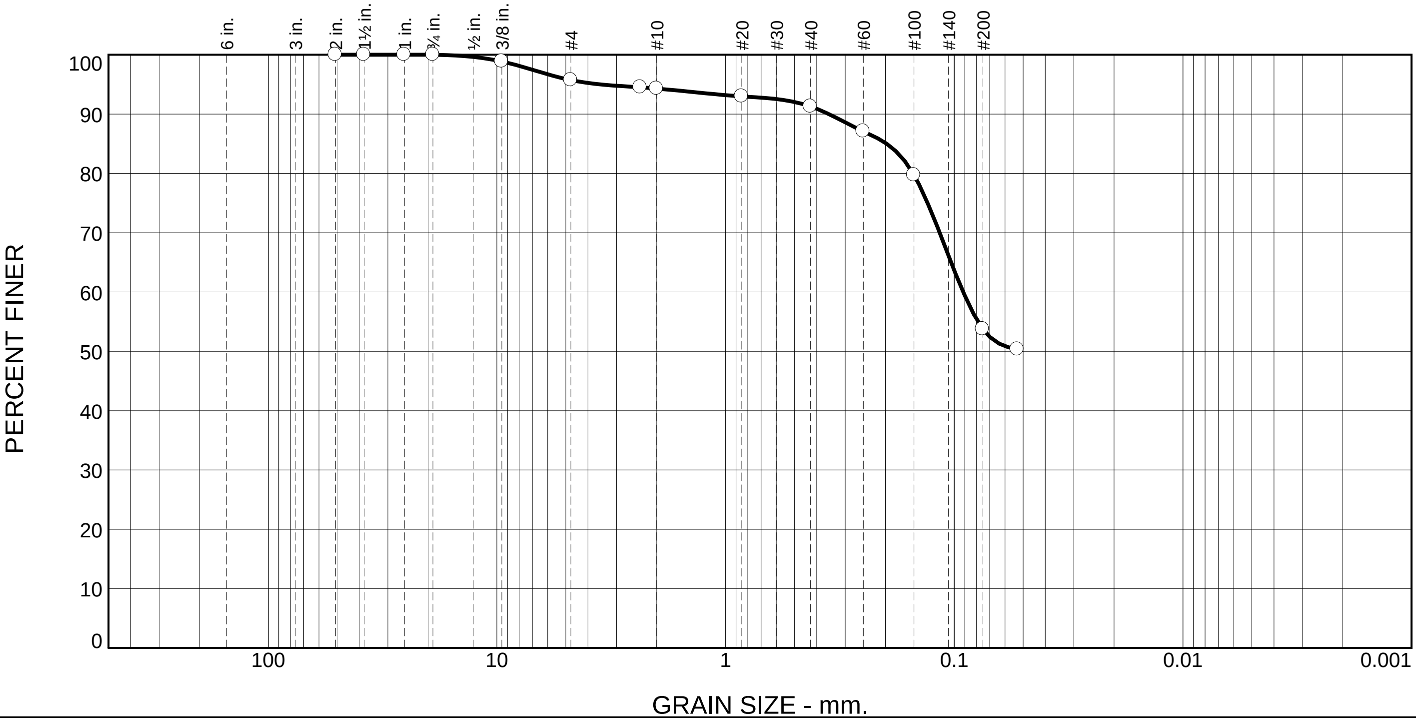
Moisture Content

Sample ID	**HA-1/WP (0.2'-0.5')**	**HA-2 (0.2'-0.5')**
Wet Weight + Pan	**1088.31**	**971.05**
Dry Weight + Pan	**996.60**	**889.95**
Weight of Pan	**517.26**	**534.55**
Weight of Moisture	**91.71**	**81.10**
Dry Weight of Soil	**479.34**	**355.40**
% Moisture	**16.1**	**18.6**

Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	**613.14**	**577.91**
Dry Soil After Burn + Pan	**603.36**	**563.89**
Weight of Pan	**391.92**	**357.91**
Wt. Loss Due to Ignition	**9.78**	**14.02**
Actual Wt. Of Soil After Burr	**211.44**	**205.98**
% Organics	**4.4**	**6.4**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.3	1.4	3.0	37.5	53.8	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
0.75	100.0		
.375	98.9		
#4	95.7		
#8	94.5		
#10	94.3		
#20	93.0		
#40	91.3		
#60	87.1		
#100	79.7		
#200	53.8		
#270	50.3		

* (no specification provided)

Material Description

very sandy SILT, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 0.3539 D_{85}= 0.1977 D_{60}= 0.0914
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 10/16/2018 **Date Tested:** 10/18/2018

Tested By: MS

Checked By: JHS

Title:

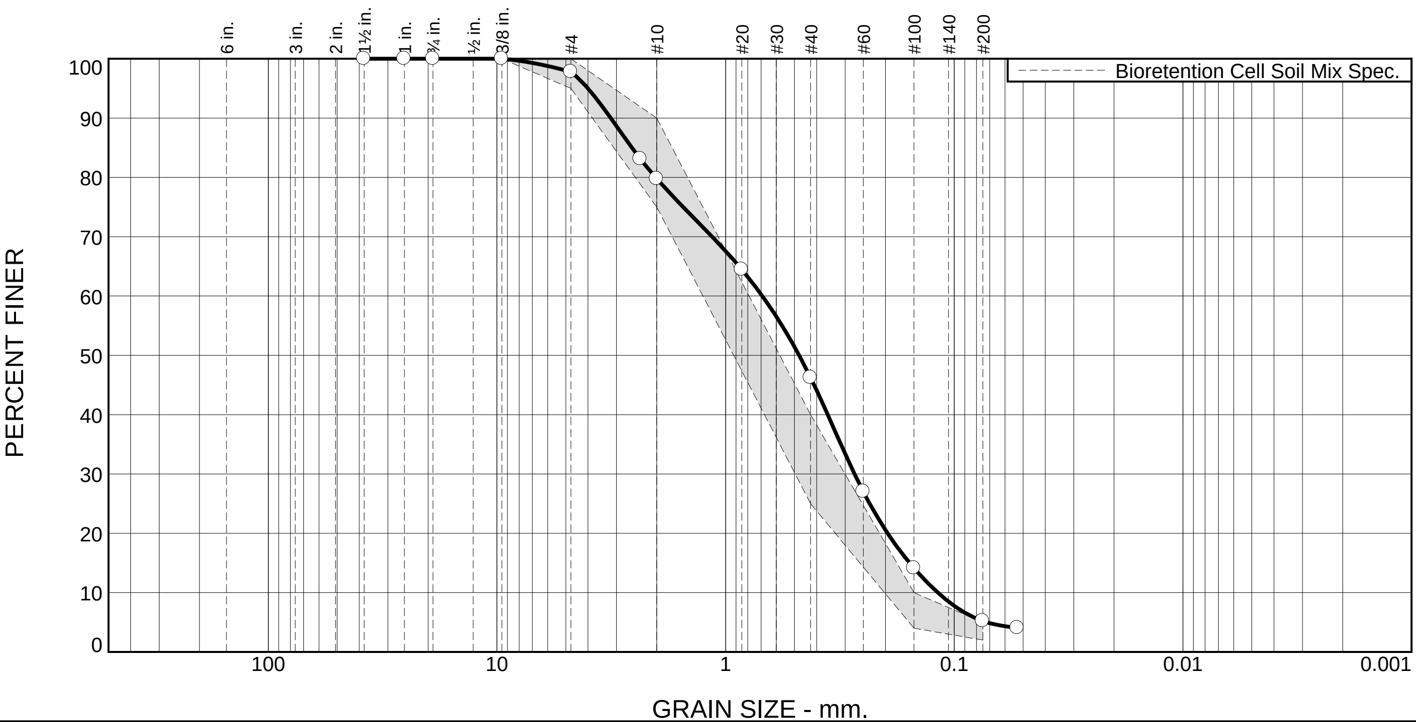
Source of Sample: (RSH) Renton- Sunset Harrington Green Street **Depth:** 2'-2.5' **Date Sampled:** 10/10/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.2	18.0	33.6	41.0	5.2	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.8	95.0 - 100.0	
#8	83.1		
#10	79.8	75.0 - 90.0	
#20	64.5		
#40	46.2	25.0 - 40.0	X
#60	27.0		
#100	14.1	4.0 - 10.0	X
#200	5.2	2.0 - 5.0	X
#270	4.1		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.1786 D_{85}= 2.5689 D_{60}= 0.6912
D_{50}= 0.4769 D_{30}= 0.2730 D_{15}= 0.1567
D_{10}= 0.1180 C_u= 5.86 C_c= 0.91

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/16/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

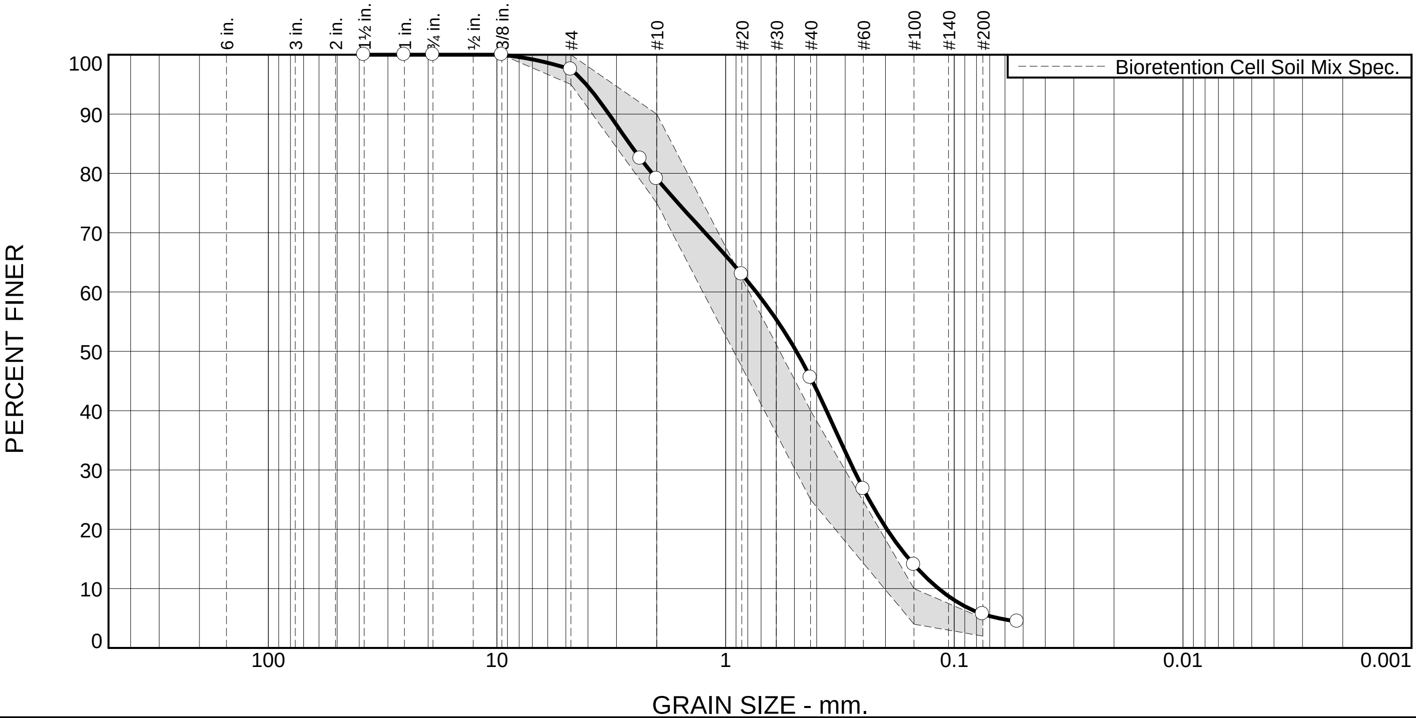
Source of Sample: (RSH) Renton- Sunset Harrington Green Street **Depth:** 0.2'-0.5' **Date Sampled:** 10/10/2018
Sample Number: HA-1/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.5	18.4	33.5	39.9	5.7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.5	95.0 - 100.0	
#8	82.5		
#10	79.1	75.0 - 90.0	
#20	63.0		
#40	45.6	25.0 - 40.0	X
#60	26.8		
#100	14.0	4.0 - 10.0	X
#200	5.7	2.0 - 5.0	X
#270	4.5		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.2387 D_{85}= 2.6301 D_{60}= 0.7349
D_{50}= 0.4906 D_{30}= 0.2748 D_{15}= 0.1578
D_{10}= 0.1171 C_u= 6.27 C_c= 0.88

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/12/2018 **Date Tested:** 12/12/2018

Tested By: BN

Checked By: JHS

Title:

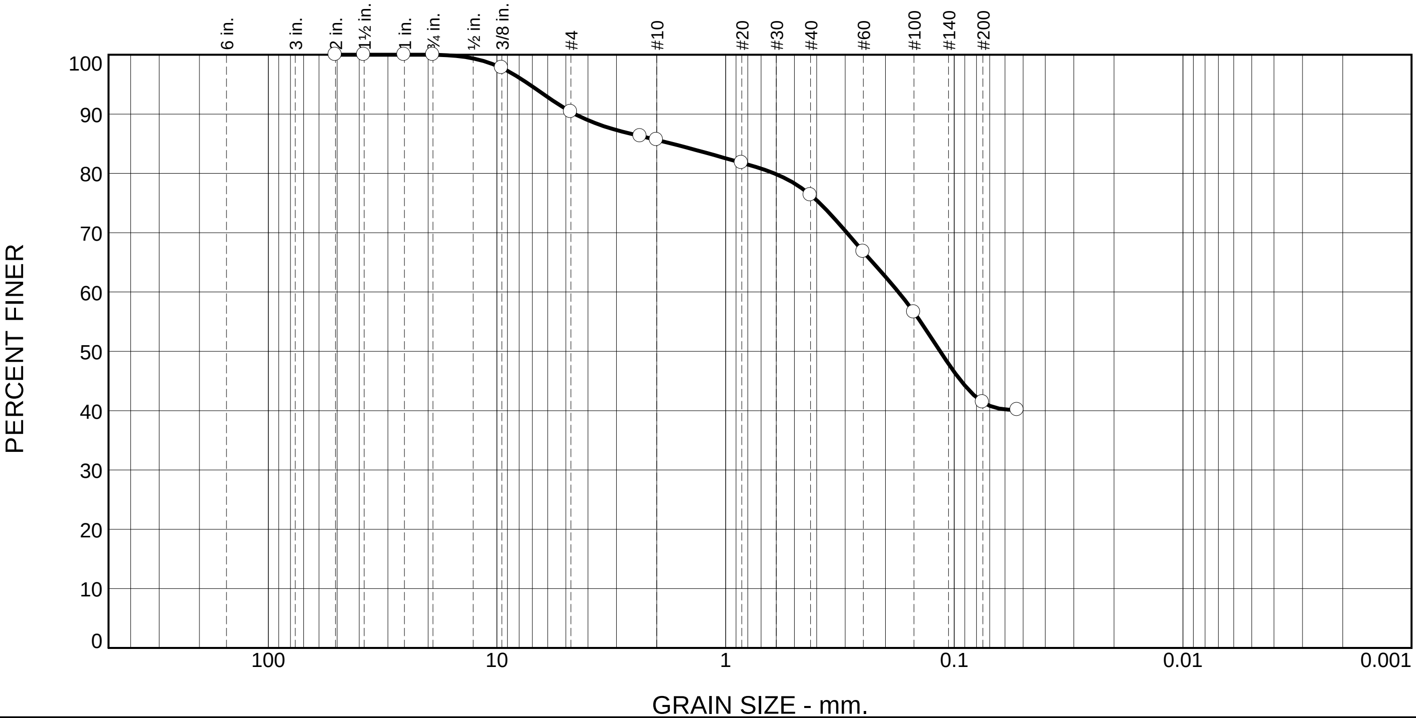
Source of Sample: (RSH) Renton- Sunset Harrington Green Street **Depth:** 0.2'-0.5' **Date Sampled:** 10/10/2018
Sample Number: HA-2/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	9.6	4.8	9.2	35.0	41.4	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	97.8		
#4	90.4		
#8	86.3		
#10	85.6		
#20	81.8		
#40	76.4		
#60	66.8		
#100	56.6		
#200	41.4		
#270	40.1		

* (no specification provided)

Material Description

very silty SAND, some gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 4.5609 D_{85}= 1.7135 D_{60}= 0.1754
D_{50}= 0.1153 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 10/16/2018 **Date Tested:** 10/18/2018

Tested By: MS

Checked By: JHS

Title:

Source of Sample: (RSH) Renton- Sunset Harrington Green Street **Depth:** 1.3'-2'
Sample Number: HA-2/WP **Date Sampled:** 10/10/2018

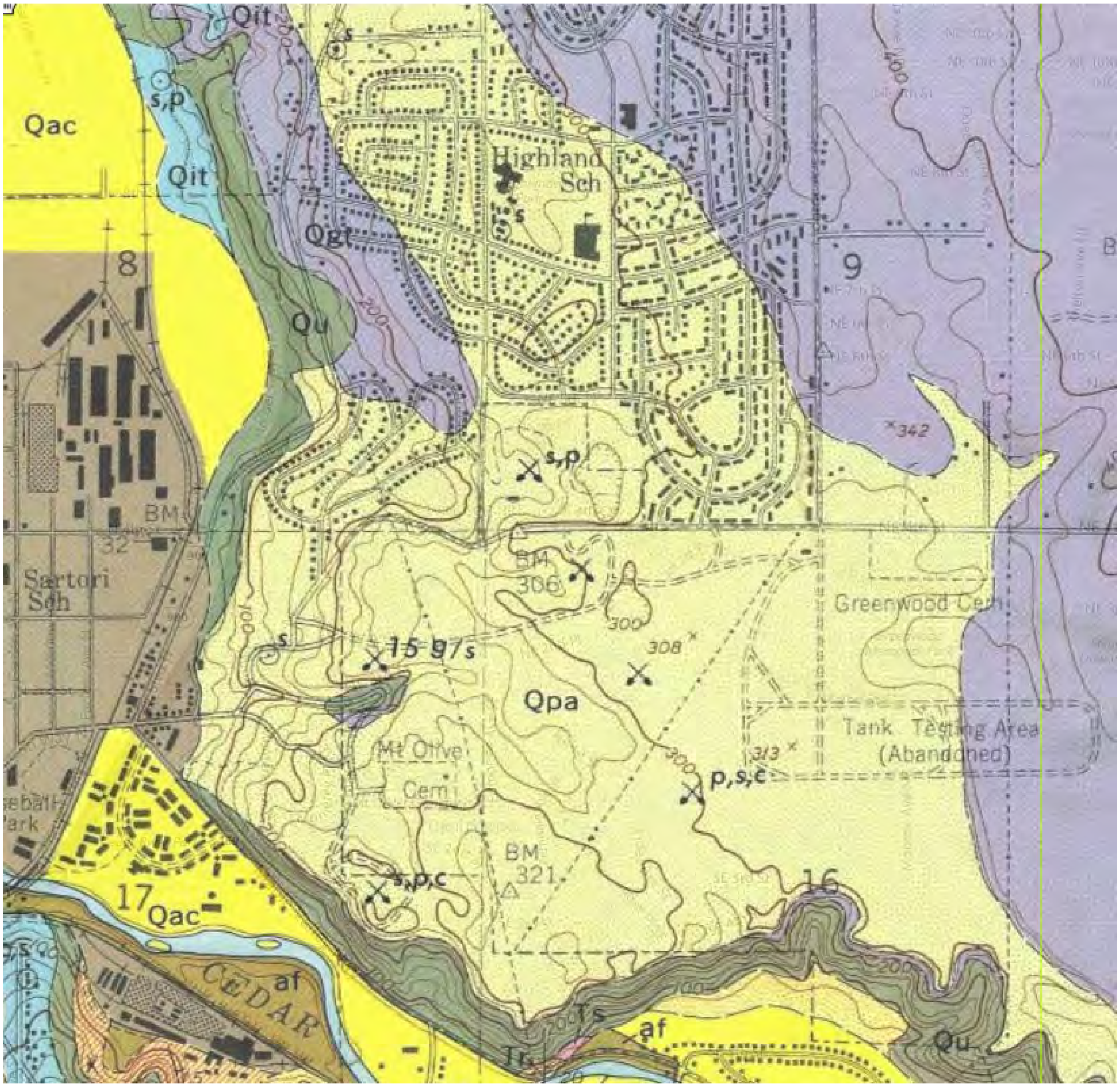
associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Excerpt from:

Mullineaux, D.R., *Geologic Map of the Renton Quadrangle, King County, Washington*, 1965, U.S. Geological Survey (USGS), Geologic Quadrangle Map GQ-405, scale 1:24,000.

Soil Map—King County Area, Washington

Map Scale: 1:20,600 if printed on A portrait (8.5" x 11") sheet.

Meters: 0, 300, 600, 1200, 1800

Feet: 0, 1000, 2000, 4000, 6000

N

Map projection: Web Mercator   Corner coordinates: WGS84   Edge tics: UTM Zone 10N WGS84

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: King County Area, Washington
Survey Area Data: Version 14, Sep 10, 2018

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 31, 2013—Jul 15, 2014

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
AgC	Alderwood gravelly sandy loam, 8 to 15 percent slopes	340.3	15.4%
AgD	Alderwood gravelly sandy loam, 15 to 30 percent slopes	21.5	1.0%
AkF	Alderwood and Kitsap soils, very steep	100.9	4.6%
AmC	Arents, Alderwood material, 6 to 15 percent slopes	416.2	18.8%
An	Arents, Everett material	244.4	11.1%
EvC	Everett very gravelly sandy loam, 8 to 15 percent slopes	29.7	1.3%
EvD	Everett very gravelly sandy loam, 15 to 30 percent slopes	38.5	1.7%
InC	Indianola loamy sand, 5 to 15 percent slopes	257.9	11.7%
InD	Indianola loamy sand, 15 to 30 percent slopes	25.5	1.2%
Pc	Pilchuck loamy fine sand	22.6	1.0%
PITS	Pits	182.5	8.3%
RdC	Ragnar-Indianola association, sloping	215.6	9.8%
RdE	Ragnar-Indianola association, moderately steep	12.9	0.6%
Rh	Riverwash	23.2	1.1%
Sm	Shalcar muck	1.4	0.1%
Ur	Urban land	271.6	12.3%
W	Water	4.0	0.2%
Totals for Area of Interest		**2,208.6**	**100.0%**

Estimated area where till is between 1 and 5 feet below the ground surface.

Figure 4
Shallow Till Locations
Renton Sunset Stormwater Retrofit / LID Project
DRAFT Geotechnical Data and Recommendations Report

APPENDIX D

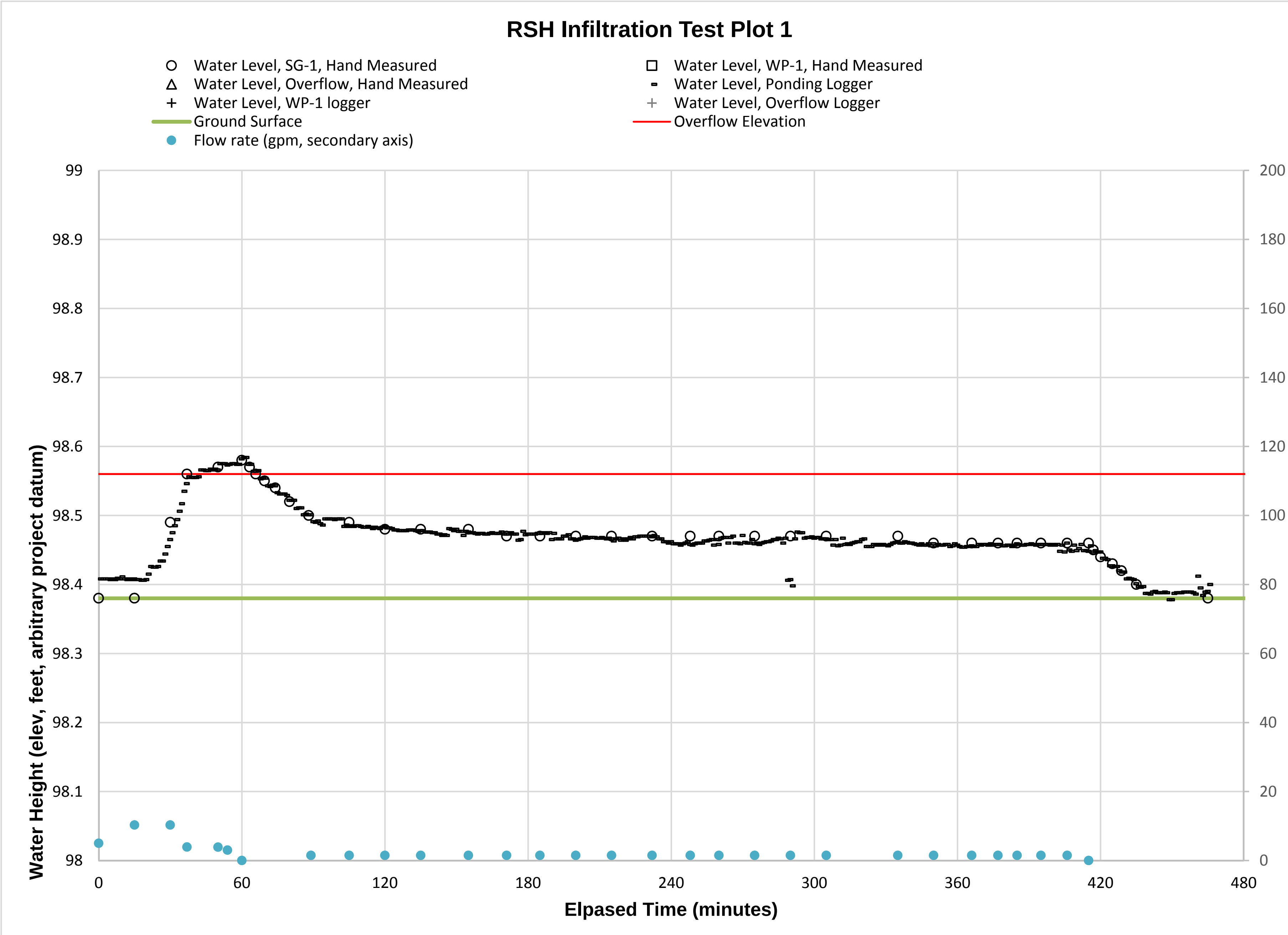
Soil Probe, Level Survey, and Field Infiltration Testing Data

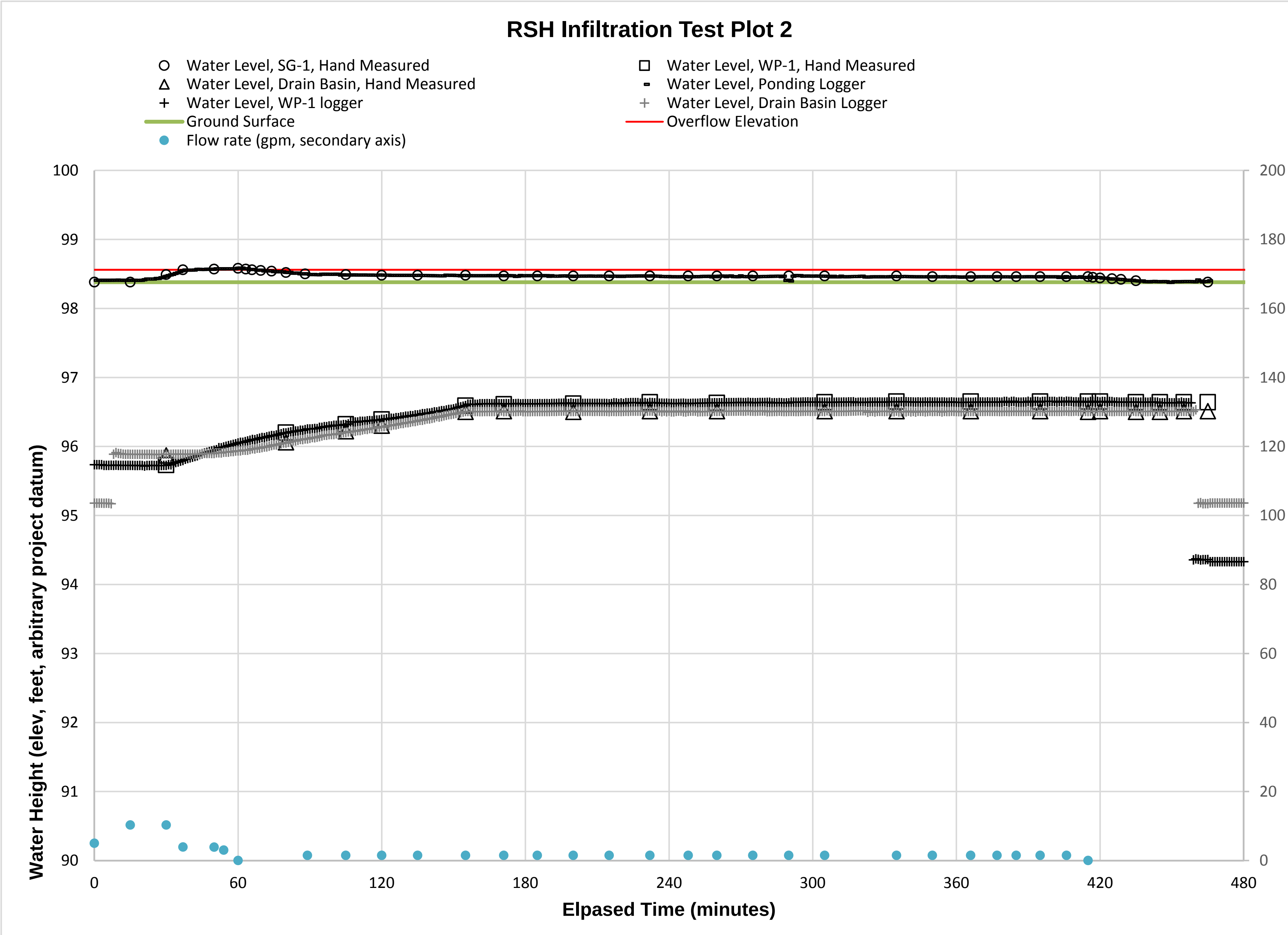
Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM9
Date:	11/5/2018	**Base Area (sq.ft.):**	NA
Weather:	Partly cloudy, 60's	**Ponded Area(sq.ft.):**	80.0
Test No.:	RSH	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
8:18				
8:23				
8:25	5.01	0	0	Flow on
8:40	10.3	0	77.84	
8:55	10.28	0.11	231	Ponding below inlet
9:02	3.91	0.18		
9:15	3.89	0.19	352.23	
9:19	3.02		369.89	
9:25	0	0.2		Flow off.
9:28		0.19		
9:30		0.18		
9:34		0.17		
9:39		0.16		
9:45		0.14		Dripping aroud overflow rim, into overflow.
9:53		0.12		
9:54	1.5		0	Flow on FM8
10:10	1.51	0.11	24.4	
10:25	1.5	0.1	47.52	
10:40	1.49	0.1	70.22	
11:00	1.49	0.1	99.38	dribbling into overflow around edge of metal
11:16	1.5	0.09	123.8	rifice from underdrain, continues through re
11:30	1.5	0.09	145.81	
11:45	1.5	0.09	166.96	
12:00	1.5	0.09	189.64	
12:17	1.49	0.09	214.88	
12:33	1.5	0.09	240	
12:45	1.49	0.09	258	
13:00	1.49	0.09	279	
13:15	1.5	0.09	302	
13:30	1.5	0.09	324	Light rain begins
14:00	1.49	0.09	369	infall becomes moderate. No inflow observe
14:15	1.49	0.08	392	Rain stops. No inflow observed.
14:31	1.49	0.08	416	
14:42	1.5	0.08	433	
14:50	1.49	0.08	446	
15:00	1.49	0.08	459	
15:11	1.49	0.08	475	
15:20	0	0.08	489	Flow off
15:22		0.07		
15:25		0.06		
15:30		0.05		
15:33		0.04		
15:40		0.02		Underdrain still flowing.
15:50		dry		
16:00				

16:10				

	Average Infiltration Rate (in/hr) during last hour of inflow:	1.8
	Average Infiltration Rate (in/hr) during falling head:	2.2


RSH Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, Overflow, Hand Measured
Water Level, WP-1 logger
Ground Surface
Flow rate (gpm, secondary axis)
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, Overflow Logger
Overflow Elevation
Water Height (elev, feet, arbitrary project datum)
99
98.9
98.8
98.7
98.6
98.5
98.4
98.3
98.2
98.1
98
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)


RSH Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, Drain Basin, Hand Measured
Water Level, WP-1 logger
Ground Surface
Flow rate (gpm, secondary axis)
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, Drain Basin Logger
Overflow Elevation
Water Height (elev, feet, arbitrary project datum)
100
99
98
97
96
95
94
93
92
91
90
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elapsed Time (minutes)

APPENDIX E

Site Photos

Cell RSH, primary curb cut inlet. Above photo is prior to install of weir.
Lower photo is after weir install and during infiltration testing. Well point visible.

Above photo: RSH secondary curbcut. Overflow beehive visible in vegetation. Orange cone next to drain basin structure. Lower Photo: view of secondary curbcut, overflow and drain basin.

APPENDIX 10

Deliverable Task 4.5, Site SSW, Geotechnical/Soils Assessment Design Data and Current Conditions, Salem Woods Elementary School, Snohomish County, Washington. Associated Earth Sciences, Inc. 6/14/2019

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ympa Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site SSW, Geotechnical/Soils Assessment Design Data and Current Conditions, Salem Woods Elementary School, Snohomish County, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in Bioretention Cell #2 of the Salem Woods Elementary School Project, located in the Monroe area of unincorporated Snohomish County, Washington (Figure SSW F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 9, 2018, infiltration testing on November 1, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure SSW F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Salem Woods Elementary School Project, located in the Monroe area of unincorporated Snohomish County, Washington as shown on the attached "Vicinity Map" (Figure SSW F1). The Salem Woods Elementary School is located on an approximate 14-acre parcel. The site is located in a rural residential area north of the city of Monroe, bordered by Wagner Road on the east and residential parcels to the north, south, and west. The southwest portion of the site is undeveloped and vegetated with young to mature trees and is occupied by Richardson Creek which enters the site at the western property line and exists to the south. As described in the Drainage Report (Harmsen & Associates, Inc. [Harmsen], 2017), the topography of the site slopes at an average of 2.0 percent from elevation 325 at the northeast corner of the existing parking lot to 310 along the south property line, Richardson Creek and associated wetland is located in a lower area on the southwestern corner of the site, and there is an associated 100-year flood plain along Richardson creek that extends partly onto the school site. According to the Critical Aquifer Recharge Areas Report (AESI, 2016), the site is located in a moderate aquifer sensitivity area with a depth of aquifer between 40 and 100 feet.

Our specific area of study for this project includes bioretention facility cell #2 located on the west-central portion of campus referred to as cell SSW for this study. The attached "Facility and Exploration Plan" (Figure SSW F2) illustrates the cell area and some of the surrounding site features and utilities.

Details of the bioretention facility design and basis for design were presented in the following documents:

- Associated Earth Sciences, Inc., 2016, Subsurface Exploration, Geologic Hazards, and Geotechnical Engineering Report, Salem Woods Elementary School, 12802 Wagner Road, Snohomish County, Washington: Prepared for Monroe Public Schools, July 6, 2016.
- Associated Earth Sciences, Inc., 2016, Critical Aquifer Recharge Areas Report, Salem Woods Elementary School, Snohomish County, Washington: Prepared for Monroe Public Schools, September 28, 2016.
- Associated Earth Sciences, Inc., 2017, In-Situ Infiltration Testing and Design Infiltration Rate Recommendations, Salem Woods Elementary School: Prepared for Monroe Public Schools, May 1, 2017.
- Harmsen & Associates, Inc., 2017, Full Drainage Report for Salem Woods Elementary School, Snohomish County, Washington, January 19, 2017.
- DLR Group, 2017, Salem Woods Elementary School, Construction Documents, May 16, 2017 (plan set).
- Associated Earth Sciences, Inc., 2018, Salem Woods Elementary School, Project No. 160200E004, Selected Field Reports, August 2018.
-

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell SSW consists of an approximately kidney-shaped bioretention cell with approximately 1,170 square feet of base area (DLR Group, 2017), as shown on Figure SSW F2, "Facility and Exploration Plan." We understand that the site was developed under the 2016 *Snohomish County Drainage Manual* for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 1.5 inches per hour (in/hr) for the bioretention soil; in the native subgrade infiltration rate exceeded the bioretention soil rate. As described in the drainage report, land use within the drainage basin consists primarily of pavement and walks (0.46 acres), and landscaping (0.22 acres) with minor roof area (0.03 acres). Per plan sheet C3.20, "Full Drainage Notes & Details" (DLR Group, 2017), the facility design includes 18 inches of bioretention soil mix overlying existing subgrade (native soil).

The facility is designed to infiltrate 100 percent of inflow into the subgrade. Stormwater is designed to enter the facility through two inlets. One inlet is designed as asphalt pavement graded to allow sheet flow to enter the cell on the west side via a small swale at the pavement edge. The second inlet (apparent not installed) is designed as a 6-inch outfall draining a yard drain via a 6-inch polyvinyl chloride (PVC) pipe on the east end. If water ponds up on the bioretention soil, the ponded water would discharge into a Type I Catch Basin (SDCB #4) with a beehive grate located near the west edge of the cell, and then into the perforated pipe laterals in the rock-filled trench situated beneath the bioretention soil. The rim of the Type I Catch Basin was designed to be 12 inches higher than the cell base to create 12 inches of ponding depth. The facility was constructed during July through October 2018 and began receiving runoff in November 2018.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure SSW F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the south corner of the fire hydrant concrete pad north of the cell defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: Although two inflows are indicated on the plan, only one inflow to cell SSW was observed.
    - Primary inflow: The primary inflow to the facility consists of asphalt pavement graded to allow sheet flow to enter the cell on the west side via a small swale at the pavement edge. Inflow discharges onto a quarry spalls energy dissipation pad approximately 6 feet wide and 9 feet long. A significant amount of water was discharging at the time of our November 1, 2018 site visit, and formed a pool of water (about 21 feet by 12 feet) near the inlet and west portion of the cell.

    - Secondary inflow (apparently not installed): A second inflow outfall on the east end of the facility was not observed. A large quarry spall pad was observed on the east end, but the outfall (#9A) and yard drain pipe was not installed. A yard drain (YD#9) is present near the location indicated on plans east of the cell, however the yard drain pipe is directed east away from the cell.

- Overflow: The overflow consists of a Type I Catch Basin (SDCB #4) with a beehive grate. The rim of this grate was approximately 1.4 feet above the base of the facility which is higher than designed at 12 inches of ponding depth (DLR Group, 2017).

- AESI investigated the loose bioretention soil thickness present in cell SSW using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 4-foot to 5-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 0.3 feet to 2.1 feet, and averaged 1.5 feet. Probe data and hand-auger SSW-HA-3 indicate that some compaction of soils has occurred near the north-central portion of the cell. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell SSW
Level Survey Data

Location	Elevation (feet, project datum)
Hydrant concrete pad - south corner	100.00
SSW-WP-1 TOC	97.87
Ground surface at SSW-WP-1 (north) and temporary staff gauge SSW-SG-1	96.21
Ponding Tube TOC (DL)	98.16
Inflow, center inside lip asphalt	97.53
Temporary inlet pipe top/end	97.54
Overflow rim corner (southeast)	97.56
Concrete pad #1, south corner	98.66
Concrete pad #2, south corner	97.87

WP: well point; TOC: top of Casing; DL: datalogger;

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under “Project and Site Description.”

- Dragovich, J., et al., 2015, *Geologic Map of the Lake Roesiger 7.5-minute Quadrangle, Snohomish County, Washington*, Washington State Department of Natural Resources (DNR), scale 1:24,000
- Natural Resources Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed December 2018.
- *Soil Survey of Snohomish County Area, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1983.
- Thomas, B.E., Wilkinson, J.M., and Embrey, S.S., 1997, *The Ground-water System and Groundwater Quality in Western Snohomish County, Washington*: U.S. Geological Survey (USGS), U.S. Department of the Interior.

5.1 Regional Topography and Project Grading

The site and vicinity are generally north of the city of Monroe and west of Wagner Lake. Topographic features in the vicinity of the site were formed by glacial and post-glacial processes. Elongate, northwest-southeast-trending hills and swales parallel the flow direction of an ice sheet that occupied the Puget Lowland about 15,000 years ago, which have been incised by glacial and post-glacial river channels. Elevations on the larger project site range from about 310 to 325 feet.

On a closer scale, the area near cell SSW is relatively level, situated on an outwash terrace at about elevation 310 to 320 feet, and gently sloping southwestward toward Richardson Creek, approximately 200 feet away. The cell is about 10 feet higher in elevation than Richardson Creek. Cell SSW is surrounded generally by access road and parking to the north and west, a large building to the south and lawn to the east.

The project site was previously developed as Salem Woods Elementary School which was demolished to allow for the construction of the new Salem Woods Elementary School. Cell SSW area was previously a relatively level field with elevations of about 316 to 317 feet. Minor cutting (about 5 to 6 feet) was needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the geology map, (Dragovich et al., 2015), the site vicinity is underlain by fluvial outwash deposited during the Vashon Stade of the Fraser Glaciation. The geologic unit was deposited in valleys that remained after the Vashon glacier retreated at the end of the Vashon Stade of the Fraser Glaciation. The interpretation of the sediments encountered at the subject site during our geotechnical and infiltration studies (AESI, 2016 and 2017) is generally consistent with the regional geologic map.

- Fluvial Outwash Qgof/Vashon Recessional Outwash (Qvr): Sediments encountered below the existing topsoil and/or fill generally consisted of gray sandy gravel with cobbles and trace amounts of silt. Fluvial outwash deposits were deposited by the retreating continental glacier during the Vashon Stade of the Fraser Glaciation approximately 12,500 to 15,000 years ago. Therefore, these sediments were not glacially consolidated.

Background geotechnical information includes explorations EP-1 to EP-3, EP-11, IT-2, and EB-2 within 100 feet of cell SSW dated June and September 2016 reached depths of about 4 to 19 feet below current grades, and describe material interpreted to be Vashon recessional - fluvial outwash deposits near the surface or underlying existing fill soils. In the explorations, the outwash consisted of sandy gravel to gravelly sand with trace to some silt. The fluvial outwash deposits contain cobbles and occasional boulders and were encountered to depths up to 17 feet below the surface. Interbeds of laminated silts and fine sands were also encountered at a variety of depths between 3 and 12 feet below the surface, within the fluvial deposits in the exploratory pits and the infiltration test pits (AESI, 2016 and 2017). This interpretation is consistent with the geologic mapping in the area.

Infiltration testing was conducted as part of design. Infiltration test IT-2 was located near cell SSW (bioretention cell #2) with a field infiltration rate of about 40 inches per hour. Subsurface information from the footprint of the bioretention cell during construction (Appendix C, August 2018 field report) indicates that the base of the cell was situated in outwash (sandy gravel).

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the soil survey (Natural Resources Conservation Service [NRCS], 1983) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Tokul gravelly loam, 0 to 8 percent slopes. This unit is described as being associated with till plains and hillslopes, and its parent material is listed as volcanic ash mixed with loess over glacial till. A small portion of the site along the north-central property line is classified as Tokul-Winston gravelly loams, 25 to 65 percent slopes. This unit is described as being associated with escarpments and till plains, with parent material being described as volcanic ash over basal till. We recommend that the site soils be considered “outwash” where the outwash soils were more than 5 feet in thickness, consistent with our subsurface explorations. NRCS describes the permeability as moderate above the glacial till and very slow within glacial till (NRCS, 1983).

As described in the Drainage Report (Harmsen, 2017), the pre-developed condition was modeled as Type C soils, not consistent with the background geotechnical data that indicates surface soils in the vicinity of bioretention cell #2 consisting of sand and gravel. Other areas of the site had glacial till at the ground surface.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in Thomas et al. (1997). Thomas et al. (1997) indicate that recessional outwash can be an aquifer where saturated, and that perched groundwater conditions can occur locally within these units. This unit typically overlies Vashon lodgement till, which is described by Thomas et al. (1997) as typically a confining bed.

According to our geotechnical studies at the site (AESI, 2016 and 2017), a thin groundwater-bearing interval is present at shallow depths beneath the site within the coarse-grained fluvial outwash deposits at the contact with the underlying glacial till. Groundwater seepage was encountered in exploration pits EP-1 and EP-2 near cell SSW and was typically encountered just above the top of the Vashon lodgement till. This groundwater likely represents an unconfined shallow aquifer within the fluvial outwash deposits measuring a few to less than 10 feet thick in our explorations. Limited background groundwater level data was collected at two monitoring wells and two well points; groundwater ranged from approximately 8 to 11 feet below ground surface in March 2017 (AESI, 2017), or within about 4 to 6 feet below the top of bioretention soil layer (planned elevation of 312 feet). Hydrographs are included in Appendix C.

Based on groundwater levels recorded during our studies, the aquifer flow direction is generally to the southwest, downslope toward Richardson Creek. The aquifer is recharged by precipitation and responds relatively quickly to rainfall events (AESI, 2017).

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil. Two of the borings were also advanced into native material underlying the bioretention soil (SSW-HA-2 and SSW-HA-3). Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure SSW F2, "Facility and Exploration Plan."

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell SSW were completed on October 9, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring locations are presented on Figure SSW-F2. The hand-auger borings encountered a thin layer of wood chips overlying bioretention soil to a depth of 2.1 to 2.2 feet overlying native Vashon recessional outwash (SSW-HA-2 and SSW-HA-3). Hand-auger SSW-HA-1 was terminated on gravel at the base of the bioretention soil at 2.2 feet. Bioretention soil thickness was 1.9 to 2.0 feet in each boring. No seepage or caving was observed.

6.2 Well Points

One well point was installed in SSW-HA-2 (WP-1) a depth of 3.0 feet, and screened within the bioretention soil and into the native sandy gravel beneath the soil. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell SSW
Well Point Dimensions

Well Point	Exploration in which Well Point was installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
SSW-WP-1	SSW-HA-2	4.7	1.25 inch nominal	1.7	3.0

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Washington State Department of Ecology (Ecology) *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). Two samples of material interpreted as representative of the bioretention soil were tested for grain-size distribution. The data are summarized in Table 3.

Table 3
Summary of Cell SSW
Organic Content and Grain-Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
SSW-HA-2	0.2-0.5	Bioretention Soil	16.8	SAND, some silt, trace gravel (SP-SM)	5.7	9.2	0.8	Sand
SSW-HA-3	0.2-0.5	Bioretention Soil	14.2	SAND, some silt, trace gravel (SW-SM)	5.0	10.0	1.1	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 16.8 to 14.2 percent by weight. This is significantly higher than the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with some silt and trace gravel based on ASTM D2487 USCS. The respective fines content as measured on the No. 200 sieve was 5.0 to 5.7 percent, higher than the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 9.2 to 10.0, meeting the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 0.8 to 1.1, one sample below the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix was also out of the recommended ranges for other sand gradations, containing more than the recommended range of coarse sand. The tested bioretention soil was a poorly to well-graded sand.

7.2 Subgrade

In cell SSW, a sample of native recessional outwash was sieved. The tested material correlates to a very gravelly SAND, trace silt with 1 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the USDA soil texture. The grain-size distributions were normalized to the No. 10 sieve—i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 2.5 percent for the native recessional outwash material.

Grain-size testing from a nearby infiltration test at the time of design (AESI, 2017) is included in Appendix C.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell SSW Site Data

Parameter	Recommended Range	Cell SSW
Organic Content (by weight)	5 to 8 percent	15.5 percent by weight
Cu coefficient of uniformity	4 or greater	9.6
Cc coefficient of curvature	1 to 3	1.0
Sieve Size	**Percent Passing**	
3/8” (9.51 mm)	100	100
#4 (4.76 mm)	95 to 100	96.6
#10 (2.0 mm)	75 to 90	69.9
#40 (0.42 mm)	25 to 40	29.6
#100 (0.15 mm)	4 to 10	10.2
#200 (0.074 mm)	2 to 5	5.4

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a “soaking period,” to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the “constant-head” phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the “falling-head” portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell SSW with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Ponded water levels within the cell were monitored using a temporary staff gauge (SSW-SG-1) marked in 0.01-foot increments installed adjacent well point SSW-WP-1 and within a piezometer (“ponding tube”) with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell SSW is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell SSW

AESI performed infiltration testing on November 1, 2018. Steady rain was noted during the soaking portion of the testing but no rainfall was occurring during the constant-head portion of the test. Significant flow (between 5 and 40 gpm) from the inflow was present from the beginning of the testing through an elapsed time of about 290 minutes. Less than 1 gpm inflow was observed after 290 minutes to the end of the testing.

Table 5
Cell SSW
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant Head Level (feet)	Field Infiltration Rates	
					Constant Head Test (in/hr)	Falling Head Test (in/hr)
SSW (bioretention soil)	940	423	55,522	0.53	greater than native soil infiltration rate	
SSW (subgrade)	interpreted to be similar to wetted area				16	10

in/hr: inches per hour.

During this test, flow was initially adjusted between about 50 and 180 gpm to fill the cell bottom and stabilize the wetted area, then maintained at about 160 gpm for the duration of test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. The entire cell base was wetted after about 30 minutes and a water level of about 0.5 feet was maintained at the staff gauge after approximately 160 minutes (SSW-SG-1, Figure SSW F2). The wetted pool area had been generally stable through most of the soaking and testing period covering an area of about 940 square feet. Approximately 55,500 gallons of water were used.

Perched water in the bioretention cell was monitored in well point SSW-WP-1 using a data logger during the infiltration test and responded to inflow. Groundwater was not observed within the bioretention soil prior to the start of inflow to the bottom depth of SSW-WP-1 (3 feet). The water level in SSW-WP-1 responded to inflow after about 140 minutes, and rose approximately 1.2 feet above the base of the well point to 0.7 feet below ground surface during the course of testing. AESI interprets this lag in response to indicate the time for water from infiltration testing to infiltrate through the bioretention soil and spread out along the contact with the native recessional outwash sediments. The shallow subsurface ponded water level mirrored the surface water ponding level.

After about 7 hours, AESI shut off the flow and monitored water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 40 minutes.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the infiltration rate of the native subgrade.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell SSW was generally consistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- Drainage area: is generally consistent with the plans. Site design documents indicate that the drainage area consists of 0.49 acres of pavement and roof tops and 0.22 acres of lawn. However, we observed that second inflow (outfall #9A) from a yard drain (YD #9) to the east was not directed to cell SSW, but toward the east. Therefore, a portion of the lawn that drains to YD #9 is not draining to cell SSW.

- The overflow is higher than design. Site plans (DLR Group, 2017) indicate that the ponding level was designed as 12 inches and the overflow rim was measured at 1.4 feet.

- Bioretention soil:
  - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was on average about 1.5 feet as indicated on the plan. However an area of compacted soil was identified near the north-central portion of the cell bottom and hand-auger SSW-HA-3.
  - Composition: The soil tested out of the recommended ranges for sand gradations, containing more than the recommended range of coarse sand and slightly too much fine sand and silt.The organic content was significantly higher than the recommended range with an average of 15 percent.

- Subgrade conditions: The subgrade is interpreted to consist of Vashon recessional outwash, as documented during construction (AESI, 2018) and design reports (AESI, 2016 and 2017).

- During infiltration testing, water readily soaked through the bioretention soil mix. Water was observed in the shallow well point (screened at the base of the bioretention soil and into the upper portion of the recessional outwash), demonstrating that water accumulated on the underlying subgrade. The native recessional outwash is interpreted to have a lower permeability than the overlying bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

- Bioretention soil field infiltration rate:

    - Greater than the measured field rate of 16 in/hr.
    - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the native subgrade infiltration rate.
- Shallow groundwater is expected to be present in the location of the SSW facility below the bottom of well point SSW-WP-1 since it was encountered in several explorations onsite (AESI, 2016 and 2017).

- The effects of shallow groundwater mounding will increase during the wetter winter months, and will reduce the effective infiltration rate by reducing the vertical gradient. The ongoing monitoring data will be reviewed for groundwater influence.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall
6/14/19

Anton D. Ypma
Staff Geologist

Suzanne S. Cook, L.G.
Senior Project Geologist

Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure SSW F1:	Vicinity Map
	Figure SSW F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

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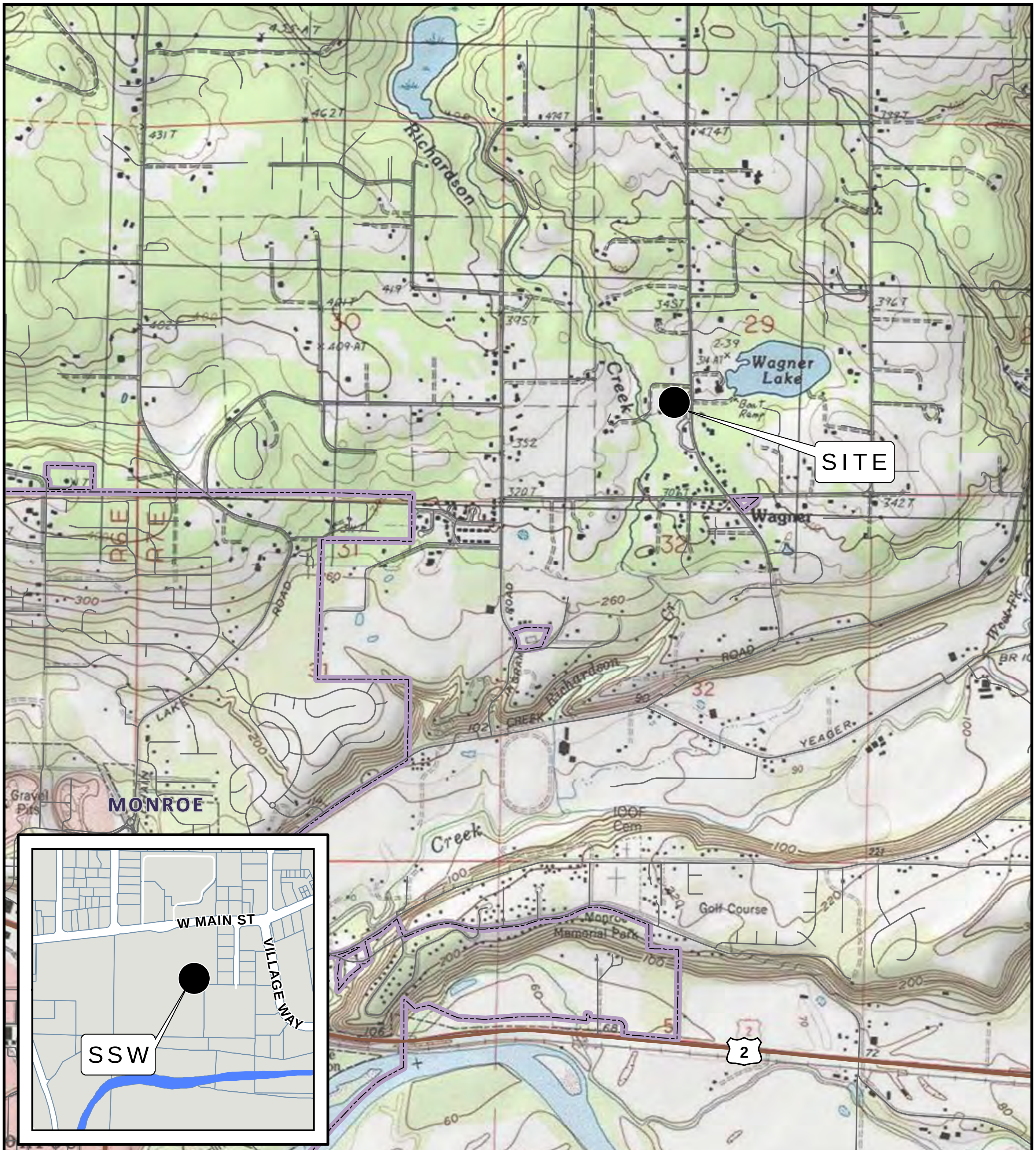
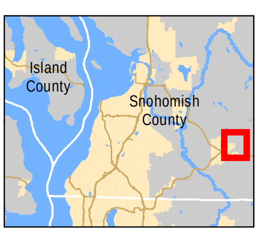




DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NATIONAL GEOGRAPHIC SOCIETY 2013
SNOHOMISH CO: STREETS, CITY LIMITS, PARCELS, 1/18
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 1000 2000
FEET

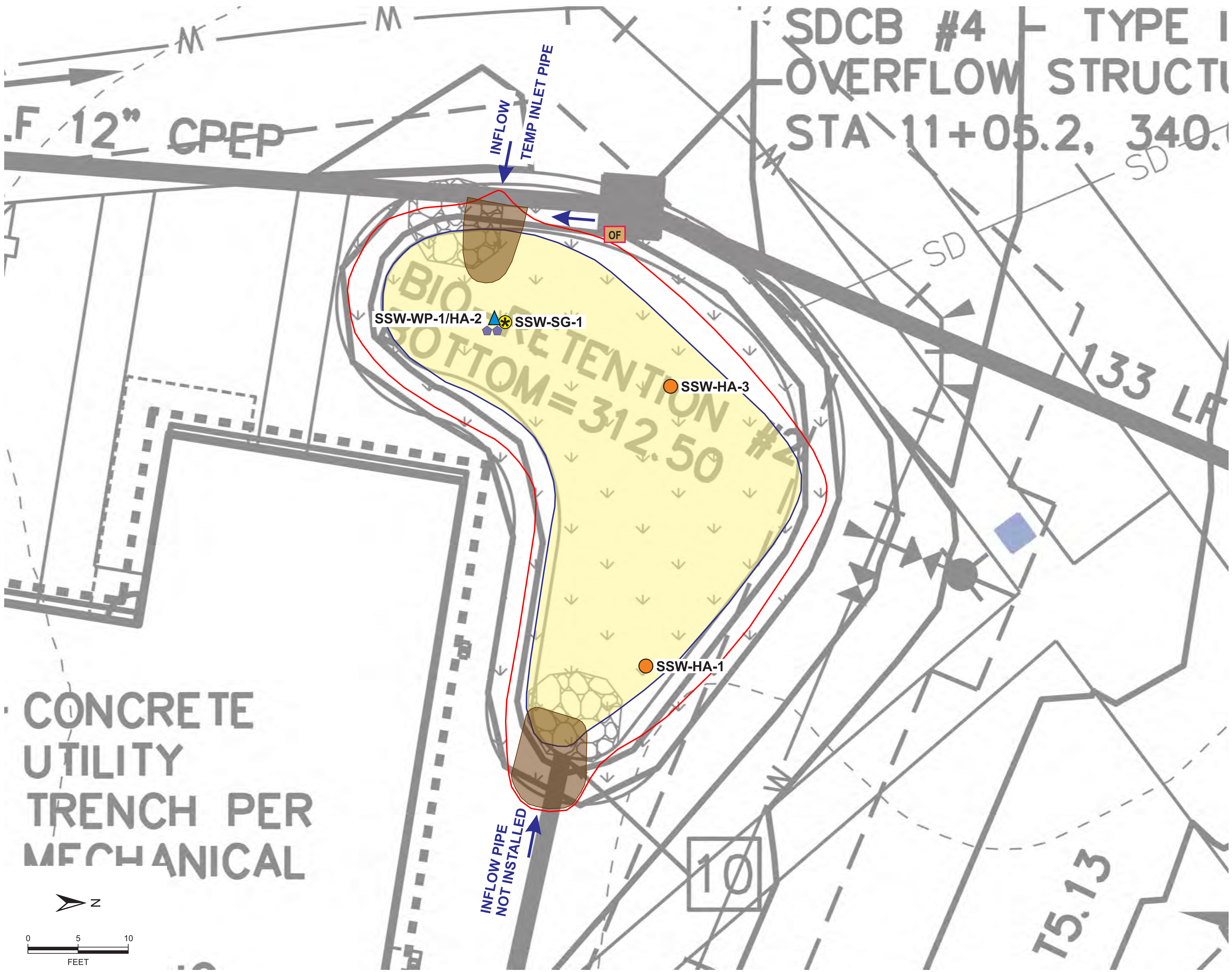
NOTE: BLACK AND WHITE REPRODUCTION OF THIS COLOR ORIGINAL MAY REDUCE ITS EFFECTIVENESS AND LEAD TO INCORRECT INTERPRETATION

associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, SSW SITE
SNOHOMISH COUNTY, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	SSW F1



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:

1. BASE MAP REFERENCE: DLR GROUP, SALEM WOODS ELEMENTARY SCHOOL CONSTRUCTIONS DOCUMENTS, FULL DRAINAGE PLAN, SHEET C3.00, CONFORMED SET, 5/16/17

associated earth sciences incorporated

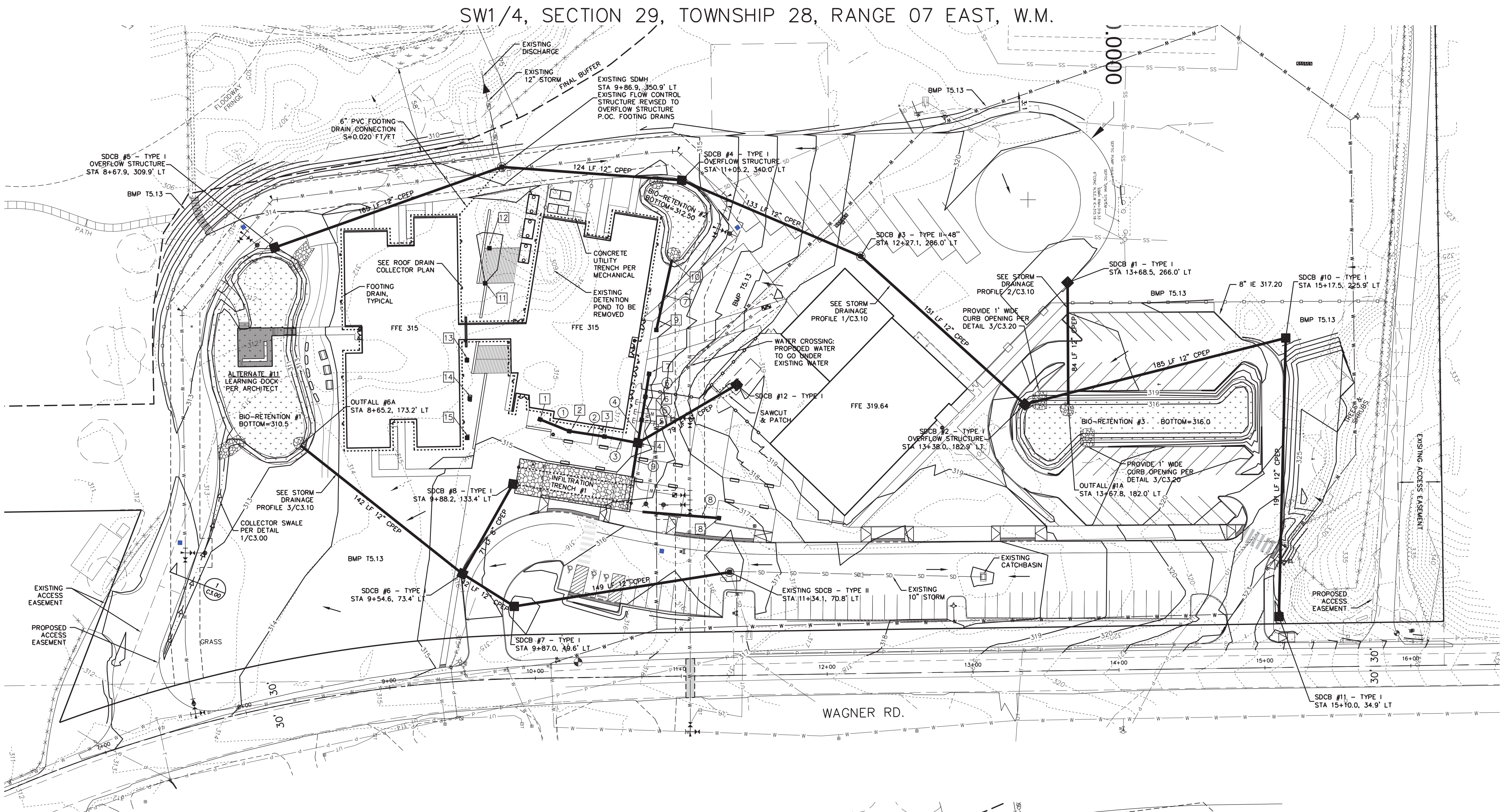
FACILITY AND EXPLORATION PLAN
SSW SITE
BIORETENTION HYDROLOGIC PERFORMANCE
SNOHOMISH COUNTY, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	SSW F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: SSW F2

APPENDIX A

Project Civil Plans



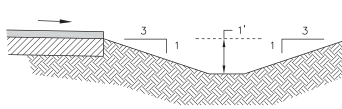
VERTICAL DATUM
NAVD 88 GEOID 12A
ESTABLISHED BY GPS

EQUATION: NAVD 88 – 3.7' = NGVD 29

BENCHMARKS:

TBM #1: PK NAIL SET NORTH SIDE OF DRIVEWAY TO #12620 WAGNER RD. (PT #8) ELEV=329.93'

TBM #2: MAGNETIC NAIL SET IN ASPHALT 1.5' E OF WEST EDGE OF ASPHALT OF WAGNER ROAD 53' S OF SOUTH ENTRANCE TO SCHOOL 13' N OF WATER GATE VALVE. (PT #901) ELEV=315.63'



1 COLLECTOR SWALE DETAIL

SCALE: NONE

YARD DRAIN NOTES

1. YARD DRAINS TO BE CUZ CONCRETE DRIVEWAY CB'S (17"x17") WITH 12"x12" MINIMUM GRATES OR APPROVED EQUAL UNLESS OTHERWISE NOTED
2. DISCHARGE YARD DRAINS TO STORM FACILITY PER YARD DRAIN TABLE.
3. CONNECT YARD DRAINS TO ROOF DRAIN COLLECTOR OR DIRECTLY TO INFILTRATION FACILITY OR BIORETENTION CELL AS APPROPRIATE.

ROOF & YARD DRAIN PIPE NOTES

CONTRACTOR TO DESIGN AND INSTALL ROOF DRAIN COLLECTOR SYSTEM AND CONNECT TO INFILTRATION TRENCH #1.

1. VERIFY DOWNSPOUT LOCATIONS WITH ARCHITECTURAL PLANS.
2. PIPE RUNS SHALL HAVE MINIMUM POSITIVE SLOPE OF 1% AND 6" MIN DIAMETER SMOOTH WALL PIPE PER PLAN.
3. INSTALL CLEANOUTS AT TEES, BENDS 45° OR GREATER AND AT INTERVALS NO GREATER THAN 150 LF.
4. PROVIDE NECESSARY FITTINGS TO CONNECT ROOF STUB TO DOWNSPOUT.

FOOTING DRAIN NOTES

1. CONNECT BUILDING PERIMETER FOOTING DRAINS TO STORM COLLECTION SYSTEM. PROVIDE TO THE ENGINEER A CONNECTION PLAN FOR APPROVAL PRIOR TO CONSTRUCTION OF THE FOOTING DRAIN SYSTEM.
2. PROVIDE 6" PVC PIPE WITH MINIMUM PIPE SLOPE OF 0.5% FROM BOTTOM OF FOOTING DRAIN ELEVATION AT BUILDING TO LOCAL STORM FACILITY.

YARD DRAIN

1 YD #1
STA 10+05.7, 177.4' LT
RIM 314.20
6" IE OUT 312.20

2 YD #2
STA 10+25.7, 169.0' LT
RIM 314.20
6" IE IN 312.00
6" IE OUT 312.00

3 YD #3
STA 10+49.7, 165.0' LT
RIM 314.20
6" IE IN 311.80
6" IE OUT 311.80

4 YD #4 – SDCB TYPE I
STA 10+72.6, 160.3' LT
RIM 314.40
6" IE IN 311.60
8" IE IN 311.52
6" IE OUT 311.60
8" IE OUT 311.52

5 YD #5
STA 10+75.4, 176.0' LT
RIM 314.40
6" IE IN 311.80
6" IE OUT 311.80

6 YD #6
STA 10+78.2, 191.8' LT
RIM 314.40
6" IE IN 312.00
6" IE OUT 312.00

7 YD #7
STA 10+80.9, 207.6' LT
RIM 314.40
6" IE IN 312.20

8 YD #8
STA 11+27.3, 108.0' LT
RIM 316.00
6" IE OUT 314.00

9 YD #9
STA 10+86.3, 237.6' LT
RIM 314.40
6" IE OUT 313.00

10 OUTFALL #9A
STA 10+97.7, 285.5' LT
6" IE IN 312.50

11 YD #10
STA 9+76.3, 271.6' LT
RIM 314.00
CONNECT TO ROOF DRAIN COLLECTOR

12 YD #11
STA 9+79.2, 295.5' LT
RIM 313.55
CONNECT TO ROOF DRAIN COLLECTOR

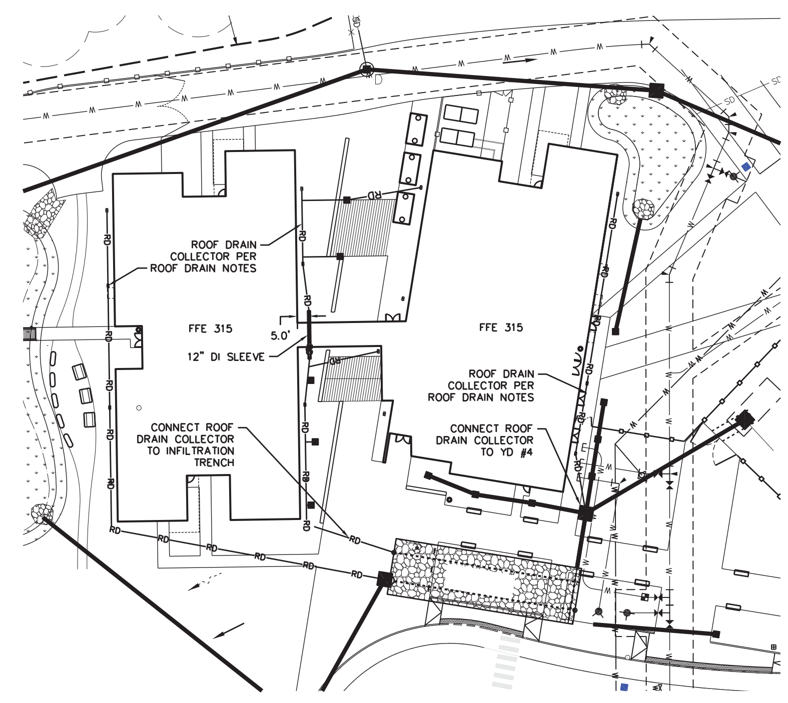
13 YD #12
STA 9+64.4, 219.5' LT
RIM 313.90
CONNECT TO ROOF DRAIN COLLECTOR

14 YD #13
STA 9+64.9, 193.2' LT
RIM 313.90
CONNECT TO ROOF DRAIN COLLECTOR

15 YD #14
STA 9+62.2, 166.3' LT
RIM 313.90
CONNECT TO ROOF DRAIN COLLECTOR

YARD DRAIN PIPES

(1) 22 LF 6" PVC S = 0.009 FT/FT
(2) 24 LF 6" PVC S = 0.008 FT/FT
(3) 23 LF 6" PVC S = 0.009 FT/FT
(4) 16 LF 6" PVC S = 0.012 FT/FT
(5) 16 LF 6" PVC S = 0.013 FT/FT
(6) 16 LF 6" PVC S = 0.013 FT/FT
(7) 49 LF 6" PVC S = 0.010 FT/FT
(8) 53 LF 6" PVC S = 5.977 FT/FT
(9) 23 LF 8" CPEP S = 0.022 FT/FT



ROOF DRAIN COLLECTOR PLAN

SCALE: 1" = 30'

FULL DRAINAGE NOTES

1. THE EXISTING DRAINAGE PATTERN IN THE WORK AREA CONSISTS OF COLLECTION OF STORM WATER IN CATCHBASINS AND DOWNSPOUT LEADERS WITH DISCHARGE TO A DETENTION POND. THE DETENTION SYSTEM DISCHARGES TO THE RICHARDSON CREEK. THE EXISTING SITE FIELDS SHEETFLOW SOUTHWEST INTO THE RICHARDSON CREEK AREA. THE OLD WAGNER COMMUNITY CLUB SITE HAS NO SPECIFIC STORM CONTROLS AND RUNOFF SHEETFLOWS FROM IMPERVIOUS SURFACES AND EITHER INFILTRATES OR FLOWS TOWARDS THE FRONTAGE AND TOWARDS RICHARDSON CREEK DEPENDING ON LOCATION. IN THE DEVELOPED CONDITION, RUNOFF FROM THE NEW STRUCTURES AND PAVED AREAS WILL BE INFILTRATED WITH AN EMERGENCY OVERFLOW SYSTEM THAT UTILIZES THE EXISTING POND DISCHARGE SYSTEM.
2. THERE ARE NO NATURAL STEEP SLOPE AREAS ON THE LOTS. THERE ARE MAN MADE SLOPES AROUND THE EXISTING SCHOOL THAT REACH 50%.
3. THE LOT IS WITHIN A MODERATE AQUIFER SENSITIVITY AREA AND IS NOT WITHIN A WELLHEAD PROTECTION AREA.
4. THERE IS AN EXISTING DETENTION SYSTEM ON FOR THE SCHOOL THAT WILL BE REMOVED. THERE ARE NO EXISTING TREATMENT SYSTEMS. THERE ARE NO EXISTING STORM WATER POLLUTION CONTROL, DETENTION, OR OTHER BMP'S OFF SITE WITHIN 15'.
5. ASSOCIATED EARTH SCIENCE, INC PREPARED A GEOTECHNICAL INVESTIGATION. THE UNDERLYING SOIL IS TOPSOIL OVER SANDS AND GRAVELS (OUTWASH) OVER LODGEMENT TILL. IN SOME AREAS THERE IS SEVERAL FEET OF NATIVE FILL.
6. THE EXISTING GROUND COVER CONSISTS OF TREES, LAWN, ROOFS, PAVEMENT, AND GRAVEL.
7. RICHARDSON CREEK AND ITS ASSOCIATED WETLANDS RUN NORTHWEST TO SOUTH THROUGH THE SOUTHWEST CORNER OF THE PROPERTY.
8. THE DESIGNATED DRAINAGE BASIN FOR THE SITE CONSISTS OF SUBBASINS TRIBUTARY TO BIO-RETENTION CELLS AND INFILTRATION TRENCHES. SEE CALCULATIONS IN THE FULL DRAINAGE REPORT PREPARED FOR THE SITE.
9. SEE LEGAL DESCRIPTION FOR SECTION TIE.
10. FLOOD BOUNDARY PER FIRM PANEL 53061C1100E, NOV 8 1999

PFN: 16-117632 CUP/ 17-101024 LDA

SNOHOMISH COUNTY
PLANNING AND DEVELOPMENT SERVICES
APPROVED FOR CONSTRUCTION

BY__________ DATE:________

R/W PERMIT NO.__________

811 Know what's below. Call before you dig.

CONFORMED SET

12802 WAGNER ROAD
MONROE, WA 98272

FULL DRAINAGE PLAN

SALEM WOODS ELEMENTARY SCHOOL
CONSTRUCTION DOCUMENTS

C3.00

73-16127-00
05/16/2017

DLR Group
Architecture Engineering Planning Interiors

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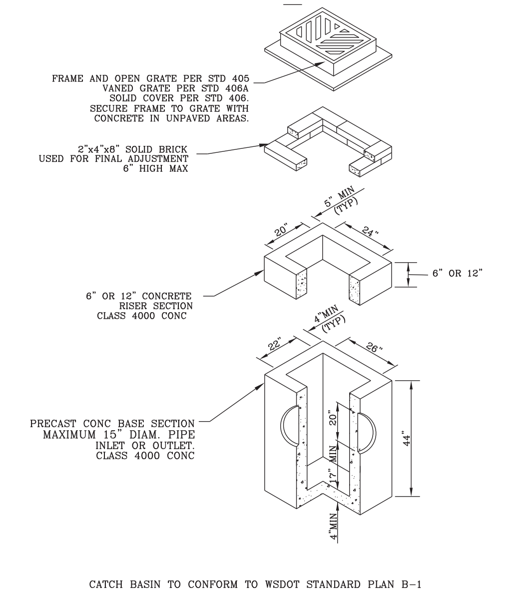


CATCH BASIN TO CONFORM TO WSDOT STANDARD PLAN B-1

NOTES:
MAXIMUM DEPTH FROM FINISH GRADE TO PIPE INVERT SHALL BE 5 FEET.
DEPTHS OVER 5 FEET SEE DETAIL #404

MONROE	TYPE 1 CATCH BASIN	NUMBER 402
	CITY OF MONROE DEPARTMENT OF PUBLIC WORKS	3-1-00

INFILTRATION NOTE:

TO ENSURE PROPER FUNCTIONING OF THE BIO-RETENTION AND INFILTRATION TRENCH AREAS IT IS ABSOLUTELY NECESSARY TO AVOID COMPACTION OF THE UNDERLYING SOILS DURING CONSTRUCTION AND SEDIMENT TRANSPORT INTO THE EXCAVATION DURING CONSTRUCTION. NO HEAVY EQUIPMENT SHALL RUN ACROSS THE BASE OF THE POROUS PAVING AREAS TO PREVENT ANY DAMAGE TO THE UNDERLYING SOILS DURING CONSTRUCTION ACTIVITIES. GEOTECHNICAL ENGINEER SHALL INSPECT AND APPROVE THE SUBGRADE SOILS OF INFILTRATION TRENCHES AND THE EMBEDMENT INTO NATIVE SOILS. SEE GEOTECHNICAL REPORT FOR ADDITIONAL INFORMATION.

BIO-RETENTION CELL CONSTRUCTION NOTES

1. THE BIO-RETENTION CELL SHALL BE OVEREXCAVATED TO ELEVATIONS SHOWN ON GRADING SECTIONS AND FILLED WITH 18" DEPTH OF COMPOST AMENDED SOIL.
2. MINIMUM COMPACTION OF SIDEWALLS AND BASE OF BIO-RETENTION CELL IS ESSENTIAL. KEEP ALL MACHINERY OUTSIDE OF CELL AREA UNDER DIRECTION OF GEOTECHNICAL ENGINEER.
3. SUB-GRADES SHALL BE SCARIFIED, CLEARED OF ALL WEEDS, ROCKS, AND DEBRIS, AND ROUGH GRADED. TOPSOIL SHALL BE ROTOTILLED INTO SUB-GRADE TO A MIN DEPTH OF 8".
4. IF COMPACTION OCCURS IN BOTTOM OF FACILITY DURING EXCAVATION, RIP A MINIMUM OF 12" AND TILL 2 TO 3 INCHES OF AND INTO BASE BEFORE BACKFILLING WITH COMPOST AMENDED SOILS.
5. EXCAVATION FOR THE BIO-RETENTION CELL WILL NOT BE ALLOWED DURING WET WEATHER OR SATURATED SOIL CONDITIONS.
6. SOIL MIXING SHALL OCCUR OUTSIDE/ADJACENT TO THE CELL AREA AND THEN PLACED IN BOTTOM OF CELL.
7. ON-SITE SOIL MIXING SHALL NOT BE PERFORMED IF SOILS ARE SATURATED.
8. FINAL GRADING TO BE ACCOMPLISHED BY HAND.
9. PLANT BOTTOM AND SIDES OF CELL PER LANDSCAPE PLAN.
10. TO PROTECT THE BIORETENTION CELL FROM SEDIMENT LOADING DURING CONSTRUCTION THE INSTALLATION OF THE BIO-RETENTION SOIL AND PLANTINGS SHALL NOT OCCUR UNTIL THE TRIBUTARY AREA DRAINING TO THE CELL HAS BEEN STABILIZED.
DO NOT ROUTE VEHICULAR TRAFFIC THROUGH BIO-RETENTION AREAS AFTER SUBGRADE IS ESTABLISHED.
11. GEOTECHNICAL ENGINEER SHALL VERIFY AND APPROVAL ALL EMBEDMENT INTO NATIVE SOILS FOR INFILTRATION AND BIO-RETENTION SYSTEMS.

STORM DRAINAGE NOTES:

1. ALL STORM DRAIN PIPE MAY BE CONSTRUCTED OF ONE OF THE FOLLOWING MATERIALS UNLESS OTHERWISE SPECIFIED IN THE PLANS. ALL PIPE JOINTS MUST BE GASKETED AND MUST BE OF THE SAME MATERIAL AS THE PIPE. THE PIPE SHALL HAVE MINIMUM COVER AS SHOWN BELOW.
*COVERAGE REQUIREMENTS FOR 18" OR SMALLER:
   < 1.0' REQUIRES RCP (REINFORCED CONCRETE PIPE WITH GASKETED JOINTS, ASTM C-76 CLASS II) MINIMUM OR DUCTILE IRON PIPE.
   1.0' - 1.5' REQUIRES CP (CONCRETE PIPE WITH RUBBER GASKETED JOINTS, ASTM C-14) MINIMUM OR DUCTILE IRON PIPE.
   > 1.5' REQUIRES 16 GAUGE CMP (CORRUGATED METAL PIPE AASHTO M236 TYPE I & II) OR CPEP PIPE WITH DOUBLE GASKETED SLEEVED JOINTS. IN HIGH WATER TABLE AREAS PVC (PVC ASTM D 3034, SDR 35 WITH GASKETED JOINTS SHALL BE REQUIRED.
2. ALL PLASTIC PIPE SHALL BE MADE LOCATABLE BY LAYING VINYL COATED 10 GA. WIRE 1' ABOVE PIPE.
3. ALL STORM DRAIN WORK MUST BE STAKED BY SURVEY FOR LINE AND GRADE PRIOR TO STARTING CONSTRUCTION.
4. THE BACKFILL SHALL BE PLACED EQUALLY ON BOTH SIDES OF THE PIPE IN LAYERS WITH A LOOSE AVERAGE DEPTH OF 6 INCHES, MAXIMUM DEPTH 8 INCHES, THOROUGHLY TAMPING EACH LAYER. THESE COMPACTED LAYERS MUST EXTEND FOR ONE DIAMETER ON EACH SIDE OF THE PIPE OR TO THE SIDE OF THE TRENCH. TO DETERMINE MATERIAL REQUIREMENTS FOR BACKFILL REFER TO WSDOT STANDARD SPEC. 7.08.3(3) AND STANDARD SPEC. 2.03.3(14)C, METHOD B & C.
5. ALL CATCH BASINS WITH A DEPTH OVER 5 FEET TO THE FLOW LINE SHALL BE A TYPE II CB (48" DIAMETER OR LARGER).
6. STORM WATER RETENTION/DETENTION FACILITIES, STORM PIPE, AND CATCH BASINS SHALL BE FLUSHED AND CLEANED PRIOR TO CITY ACCEPTANCE. CONTAMINATED WATER SHALL NOT BE PUMPED INTO AN EXISTING CITY STORM SYSTEM.
7. ALL PIPE AND APPURTENANCES SHALL BE LAID ON A PROPERLY PREPARED FOUNDATION IN ACCORDANCE WITH WSDOT 7.08.3(1). IF, IN THE OPINION OF THE INSPECTOR THE EXISTING FOUNDATION IS UN-SATISFACTORY, THEN IT SHALL BE EXCAVATED BELOW GRADE AND BACKFILLED IN ACCORDANCE WITH STANDARD SPECIFICATIONS (WSDOT 7-08.3(3). PIPE SHALL NOT BE INSTALLED ON SOD, FROZEN EARTH, OR LARGE BOULDERS OR ROCK.
8. ALL GRATES (INLETS AND CATCH BASINS) SHALL BE DEPRESSED 0.1 FEET BELOW PAVEMENT LEVEL.
9. ALL CATCH BASINS AND CURB INLETS SHALL HAVE LOCKING LIDS.
10. STORM STUB OUTS SHALL BE MARKED WITH A 2" X 4" BOARD AND LABELED "STORM" AND EXTENDED 5 FEET ONTO PROPERTY. LOCATOR WIRE TO EXTEND TO TOP OF MARKER BOARD.
11. TESTING AND TV INSPECTION OF STORM DRAIN LINES ARE AT THE CITY OF MONROE OPTION. TRASH RACKS SHALL BE INSTALLED ON THE UPSTREAM AND DOWNSTREAM END OF PIPES, CULVERTS, AND BIOSWALES.
12. HANDHOLDS IN RISER OR ADJUSTMENT SECTION SHALL HAVE 3' MINIMUM CLEARANCE. STEPS IN CATCH BASIN SHALL HAVE 6" CLEARANCE.
13. FOR CATCH BASINS AND CURB INLETS SHALL BE PER CITY OF MONROE STANDARD PLANS.

BMP T5.13: POST-CONSTRUCTION SOIL QUALITY

THIS BMP SHALL BE USED IN THE LANDSCAPED AREAS ON THE SITE AND ANY OTHER DISTURBED AREAS.

PURPOSE AND DEFINITION
NATURALLY OCCURRING (UNDISTURBED) SOIL AND VEGETATION PROVIDE IMPORTANT STORMWATER FUNCTIONS INCLUDING: WATER INFILTRATION; NUTRIENT, SEDIMENT, AND POLLUTANT ADSORPTION; SEDIMENT AND POLLUTANT BIOFILTRATION; WATER INTERFLOW STORAGE AND TRANSMISSION; AND POLLUTANT DECOMPOSITION. THESE FUNCTIONS ARE LARGELY LOST WHEN DEVELOPMENT STRIPS AWAY NATIVE SOIL AND VEGETATION AND REPLACES IT WITH MINIMA! TOPSOIL AND SOD. NOT ONLY ARE THESE IMPORTANT STORMWATER FUNCTIONS LOST, BUT SUCH LANDSCAPES THEMSELVES BECOME POLLUTION-GENERATING PERVIOUS SURFACES DUE TO INCREASED USE OF PESTICIDES, FERTILIZERS AND OTHER LANDSCAPING AND HOUSEHOLD/INDUSTRIAL CHEMICALS, THE CONCENTRATION OF PET WASTES, AND POLLUTANTS THAT ACCOMPANY ROADSIDE LITTER,

ESTABLISHING SOIL QUALITY AND DEPTH REGAINS GREATER STORMWATER FUNCTIONS IN THE POST DEVELOPMENT LANDSCAPE, PROVIDES INCREASED TREATMENT OF POLLUTANTS AND SEDIMENTS THAT RESULT FROM DEVELOPMENT AND HABITATION, AND MINIMIZES THE NEED FOR SOME LANDSCAPING CHEMICALS, THUS REDUCING POLLUTION THROUGH PREVENTION.

APPLICATIONS AND LIMITATIONS
ESTABLISHING A MINIMUM SOIL QUALITY AND DEPTH IS NOT THE SAME AS PRESERVATION OF NATURALLY OCCURRING SOIL AND VEGETATION. HOWEVER, ESTABLISHING A MINIMUM SOIL QUALITY AND DEPTH WILL PROVIDE IMPROVED ON-SITE MANAGEMENT OF STORMWATER FLOW AND WATER QUALITY.

SOIL ORGANIC MATTER CAN BE ATTAINED THROUGH NUMEROUS MATERIALS SUCH AS COMPOST, COMPOSTED WOODY MATERIAL, BIOSOLIDS, AND FOREST PRODUCT RESIDUALS. IT IS IMPORTANT THAT THE MATERIALS USED TO MEET THE SOIL QUALITY AND DEPTH BMP BE APPROPRIATE AND BENEFICIAL TO THE PLANT COVER TO BE ESTABLISHED. LIKEWISE, IT IS IMPORTANT THAT IMPORTED TOPSOILS IMPROVE SOIL CONDITIONS AND DO NOT HAVE AN EXCESSIVE PERCENT OF CLAY FINES.

DESIGN GUIDELINES
SOIL RETENTION
THE DUFF LAYER AND NATIVE TOPSOIL SHOULD BE RETAINED IN AN UNDISTURBED STATE TO THE MAXIMUM EXTENT PRACTICABLE. IN ANY AREAS REQUIRING GRADING REMOVE AND STOCKPILE THE DUFF LAYER AND TOPSOIL ON SITE IN A DESIGNATED, CONTROLLED AREA, NOT ADJACENT TO PUBLIC RESOURCES AND CRITICAL AREAS, TO BE REAPPLIED TO OTHER PORTIONS OF THE SITE WHERE FEASIBLE.

SOIL QUALITY
ALL AREAS SUBJECT TO CLEARING AND GRADING THAT HAVE NOT BEEN COVERED BY IMPERVIOUS SURFACE, INCORPORATED INTO A DRAINAGE FACILITY OR ENGINEERED AS STRUCTURAL FILL OR SLOPE SHALL, AT PROJECT COMPLETION, DEMONSTRATE THE FOLLOWING:

1. A TOPSOIL LAYER WITH A MINIMUM ORGANIC MATTER CONTENT OF TEN PERCENT DRY WEIGHT IN PLANTING BEDS, AND 5% ORGANIC MATTER CONTENT (BASED ON A LOSS-ON-IGNITION TEST) IN TURF AREAS, AND A PH FROM 6.0 TO 8.0 OR MATCHING THE PH OF THE ORIGINAL UNDISTURBED SOIL. THE TOPSOIL LAYER SHALL HAVE A MINIMUM DEPTH OF EIGHT INCHES EXCEPT WHERE TREE ROOTS LIMIT THE DEPTH OF INCORPORATION OF AMENDMENTS NEEDED TO MEET THE CRITERIA. SUBSOILS BELOW THE TOPSOIL LAYER SHOULD BE SCARIFIED AT LEAST 4 INCHES WITH SOME INCORPORATION OF THE UPPER MATERIAL TO AVOID STRATIFIED LAYERS, WHERE FEASIBLE.

2. PLANTING BEDS MUST BE MULCHED WITH 2 INCHES OF ORGANIC MATERIAL

3. QUALITY OF COMPOST AND OTHER MATERIALS USED TO MEET THE ORGANIC CONTENT REQUIREMENTS:
A. THE ORGANIC CONTENT FOR "PRE-APPROVED" AMENDMENT RATES CAN BE MET ONLY USING COMPOST THAT MEETS THE DEFINITION OF "COMPOSTED MATERIALS" IN WAC 173-350-220. THIS CODE IS AVAILABLE ONLINE AT:
HTTP://WWW.ECY.WA.GOVFPROGRAMS/SWFA/FACILITIES/350.HTML.

COMPOST USED IN BIORETENTION AREAS SHOULD BE STABLE, MATURE AND DERIVED FROM YARD DEBRIS, WOOD WASTE, OR OTHER ORGANIC MATERIALS THAT MEET THE INTENT OF THE ORGANIC SOIL AMENDMENT SPECIFICATION. BIOSOLIDS AND MANURE COMPOSTS CAN BE HIGHER IN BIO-AVAILABLE PHOSPHORUS THAN COMPOST DERIVED FROM YARD OR PLANT WASTE AND THEREFORE ARE NOT ALLOWED IN BIORETENTION AREAS DUE TO THE POSSIBILITY OF EXPORTING BIO-AVAILABLE PHOSPHORUS IN EFFLUENT.

THE COMPOST MUST ALSO HAVE AN ORGANIC MATTER CONTENT OF 35% TO 65%, AND A CARBON TO NITROGEN RATIO BELOW 25:1.

THE CARBON TO NITROGEN RATIO MAY BE AS HIGH AS 35:1 FOR PLANTINGS COMPOSED ENTIRELY OF PLANTS NATIVE TO THE PUGET SOUND LOWLANDS REGION.

B. CALCULATED AMENDMENT RATES MAY BE MET THROUGH USE OF COMPOSTED MATERIALS AS DEFINED ABOVE; OR OTHER ORGANIC MATERIALS AMENDED TO MEET THE CARBON TO NITROGEN RATIO REQUIREMENTS, AND MEETING THE CONTAMINANT STANDARDS OF GRADE A COMPOST.

THE RESULTING SOIL SHOULD BE CONDUCIVE TO THE TYPE OF VEGETATION TO BE ESTABLISHED.

IMPLEMENTATION OPTIONS: THE SOIL QUALITY DESIGN GUIDELINES LISTED ABOVE CAN BE MET BY USING ONE OF THE METHODS LISTED BELOW.
1. LEAVE UNDISTURBED NATIVE VEGETATION AND SOIL, AND PROTECT FROM COMPACTION DURING CONSTRUCTION.

2. AMEND DISTURBED SOIL ACCORDING TO THE FOLLOWING PROCEDURES:

A. SCARIFY SUBSOIL TO A DEPTH OF ONE FOOT
B. IN PLANTING BEDS, PLACE THREE INCHES OF COMPOST AND TILL IN TO AN EIGHT-INCH DEPTH.
C. IN TURF AREAS, PLACE TWO INCHES OF COMPOST AND TILL IN TO AN EIGHT-INCH DEPTH.
D. APPLY TWO TO FOUR INCHES OF ARBORIST WOOD CHIP, COARSE BARK MULCH, OR COMPOST MULCH TO PLANTING BEDS AFTER FINAL PLANTING.

ALTERNATIVELY, DISTURBED SOIL CAN BE AMENDED ON A SITE-CUSTOMIZED MALULER SO THAT IT MEETS THE SOIL QUALITY CRITERIA SET FORTH ABOVE, AS DETERMINED BY A LICENSED ENGINEER, GEOLOGIST, LANDSCAPE ARCHITECT, OR OTHER PERSON AS APPROVED BY SNOHOMISH COUNTY.

3. STOCKPILE EXISTING TOPSOIL DURING GRADING, AND REPLACE IT PRIOR TO PLANTING. STOCKPILED TOPSOIL MUST BE AMENDED IF NEEDED TO MEET THE ORGANIC MATTER AND DEPTH REQUIREMENTS BY FOLLOWING THE PROCEDURES IN METHOD (2) ABOVE.

4. IMPORT TOPSOIL MIX OF SUFFICIENT ORGANIC CONTENT AND DEPTH TO MEET THE ORGANIC MATTER AND DEPTH REQUIREMENTS.

MORE THAN ONE METHOD MAY BE USED ON DIFFERENT PORTIONS OF THE SAME SITE. SOIL THAT ALREADY MEETS THE DEPTH AND ORGANIC MATTER QUALITY STANDARDS, AND IS NOT COMPACTED, DOES NOT NEED TO BE AMENDED.

MAINTENANCE
1. SOIL QUALITY AND DEPTH SHOULD BE ESTABLISHED TOWARD THE END OF CONSTRUCTION AND ONCE ESTABLISHED, SHOULD BE PROTECTED FROM COMPACTION, SUCH AS FROM LARGE MACHINERY USE, AND FROM EROSION.

2. SOIL SHOULD BE PLANTED AND MULCHED AFTER INSTALLATION.

3. PLANT DEBRIS OR ITS EQUIVALENT SHOULD BE LEFT ON THE SOIL SURFACE TO REPLENISH ORGANIC MATTER.

BIO-RETENTION CELL SOIL MIX SPECIFICATIONS

SHOULD HAVE A TESTED LONG TERM DESIGN INFILTRATION RATE OF 2"/HR MINIMUM.

MINERAL AGGREGATE

PERCENT FINES: A RANGE OF 2 TO 4 PERCENT PASSING THE #200 SIEVE IS IDEAL AND FINES SHOULD NOT BE ABOVE 5 PERCENT FOR A PROPER FUNCTIONING SPECIFICATION ACCORDING TO ASTM D422.

AGGREGATE GRADATION

THE AGGREGATE PORTION OF THE BSM SHOULD BE WELL-GRADED. ACCORDING TO ASTM D 2487-98 (CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (UNIFIED SOIL CLASSIFICATION SYSTEM)), WELL-GRADED SAND SHOULD HAVE THE FOLLOWING GRADATION COEFFICIENTS:

- COEFFICIENT OF UNIFORMITY (CU = D60/D10) EQUAL TO OR GREATER THAN 4, AND
- COEFFICIENT OF CURVE (CC = (D30)2/D60 X D10) GREATER THAN OR EQUAL TO 1 AND LESS THAN OR EQUAL TO 3.

TABLE 7.4.1 PROVIDES A GRADATION GUIDELINE FOR THE AGGREGATE COMPONENT OF A BIORETENTION SOIL MIX SPECIFICATION IN WESTERN WASHINGTON (HINMAN, ROBERTSON, 2007). THE SAND GRADATION BELOW IS OFTEN SUPPLIED AS A WELL- GRADED UTILITY OR SCREENED. WITH COMPOST THIS BLEND PROVIDES ENOUGH FINES FOR ADEQUATE WATER RETENTION, HYDRAULIC CONDUCTIVITY WITHIN RECOMMENDED RANGE (SEE BELOW), POLLUTANT REMOVAL CAPABILITY, AND PLANT GROWTH CHARACTERISTICS FOR MEETING DESIGN GUIDELINES AND OBJECTIVES.

TABLE 7.4.1

GENERAL GUIDELINE FOR MINERAL AGGREGATE GRADATION	
SIEVE SIZE	PERCENT PASSING
3/8"	100
#4	95-100
#10	75-90
#40	25-40
#100	4-10
#200	2-5

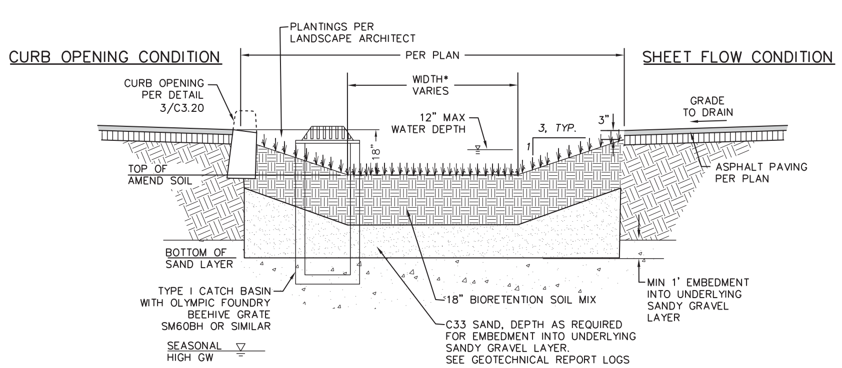
WHERE EXISTING SOILS MEET THE ABOVE AGGREGATE GRADATION, THOSE SOILS MAY BE AMENDED RATHER THAN IMPORTING MINERAL AGGREGATE.
COMPOST TO AGGREGATE RATIO, ORGANIC MATTER CONTENT, CATION EXCHANGE CAPACITY

- COMPOST TO AGGREGATE RATIO: 60-65 PERCENT MINERAL AGGREGATE, 35 - 40 PERCENT COMPOST.
- ORGANIC MATTER CONTENT: 5 - 8 PERCENT BY WEIGHT.
- CATION EXCHANGE CAPACITY (CEC) MUST BE ≥ 5 MILLIEQUIVALENTS/100 G DRY SOIL NOTE: SOIL MIXES MEETING THE ABOVE SPECIFICATIONS DO NOT HAVE TO BE TESTED FOR CEC. THEY WILL READILY MEET THE MINIMUM CEC.

COMPOST

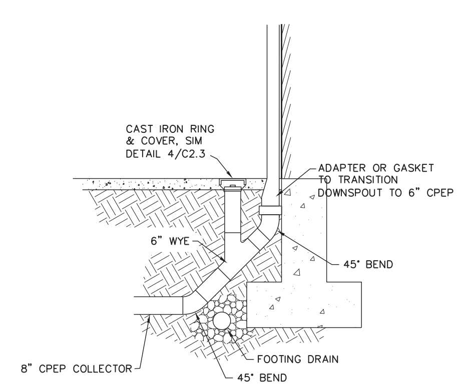
TO ENSURE THAT THE BSM WILL SUPPORT HEALTHY PLANT GROWTH AND ROOT DEVELOPMENT, CONTRIBUTE TO BIOFILTRATION OF POLLUTANTS, AND NOT RESTRICT INFILTRATION WHEN USED IN THE PROPORTIONS CITED HEREIN, THE FOLLOWING COMPOST STANDARDS ARE REQUIRED.

- MEETS THE DEFINITION OF "COMPOSTED MATERIALS" IN WAC 173-350-220 (INCLUDING CONTAMINANT LEVELS AND OTHER STANDARDS), AVAILABLE ONLINE AT HTTP://WWW.ECY.WA.GOV/PROGRAMS/SWFA/ORGANICS/SOIL.HTML
- PRODUCED AT A COMPOSTING FACILITY PERMITTED BY THE WA DEPARTMENT OF ECOLOGY. A CURRENT LIST OF PERMITTED FACILITIES IS AVAILABLE AT HTTP://WWW.ECY.WA.GOV/PROGRAMS/SWFA/COMPOST/
- THE COMPOST PRODUCT MUST ORIGINATE A MINIMUM OF 65 PERCENT BY VOLUME FROM RECYCLED PLANT WASTE AS DEFINED IN WAC 173-350-100 AS "TYPE I FEEDSTOCKS." A MAXIMUM OF 35 PERCENT BY VOLUME OF OTHER APPROVED ORGANIC WASTE AS DEFINED IN WAC 173-350-100 AS "TYPE III", INCLUDING POSTCONSUMER FOOD WASTE, BUT NOT INCLUDING BIOSOLIDS,
- MAY BE SUBSTITUTED FOR RECYCLED PLANT WASTE. TYPE II AND IV FEEDSTOCKS SHALL NOT BE USED FOR THE COMPOST GOING INTO BIORETENTION FACILITIES OR RAIN GARDENS.
- STABLE (LOW OXYGEN USE AND CO2 GENERATION) AND MATURE (CAPABLE OF SUPPORTING PLANT GROWTH) BY TESTS SHOWN BELOW. THIS IS CRITICAL TO PLANT SUCCESS IN A BIORETENTION SOIL MIXES.
- MOISTURE CONTENT RANGE: NO VISIBLE FREE WATER OR DUST PRODUCED WHEN HANDLING THE MATERIAL.
- TESTED IN ACCORDANCE WITH THE U.S. COMPOSTING COUNCIL "TESTING METHODS FOR THE EXAMINATION OF COMPOST AND COMPOSTING" (TMECC), AS ESTABLISHED IN THE COMPOSTING COUNCIL'S "SEAL OF TESTING ASSURANCE" (STA) PROGRAM. MOST WASHINGTON COMPOST FACILITIES NOW USE THESE TESTS.
- SCREENED TO THE SIZE GRADATIONS FOR FINE COMPOST UNDER TMECC TEST METHOD 02.02-B (GRADATIONS ARE SHOWN IN THE SPECIFICATION IN AN APPENDIX OF THE LOW IMPACT DEVELOPMENT TECHNICAL GUIDANCE MANUAL FOR PUGET SOUND)
- PH BETWEEN 6.0 AND 8.5 (TMECC 04.11-A). IF THE PH FALLS OUTSIDE OF THE ACCEPTABLE RANGE, IT MAY BE MODIFIED WITH LIME TO INCREASE THE PH OR IRON SULFATE PLUS SULFUR TO LOWER THE PH. THE LIME OR IRON SULFATE MUST BE MIXED UNIFORMLY INTO THE SOIL PRIOR TO USE IN THE BIORETENTION AREA.
- MANUFACTURED INERT CONTENT LESS THAT 1% BY WEIGHT (TMECC 03.08-A)
- MINIMUM ORGANIC MATTER CONTENT OF 40% (TMECC 05.07-A)
- SOLUBLE SALT CONTENT LESS THAN 4.0 MMHOS/CM (TMECC 04.10-A)
- MATURITY GREATER THAN 80% (TMECC 05.05-A "GERMINATION AND VIGOR")
- STABILITY OF 7 OR BELOW (TMECC 05.08-B "CARBON DIOXIDE EVOLUTION RATE")
- CARBON TO NITROGEN RATIO (TMECC 04.01 "TOTAL CARBON" AND 04.02D "TOTAL KJELDAHL NITROGEN") OF LESS THAN 25:1. THE C:N RATIO MAY BE UP TO 35:1 FOR PLANTINGS COMPOSED ENTIRELY OF PUGET SOUND LOWLAND NATIVE SPECIES AND UP TO 40:1 FOR COARSE COMPOST TO BE USED AS A SURFACE MULCH (NOT IN A SOIL MIX).

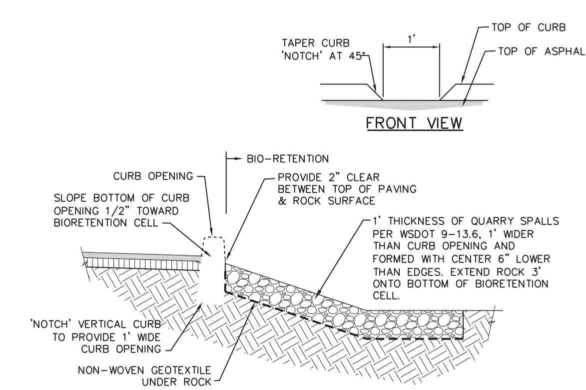


BIORETENTION CELL #	BOTTOM AREA	WIDTH	TOP OF AMEND SOIL	BOTTOM OF SAND LAYER	GROUNDWATER ELEVATION
1	6,700	VARIES	310.5	306.0	303.2
2	1,170	VARIES	312.0	N/A	310.5
3	3,630	VARIES	316.0	N/A	314.5

1 *TYPICAL BIORETENTION CELL DETAIL*
SCALE: *NONE*



2 *DOWNSPOUT CONNECTION & CLEANOUT DETAIL*
SCALE: *NONE*



3 *CURB OPENING DETAIL*
SCALE: *NONE*

PFN: 16-117632 CUP/
17-101024 LDA

SNOHOMISH COUNTY
PLANNING AND DEVELOPMENT SERVICES
APPROVED FOR CONSTRUCTION
BY:____________ DATE:________
R/W PERMIT NO.____________

Know what's below. Call before you dig.

CONFORMED SET

12802 WAGNER ROAD
MONROE, WA 98272

FULL DRAINAGE NOTES & DETAILS
SALEM WOODS ELEMENTARY SCHOOL
CONSTRUCTION DOCUMENTS

C3.20
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05/16/2017
Revisions

DLR Group
Architecture Engineering Planning Interiors

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associated earth sciences incorporated

FIELD REPORT

911 Fifth Avenue
Kirkland, Washington 98033
Phone: 425-827-7701
Fax: 425- 827-5424
www.aesgeo.com

Date	Project Name		Project No.
08/02/2018	Salem Woods Elem. School		KE160200E004
Location		**Municipality**	**Weather**
12802 Wagner Road		Snohomish County	Rain, 60s
Permit No.		**DPD No.**	**Report No.**
N/A		N/A	57
Engineer/Architect			
Harmsen & Associates/ DLR Group			
Client/Owner			
Monroe School District			
General Contractor/Superintendent			
Tiger Construction and Excavation Inc.			
Grading Contractor/Superintendent			
Tiger Construction and Excavation Inc. / Chuck			

TO: Monroe Public Schools
200 East Freemont Street
Monroe, WA 98272

ATTN: Heidi Hansen

AS REQUESTED BY: Contractor

THE FOLLOWING WAS NOTED:

AESI (Matthew Porter) on site from 09:15 to 16:00 to observe the excavation and construction of bioretention cell #3 and previously excavated bioretention cell #2. Excavation was performed by Tiger Construction using a Hitachi Zaxis Steel-tracked excavator with an approximately 5-foot flat edge bucket.

BC-2 Excavation
Chuck (Tiger) informed AESI that the cell was excavated the previous day (August 1, 2018). AESI observed the bottom of cell was in native sand and gravel. Pictures are included in this field report.

BC-3 Excavation
AESI recommended that the bottom of Bioretention Pond #3 is situated in the native gravels and should be deepened to extend below the observed silt layer. Our recommendation for pond construction also includes a pit drain down the center of the cell extending down to 3 feet above groundwater. AESI was in contact with Chuck (Tiger) and Harmsen in the morning and received updated detail. During excavation of the northern side of the infiltration region of the cell, the subgrade was observed to be a poorly-graded fine to medium sand with trace silt and some gravel. This contrasts with the material to south which is a poorly-graded sandy gravel with trace silt. The observed native sand and gravel is suitable for bioretention pond subgrade. No till was encountered during excavation of the infiltration region.

Elevation (feet)	Feature
~310	Top of silt layer
~309	Bottom of silt layer
308.0	Bottom of cell
306.5	Bottom of pit drain (5 feet wide)
303.5	Groundwater

Construction
After excavation had finished, Tiger began placing drain rock using a front-end loader and the trackhoe excavator. AESI confirmed with Harmsen that no filter fabric will be used on the sides or the bottom of bioretention cell mix. For the future water measurements a piezometer, a 2" PVC with the bottom 3 feet hand slotted with a saw was placed at 306.5' at approximately 18 feet south of the north edge of the infiltration area.

Copies To:
Field Rep: Matthew J. Porter

Date Mailed:
Principal / PM: Kurt Merriman / Tony Romanick

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

AESI FIELD REPORT

To:		Project Name:	Salem Woods Elem. School
Date:	8/2/2018	Project No.:	160200E004
Permit No.		DPD No.	

Photos:

Picture 1: Bioretention Cell #3 excavation showing existing subgrade (310.5'), silt layer, underlying gravel, and groundwater.

Copies To:		Field Rep:	Matthew J. Porter
Date Mailed:		Principal / PM:	Kurt Merriman / Tony Romanick

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AESI FIELD REPORT

To:		Project Name:	Salem Woods Elem. School
Date:	8/2/2018	Project No.:	160200E004
Permit No.		DPD No.	

Picture 2: [Looking NW] BC-3 installation of 2" PVC for piezometer in pit drain area. Subgrade at northern end of infiltration region is a sand rather than a gravel.

Picture 3: [Looking S] BC-3 Top of drain rock.

Copies To:		Field Rep:	Matthew J. Porter
Date Mailed:		Principal / PM:	Kurt Merriman / Tony Romanick

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

AESI FIELD REPORT

To:		Project Name:	Salem Woods Elem. School
Date:	8/2/2018	Project No.:	160200E004
Permit No.		DPD No.	

Picture 4: [Looking W] BC-2 bottom of cell

Picture 5: [Looking S/SW] BC-2 bottom of cell.

Copies To:		Field Rep:	Matthew J. Porter
Date Mailed:		Principal / PM:	Kurt Merriman / Tony Romanick

This document is considered a DRAFT until signed or initialed by an AESI Principal or Project Manager

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	SSW-HA-1	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Snohomish County, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/9/18,10/9/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
				Wood Chips					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some silt, trace gravel; organic rich; massive; organic fragments typically range to 1 inch in size (SP/SP-SM).					
				Bottom of exploration boring at 2.2 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Geologic & Monitoring Well Construction Log

Project Number	Well Number	Sheet
150387H007	SSW-HA-2/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Snohomish County, WA
Elevation (Top of Well Casing)	97.9 (Project Datum)	Surface Elevation (ft)	96.2 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/9/18,10/9/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Wood chips 0 to 0.2 feet				**Wood Chips**
		Threaded steel pipe 1.25-inch I.D. with threaded and vented PVC cap -1.7 to 0.7 feet				**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some silt, trace gravel; organic rich; massive; organic fragments typically range to 1 inch in size (SP/SP-SM).
		Bioretention soil mix 0.2 to 2.4 feet				
		Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 0.7 to 2.6 feet				
						Vashon Recessional Outwash Medium dense, moist, brown, very gravelly, medium SAND, trace silt; no stratification observed (SP).
		Driven into existing sediments 2.4 to 3.3 feet Threaded steel pipe 1.25-inch I.D. and drive point 2.6 to 3.3 feet				Boring terminated at 2.4 feet Well completed at 3.3 feet on 10/9/18. No seepage. No caving. Steel drive point placed in borehole and hand driven with slide hammer to depth of 3.3 feet.
		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 4.7 feet.				
5						

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	SSW-HA-3	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Snohomish County, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/9/18,10/9/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Wood Chips					
		S-1		**Bioretention Soil Mix** Loose to medium dense, moist, dark brown, medium SAND, trace to some silt, trace gravel; organic rich; massive; organic fragments typically range to 1 inch in size (SP/SP-SM). Difficult to advance hand auger - compaction may have occurred.					
				At 2.2 feet Vashon Recessional Outwash - Medium dense, moist, brown, very gravelly, medium SAND, trace silt; no stratification observed (SP).					
				Bottom of exploration boring at 2.3 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/9/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- SSW			

Moisture Content

Sample ID	**HA-2 (0.2'-0.5')**	**HA-3 (0.2'-0.5')**
Wet Weight + Pan	**902.52**	**802.93**
Dry Weight + Pan	**778.69**	**705.54**
Weight of Pan	**467.42**	**426.30**
Weight of Moisture	**123.83**	**97.39**
Dry Weight of Soil	**311.27**	**279.24**
% Moisture	**28.5**	**25.9**

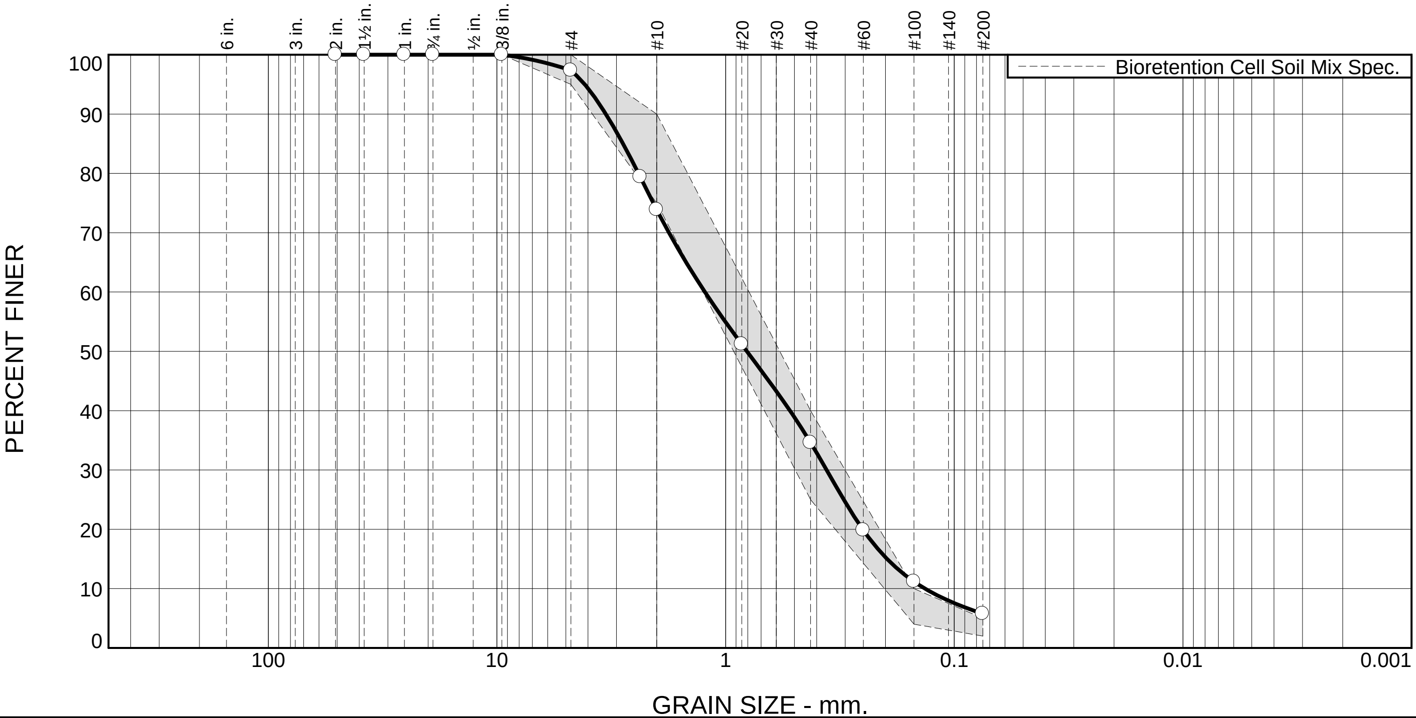
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	**592.05**	**570.04**
Dry Soil After Burn + Pan	**558.51**	**539.98**
Weight of Pan	**391.92**	**357.91**
Wt. Loss Due to Ignition	**33.54**	**30.06**
Actual Wt. Of Soil After Burr	**166.59**	**182.07**
% Organics	**16.8**	**14.2**

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.6	23.5	39.3	28.9	5.7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.4	95.0 - 100.0	
#8	79.4		
#10	73.9	75.0 - 90.0	X
#20	51.2		
#40	34.6	25.0 - 40.0	
#60	19.9		
#100	11.2	4.0 - 10.0	X
#200	5.7	2.0 - 5.0	X

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=**

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.3390 D_{85}= 2.8093 D_{60}= 1.2316
D_{50}= 0.8069 D_{30}= 0.3617 D_{15}= 0.1967
D_{10}= 0.1344 C_u= 9.16 C_c= 0.79

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/16/2018 **Date Tested:** 11/13/2018

Tested By: BN

Checked By: JHS

Title:

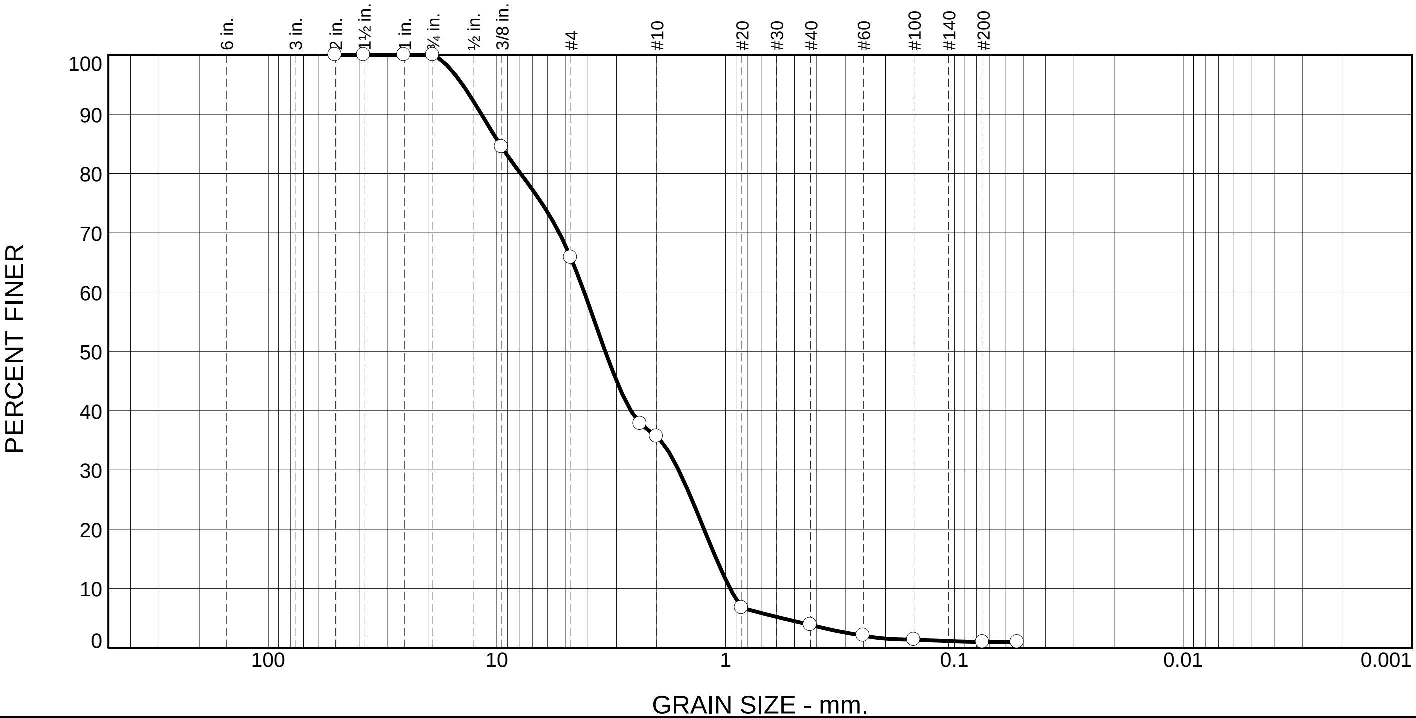
Source of Sample: (SSW) Snohomish County- Salem Woods ES **Depth:** 0.2'-0.5' **Date Sampled:** 10/09/2018
Sample Number: HA-2/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	34.2	30.2	31.7	2.9	1.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	84.5		
#4	65.8		
#8	37.8		
#10	35.6		
#20	6.7		
#40	3.9		
#60	2.1		
#100	1.3		
#200	1.0		
#270	0.9		

* (no specification provided)

Material Description

very gravelly SAND, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-a

Coefficients

D_{90}= 11.6822 D_{85}= 9.7242 D_{60}= 4.1537
D_{50}= 3.3596 D_{30}= 1.6063 D_{15}= 1.0988
D_{10}= 0.9565 C_u= 4.34 C_c= 0.65

Remarks

Collected by: ADY

Date Received: 10/16/2018 **Date Tested:** 10/18/2018

Tested By: MS

Checked By: JHS

Title:

Source of Sample: (SSW) Snohomish County- Salem Woods ES **Depth:** 2.1'-2.4' **Date Sampled:** 10/09/2018

Sample Number: HA-2/WP

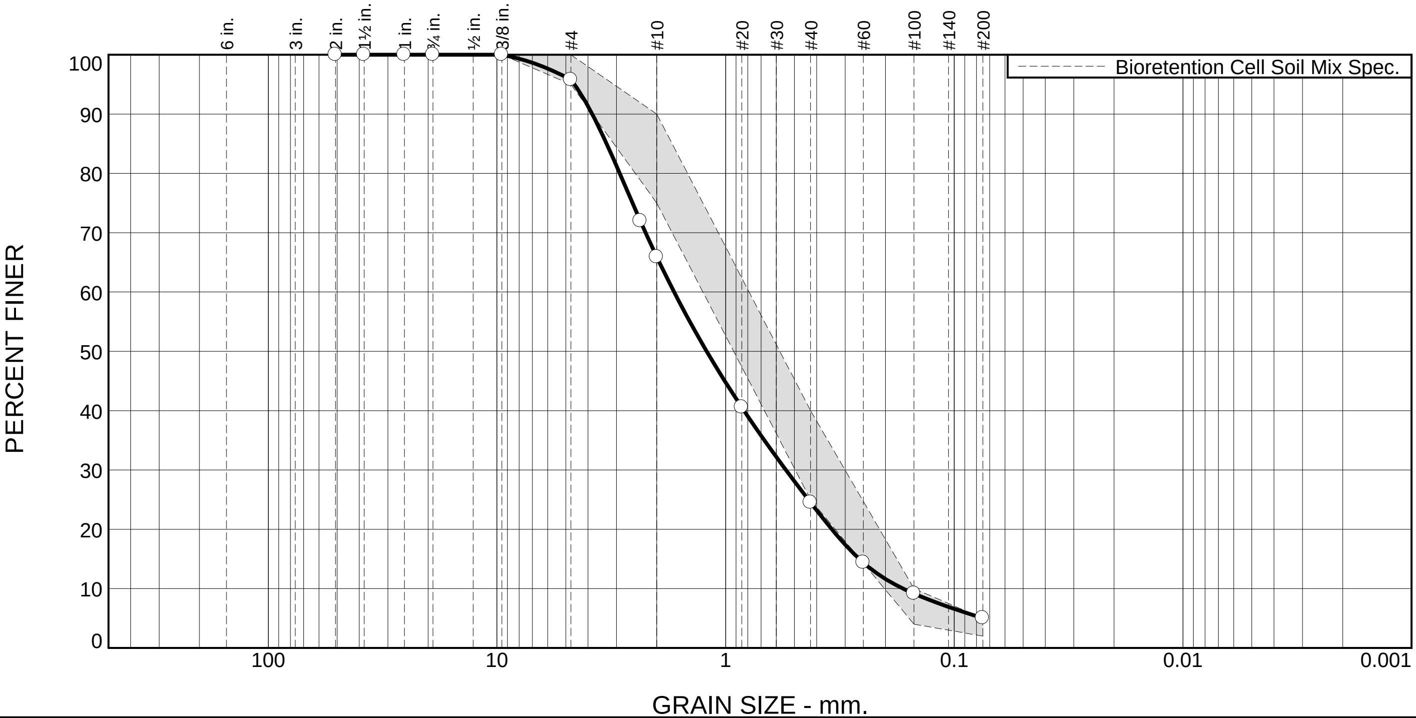
associated earth sciences incorporated

Client: Clear Creek Solutions

Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.2	29.9	41.4	19.5	5.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	95.8	95.0 - 100.0	
#8	72.0		
#10	65.9	75.0 - 90.0	X
#20	40.6		
#40	24.5	25.0 - 40.0	X
#60	14.4		
#100	9.2	4.0 - 10.0	
#200	5.0	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=**

Classification

USCS (D 2487)= SW-SM **AASHTO (M 145)=** A-1-b

Coefficients

$D_{90}=$ 3.8293 $D_{85}=$ 3.3133 $D_{60}=$ 1.6799
$D_{50}=$ 1.2097 $D_{30}=$ 0.5450 $D_{15}=$ 0.2603
$D_{10}=$ 0.1674 $C_u=$ 10.04 $C_c=$ 1.06

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/16/2018 **Date Tested:** 11/13/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (SSW) Snohomish County- Salem Woods ES **Depth:** 0.2'-0.5' **Date Sampled:** 10/09/2018
Sample Number: HA-3

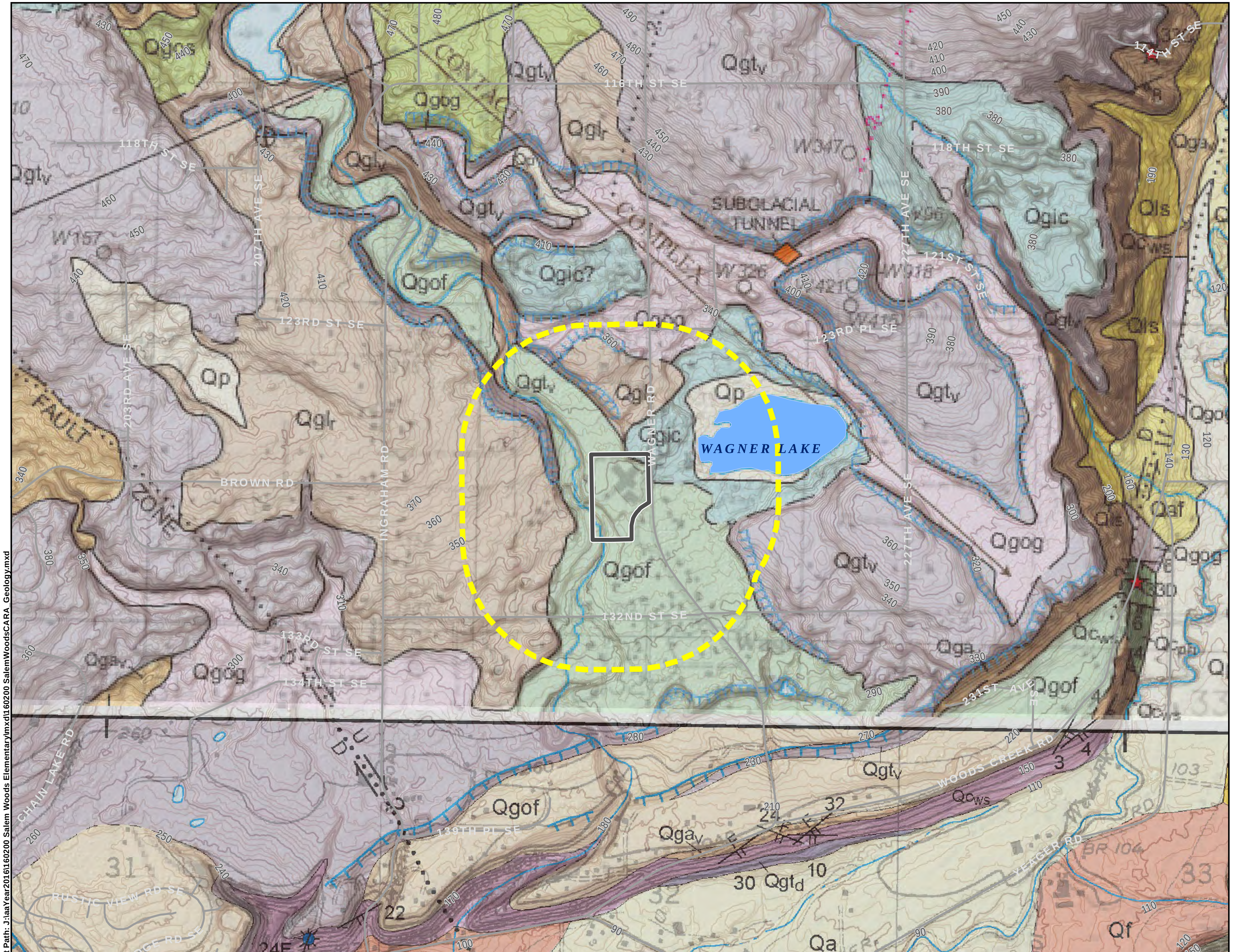
associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



LEGEND:

PROJECT LOCATION

1300 FT BUFFER FROM SITE

CONTOUR 10 FT

CONTOUR 2 FT

GEOLOGY:
Qf- ARTIFICIAL FILL AND MODIFIED LAND
Qp - PEAT
Qa - ALLUVIUM
Qls - LANDSLIDE
Qaf - ALLUVIAL FAN DEPOSITS
Qglr - RECESSIONAL GLACIOLACUSTRINE
Qgos - OUTWASH SAND
Qgod - DELTAIC OUTWASH AND KAME-DELTA
Qgof - FLUVIAL OUTWASH
Qgic - ICE-CONTACT
Qgog - OUTWASH GRAVEL, UNDIVIDED
Qgtv - LODGEMENT TILL
Qgav - ADVANCE OUTWASH
Qglv - ADVANCE GLACIOLACUSTRINE
Qco - DEPOSITS OF OLYMPIA NONGLACIAL INTERVAL
Qcws - WHIDBEY FORMATION
Qcphl - PRE-HAMM CREEK NON-GLACIAL

DATA SOURCES / REFERENCES:
PSLC: LIDAR 2014, GRID CELL SIZE IS 3'.
WA STATE PLANE NORTH, NAD83(HARN) NAVD88, US SURVEY FEET.
CONTOURS CREATED FROM 6' LIDAR 2005

SNOHOMISH CO:STREETS, WATER, PARCELS, CARA, FLOOD
WADOE: WELL REPORTS
WADNR: MAP SERIES 2015-01, LAKE ROESIGER 7.5-MINUTE QUADRANGLE
OFR2011-1, MONROE 7.5-MINUTE QUADRANGLE

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 500 1000
FEET

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

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SURFACE GEOLOGY

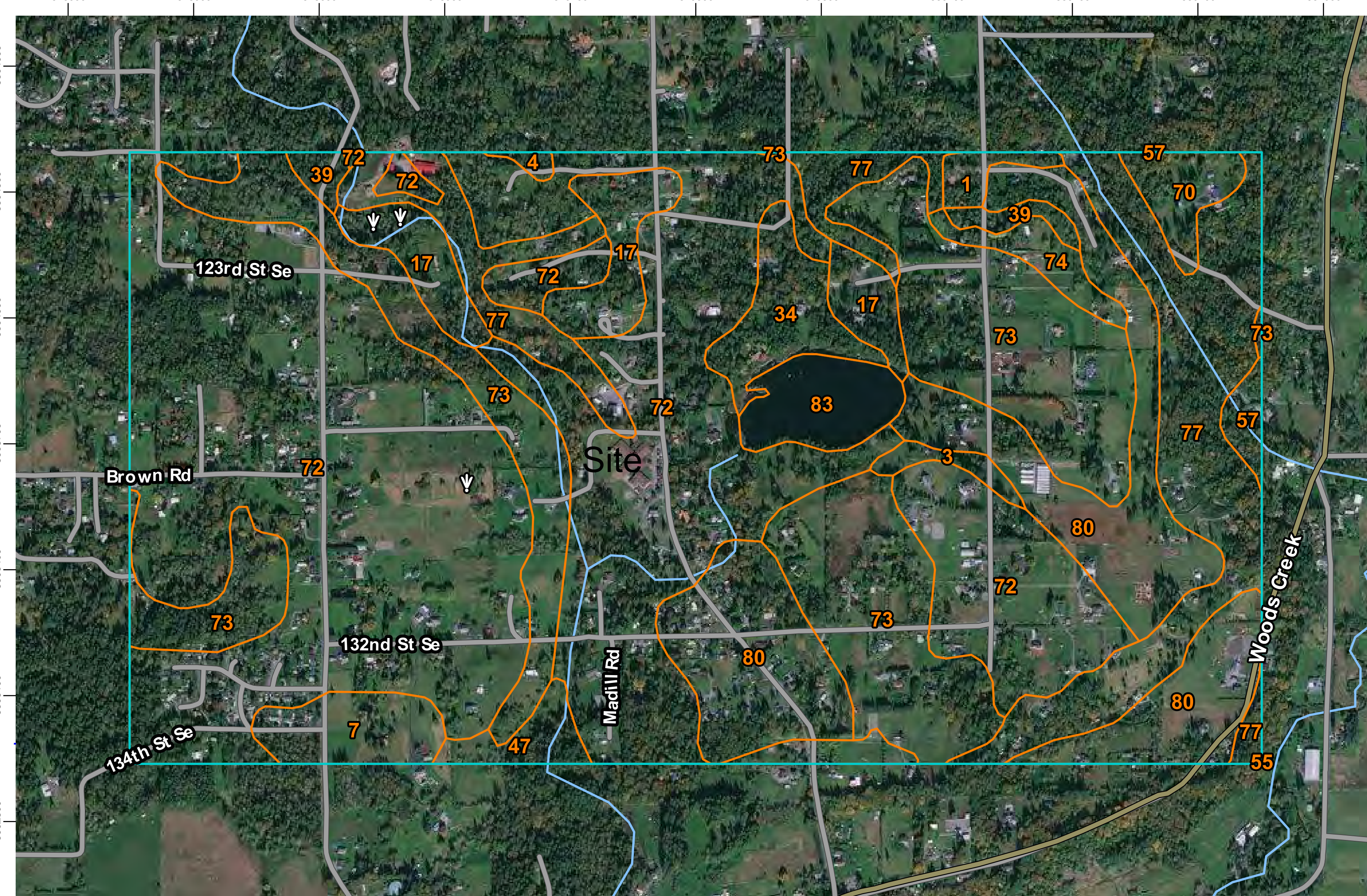
SALEM WOODS ELEMENTARY SCHOOL
SNOHOMISH COUNTY, WASHINGTON

PROJ NO.	DATE:	FIGURE:
KH160200A	9/16	5

Document Path: J:\aaYear2016\160200 Salem Woods Elementary\mxd\160200 SalemWoodsCARA_Geology.mxd

121° 57' 29" W — 121° 54' 52" W

47° 53' 27" N — 47° 52' 19" N



Map Scale: 1:14,900 if printed on A landscape (11" x 8.5") sheet.

Meters: 0, 200, 400, 800, 1200

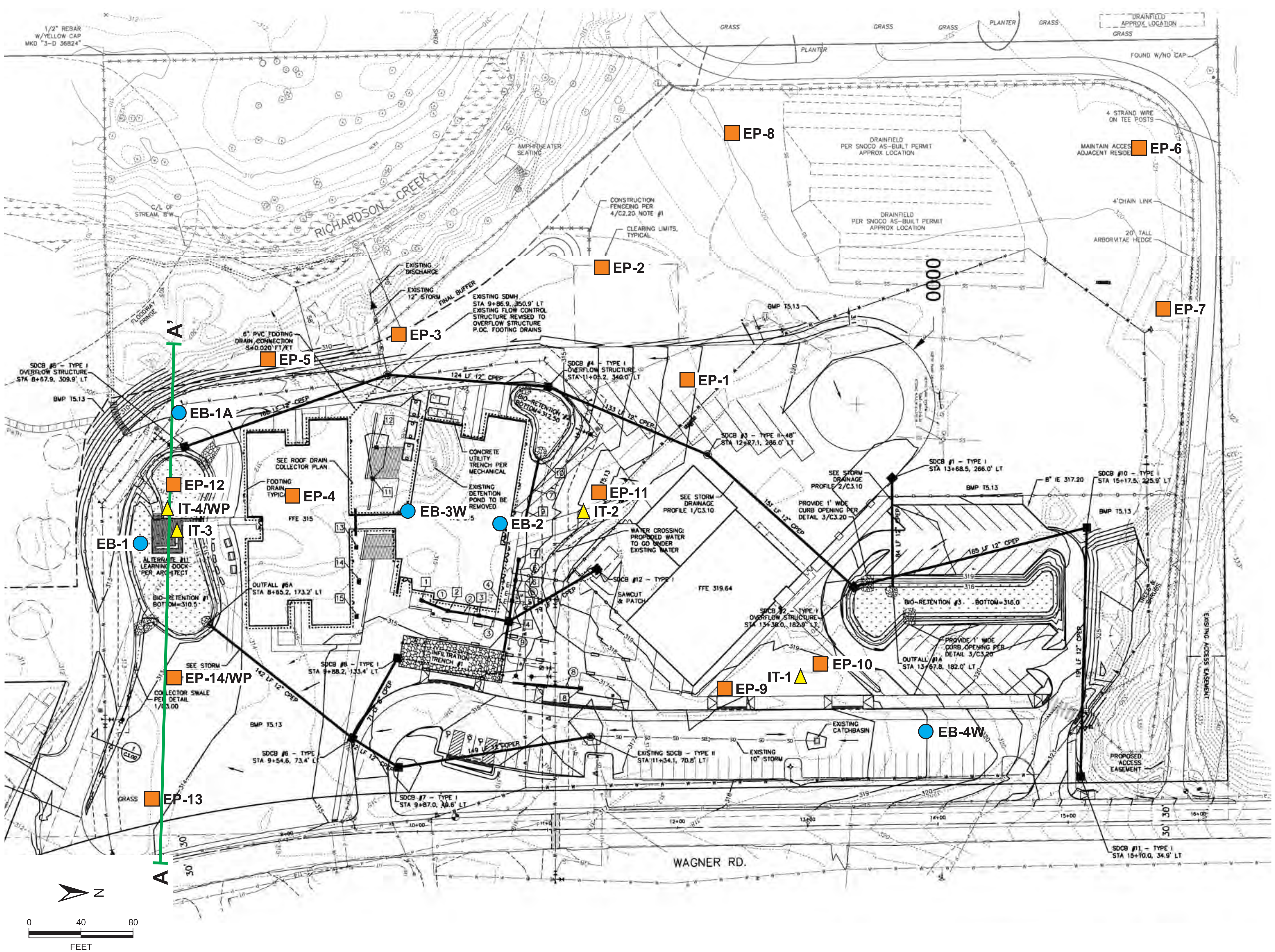
Feet: 0, 500, 1000, 2000, 3000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
1	Alderwood gravelly sandy loam, 0 to 8 percent slopes	4.8	0.5%
3	Alderwood gravelly sandy loam, 15 to 30 percent slopes	4.3	0.4%
4	Alderwood-Everett gravelly sandy loams, 25 to 70 percent slopes	1.4	0.1%
7	Bellingham silty clay loam	16.8	1.7%
17	Everett very gravelly sandy loam, 0 to 8 percent slopes	36.7	3.8%
34	Mukilteo muck	19.6	2.0%
39	Norma loam	7.1	0.7%
47	Pastik silt loam, 0 to 8 percent slopes	8.4	0.9%
55	Puget silty clay loam	0.0	0.0%
57	Ragnar fine sandy loam, 0 to 8 percent slopes	4.5	0.5%
70	Tokul silt loam, 2 to 8 percent slopes	11.0	1.1%
72	Tokul gravelly medial loam, 0 to 8 percent slopes	440.6	45.0%
73	Tokul gravelly medial loam, 8 to 15 percent slopes	173.1	17.7%
74	Tokul gravelly medial loam, 15 to 30 percent slopes	8.9	0.9%
77	Tokul-Winston gravelly loams, 25 to 65 percent slopes	107.1	10.9%
80	Winston gravelly loam, 0 to 3 percent slopes	117.3	12.0%
83	Water	17.5	1.8%
Totals for Area of Interest		**978.9**	**100.0%**



LEGEND:

EB	EXPLORATION BORING
EP	EXPLORATION PIT
IT	INFILTRATION TEST
W	MONITORING WELL
WP	WELL POINT
	SECTION LINE

CONTOUR INTERVAL = 1'

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:

1. BASE MAP REFERENCE: DLR GROUP, FULL DRAINAGE PLAN, SHEET 3.00, 5/16/17 AND WESTERN MARGIN OF SITE PLAN FROM DEMOLITION AND SWPP PLAN, SHEET C2.10, 5/16/17.

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

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SITE AND EXPLORATION PLAN

SALEM WOODS ELEMENTARY SCHOOL
SNOHOMISH COUNTY, WASHINGTON

PROJ NO.	DATE:	FIGURE:
160200H002	8/17	2

160200 Salem Woods Elem \ 160200H002 F2 Site-Explr 8-17. cdr

LOG OF EXPLORATION PIT NO. EP-1

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION Elev. ~317
	Fill
1–2	Loose to medium dense, moist, dark brown, fine to medium sandy GRAVEL, trace silt; contains cobbles (GP).
	Fluvial Outwash Deposits
3–4	Loose to medium dense, moist to very moist, gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles; roughly stratified (GP).
6	Operator notes easier digging.
7	Medium dense, wet, tan, silty, fine to medium SAND, some gravel (SM).
8	Bottom of exploration pit at depth 7.5 feet Light seepage at 7 feet. Light caving from 0 to 7.5 feet.

Depth scale: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Salem Woods Elementary School
Snohomish County, WA

Logged by: AWR

Approved by: JHS

associated earth sciences incorporated

Project No. 160200E002

6/30/16

LOG OF EXPLORATION PIT NO. EP-2

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION Elev. ~317
	Grass / Topsoil
1	**Fluvial Outwash Deposits**
2	Loose to medium dense, moist, tannish brown, fine to medium sandy GRAVEL, trace silt; contains cobbles; oxidized (GP).
3	Becomes gray, more coarse sand.
4	
5	Medium dense, very moist, gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles (GP).
6	Becomes wet, less sand.
7	**Vashon Lodgement Till ?** Loose to medium dense, wet, tannish gray, fine to medium SAND, trace to some silt (SP-SM).
8	Bottom of exploration pit at depth 7.5 feet Moderate to heavy seepage at 6 feet; light seepage at 6.5 feet. Light caving from 0 to 7 feet.
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Salem Woods Elementary School
Snohomish County, WA

Logged by: AWR
Approved by: JHS

associated earth sciences incorporated

Project No. 160200E002

6/30/16

LOG OF EXPLORATION PIT NO. EP-3

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered.

Depth (ft)	DESCRIPTION — Elev. ~315
	Grass / Topsoil
	Fill
1	
2	Loose, moist, dark brown, fine to medium sandy GRAVEL, trace silt; contains cobbles (GP). Becomes brownish gray.
3	
4	
5	
6	
7	
8	**Fluvial Outwash Deposits**
9	Loose to medium dense, moist, tannish brown, silty, fine SAND, some gravel, trace organics (SM). Medium dense, very moist, gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles, occasional boulders (GP).
10	**Vashon Lodgement Till**
11	Dense, moist, tan, silty, fine SAND, some gravel; unsorted (SM).
12	
13	Dense, moist to very moist, silty, fine to medium SAND, some gravel; contains till-like clasts (SM).
14	
15	Bottom of exploration pit at depth 14 feet No seepage. No caving.
16	
17	
18	
19	
20	

Salem Woods Elementary School
Snohomish County, WA

Logged by: AWR
Approved by: JHS

associated earth sciences incorporated

Project No. 160200E002

6/30/16

LOG OF EXPLORATION PIT NO. EP-11

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Sand Surfacing - 6 inches
1	**Fluvial Outwash Deposits** Medium dense, moist, tan, fine to medium SAND, some silt, some gravel; oxidized (SP-SM). Becomes less oxidized.
2	
3	
4	Medium dense, moist, gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles; oxidized (GP).
5	
6	
7	Medium dense, moist, gray, fine to coarse sandy GRAVEL; contains cobbles (GP). Boulder encountered.
8	
9	
10	As above.
11	
12	Medium dense, very moist, gray, fine SAND, some silt; laminated (SP-SM).
13	Bottom of exploration pit at depth 12.5 feet No seepage. Light caving from 11 to 12.5 feet.
14	
15	
16	
17	
18	
19	
20	

Salem Woods Elementary School
Snohomish County, WA

Logged by: AWR
Approved by: JHS

associated earth sciences incorporated

Project No. 160200E002

9/10/16

LOG OF EXPLORATION PIT NO. IT-2

Depth (ft)	This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplfication of actual conditions encountered. **DESCRIPTION**
	Sand Surfacing - 6 inches
1	**Fluvial Outwash Deposits**
2	Medium dense, moist, tan, fine to medium SAND, some silt, some gravel; oxidized (SP-SM).
3	
4	Medium dense, moist, gray, fine to coarse sandy GRAVEL, trace silt; contains cobbles (GP).
5	
6	
7	Layer (~12 inches thick) of fine to coarse SAND, some gravel (SP).
8	Medium dense, wet, gray, fine to coarse sandy GRAVEL (GP).
9	Minor post-test seepage at 8.5 feet.
10	
11	
12	Medium dense, wet, gray, silty, fine SAND; laminated (SM).
13	Medium dense, wet, gray, gravelly, fine to coarse SAND, trace silt (SP).
14	
15	
16	Medium dense, wet, gray, gravelly SAND / sandy GRAVEL, some cobbles, trace silt (SP/GP).
17	**Vashon Lodgement Till** Dense, very moist, gray, silty, fine SAND, some gravel; unsorted (SM).
18	Bottom of exploration pit at depth 17 feet Moderate post-test seepage at 12 feet. Light caving. Infiltration test completed at 6.5 feet.
19	
20	

KCTP3 160200 NEW#.GPJ March 29, 2017

Salem Woods Elementary School
Snohomish County, WA

Logged by: AWR
Approved by: JHS

associated earth sciences incorporated

Project No. 160200E002

9/10/16

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
KE160200A	EB-2	1 of 1

Project Name	Salem Woods Elementary School	Ground Surface Elevation (ft)	~314
Location	Snohomish County, WA	Datum	N/A
Driller/Equipment	GDI / D50	Date Start/Finish	6/16/16,6/16/16
Hammer Weight/Drop	140# / 30"	Hole Diameter (in)	4 inches

Depth (ft)	Samples	DESCRIPTION	Blows/6"	Blows/Foot
		Grass / Topsoil		
		Fluvial Outwash Deposits Gravelly drill action.		
	S-1	Very dense, moist, tannish gray, fine to medium sandy GRAVEL; interbed of oxidized fine sand; broken gravel in sampler (GP).	28 45 50/3"	50/3"
5	S-2	Very dense, moist, gray, fine to coarse sandy GRAVEL (GP).	14 42 18	60
10	S-3	Very dense, moist, gray, fine to coarse sandy GRAVEL; sand may be cemented (GP).	12 23 50/5"	50/5"
15	S-4		50/6"	50/6"
20	S-5	**Vashon Lodgement Till** Very dense, moist, gray, gravelly, silty, fine to coarse SAND; unsorted (SW/SM).	100/5"	100/5"
		Bottom of exploration boring at 20.5 feet No ground water encountered.		

Column headings also include: S T; Graphic Symbol; Well Completion; Water Level; Other Tests. Blows/Foot scale: 10, 20, 30, 40.

Sampler Type (ST):

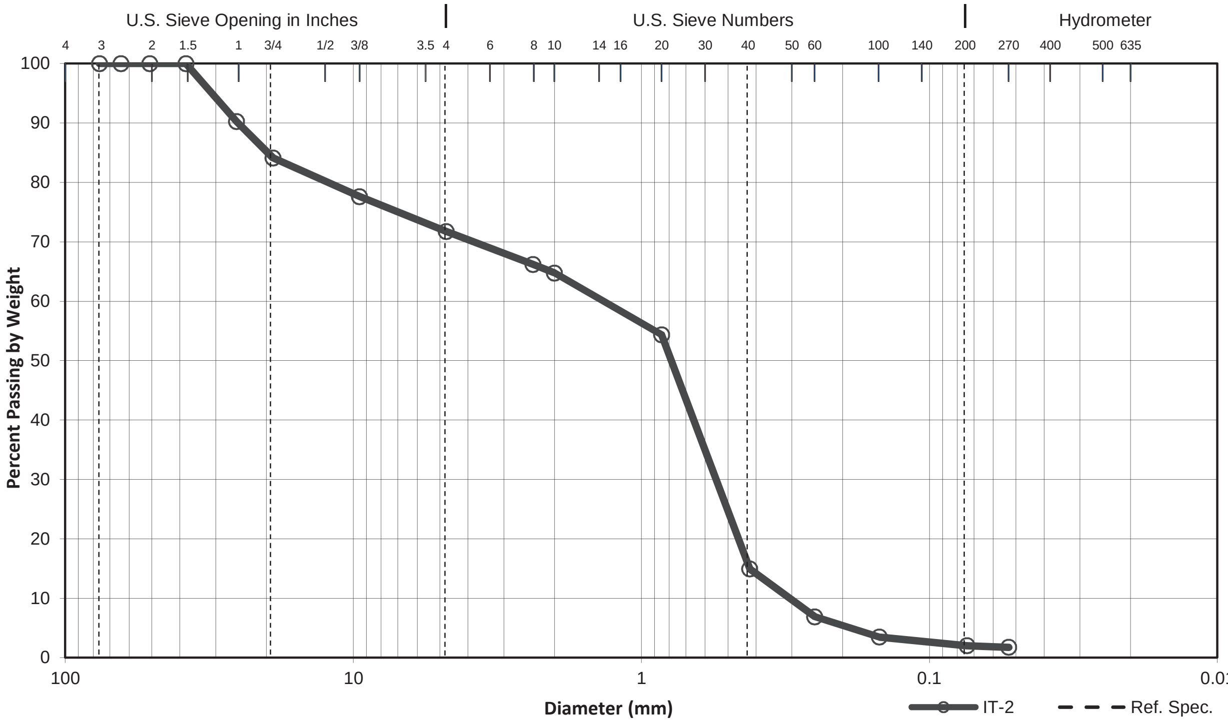
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: AWR
Approved by: JHS

associated earth sciences incorporated

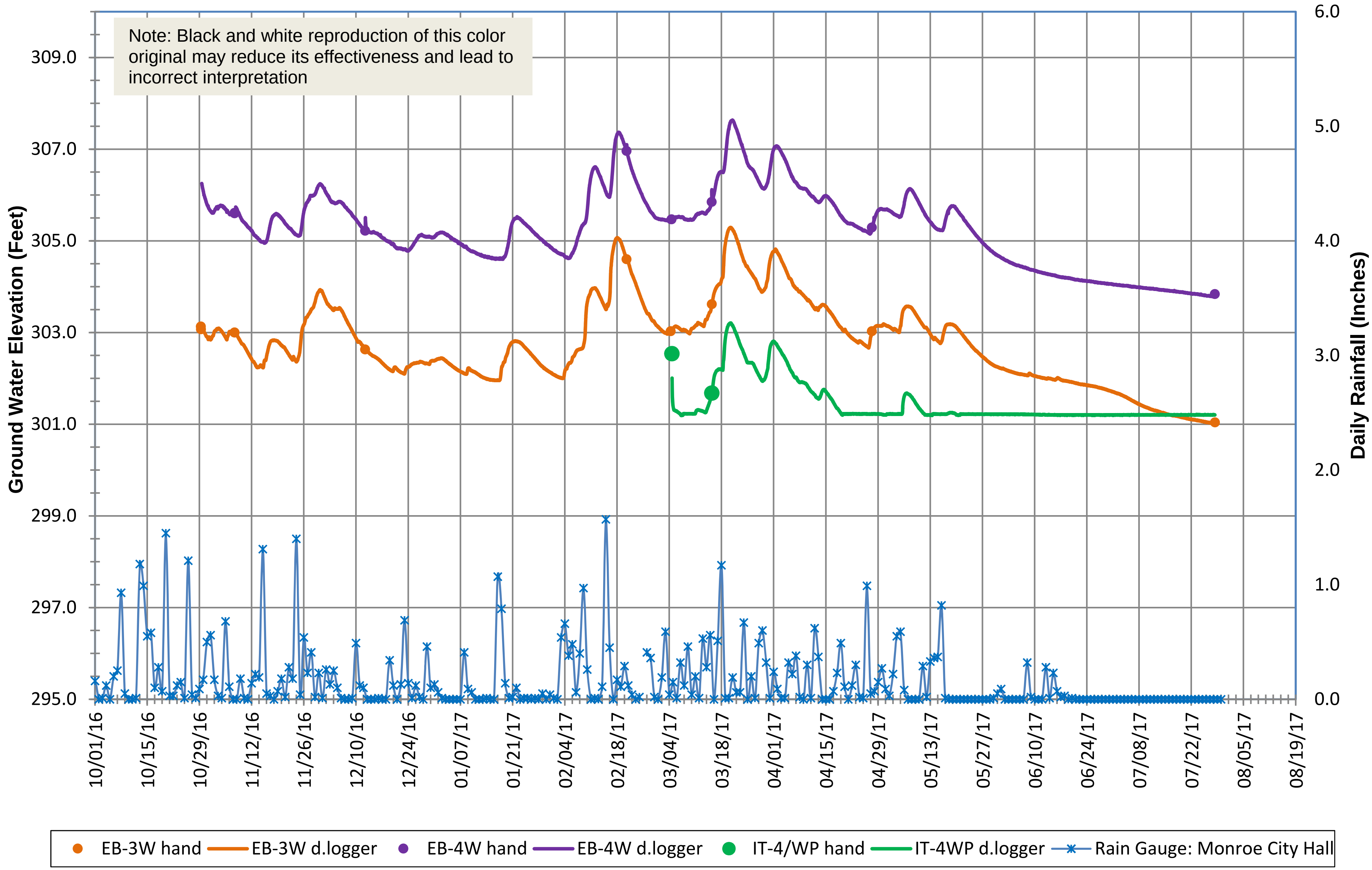
GRAIN SIZE ANALYSIS - MECHANICAL ASTM D422

Project Name	Project Number	Date Sampled	Date Tested	Tested By
Salem Woods Elementary	**KE160200A**	**9/10/2016**	**9/15/2016**	**MS**
Sample Source	Sample No.	Depth (ft)	Soil Description	
Onsite	**IT-2**	**6.5**	**gravelly SAND, trace silt (SP)**	
Total Sample Dry Wt. (g)	Moisture Content (%)	D_{10} (mm)	Reference Specification	
1853.3	**13**	**0.305**		



Cobb.	Gravel		Sand			Silt or Clay
	Coarse	Fine	Coarse	Medium	Fine	

Sieve No.	Diam. (mm)	Cum. Wt. Ret. (g)	% Ret. by Wt.	% Passing by Wt.	% Specs. Pass. by Wt.	
					Min	Max
3	76.1		0.0	100.0		
2.5	64		0.0	100.0		
2	50.8		0.0	100.0		
1.5	38.1		0.0	100.0		
1	25.4	180.9	9.8	90.2		
3/4	19	294.2	15.9	84.1		
3/8	9.51	415.0	22.4	77.6		
#4	4.76	523.3	28.2	71.8		
#8	2.38	626.1	33.8	66.2		
#10	2	653.1	35.2	64.8		
#20	0.85	845.5	45.6	54.4		
#40	0.42	1576.1	85.0	15.0		
#60	0.25	1725.4	93.1	6.9		
#100	0.149	1788.5	96.5	3.5		
#200	0.074	1815.5	98.0	2.0		
#270	0.053	1820.6	98.2	1.8		



Ground Water Hydrograph
Salem Woods Elementary School
Snohomish County, Washington

Figure 4
Project Number: 160200H002
Date: August 2017

Associated Earth Sciences, Inc.

APPENDIX D

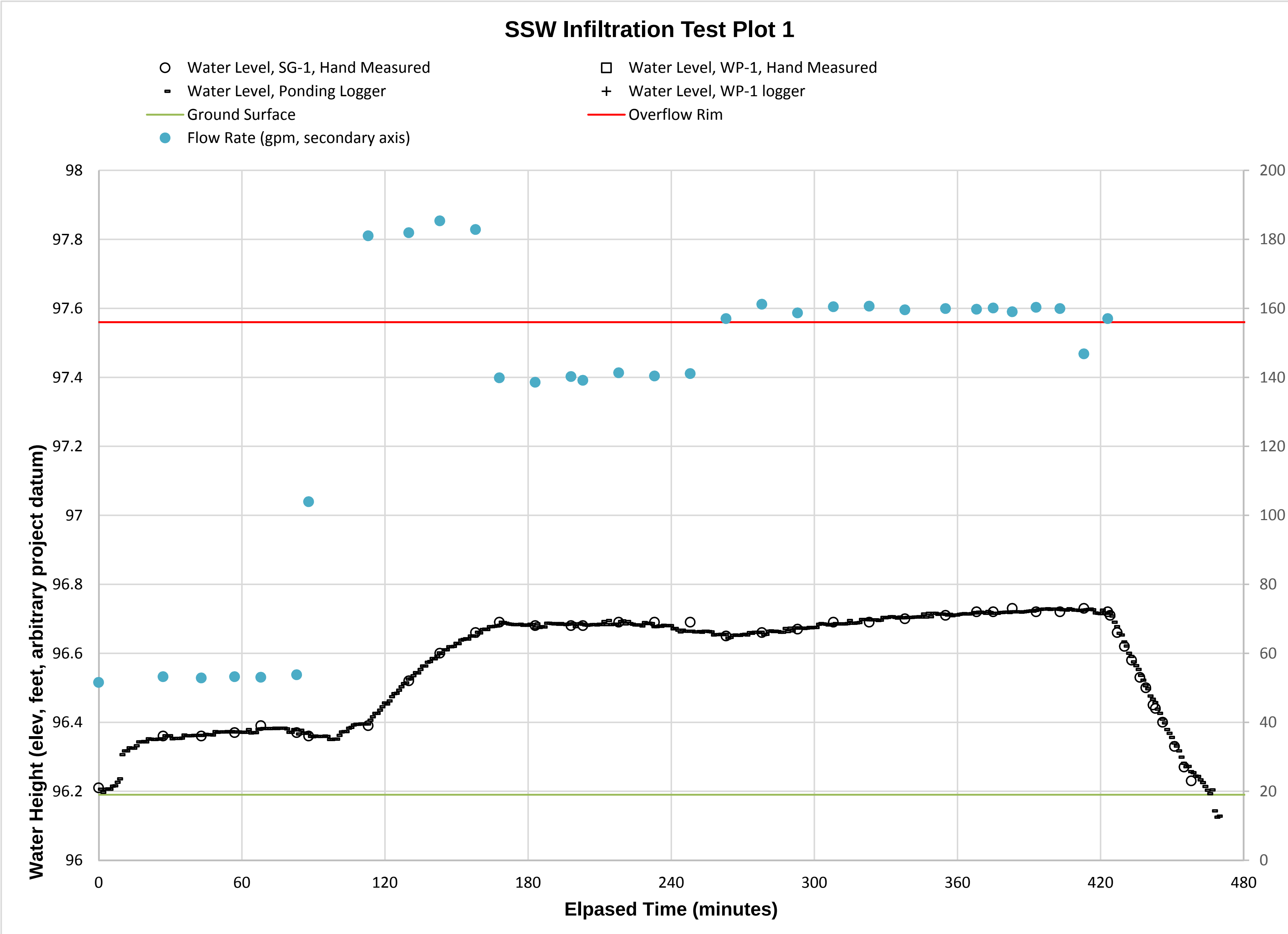
Soil Probe, Level Survey, and Field Infiltration Testing Data

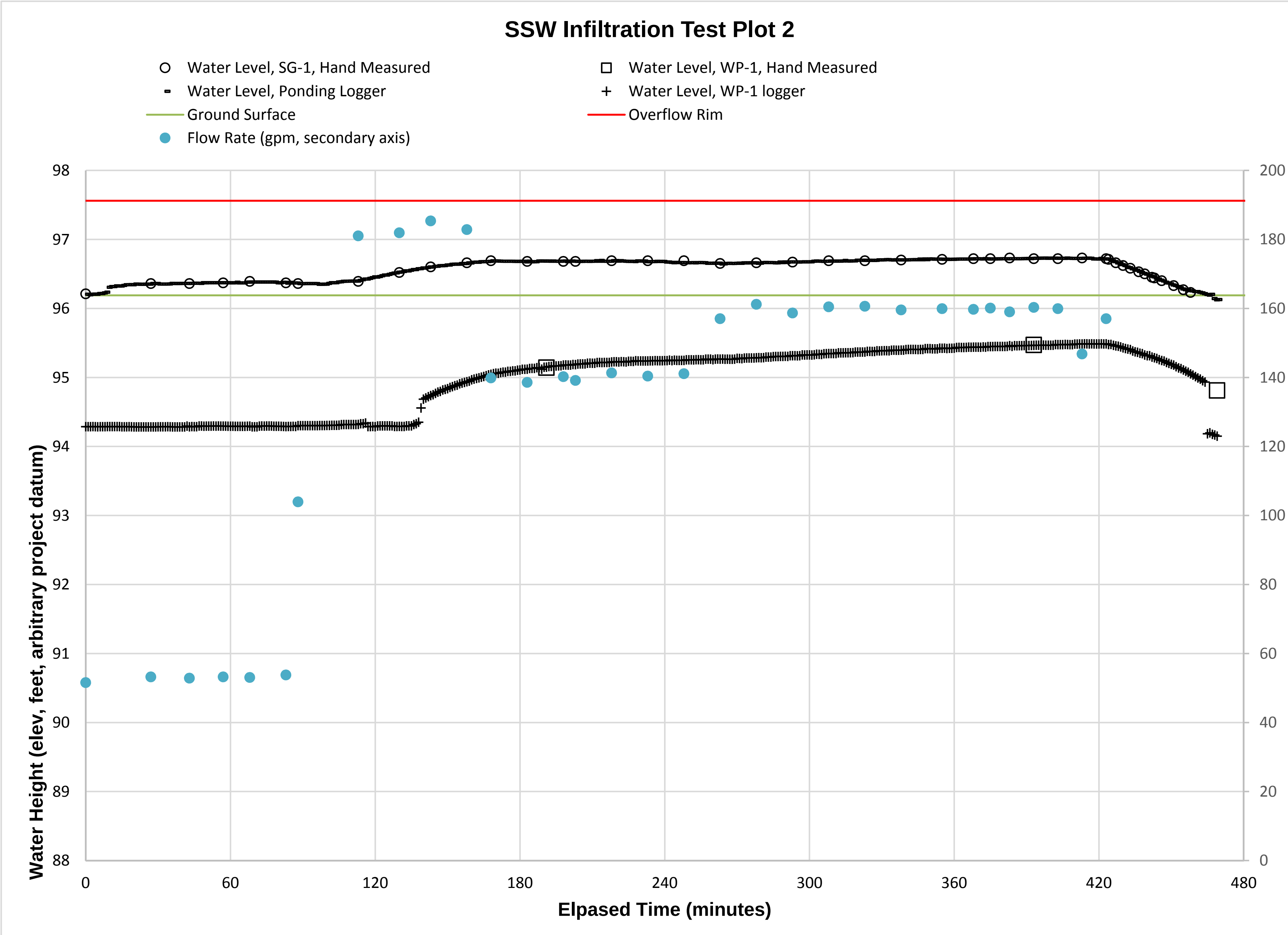
Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM7
Date:	11/1/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	940.0
Test No.:	SSW	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
8:37	51.53	0.02	0	Raining. Flow on.
9:04	53.2	0.17	1432	
9:20	52.85	0.17	2281	
9:34	53.2	0.18	3045	
9:45	53.03	0.2	3602	
10:00	53.76	0.18	4413	
10:05	103.94	0.17	5182	Flow increased to approx 100 gpm.
10:30	181	0.2	6527	Flow increased to approx 181 gpm.
10:47	181.9	0.33	9856	
11:00	185.34	0.41	12215	
11:15	182.82	0.47	14974	
11:25	139.84	0.5	16756	
11:40	138.54	0.49	18939	
11:48				
11:55	140.2	0.49	209413	Sprinkler testing on nearby landscaping area, runoff from parking lot entering inlet. Rain continues.
12:00	139.1	0.49	21622	
12:15	141.28	0.5	23746	
12:30	140.37	0.5	25814	
12:45	141.05	0.5	27921	
13:00	156.99	0.46	30087	
13:15	161.17	0.47	32480	
13:30	158.64	0.48	34745	Rain stops.
13:45	160.45	0.5	37158	
14:00	160.62	0.5	39483	
14:15	159.54	0.51	42005	
14:32	159.9	0.52	44759	
14:45	159.71	0.53	46732	
14:52	160.08	0.53	47903	
15:00	158.97	0.54	49220	
15:10	160.26	0.53	50855	No rain.
15:20	159.9	0.53	52414	
15:30	146.78	0.54	54033	Flow rate fluctuation.
15:40	156.99	0.53	55522	Flow off.
15:41		0.52		
15:44		0.47		
15:47		0.43		
15:50		0.39		
15:53		0.34		
15:56		0.31		
15:59		0.26		
16:00		0.25		
16:03		0.21		

16:08		0.14		
16:12		0.08		
16:15		0.04		
16:26		dry		

	Average Infiltration Rate (in/hr) during last hour of inflow:	16.4
Average Infiltration Rate (in/hr) during falling head:		10.2


SSW Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, WP-1 logger
Ground Surface
Overflow Rim
Flow Rate (gpm, secondary axis)
Water Height (elev, feet, arbitrary project datum)
98
97.8
97.6
97.4
97.2
97
96.8
96.6
96.4
96.2
96
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)


SSW Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, Ponding Logger
Ground Surface
Flow Rate (gpm, secondary axis)
Water Level, WP-1, Hand Measured
Water Level, WP-1 logger
Overflow Rim
Water Height (elev, feet, arbitrary project datum)
98
97
96
95
94
93
92
91
90
89
88
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)

APPENDIX E

Site Photos

Cell SSW overview during infiltration testing.

Above photo: Cell SSW inlet modified for monitoring. Note straw waddle attempt to limit turbid inflow.
Lower Photo: close up of curb cut inlet prior to weir installation. Well point in foreground.

APPENDIX 11

Deliverable Task 4.5, Site TBM, Geotechnical/Soils Assessment Design Data and Current Conditions, George W. Bush Middle School, Tumwater, Washington. Associated Earth Sciences, Inc. 6/14/2019

associated earth sciences incorporated

Technical Memorandum

Date:	June 14, 2019	**From:**	Anton Ympa Sue Cook
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site TBM, Geotechnical/Soils Assessment Design Data and Current Conditions, George W. Bush Middle School, Tumwater, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in the Basin 2A Bioretention Cell (north parking stalls) of the George W. Bush Middle School Project, located in the City of Tumwater, Washington (Figure TBM F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 2, 2018, infiltration testing on October 25, 2018, provisional results of hydrologic monitoring, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review of project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand-augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure TBM F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the George W. Bush Middle School Project, located in Tumwater, Washington as shown on the attached "Vicinity Map" (Figure TBM F1). The George W. Bush Middle School is located on a 21.4-acre parcel. The site is situated in a rural residential area northeast of the intersection of Kimmie Street SW and 83^{rd} Avenue SW, bound to the north by 80^{th} Avenue SW, and bound to the east by undeveloped land owned by the Port of Olympia. Site topography is generally flat-lying with the total relief of the site of approximately 10 feet. No on-site surface water features are present. As described in the Drainage Report, the site is located in the Salmon Creek Drainage Basin and two City of Tumwater water production wells exist immediately north of the site (BCRA, 2016). The Salmon Creek Drainage Basin has high groundwater conditions and is subject to specific stormwater regulations. Per the Washington State Source Water Assessment Program Mapping Application, the site is located within the 6-month time of travel for several wells in City of Tumwater Water System ID#89700.

Our specific area of study for this project includes the bioretention cell for Basin 2A (north parking stalls) located on the north-central portion of campus referred to as cell TBM for this study. The attached "Facility and Exploration Plan" (Figure TBM F2) illustrates the cell area and some of the surrounding site features and utilities.

Details of the bioretention facility design and basis for design were presented in the following documents:

- Landau Associates, 2016a, "Geotechnical Engineering Report, George Washington Bush Middle School, Modernization and Addition, Tumwater, Washington": Prepared for Tumwater School District No. 33, March 4, 2016.
- Landau Associates, 2016b, "Draft Technical Memorandum, Groundwater Mounding Analysis, Bush Middle, School, Tumwater, Washington": Prepared for City of Tumwater, March 4, 2016.
- BCRA, 2016, "Drainage Report, George Washington Bush Middle School Renovations and Additions": Prepared for Tumwater School District, March 3, 2016.
- BCRA, 2017, "George W. Bush Middle School Renovations and Additions, Tumwater School District, Plan Set": December 29, 2017.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell TBM consists of an L-shaped bioretention cell with approximately 294 square feet of base area, as shown on Figure TBM F2, "Facility and Exploration Plan." We understand that the site was developed under the City of Tumwater *Drainage Design and Erosion Control Manual*, 2010 and the 2005 Washington State Department of Ecology (Ecology) *Stormwater Management Manual for Western Washington* (2005 Ecology Manual). In addition, due to known shallow groundwater conditions within the Salmon Creek Drainage Basin, the site was also subject to specific stormwater facility requirements from: (1) City of Tumwater Ordinance No. 02005-003, Site Development Standards for New Development in the Salmon Creek Basin and Other High Groundwater Areas, October 4th of 2005, and (2) Thurston County's Salmon Creek Comprehensive Drainage Basin Plan Phase II: Alternatives Analysis and Recommendations, June, 2004.

The site was modeled using WWHM2012 based on developed condition drainage basins of 0.19 acres, of which is 0.13 acres was impervious and 0.06 was pervious. The modeled design infiltration rate was 0.9 inches per hour (in/hr). The design infiltration rate was derived from the geometric mean of estimate hydraulic conductivity used grain-size-based correlations, and conservative assumptions for depth to groundwater and hydraulic gradient. Land use within the drainage basin is primarily parking and roadway with minor lawn area. Per plan sheet C5.09 "Civil Details," item 1, Bioretention Cell (BCRA, 2016), the facility design includes 3 inches of coarse compost over 18 inches of bioretention soil mix overlying native subgrade.

The facility is designed to infiltrate 100 percent of inflow into the subgrade. Stormwater enters the facility through one inlet curb cut on the south side near the center. Sheet C5.09, "Civil Details," item 1, Bioretention Cell, shows a Type 1 Catch Basin to be installed in cell TBM as an overflow in case water ponds up on the bioretention soil. The overflow rim of the Type I Catch Basin is shown to be 10 inches higher than the cell base to create 10 inches of ponding depth. However, the catch basin was not installed. The low area in the rim of the cell is the actual overflow, and if overflow occurs, it generally would flow across a grassy field toward an infiltration pond located east of the cell. The facility was constructed during Summer 2016 based on a review of aerial photography.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure TBM F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the northwest edge of the lamp post concrete base immediately south of cell defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: One inflow consisting of a curb cut and concrete ramp to cell TBM was observed on the south-central edge of cell.

    - The inflow to the facility consists of a curb cut and concrete ramp, 1.5 feet wide and 2 feet long, that allows sheet flow from the parking area to discharge onto an angular rock energy dissipation pad approximately 4 feet wide and 5 feet long. No erosion was noted. The inlet was clear of debris and vegetation at the time of our site visit.

- Overflow: No overflow structure for cell TBM was observed. The natural overflow is a low area along the east side of the cell rim and was 1.1 feet above the cell base, 0.7 feet below the curb cut low and 0.4 feet below the concrete ramp low. If ponded water filled the cell, overflow would discharge over the cell rim to the east and flow easterly toward the existing infiltration pond.

- AESI investigated the loose bioretention soil thickness present in cell TBM using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 3-foot to 4-foot grid on the facility base. Penetration of the T-probe generally ranged from approximately 1.0 feet to 2.5 feet, and averaged 1.7 feet. Probe penetration data is included in Appendix D to this document.

Table 1
Summary of Cell TBM
Level Survey Data

Location	Elevation (feet, project datum)
Lamp post, concrete base, northwest	100
TBM-WP-1 TOC	99.75
TBM-WP-2 TOC	98.14
Ground surface at temporary staff gauge	96.17
Temporary inflow pipe top/end	97.66
Ponding tube TOC (DL)	98.19
Curb cut, inside lip, low	97.97
Concrete inflow ramp, inside lip, low	97.67
Cell rim low, east	97.30
Curb top, east of curb cut	98.58

WP: well point; TOC: top of casing; DL: datalogger

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under "Project and Site Description."
- Logan, R.L. et al., 2009, *Geologic Map of the Maytown 7.5-minute Quadrangle, Thurston County, Washington*, Washington Division of Geology and Earth Resources, Geologic Map GM-72, Scale 1:24,000 (geologic map).
- Natural Resources Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed December 2018.
- *Soil Survey of Thurston County, Washington*, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS), in cooperation with Washington Agricultural Experiment Station, 1990.

- Drost, 1998, *Hydrology and Quality of Ground Water in Northern Thurston County, Washington*.

5.1 Regional Topography and Project Grading

The project site is situated on a relatively flat-lying glacial outwash terrace near the southern extent of the Puget Sound Lowland. Elevations on the larger project site range from about 185 to 200 feet. The site is located about 2.5 miles southeast of Black Lake. Other small lakes and creeks are within 1 to 2 miles of the site but surface water is not present on the project site.

On a closer scale, the area near cell TBM is relatively level, situated on a recessional outwash terrace at about elevation 185 to 190 feet. Level parking stalls and access road areas are on the south side of the cell. Lawn surrounds the cell on the north, west, and east. A curb separates the paved surfaces from the cell. A large infiltration pond is approximately 100 feet to the east and the area east of cell TBM is graded gently toward the infiltration pond.

The project site was previously developed as George W. Bush Middle School and was renovated, including additions. Minor cutting (less than 3 feet) was needed to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the geology map (Logan, 2009), the site vicinity is underlain by Vashon recessional outwash sand and silt (Qgos). Recessional outwash sediments in the project area are described on the referenced map to consist of sand and silt with variable gravel content deposits from glacial meltwater, which is consistent with our observations and interpretations of subsurface materials encountered in our explorations for this project.

- <u>Vashon Recessional Outwash (Qgos)</u>: This unit is composed of stratified sand and silt with minor gravel interbeds, generally well sorted. Recessional outwash in the project area was deposited by glacial meltwater derived from stagnant ice and drainage from glacial Lake Puyallup farther east during ice retreat. Recessional outwash was deposited during the retreat of glacial ice, and has not been glacially overridden.

Background geotechnical information includes exploration logs B-1 and B-8 approximately 50 feet and 150 feet east of cell TBM, respectively, reached depths of about 20 feet below current grades, and describe material generally consisting of sand and silt with variable gravel grading to gravel with sand (Landau, 2016a). Boring EB-8 was completed as a well. Landau (2016a) interpreted the sediments as recessional outwash, which is consistent with the geologic mapping in the area.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

AESI reviewed the soil survey (Natural Resources Conservation Service [NRCS], 1990) and soils mapping from the NRCS web portal (NRCS, 2018). The soil survey identifies different soil map units based on parent material, climate, topography (slope), organisms (biota), and time. The soils in the study area formed mostly from young glacial deposits and have not had time to develop the deep weathering profiles present in soils in unglaciated terrains. Instead, they exhibit a direct relationship to the underlying parent material, local climate, topography, and vegetation.

Mapped soils in the project area consist of Cagey loamy sand (NRCS, 2018). Cagey soils are typically situated on terraces and formed from the weathering of sandy glacial drift. NRCS describes the permeability as rapid (6 to 20 in/hr) (NRCS, 1990)].

As described in the drainage report (BCRA, 2016), the pre-developed condition was modeled as Type A/B soils, consistent with mapped soil and background geotechnical data.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in Drost et al. (1998). Drost et al. (1998) indicates that recessional outwash and end moraine deposits can be an aquifer where saturated, and that perched groundwater conditions can occur locally within these units. This unit typically overlies Vashon lodgement till, which is described by Drost et al. (1998) as typically a confining bed.

On a closer scale, as described in the drainage report (BCRA, 2016), the site is within the Salmon Creek Drainage Basin, which has high groundwater conditions and is subject to specific site development standards. A groundwater mounding analysis was performed by Landau (2016b), to model high groundwater conditions. According to Landau (2016b), the development standards include steps the project must take in order to minimize potential flooding due to proposed project stormwater infiltration facilities.

Limited background groundwater level data was collected at six on-site monitoring wells; groundwater ranged from approximately 1 to 7 feet (about 5 feet near cell TBM) below ground surface in February 2016. Historical groundwater fluctuations are on the order of 8 feet, and peak groundwater is predicted to be at ground surface under extreme conditions (Landau, 2016b).

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Three hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and into the underlying fill and native Vashon recessional outwash. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI’s offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure TBM F2, "Facility and Exploration Plan."

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell TBM were completed on October 2, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring locations are presented on Figure TBM F2. The hand-auger borings encountered approximately 1.2 feet to 1.5 feet of bioretention soil, overlying fill (TBM-HA-3) and/or native material interpreted to be Vashon recessional outwash. TBM-HA-3, located on the northwest end of the cell, encountered a thin layer of compost and topsoil at the surface and a thin layer of fill (about 5 inches thick) between the bioretention soil and the native material. The native recessional outwash was observed to the maximum depth explored of 7.7 feet (TBM-HA-1). No seepage or caving was observed. The recessional outwash contained a silty interbed.

6.2 Well Points

Two well points were installed in cell TBM within TBM-HA-1 (WP-1) and TBM-HA-2 (WP-2). Key well point dimensions are provided in Table 2, below. WP-1 was installed to a depth of 7.6 feet to measure groundwater in the shallow aquifer below the bioretention soil. WP-2 was installed to a depth of 1.9 feet, and screened primarily within the bioretention soil.

Table 2
Summary of Cell TBM
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
TBM-WP-1	TBM-HA-1	11.2	1.25 inch nominal	3.6	7.6
TBM-WP-2	TBM-HA-2	3.7	1.25 inch nominal	1.8	1.9

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology *Stormwater Management Manual for Western Washington* (2014 Ecology Manual). Two samples of material interpreted as representative of bioretention soil were tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell TBM
Organic Content and Grain-Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
TBM-HA-1	0.1-0.5	Bioretention Soil	8.4	SAND, some gravel, some silt (SP-SM)	5.2	8.1	0.9	Sand
TBM-HA-3	0.2-0.7	Bioretention Soil	4.6	SAND, trace gravel, trace silt (SP)	3.0	5.3	0.8	Sand
TBM-HA-1	3.5-4.0	Recessional Outwash	--	Very silty SAND (SM)	33	--	--	Sandy loam to sandy clay loam
TBM-HA-2	1.5-2.0	Recessional Outwash	--	SAND, some gravel, some silt (SP-SM)	9.0	--	--	Sand to Loamy Sand
TBM-HA-3	1.8-2.4	Recessional Outwash	--	SAND, some gravel, trace silt (SP)	4.6	--	--	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture;
*No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 4.6 and 8.4 percent by weight. These results are slightly above (TBM-HA-1, located near the inlet) and slightly below (TBM-HA-3, located near the north end of cell) the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace to some silt and trace to some gravel based on ASTM D2487 USCS. The respective fines content as measured on the No. 200 sieve was 3.0 to 5.2 percent. The coefficient of uniformity ranged from 5.3 to 8.1, meeting the recommended value of equal to or greater than 4. The coefficient of curvature ranged from 0.8 to 0.9, below the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix was generally coarser-graned with more than the recommended range of gravel and coarse sand. The tested bioretention soil was a poorly-graded sand.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell TBM Site Data

Parameter	Recommended Range	Cell TBM
Organic Content (by weight)	5 to 8 percent	6.5 percent by weight
Cu coefficient of uniformity	4 or greater	6.7
Cc coefficient of curvature	1 to 3	0.9
Sieve Size	**Percent Passing**	
3/8” (9.51 mm)	100	99.2
#4 (4.76 mm)	95 to 100	94.7
#10 (2.0 mm)	75 to 90	63.5
#40 (0.42 mm)	25 to 40	18.3
#100 (0.15 mm)	4 to 10	5.9
#200 (0.074 mm)	2 to 5	4.1

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm = millimeters.

7.2 Subgrade

In cell TBM, three samples of native recessional outwash were sieved. The tested materials illustrate the variability in silt content with depth with 5 to 33 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the U.S. Department of Agriculture (USDA) soil texture. The grain-size distributions were normalized to the No. 10 sieve—

i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 4 to 29 percent for the native recessional outwash material.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and conveyed to cell TBM with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Ponded water levels within the cell were monitored using a temporary staff gauge (TBM-SG-1) marked in 0.01-foot increments installed adjacent to TBM-WP-1, and within a piezometers ("ponding tube") with a digital water level tape, and with digital pressure transducers for the duration of the test. The water level at the base of the bioretention soil and the shallow groundwater table were monitored in well point TBM-WP-2 and TBM-WP-1, respectively, with a digital water level tape, and with digital pressure transducers. Data from the digital pressure transducers were compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell TBM is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell TBM

AESI performed infiltration testing on October 25, 2018. Light rainfall was noted during testing, and approximately 0.3 gpm of flow from the inflow was present at the start of the test.

During this test, flow was initially adjusted between about 45 and 85 gpm to fill the cell bottom and stabilize the wetted area, then maintained at about 42 gpm for the duration of test. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. The entire cell base was wetted after about 65 minutes and a water level of about 1.0 feet was maintained at the staff gauge after about 215 minutes (TBM-SG-1). The wetted pool area had been generally stable for about 3.4 hours, covering an area of about 520 square feet. Approximately 20,000 gallons of water were used.

Ponded water in the bioretention cell was monitored in well point TBM-WP-2 with a data logger during the infiltration test and responded rapidly to inflow. Groundwater was not observed within the bioretention soil prior to the start of inflow. The water level in the well point responded to inflow within a few minutes of the start of the test, and was present in the well point throughout the test, generally corresponding to water level within the cell. AESI interprets this response to indicate that water from the infiltration test infiltrated relatively rapidly through the bioretention soil and then mounded on the native finer-grained recessional outwash.

Groundwater was monitored in well point TBM-WP-1 using a data logger during the infiltration test and responded to inflow. Groundwater was not present beneath the bioretention cell prior to the start of inflow to a bottom depth of TBM-WP-1 (7.6 feet). The water level in TBM-WP-1 responded to inflow above the base of the well point after about 140 minutes, and rose an additional 1.1 feet (from 7.6 feet below ground surface to 6.5 feet below ground surface) during the course of testing. AESI interprets that the infiltration test water mounded on the native finer-grained recessional outwash, slowly soaked vertically downward. During testing, the deeper well point lag was approximately 140 minutes when water appeared in the well point in response to inflow. The water in the deeper well point could represent mounding on shallow groundwater present beneath the facility (and below the bottom of well point TBM-WP-1 prior to inflow), or intermittent perching on silty interbeds.

After about 7 hours, AESI shut off the flow and monitored the water level as it fell. AESI observed that the pooled water in the base of the facility dropped about 0.7 feet and water was still ponded in the base of the facility about 0.3 feet after 70 minutes. Groundwater was still mounded approximately 0.7 feet above the base of TBM-WP-1, 70 minutes after inflow stopped.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hose for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and is interpreted to represent the infiltration rate of the native subgrade.

Table 5
Cell TBM
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant Head Level (feet)	Field Infiltration Rates	
					Constant Head Test (in/hr)	Falling Head Test (in/hr)
TBM (bioretention soil)	520	420	19,933	1.0	greater than native soil infiltration rate	
TBM (subgrade)	Interpreted to be similar to wetted area				8	8

in/hr: inches per hour.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell TBM were inconsistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- The overflow is inconsistent with the plans. The plans show for a Type 1 catch basin. No overflow structure was observed The natural overflow is a low area along the east side of the cell rim and was 1.1 feet above the cell base, 0.7 feet below the curb cut low and 0.4 feet below the concrete ramp low. If ponded water filled the cell, overflow would discharge over the cell rim to the east and flow easterly toward the existing infiltration pond. Site design documents indicate that the ponding level was designed as 12 inches.

- Bioretention soil:
    - Thickness: The apparent thickness of loose bioretention soil based on soil probe data averaged about 1.7 feet, generally consistent with the plan.
    - Composition: The soil tested was not within the recommended guidelines for organic content and sand gradation. The soil mix was generally coarser-grained with more than the recommended range of medium- and coarse-grained sand. The average organic content was within the recommended range of 5 to 8 percent; however, the individual samples were either above at 8.4 percent or slightly below at 4.6 percent. The coefficient of curvature was slightly below the recommended range.

- Subgrade conditions: The subgrade is interpreted to consist of Vashon recessional outwash, as documented in the geotechnical explorations for this study and in the design documents. A thin layer (5 inch) of sand fill was observed overlying native material at the northwest end of the cell.

- During infiltration testing, water readily soaked through the bioretention soil mix. Water was observed in the shallow well point (screened at the base of the bioretention soil), demonstrating that water accumulated on the underlying subgrade. The native fine sand is interpreted to have a lower permeability than the overlying bioretention soil. The shallow subsurface ponded water level mirrored the surface water ponding level.

- Subgrade infiltration rate: Measured at about 8 in/hr.

- Bioretention soil field infiltration rate:
    - Greater than the measured field rate of 8 in/hr.
    - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the native subgrade soil infiltration rate.

- Shallow groundwater is expected to be present in the location of the TBM facility below the bottom of well point TBM-WP-1 as measured in the on-site monitoring wells and historic water level data (Landau, 2016b). AESI interprets that the infiltration test water mounded on the native finer-grained recessional outwash, and slowly soaked vertically downward.

During testing, the deeper well point lag was approximately 140 minutes when water appeared in the well point in response to inflow. The water in the deeper well point could represent mounding on shallow groundwater present beneath the facility (and below the bottom of well point TBM-WP-1 prior to inflow), or intermittent perching on silty interbeds. AESI interprets that mounded water dissipated both laterally and vertically as shallow groundwater flow. Water was still ponded in the base of the facility about 0.3 feet above the ground surface and groundwater was still mounded approximately 0.7 feet above the base of TBM-WP-1 about 70 minutes after inflow was stopped.

- The effects of shallow groundwater mounding will increase during the wetter winter months, and will reduce the effective infiltration rate by reducing the vertical gradient. The ongoing monitoring data will be reviewed for groundwater influence.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

Anton D. Ypma
Staff Geologist

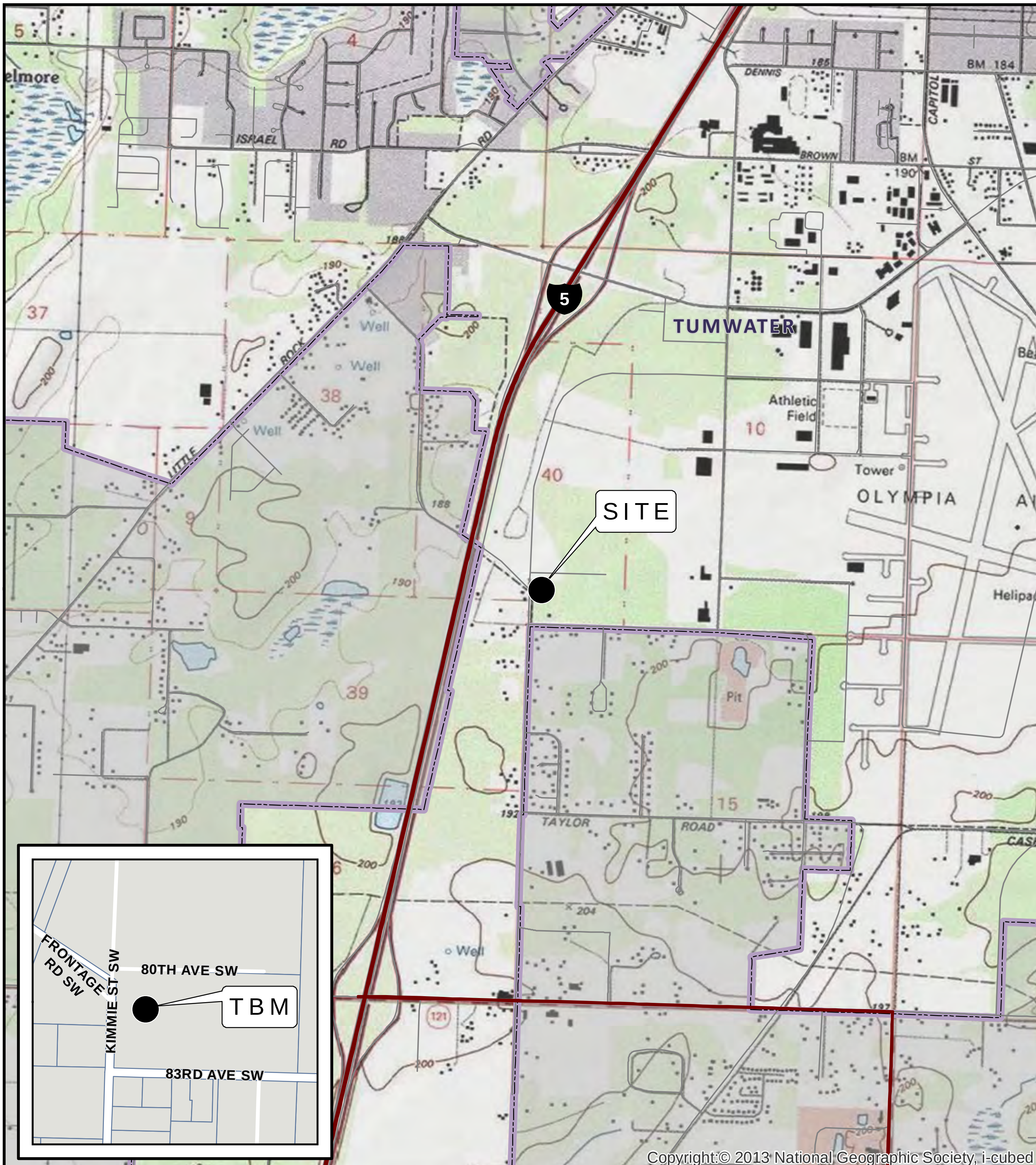
Suzanne S. Cook, L.G.
Senior Project Geologist

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall
6/14/19

Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure TBM F1:	Vicinity Map
	Figure TBM F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

JHS/ld / 150387H007-1 / Projects\20150387\KH\WP



DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
THURSTON CO: STREETS, PARCELS, CITY LIMITS 01/17

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

N

0 1000 2000

FEET

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

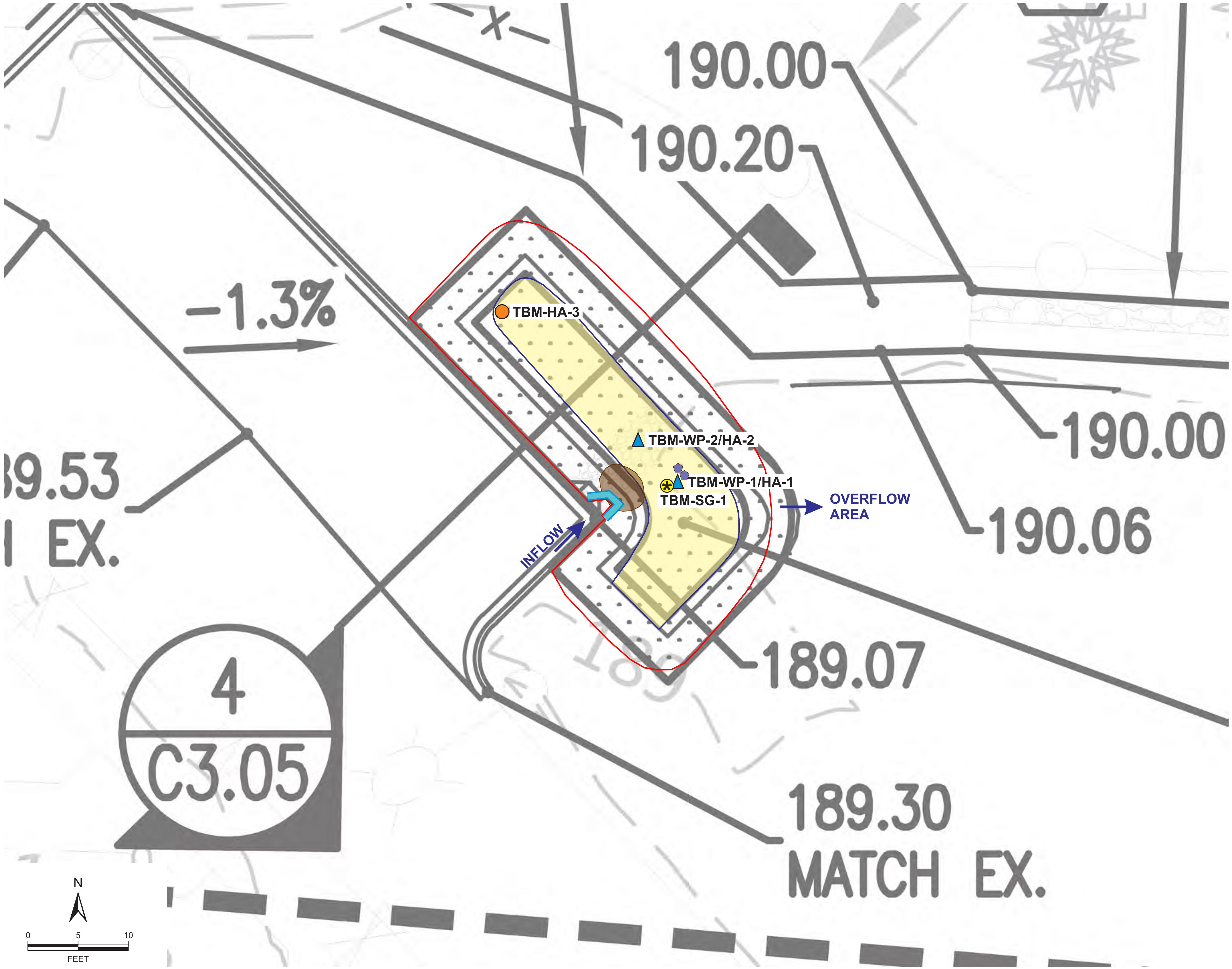
associated earth sciences incorporated

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, TBM SITE
TUMWATER, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TBM F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_TBM.mxd



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
	PVC PONDING TUBE
	CURB CUT
	ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: BCRA, TUMWATER SCHOOL DISTRICT, GEORGE W. BUSH MIDDLE SCHOOL RENOVATION AND ADDITIONS, GRADING PLAN, SHEET C3.01, 12/29/07

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN
TBM SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TUMWATER, WASHINGTON

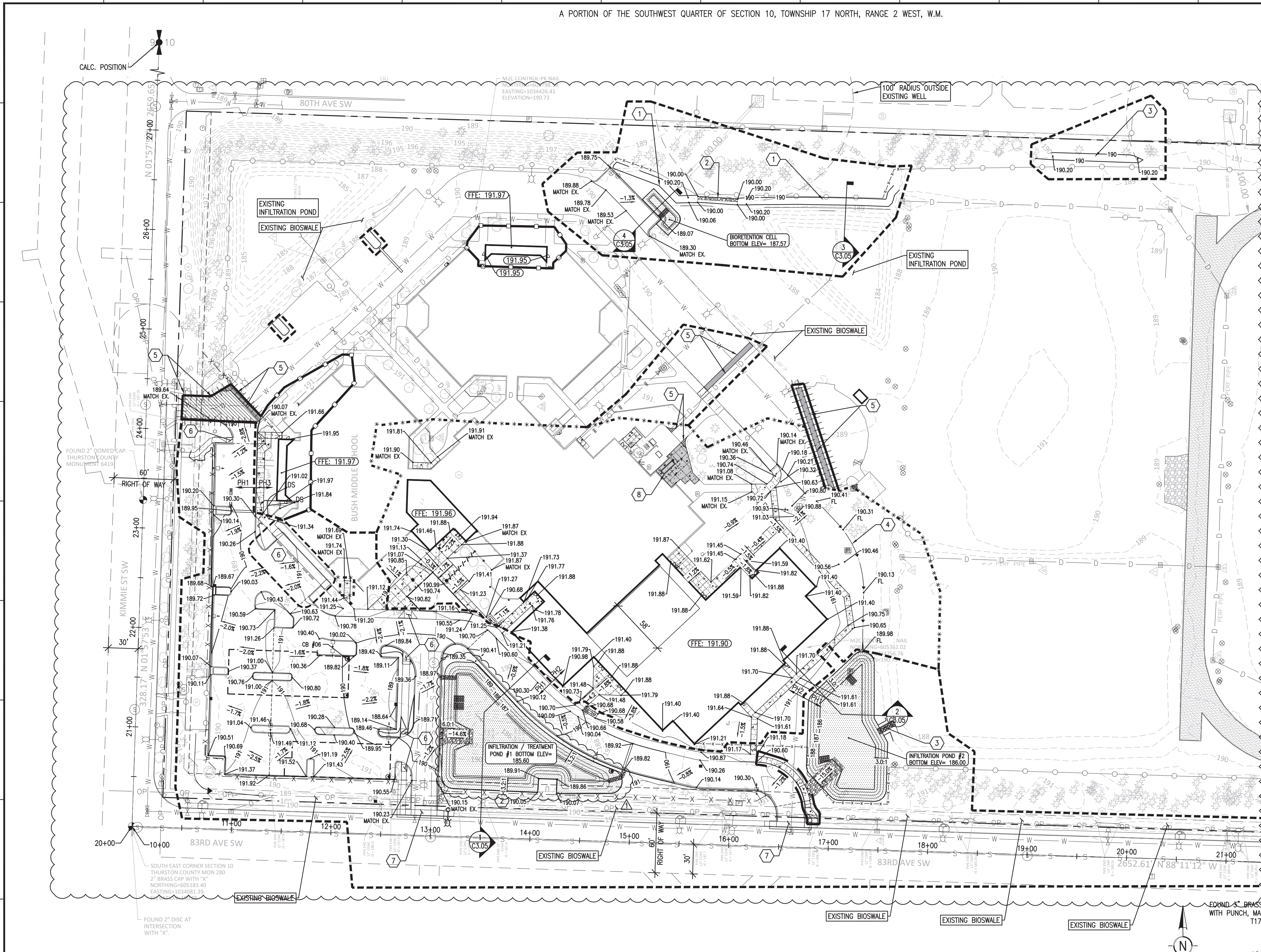
PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TBM F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: TBM F2

APPENDIX A

Project Civil Plans

A PORTION OF THE SOUTHWEST QUARTER OF SECTION 10, TOWNSHIP 17 NORTH, RANGE 2 WEST, W.M.



LEGEND

- PHASE 1 LIMIT OF WORK
- PHASE 2 LIMIT OF WORK
- PHASE 3 LIMIT OF WORK
- PHASE 4 LIMIT OF WORK
- PROPERTY LINE
- BUILDING FOOTPRINT
- GRADE BREAK
- 190 — MAJOR CONTOUR
- 191 — MINOR CONTOUR
- 136.75 — SPOT ELEVATION
- 2.0% — SLOPE ARROW
- CATCH BASIN TYPE 1
- CATCH BASIN TYPE 2
- STORMWATER INFILTRATION FACILITY
- SWALE
- PH 1 PH 2 — PHASE 1 / PHASE 2 BOUNDARY

NOTES:

1. SEE SHEET C0.03 FOR GRADING NOTES.
2. REFER TO SURVEY DATED 11/5/2015 BY MTN2COAST, LLC. FOR LEGEND OF EXISTING IMPROVEMENTS.
3. REFER TO ARCHITECTURAL DRAWINGS FOR EXACT DOWNSPOUT LOCATIONS.
4. ALL GRADING ASSOCIATED WITH STREET LIGHTING IS INCLUDED IN PHASE 1 CONSTRUCTION.
5. ROOF DRAINS AND FOOTING DRAINS NOT SHOWN FOR CLARITY.

DATUM (BY OTHERS)

HORIZONTAL – WASHINGTON STATE PLANE COORDINATES, SOUTH ZONE, NAD 83/91 BASED ON TIES TO THURSTON COUNTY MONUMENTS 280, 6418, AND 6419.

VERTICAL – NGVD 29 BASED ON TIES TO THURSTON COUNTY MONUMENT 280 ELEVATION=190.05.

SHEET NOTES:

1. 6' WIDE BERM.
2. 40' WIDE OVERFLOW SPILLWAY AT ELEV. 190.00 PER DETAIL. (2/C5.09)
3. 6' WIDE OVERFLOW SPILLWAY AT ELEV. 189.00 PER DETAIL. (2/C5.09)
4. PROVIDE SWALE WITH 0.5% MINIMUM FLOWLINE SLOPE.
5. MATCH EXISTING GRADE.
6. ADA PARKING STALL AND RAMP GRADING PER DETAILS. (6/C5.07) (5/C3.05) (6/C3.05) (7/C3.05)
7. DRIVEWAY GRADING PER DETAILS. (1/C5.04)
8. PROVIDE CAST IN PLACE CONCRETE PAD FOR EMERGENCY GENERATOR. REFER TO STRUCTURAL PLANS FOR DETAILS. TOP OF PAD ELEVATION:

△1 REFER TO ATTACHED AS–BUILT SURVEY FOR TOPOGRAPHIC INFORMATION

SCALE: 1"= 50'

FOR THE CITY OF TUMWATER

By: ______ BUILDING OFFICIAL Date: ______

EXPIRES ONE YEAR FROM ACCEPTANCE DATE

FOR THE CITY OF TUMWATER

By: ______ CITY ENGINEER Date: ______

EXPIRES ONE YEAR FROM ACCEPTANCE DATE

811 Know what's below. Call before you dig.

TUM-16-0216

BCRA

T 253.627.4367 F 253.627.4395 WWW.BCRADESIGN.COM
2106 PACIFIC AVENUE, SUITE 300, TACOMA, WA 98402

REVISIONS

△ RECORD DOCUMENTS 12/27/2017

SEAL

JUSTIN JAN GORICH — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER — 43432

PROJECT

TUMWATER SCHOOL DISTRICT
GEORGE W. BUSH MIDDLE SCHOOL
RENOVATION AND ADDITIONS
2120 83RD AVE SW
TUMWATER, WA 98512

DRAWN:	RJB/RMB
DESIGNED:	ZMC/RMB/JFR
REVIEWED:	ABE/JJG
DATE:	12.29.2017
BCRA NO.	15284
CADD FILE:	15284C0301_BMS.dwg

SHEET TITLE

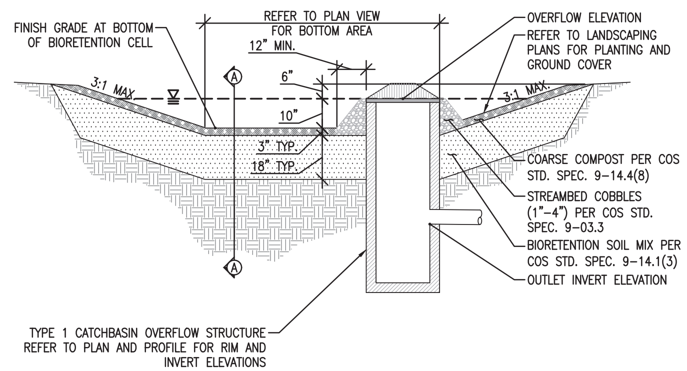
GRADING PLAN

SHEET

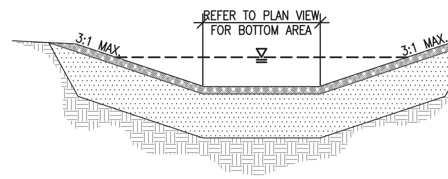
C3.01

RECORD DOCUMENTS

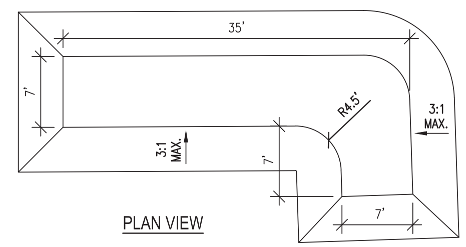
A PORTION OF THE SOUTHWEST QUARTER OF SECTION 10, TOWNSHIP 17 NORTH, RANGE 2 WEST, W.M.



NOTES:
1. RUNOFF SHALL NOT BE ALLOWED TO ENTER BIORETENTION CELL UNTIL FINAL MULCHING AND PLANTING HAS BEEN COMPLETED.
2. BIORETENTION SOIL SHALL BE PROTECTED FROM RAINFALL, SURFACE RUNOFF AND OTHER SOURCES OF ADDED MOISTURE AT THE SUPPLIER'S SITE, IN COVERED CONVEYANCE, AND AT THE PROJECT SITE UNTIL PLACED IN THE BIORETENTION CELL.
3. NO HEAVY EQUIPMENT SHALL OPERATE WITHIN THE CELL OR EARTH BERM PERIMETER ONCE BIORETENTION CELL EXCAVATION HAS BEGUN, INCLUDING DURING EXCAVATION, BACKFILLING, TREE PIT PREPARATION, MULCHING, OR PLANTING.
4. NO MATERIALS OR SUBSTANCES OTHER THAN THE BIORETENTION SOIL SHALL BE MIXED OR DUMPED WITHIN THE CELL OR EARTH BERM AREA THAT MAY BE HARMFUL TO PLANT GROWTH, OR PROVE A HINDRANCE TO THE PLANTING OR MAINTENANCE OPERATIONS.
5. SUBMIT THE INFORMATION REQUIRED BY COS STD. SPEC. 7-21.3(1)A WITH THE EXCEPTION OF THE TWO FIVE (5) GALLON SAMPLES OF THE BIORETENTION SOIL MIX.
6. A PREINSTALLATION MEETING WITH THE ENGINEER IS REQUIRED PRIOR TO COMMENCING THE CONSTRUCTION OF THE BIORETENTION CELLS.
7. EXCAVATION SHALL BE PER COS STD. SPEC. 7-21.3(2)A2.
8. SUBGRADE PREPARATION SHALL BE PER COS STD. SPEC. 7-21.3(2)A3.
9. PLACEMENT OF BIORETENTION SOIL SHALL BE PER COS STD. SPEC. 7-21.3(2)A4 WITH THE EXCEPTION OF #1.
10. FINAL MULCHING AND PLANTING SHALL BE PER COS STD. SPEC. 7-21.3(2)A5.



SECTION A-A

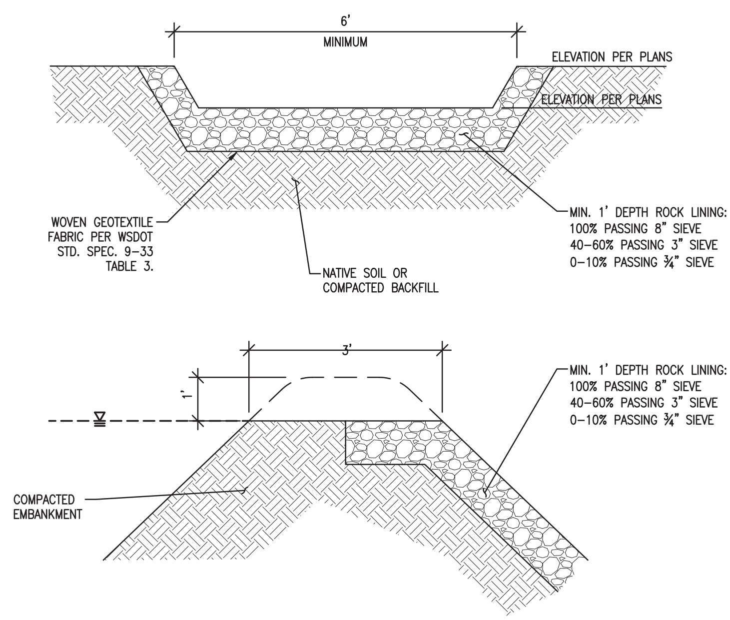


PLAN VIEW

BIORETENTION CELL

1

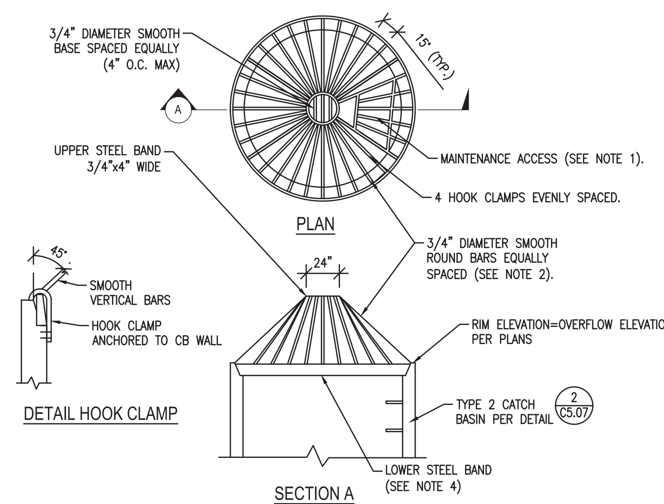
SCALE: NTS



OVERFLOW SPILLWAY

2

SCALE: NTS

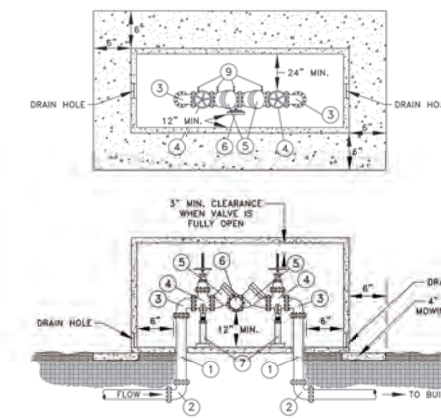


NOTES:
1. PROVIDE MAINTENANCE ACCESS BY WELDING 4 CROSSBARS TO 4 VERTICAL BARS AS SHOWN. HINGE UPPER ENDS WITH FLANGES/BOLTS AND PROVIDE LOCKING MECHANISM (PADLOCK) ON LOWER END. LOCATE STEP DIRECTLY BELOW.
2. BARS SHALL BE WELDED TO UPPER AND LOWER BANDS (24 BANDS EVENLY SPACED).
3. METAL PARTS MUST BE CORROSION RESISTANT; STEEL BARS MUST BE GALVANIZED.
4. 3/4"x4" WIDE STEEL BAND FORMED TO FIT INTO GROOVE OF CB RISER.

OVERFLOW STRUCTURE

3

SCALE: NTS



GENERAL NOTES:

1. WHERE PIPING PASSES THROUGH THE VAULT WALL, PROVIDE WATERPROOF MASTIC OR FLEXIBLE SEALANT.
2. DIAMETER OF PIPE AND FITTINGS TO BE DETERMINED BY A CERTIFIED SPRINKLER DESIGNER.
3. REFER TO DEVELOPMENT GUIDE FOR FURTHER INFORMATION.
4. THOROUGHLY FLUSH LINES PRIOR TO INSTALLING BACKFLOW ASSEMBLY.
5. DRAIN HOLES SHALL BE 1.5 TIMES THE DIAMETER OF THE SERVICE LINE AND INCLUDE SCREENING.
6. DO NOT INSTALL IN AREAS SUBJECT TO FLOODING.
7. ALL MAIN LINES UP TO THE FIRST VALVE ON THE RPBA'S SHALL BE DISINFECTED, PRESSURE TESTED, FLUSHED AND TESTED FOR PURITY PER THE CITY OF TUMWATER STANDARDS.
8. THE PLACEMENT OF THE HOT BOX SHALL BE IN AN AREA WHERE OBSTACLES SUCH AS GATES, ETC. WILL NOT DAMAGE IT.
9. PVC PIPE AND FITTINGS SHALL NOT BE ALLOWED.
10. ALL RPBA'S SHALL BE INSTALLED IN A HOT BOX TO PREVENT THE UNIT FROM FREEZING. THE HOT BOX MAY BE EQUIPPED WITH ELECTRICAL COMPONENTS (CONDUITS, WIRING, ETC.) AND POWER SUPPLIED BY THE OWNER WHEN NECESSARY OR REQUIRED.

MATERIAL LIST:

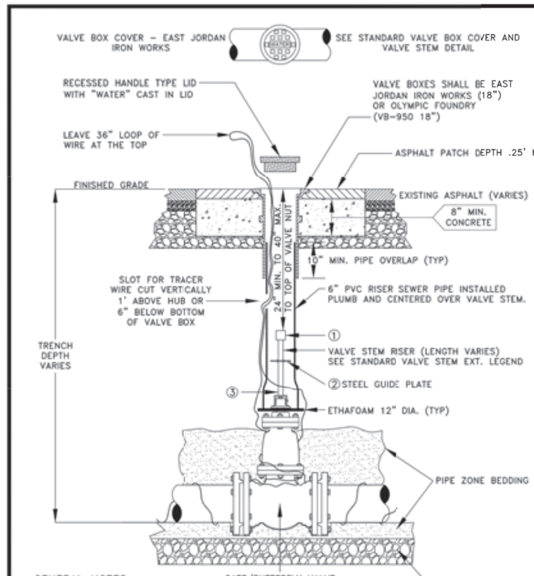
① PVC C900 OR CLASS 52 D.I. WALL PIPE FL X FL
② 90° BEND FL X MEG-A-LUG
③ 90° BEND FL X FL
④ OS&Y GATE VALVE W/HANDWHEEL FL X FL
⑤ D.S.H.S. APPROVED CHECK VALVE FL X FL
⑥ RELIEF VALVE FL
⑦ ADJUSTABLE SUPPORT STANDS
⑧ TEST COCKS – 4 REQUIRED

CITY OF TUMWATER, WASHINGTON DEPT. OF PUBLIC WORKS				
REDUCED PRESSURE BACKFLOW ASSEMBLY FOR 3" & GREATER				
APPROVED BY: CITY ENGINEER				DWG. NO. WA-38
DES. PW	DWG. BY PW	CK'D BY KMC	DATE JULY 2014	NOT TO SCALE

REDUCED PRESSURE BACKFLOW ASSEMBLY

4

SCALE: NTS



GENERAL NOTES:

1. ALL VALVES SHALL HAVE A U.S.E. 12 GAUGE BLUE COATED COPPER TRACER WIRE TIED OFF AT VALVE BODY. THE WIRE SHALL BE EXTENDED UP ON THE OUTSIDE RISER PIPE A FOOT ABOVE THE VALVE HUB BEFORE THE WIRE IS PUT INTO THE RISER THROUGH A SLOT CUT INTO THE RISER. LEAVE 36" OF WIRE ABOVE THE TOP OF VALVE BOX.
2. ALL WELDS TO THE SHAFT SHALL BE FILLET WELD, AROUND THE ENTIRE PLATE PER #2 BELOW.

VALVE STEM EXTENSION LEGEND

① VALVE OPERATING NUT OR 1-7/8" X 1- 7/8" X 2" HIGH GRADE STEEL WELDED TO GUIDE PLATE.
② 3/16" THICK X 5 1/5" DIA STEEL GUIDE PLATE WELDED TO RISER SHAFT.
③ 2"X2"X 3/16" SQUARE STRUCTURAL STEEL TUBING TO FIT OPERATING NUT. LENGTH AS REQUIRED.

CITY OF TUMWATER, WASHINGTON DEPT. OF PUBLIC WORKS				
STANDARD VALVE BOX				
APPROVED BY: CITY ENGINEER				DWG. NO. WA-12
DES. PW	DWG. BY PW	CK'D BY KMC	DATE JUNE 2014	NOT TO SCALE

STANDARD VALVE BOX

5

SCALE: NTS

FOR THE CITY OF TUMWATER

By: ______________________ Date: __________

CITY ENGINEER

EXPIRES ONE YEAR FROM ACCEPTANCE DATE

811 Know what's below. Call before you dig.

TUM-16-0216

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2106 PACIFIC AVENUE, SUITE 300, TACOMA, WA. 98402

REVISIONS

1 RECORD DOCUMENTS 12/27/2017

SEAL

JUSTIN JAN GOROCH STATE OF WASHINGTON 43432 REGISTERED PROFESSIONAL ENGINEER

PROJECT

TUMWATER SCHOOL DISTRICT

GEORGE W. BUSH MIDDLE SCHOOL

RENOVATION AND ADDITIONS

2120 83RD AVE SW
TUMWATER, WA 98512

DRAWN:	RJB/RMB
DESIGNED:	ZMC/RMB/JFR
REVIEWED:	ABE/JJG
DATE:	12.29.2017
BCRA NO.	15284
CADD FILE:	15284C0507-10_BMS.dwg

SHEET TITLE

CIVIL DETAILS

SHEET

C5.09

SHEET 25 OF 42

RECORD DOCUMENTS

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	TBM-HA-1/WP	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Elevation (Top of Well Casing): 99.8 (Project Datum)
Water Level Elevation: Dry
Drilling/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Location: Tumwater, WA
Surface Elevation (ft): 96.2 (Project Datum)
Date Start/Finish: 10/2/18,10/2/18
Hole Diameter (in): 4 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	S T	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Bioretention soil mix 0 to 1.4 feet				**Bioretention Soil Mix**
		Threaded steel pipe 1.25-inch I.D. with threaded and vented PVC cap -3.6 to 4.8 feet				Loose, moist, dark brown, medium SAND, trace to some silt, trace to some gravel; massive; organic rich (SP/SP-SM).
						Some gravel present from 0.5 to 1 foot.
		Bentonite chips 1.4 to 2.4 feet				**Vashon Recessional Outwash** Medium dense, moist, lightly oxidized brown, fine SAND, some silt, trace gravel (SP-SM).
		Vashon Recessional Outwash sands 2.4 to 3.7 feet				
		Silica sand 3.7 to 7.7				Ranges to silty from 3.5 to 4 feet (SM).
5						
		Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 4.8 to 7.2 feet				
						Increased moisture and grades to grayish brown below 6.5 feet.
		Driven into existing sediments 7.7 to 7.9 feet				
		Threaded steel pipe 1.25-inch I.D. and drive point 7.2 to 7.9 feet				Boring terminated at 7.7 feet Well completed at feet on 10/2/18. No seepage. No caving. Steel drive point placed in borehole and hand driven with slide hammer to depth of 7.9 feet.
		Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 11.2 feet.				
10						

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	TBM-HA-2/WP	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Elevation (Top of Well Casing): 98.1 (Project Datum)
Water Level Elevation: Dry
Drilling/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Location: Tumwater, WA
Surface Elevation (ft): 96.3 (Project Datum)
Date Start/Finish: 10/2/18,10/2/18
Hole Diameter (in): 4 inches

Depth (ft)	Water Level	WELL CONSTRUCTION	ST	Blows/ 6"	Graphic Symbol	DESCRIPTION
		Threaded steel pipe 1.25-inch I.D. with threaded and vented PVC cap -1.8 to -0.5 feet Tape over well point screen -0.5 to 0.3 feet Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 0.3 to 1.5 Bioretention soil mix 0 to 1 foot Vashon Recessional Outwash 1.5 to 2 feet Threaded steel pipe 1.25-inch I.D with drive point 1.5 to 2.2 feet Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 3.7 feet.				**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some silt, trace gravel; massive; organic rich (SP/SP-SM). **Vashon Recessional Outwash** Medium dense, moist, lightly oxidized brown, fine SAND, some silt, trace gravel (SP-SM). Boring terminated at 2 feet Well completed at feet on 10/2/18. No seepage. No caving. Steel drive point placed in borehole and hand driven with slide hammer to depth of 2.2 feet.
5						
10						

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample

M - Moisture
Water Level ()
Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	TBM-HA-3	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Tumwater, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A
Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/2/18,10/2/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Compost / Topsoil					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace to some silt, trace gravel; massive; organic rich (SP/SP-SM).					
		S-2		**Fill ?** Medium dense, moist, dark brown, fine SAND, some silt, some gravel; unsorted (SP-SM).					
				Vashon Recessional Outwash Medium dense, moist, lightly oxidized brown silty, fine SAND, trace gravel (SM).					
				Bottom of exploration boring at 2.4 feet. No seepage. No caving.					
5									
10									

Sampler Type (ST):
- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

Date Sampled	Project	Project No.		Soil Description
10/2/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- TBM			

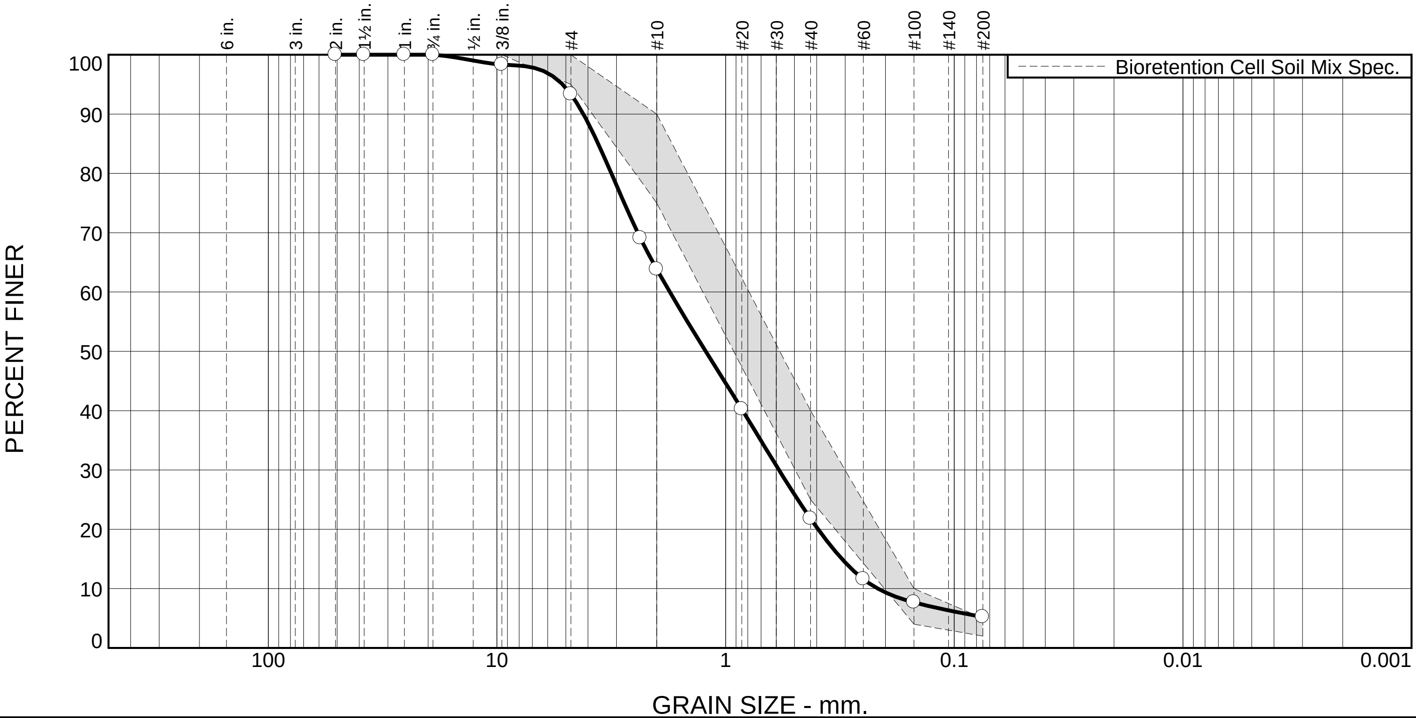
Moisture Content

Sample ID	HA-1/WP (0'-0.5')	HA-3 (0.2'-0.7')
Wet Weight + Pan	1116.25	919.89
Dry Weight + Pan	996.82	868.00
Weight of Pan	465.60	421.66
Weight of Moisture	119.43	51.89
Dry Weight of Soil	531.22	446.34
% Moisture	18.4	10.4

Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	618.01	593.26
Dry Soil After Burn + Pan	599.01	583.96
Weight of Pan	391.96	391.90
Wt. Loss Due to Ignition	19.00	9.30
Actual Wt. Of Soil After Burr	207.05	192.06
% Organics	8.4	4.6

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	6.7	29.4	42.1	16.6	5.2	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	98.3	100.0	X
#4	93.3	95.0 - 100.0	X
#8	69.1		
#10	63.9	75.0 - 90.0	X
#20	40.3		
#40	21.8	25.0 - 40.0	X
#60	11.6		
#100	7.7	4.0 - 10.0	
#200	5.2	2.0 - 5.0	X

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, some gravel, some silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 4.1886 D_{85}= 3.6085 D_{60}= 1.7539
D_{50}= 1.2213 D_{30}= 0.5845 D_{15}= 0.3099
D_{10}= 0.2161 C_u= 8.12 C_c= 0.90

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/08/2018 **Date Tested:** 11/09/2018

Tested By: BN

Checked By: JHS

Title:

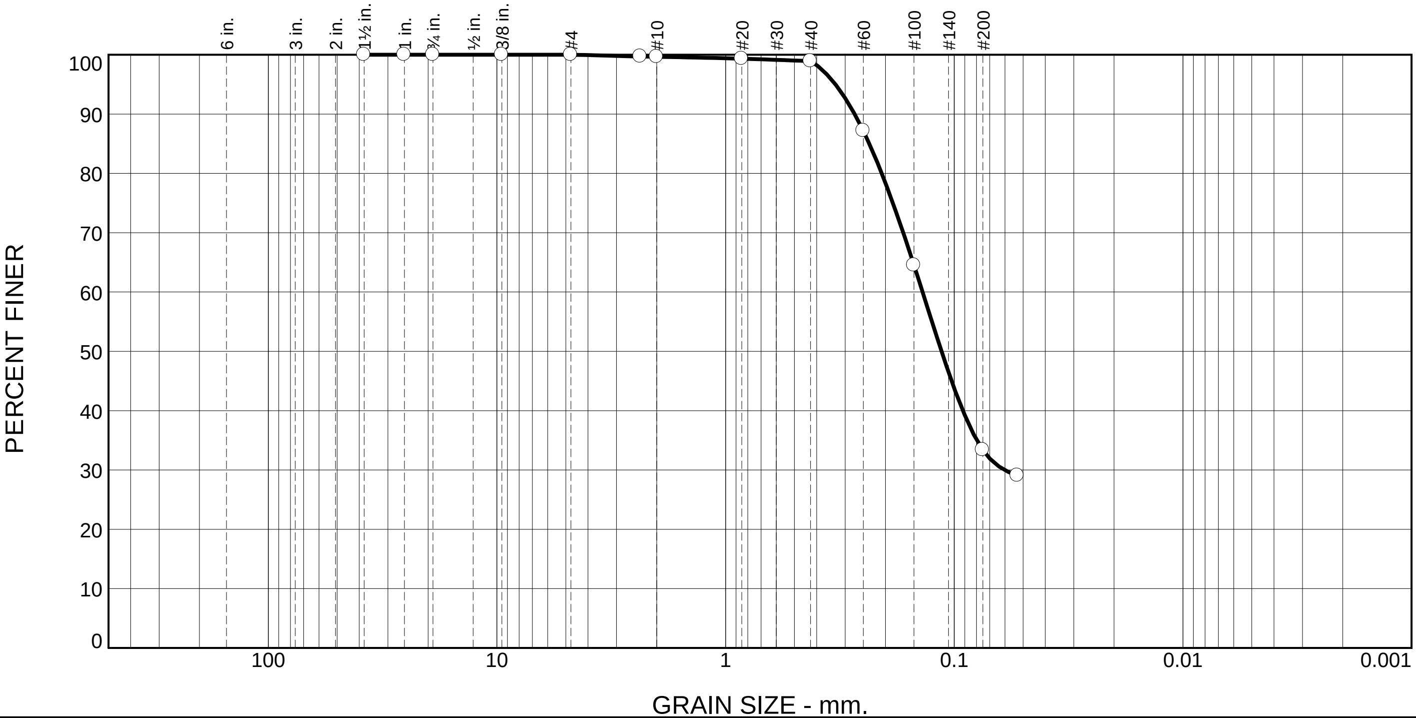
Source of Sample: (TBM) Tumwater- George W. Bush Middle School **Depth:** 0.1'-0.5' **Date Sampled:** 10/02/2018
Sample Number: HA-1/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.4	0.7	65.5	33.4	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0		
#4	100.0		
#8	99.7		
#10	99.6		
#20	99.3		
#40	98.9		
#60	87.2		
#100	64.5		
#200	33.4		
#270	29.0		

* (no specification provided)

Material Description

very silty SAND

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.2727 D_{85}= 0.2353 D_{60}= 0.1376
D_{50}= 0.1137 D_{30}= 0.0603 D_{15}=
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 12/06/2018 **Date Tested:** 12/11/2018

Tested By: BN

Checked By: JHS

Title:

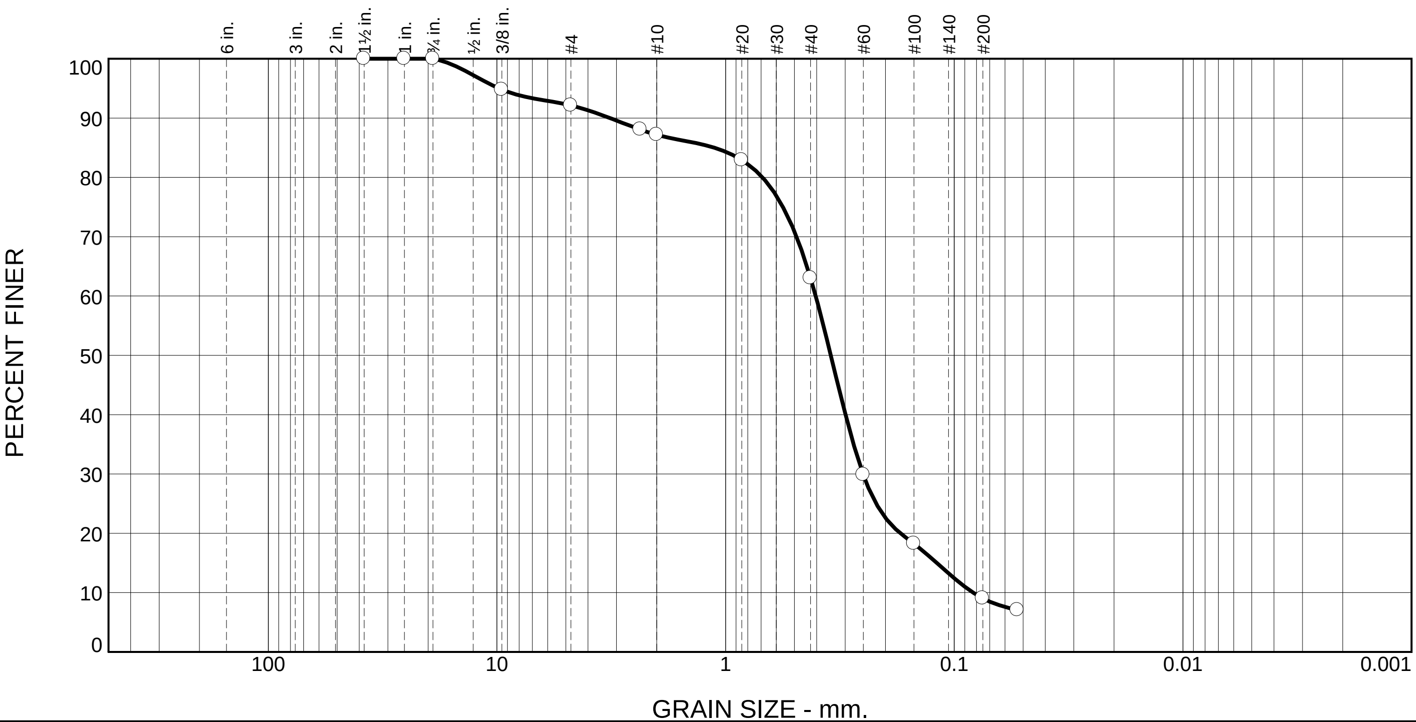
Source of Sample: (TBM) Tumwater- George W. Bush Middle School **Depth:** 3.5'-4' **Date Sampled:** 10/02/2018
Sample Number: HA-1/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	7.9	4.9	24.2	54.0	9.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	94.8		
#4	92.1		
#8	88.1		
#10	87.2		
#20	82.9		
#40	63.0		
#60	29.9		
#100	18.2		
#200	9.0		
#270	7.0		

* (no specification provided)

Material Description

SAND, some silt, some gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 3.2060 D_{85}= 1.1189 D_{60}= 0.4037
D_{50}= 0.3467 D_{30}= 0.2507 D_{15}= 0.1193
D_{10}= 0.0827 C_u= 4.88 C_c= 1.88

Remarks

Collected by: ADY

Date Received: 12/06/2018 **Date Tested:** 12/11/2018

Tested By: BN

Checked By: JHS

Title:

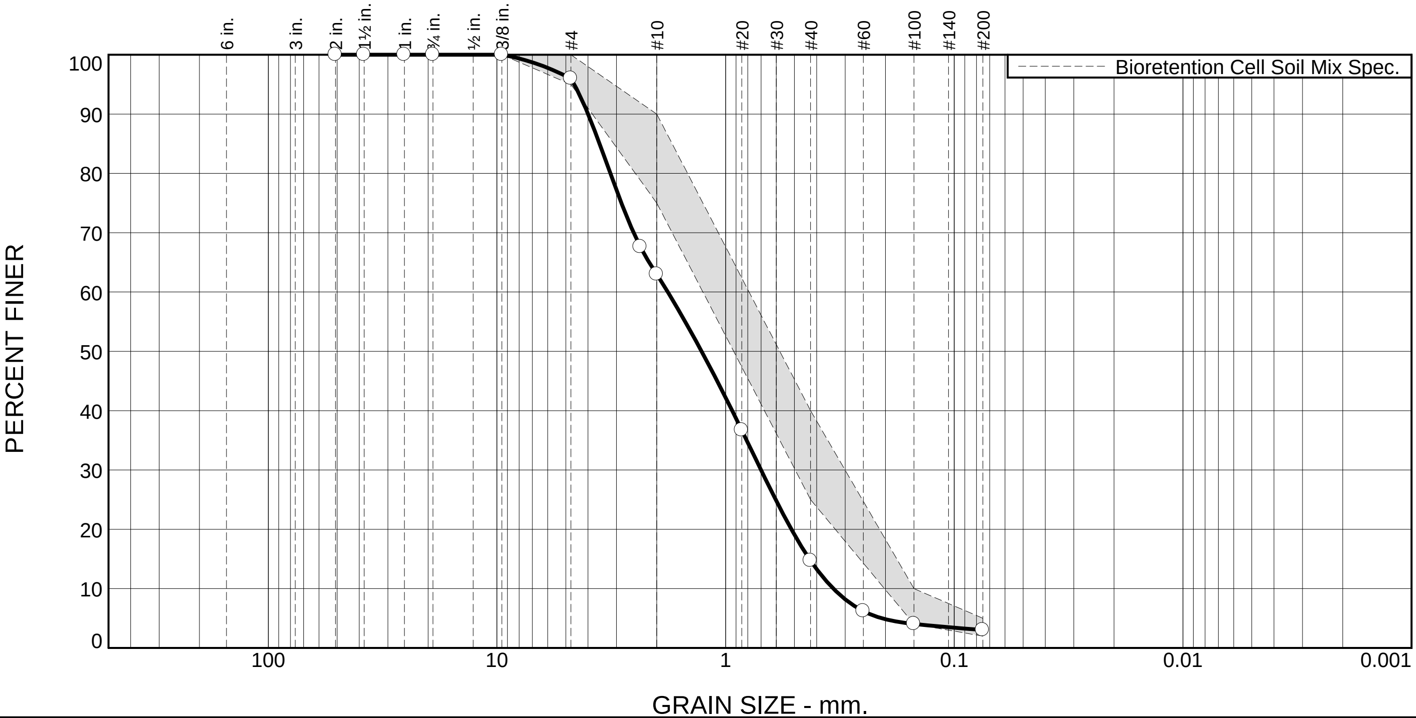
Source of Sample: (TBM) Tumwater- George W. Bush Middle School **Depth:** 1.5'-2.0' **Date Sampled:** 10/02/2018
Sample Number: HA-2/WP

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.0	33.0	48.3	11.7	3.0	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
2	100.0		
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	96.0	95.0 - 100.0	
#8	67.6		
#10	63.0	75.0 - 90.0	X
#20	36.7		
#40	14.7	25.0 - 40.0	X
#60	6.2		
#100	4.0	4.0 - 10.0	
#200	3.0	2.0 - 5.0	

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace gravel, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=**

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 3.9949 D_{85}= 3.5576 D_{60}= 1.7899
D_{50}= 1.2741 D_{30}= 0.7000 D_{15}= 0.4303
D_{10}= 0.3381 C_u= 5.29 C_c= 0.81

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/08/2018 **Date Tested:** 11/08/2018

Tested By: BN

Checked By: JHS

Title:

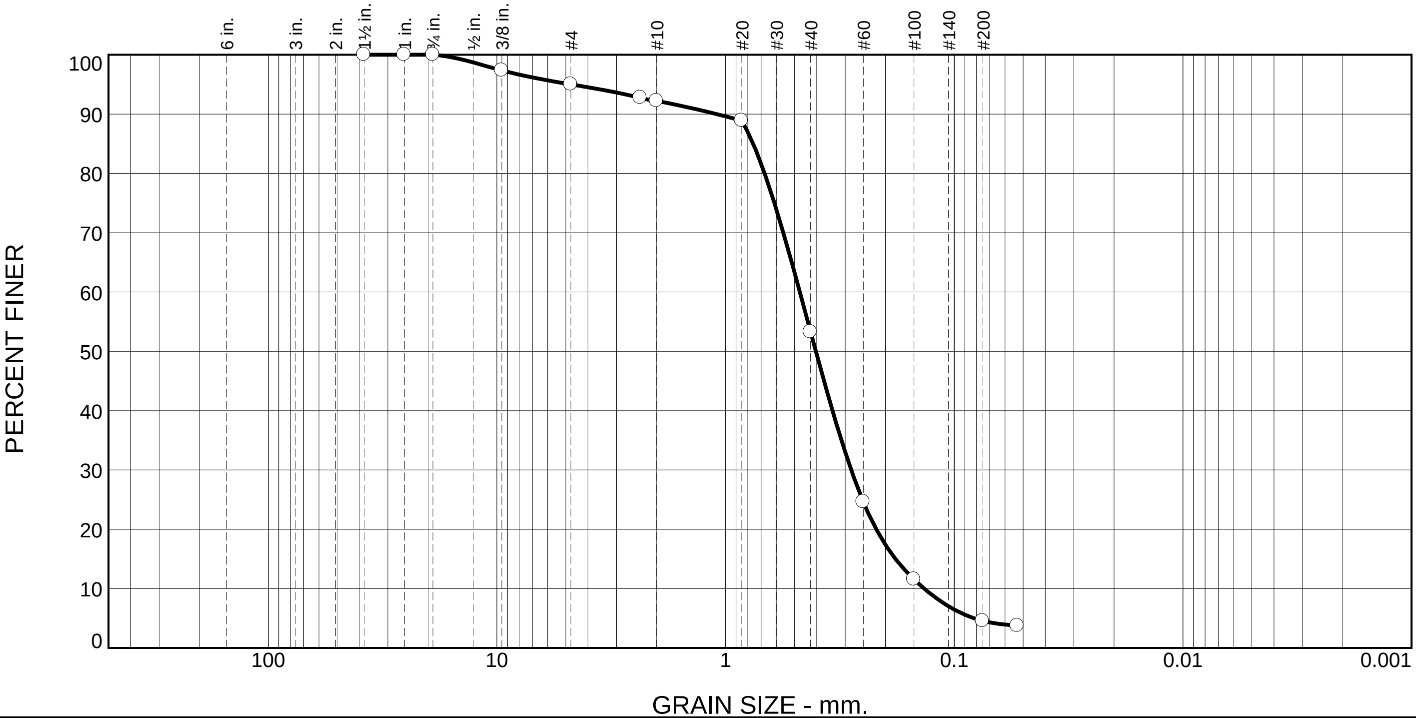
Source of Sample: (TBM) Tumwater- George W. Bush Middle School **Depth:** 0.2'-0.7' **Date Sampled:** 10/02/2018
Sample Number: HA-3

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.0	2.8	38.9	48.7	4.6	

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	97.4		
#4	95.0		
#8	92.7		
#10	92.2		
#20	88.9		
#40	53.3		
#60	24.6		
#100	11.6		
#200	4.6		
#270	3.7		

* (no specification provided)

Material Description

SAND, some gravel, trace silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 1.0983 D_{85}= 0.7574 D_{60}= 0.4737
D_{50}= 0.4030 D_{30}= 0.2823 D_{15}= 0.1808
D_{10}= 0.1354 C_u= 3.50 C_c= 1.24

Remarks

Collected by: ADY

Date Received: 12/06/2018 **Date Tested:** 12/11/2018
Tested By: BN
Checked By: JHS
Title:

Source of Sample: (TBM) Tumwater- George W. Bush Middle School **Depth:** 1.8'-2.4' **Date Sampled:** 10/02/2018
Sample Number: HA-3

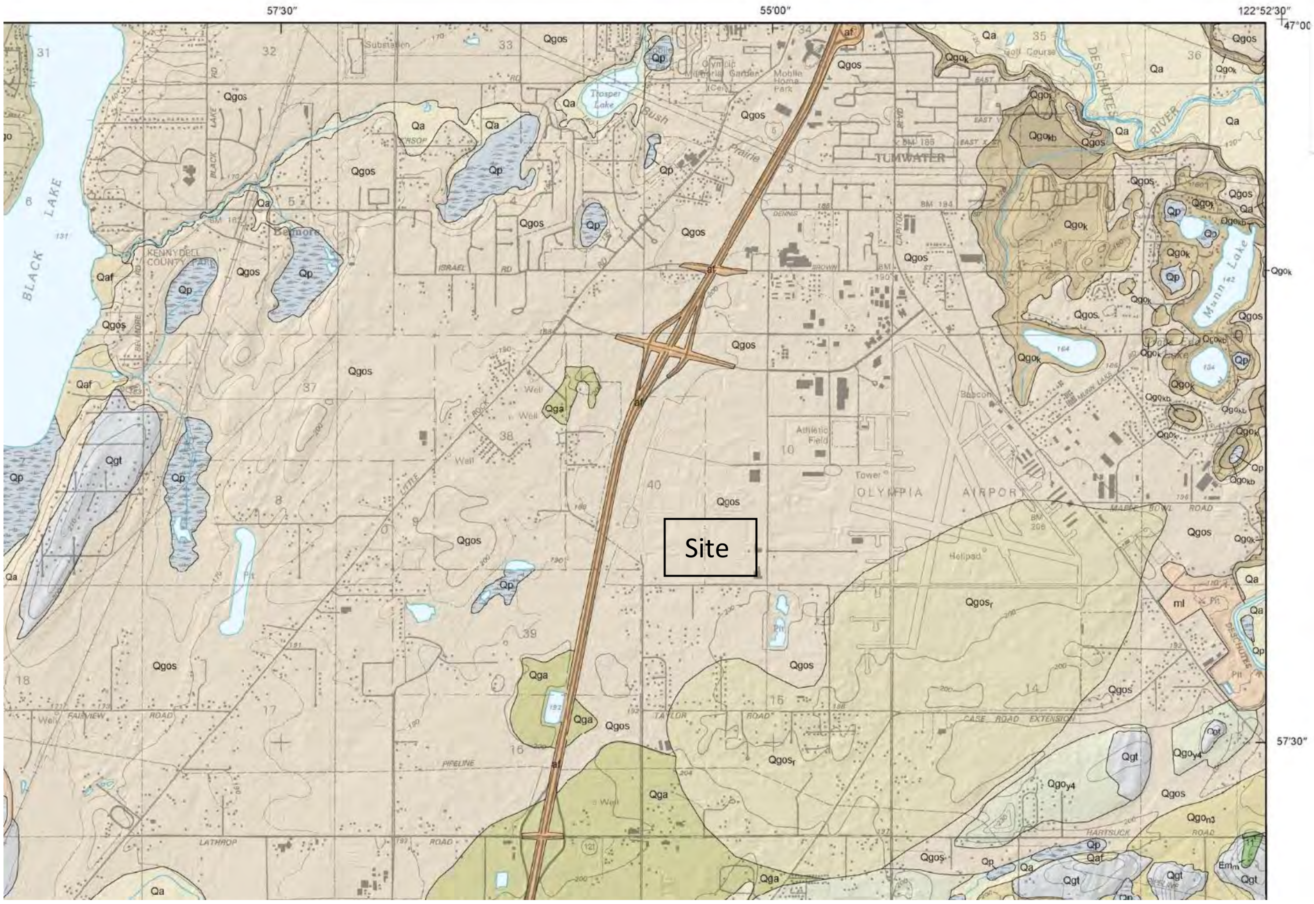
a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

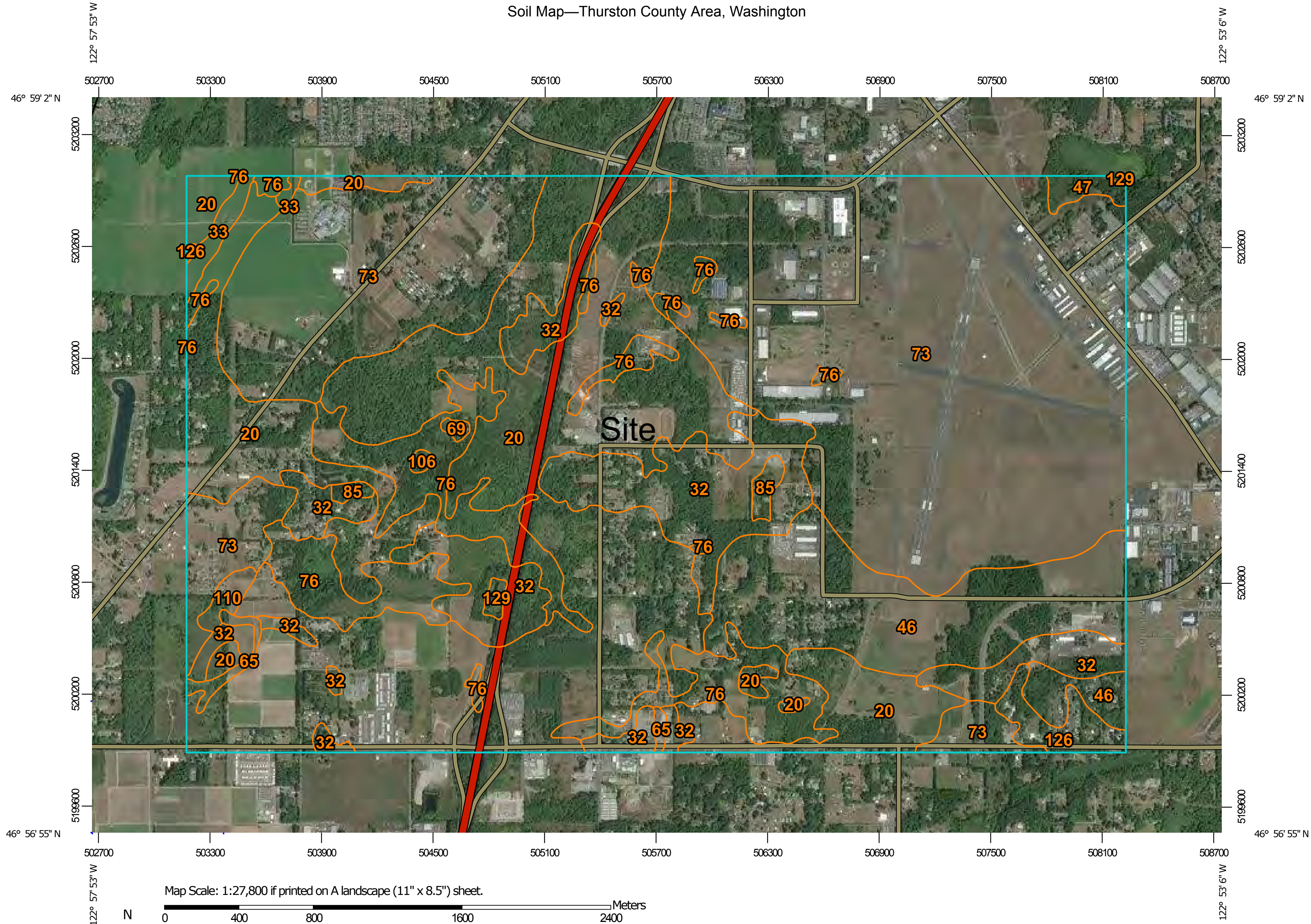
APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Site Unit: Qgos: Vashon Recessional Outwash sand and silt

Source:
Geologic map of the Maytown 7.5-minute quadrangle, Thurston County, Washington
Author(s): Logan, R.L., Walsh, T.J., Stanton, B.W., and Sarikhan, I.Y.
Publishing Organization: Washington Division of Geology and Earth Resources
Series and Number: Geologic Map GM-72
Publication Date: 2009
Map Scale: 1:24,000



Map Scale: 1:27,800 if printed on A landscape (11" x 8.5") sheet.

Meters: 0, 400, 800, 1600, 2400

Feet: 0, 1000, 2000, 4000, 6000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
20	Cagey loamy sand	1,255.2	32.4%
32	Everett very gravelly sandy loam, 0 to 8 percent slopes	367.3	9.5%
33	Everett very gravelly sandy loam, 8 to 15 percent slopes	18.0	0.5%
46	Indianola loamy sand, 0 to 5 percent slopes	320.7	8.3%
47	Indianola loamy sand, 5 to 15 percent slopes	13.6	0.4%
65	McKenna gravelly silt loam, 0 to 5 percent slopes	13.8	0.4%
69	Mukilteo muck	3.1	0.1%
73	Nisqually loamy fine sand, 0 to 3 percent slopes	1,512.5	39.0%
76	Norma silt loam	301.0	7.8%
85	Pits, gravel	13.8	0.4%
106	Shalcar variant muck	2.7	0.1%
110	Spanaway gravelly sandy loam, 0 to 3 percent slopes	11.6	0.3%
126	Yelm fine sandy loam, 0 to 3 percent slopes	36.7	0.9%
129	Water	5.6	0.1%
Totals for Area of Interest		**3,875.7**	**100.0%**

G:\Projects\1467\003\020\021\Bush Middle School\F02SitePlan.mxd 10/26/2015 NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

B-1 Approximate Borehole Location and Designation

B-8 Approximate Monitoring Well Location and Designation

Subject Property

0 200 400

Scale in Feet

Landau Associates

Data Sources: Thurston County GIS; Esri World Imagery.

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

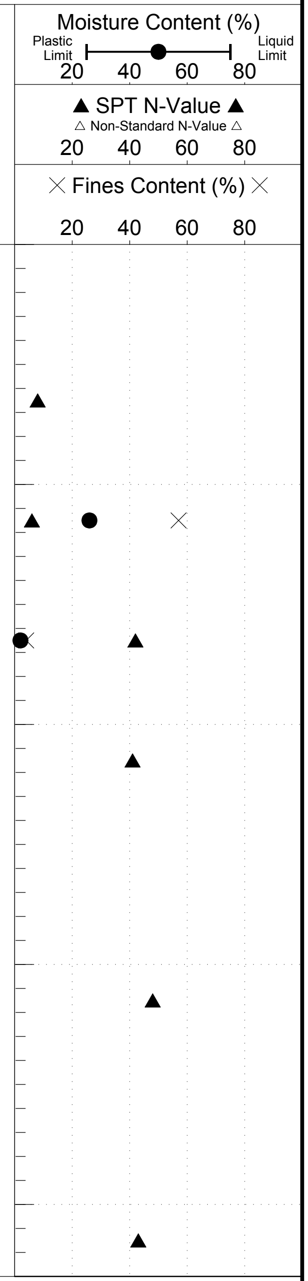
Bush Middle School Tumwater, Washington	**Site Plan**	Figure 2

B-1

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Soil Profile
0	195					SM	2 inches of sod over 5 inches of topsoil (loose, damp) **(TOPSOIL)**
						SM	Brown, silty, fine SAND (loose, damp) **(RECESSIONAL OUTWASH)**
		S-1	b2	8			
5	190					SM	Mottled brown/gray SAND with silt (loose, moist)
		S-2	b2	6	W = 26 GS		
						GP	Grayish-brown, fine to coarse GRAVEL with sand (dense, moist)
		S-3	b2	42	W = 2 GS		
10	185	S-4	b2	41			
						GP-GM	Grayish-brown, fine to coarse GRAVEL with sand and silt (dense, moist)
15	180	S-5	b2	48			
						SP	Gray, fine to coarse SAND with gravel (dense, wet)
20	175	S-6	b2	43			
25							

Drilling Method: Hollow-Stem Auger
Ground Elevation (ft): 195
Drilled By: Holocene Drilling Inc.
Logged By: DAR Date: 08/24/15

Groundwater: 17.0 ft ATD



Boring Completed 08/24/15
Total Depth of Boring = 21.5 ft.

Notes: 1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

LANDAU ASSOCIATES

Bush Middle School
Tumwater, Washington

Log of Boring B-1

Figure A-2

B-8

SAMPLE DATA / SOIL PROFILE

Drilling Method: Hollow-Stem Auger
Ground Elevation (ft): 188
Drilled By: Holocene Drilling Inc.
Logged By: DAR Date: 09/01/15

WELL DETAIL (DOE#: BJF 943)

Moisture Content (%) — Plastic Limit / Liquid Limit: 20 40 60 80
▲ SPT N-Value ▲ (△ Non-Standard N-Value △): 20 40 60 80
× Fines Content (%) ×: 20 40 60 80

Depth (ft)	Elevation (ft)	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data	USCS Symbol	Description
0	188					SM	2 inches of sod over 6 inches of topsoil (loose, moist) **(TOPSOIL)**
						SP-SM	Brownish-gray, gravelly, fine to coarse SAND with silt (medium dense, moist) **(RECESSIONAL OUTWASH)**
	185	S-1	b2	12	W = 9 GS		
5						SP	Brownish-gray, fine to coarse SAND with gravel (medium dense, moist)
		S-2	b2	20	W = 6 GS		
	180	S-3	b2	26			-grades to gravelly
10		S-4	b2	25			
	175					GP	Gray, fine to coarse GRAVEL with sand (medium dense, moist to wet)
15		S-5	b2	19			
	170						
20		S-6	b2	17			-grades to wet

16.0 ft ATD

Boring Completed 09/01/15
Total Depth of Boring = 21.5 ft.

Notes: 1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

1467003.01 3/3/16 \\OLYMPIA1\PROJECTS\1467003.010\1467003.010 - BUSH MS GW STUDY\T\1467003.010.GPJ SOIL BORING LOG WITH GRAPH

LANDAU ASSOCIATES

Bush Middle School
Tumwater, Washington

Log of Boring B-8

Figure A-9

Table 2
On-Site Piezometer Groundwater Elevation Data
Bush Middle School
Tumwater, Washington

Date of Observation	B-8	B-11	B-12	B-14	B-15	B-17
12/2/2015	176.1	176.0	175.9	176.2	176.2	176.3
12/11/2015	177.9	177.7	177.9	177.9	178.1	178.2
12/15/2015	178.9	178.8	178.9	178.9	179.1	179.1
12/22/2015	180.4	180.3	180.4	180.3	180.6	180.6
12/28/2015	181.6	181.4	181.6	181.4	181.7	181.8
1/5/2016	181.6	181.4	181.6	181.5	181.7	181.7
1/12/2016	181.09	180.94	180.73	180.94	181.12	181.17
1/18/2016	181.47	181.30	181.15	181.28	181.54	181.57
1/27/2016	183.04	182.96	182.81	182.78	183.09	183.12
2/2/2016	183.65	183.6	183.42	183.41	183.76	183.74
Average Difference Relative to B-15 (ft)	-0.1	-0.3	-0.2	-0.2	--	+0.1
Standard Deviation of Difference Relative to B-15 (ft)	0.1	0.1	0.1	0.1	--	0.1

ft = feet/foot
Notes:
1. All elevation data are shown in feet referenced to vertical datum National Geodetic Vertical Datum of 1929.
2. Groundwater elevation data recorded up to January 5, 2016 were measured relative to ground surface; data recorded after January 5, 2016 were measured relative to the top of the surveyed well casing.

B-8

SAMPLE DATA / SOIL PROFILE / GROUNDWATER

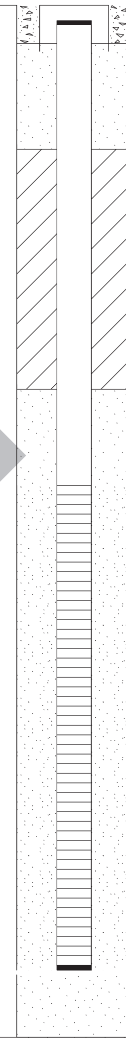
Drilling Method: Hollow-Stem Auger
Ground Elevation (ft): 188
Drilled By: Holocene Drilling Inc.

Depth (ft)	Elevation	Sample Number & Interval	Sampler Type	Blows/Foot	Test Data
0					
	185	S-1	b2	12	W = 9 GS
5		S-2	b2	20	W = 6 GS
	180	S-3	b2	26	
10		S-4	b2	25	
	175				
15		S-5	b2	19	
	170				
20		S-6	b2	17	
25					

USCS Symbol	Soil Profile
SM	2 inches of sod over 6 inches of topsoil (loose, moist) **(TOPSOIL)**
SP-SM	Brownish-gray, gravelly, fine to coarse SAND with silt (medium dense, moist) **(RECESSIONAL OUTWASH)**
SP	Brownish-gray, fine to coarse SAND with gravel (medium dense, moist) -grades to gravelly
GP	Gray, fine to coarse GRAVEL with sand (medium dense, moist to wet) -grades to wet

Water Level: ATD ▽ (approx. 15.5 ft)

On-Site Piezometer Detail (DOE#: BJF 943)



Boring Completed 09/01/15
Total Depth of Boring = 21.5 ft.

Notes:
1. Stratigraphic contacts are based on field interpretations and are approximate.
2. Reference to the text of this report is necessary for a proper understanding of subsurface conditions.
3. Refer to "Soil Classification System and Key" figure for explanation of graphics and symbols.

DRAFT

1467003.01 1/13/16 O:\1467003.010 - BUSH MS GW STUDY\T1467003.010.GPJ WELL LOG W/ ELEVATION

LANDAU ASSOCIATES

Bush Middle School
Tumwater, Washington

Log of On-Site Piezometer B-8

Figure 2-2

APPENDIX D

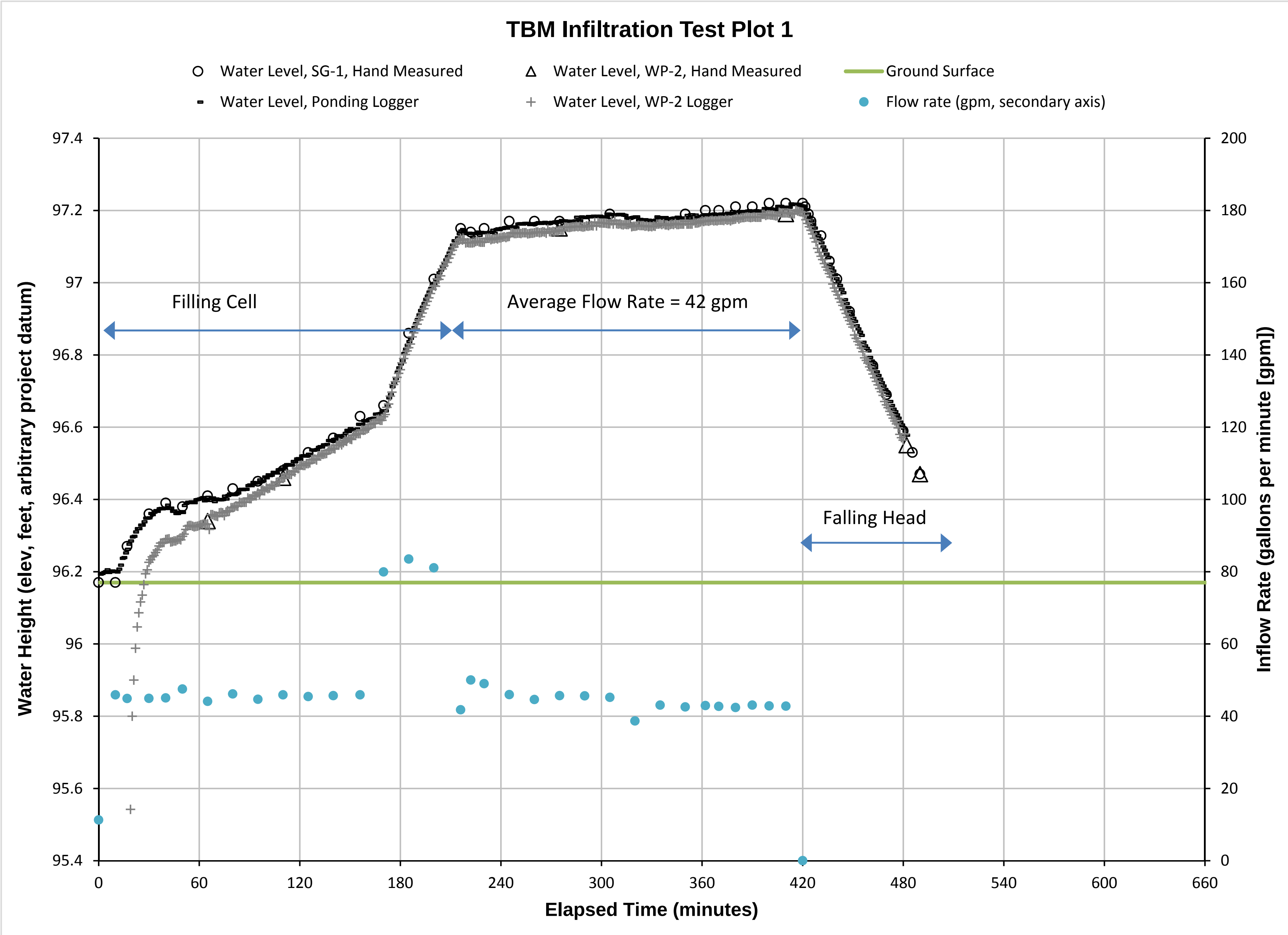
Soil Probe, Level Survey, and Field Infiltration Testing Data

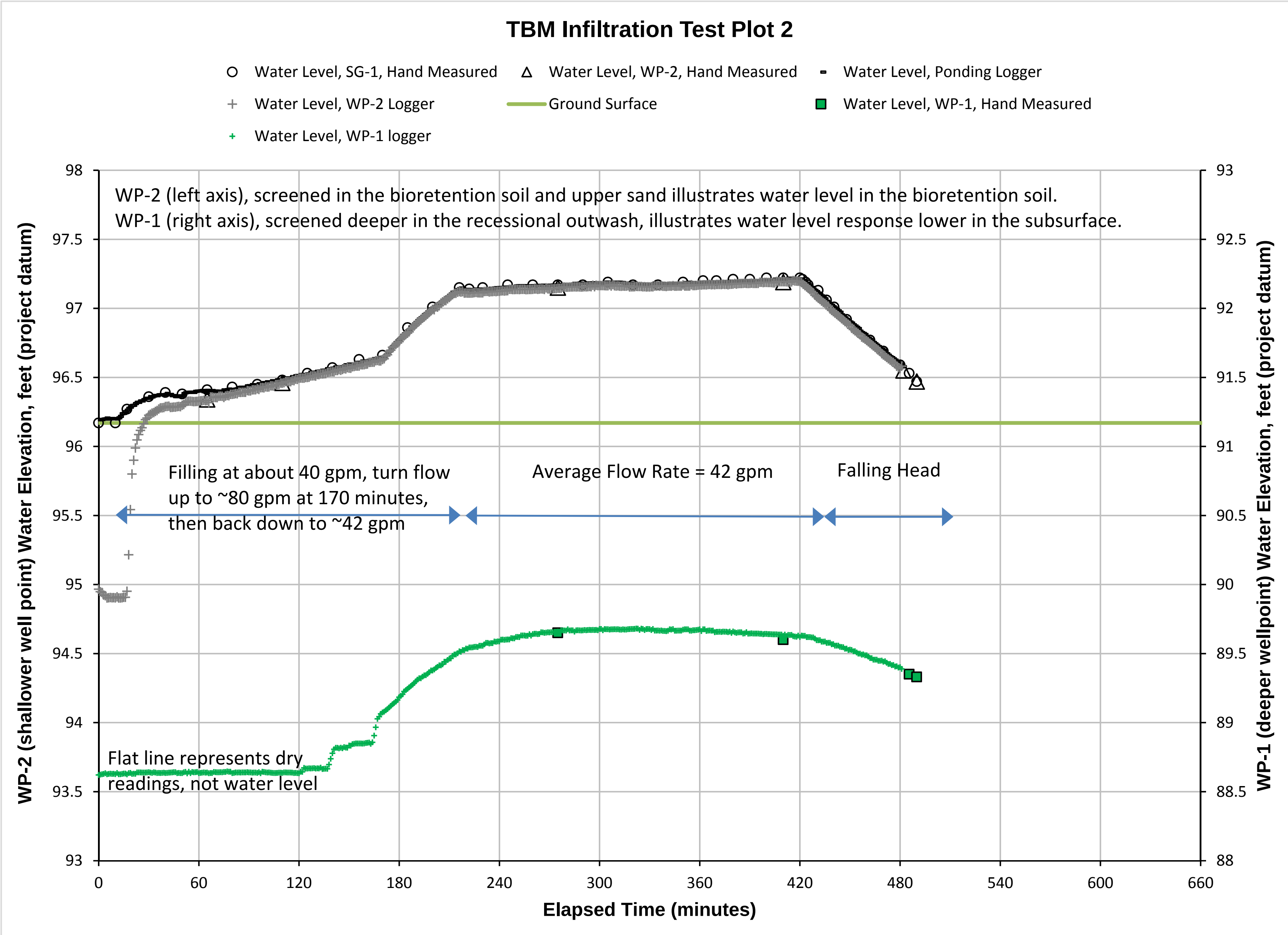
Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5
Date:	10/25/2018	**Base Area (sq.ft.):**	NA
Weather:	Intermittent rain, 60's	**Ponded Area(sq.ft.):**	520.0
Test No.:	TBM	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Recessional Outwash

Time (24-hr)	**Flow Rate (gpm)**	**Stage (feet)**	**Totalizer (gallons)**	**Comments**
9:10	11.28	0	0	Flow on. Light rain.
9:20	45.89	0	111	
9:27	44.89	0.1	449	
9:40	44.94	0.19	998	
9:50	45.06	0.22	1445	
10:00	47.5	0.21	1782	Flow rate fluctuation
10:15	44.11	0.24	2460	Base fully wetted.
10:30	46.17	0.26	3134	No rain.
10:45	44.67	0.28	3809	
11:00	45.89	0.31	4490	No rain.
11:15	45.44	0.36	5184	
11:30	45.67	0.4	5848	Light rain resumes.
11:46	45.89	0.46	6593	
12:00	79.94	0.49	7201	Light rain. Flow rate increased.
12:15	83.5	0.69	8417	
12:30	81.06	0.84	9646	Rain stopped.
12:45	41.78	0.98	10870	Flow rate decreased.
12:52	50	0.97	11190	
13:00	49	0.98	11575	
13:15	45.98	1	12358	
13:30	44.61	1	13021	No rain.
13:45	45.67	1	13699	
14:00	45.61	1	14368	No rain.
14:15	45.22	1.02	15055	
14:30	38.67	1	15664	
14:45	43.06	1	16291	
15:00	42.56	1.02	16934	
15:12	42.94	1.03	17450	
15:20	42.72	1.03	17794	
15:30	42.39	1.04	18221	
15:40	43.06	1.04	18650	
15:50	42.83	1.05	19076	
16:00	42.78	1.05	19503	
16:10	0	1.05	19933	Flow off.
16:11		1.04		
16:13		1.02		
16:15		1		
16:21		0.96		Light rain begins.
16:26		0.89		Moderate rain, minimal inflow.
16:30		0.84		
16:38		0.75		
16:52		0.6		
17:00		0.52		
17:10		0.42		Heavy rain, inflow water is silty.
17:12				

17:15		0.36		
17:20		0.3		

	Average Infiltration Rate (in/hr) during last hour of inflow:	7.7
	Average Infiltration Rate (in/hr) during falling head:	7.7


TBM Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, WP-2, Hand Measured
Ground Surface
Water Level, Ponding Logger
Water Level, WP-2 Logger
Flow rate (gpm, secondary axis)
Filling Cell
Average Flow Rate = 42 gpm
Falling Head
Water Height (elev, feet, arbitrary project datum)
Inflow Rate (gallons per minute [gpm])
Elapsed Time (minutes)
97.4
97.2
97
96.8
96.6
96.4
96.2
96
95.8
95.6
95.4
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
540
600
660


TBM Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, WP-2, Hand Measured
Water Level, Ponding Logger
Water Level, WP-2 Logger
Ground Surface
Water Level, WP-1, Hand Measured
Water Level, WP-1 logger
WP-2 (left axis), screened in the bioretention soil and upper sand illustrates water level in the bioretention soil.
WP-1 (right axis), screened deeper in the recessional outwash, illustrates water level response lower in the subsurface.
Filling at about 40 gpm, turn flow up to ~80 gpm at 170 minutes, then back down to ~42 gpm
Average Flow Rate = 42 gpm
Falling Head
Flat line represents dry readings, not water level
WP-2 (shallower well point) Water Elevation, feet (project datum)
WP-1 (deeper wellpoint) Water Elevation, feet (project datum)
Elapsed Time (minutes)
98
97.5
97
96.5
96
95.5
95
94.5
94
93.5
93
92.5
92
91.5
91
90.5
90
89.5
89
88.5
88
0
60
120
180
240
300
360
420
480
540
600
660

APPENDIX E

Site Photos

Cell TBM, drainage area includes parking lot spaces.

Cell TBM, curb cut inlet.

Cell TBM during infiltration testing, looking southwest, after about 6.5 hours of inflow.

Cell TBM during infiltration testing, looking southeast, after about 1.5 hours of inflow.

APPENDIX 12

Deliverable Task 4.5, Site TWH, Geotechnical/Soils Assessment Design Data and Current Conditions, Wilson High School, Tacoma, Washington. Associated Earth Sciences, Inc. 6/11/2019

Technical Memorandum

Date:	June 11, 2019	**From:**	Anton Ypma Suzanne Cook, L.G.
To:	Clear Creek Solutions, Inc.	**Project Manager:**	Jennifer H. Saltonstall, L.G., L.Hg.
	15800 Village Green Drive #3 Mill Creek, Washington 98012	**Principal in Charge:**	Jennifer H. Saltonstall, L.G., L.Hg.
cc:	Eric Christensen	**Project Name:**	Bioretention Hydrologic Performance Study
Attn:	Doug Beyerlein, P.E.	**Project No:**	150387H007
Subject:	Deliverable Task 4.5, Site TWH, Geotechnical/Soils Assessment Design Data and Current Conditions, Wilson High School, Tacoma, Washington		

1.0 INTRODUCTION

This technical memorandum documents existing shallow soil and groundwater conditions in the raingarden of the Wilson High School Project, located in the city of Tacoma, Washington (Figure TWH F1). This memorandum was prepared in accordance with Task 4 of the contract scope of work. Associated Earth Sciences, Inc. (AESI) collected shallow soil and groundwater conditions data related to bioretention cell function, and documented the current condition of the facility relative to the as-built drawings and available background geotechnical information. The information will be used in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). In Task 5, the team will compare the previously documented hydrologic design information with our field-collected information and will note where there are significant differences. The purpose of this technical memorandum is to document the collection of current and accurate geotechnical, geologic, and hydrogeologic site information for this later work.

The following summary of shallow soil and groundwater conditions integrates the observations made during the geotechnical assessment which included site visits on October 3, 2018, infiltration testing on November 11, 2018, and background geotechnical information.

This technical memorandum has been prepared for the exclusive use of Clear Creek Solutions and the City of Olympia and their agents for specific application to this project. Within the limitations of scope, schedule, and budget, our services have been performed in accordance with generally accepted hydrogeologic and geotechnical engineering practices in effect in this area at the time our document was prepared. No other warranty, express or implied, is made.

2.0 PURPOSE AND SCOPE

The purpose of our work was to perform a shallow soil and groundwater conditions assessment and provide baseline documentation data to assess effectiveness of bioretention hydrologic performance.

Specifically, our scope included the following activities:

- Review of project documents.
- Site reconnaissance.
- Visual condition assessment of erosion and deposition features near inlet and outlet.
- Review project plans relative to constructed facility, in particular, the number and location of inlets, energy dissipation devices, outlets, and other flow-related details.
- Survey elevations of inlet, outlet, well point rim, and other observation points relative to a project datum.
- Excavate shallow hand augers through the bioretention soil.
- Classify sediment according to the Unified Soil Classification System (USCS) and *American Society for Testing and Materials* (ASTM) D2488, "Standard Recommended Practice for Description of Soils."
- Collect samples for laboratory testing of: (1) particle size distribution in accordance with ASTM D422-63, "Standard Test Method for Particle-Size Analysis of Soils"; (2) organic matter content per ASTM D2974.
- Preparation of descriptive exploration logs for each exploration.
- Conduct qualitative assessment of soil compaction via T-probe.
- Conduct infiltration testing.
- Review of hydrologic monitoring data.
- Preparation of this summary document.

Existing facility features and the locations of hand-auger boreholes completed for this study are shown on Figure TWH F2, "Facility and Exploration Plan." Project civil plans are attached as Appendix A. Exploration logs and laboratory testing data conducted as part of this study are attached as Appendix B. Background soil, geology, and groundwater information are attached as Appendix C. Soil probe, level survey, and field infiltration testing data are attached as Appendix D. Site photos are attached as Appendix E.

3.0 SITE DESCRIPTION AND DESIGN BACKGROUND

The project site is the Wilson High School Project, located in Tacoma, Washington as shown on the attached "Vicinity Map" (Figure TWH F1). Wilson High School is located on four parcels, totaling 41.5 acres. The site is bordered by North 14th Street to the north, by North Orchard Street to the east, by North 11th Street to the south, and by North Highland Street to the west. Site topography generally slopes gently down to the south and east. No on-site surface water features are present.

As described in the Stormwater Site Plan (Sitts & Hill Engineers, Inc., 2014) the site is not located in an Aquifer Recharge Area. Our specific area of study for this project includes the raingarden located on the northern edge of campus next to the stormwater detention pond referred to as cell TWH for this study.

Details of the bioretention facility design and basis for design were presented in the following documents:

- "Limited Subsurface Exploration and Geotechnical Engineering Report, Wilson High School Field Renovation," Associated Earth Sciences, Inc., 2013.
- "Supplemental Subsurface Exploration and Infiltration Assessment, Wilson High School Athletic Field Upgrades," Associated Earth Sciences, Inc., 2014.
- "Supplemental Subsurface Exploration and Geotechnical Evaluation, Wilson High School Phase 2, Building, Pond, and Roadway Improvements, Associated Earth Sciences, Inc., 2014.
- "Western Playfield Infiltration Considerations," Technical Memorandum, Associated Earth Sciences, Inc., 2014.
- "Wilson High School Phase 2 - Stormwater Site Plan," Sitts and Hill Engineers, Inc., October 2014.
- Conformed Plan Set, Wilson High School, Sitts and Hill Engineers, Inc., December 3, 2015.

3.1 Summary of Facility Design

From our review of these documents, the bioretention facility design for cell TWH consists of an approximately rectangular-shaped bioretention cell with approximately 2,070 square feet of base area. The cell is shown on Figure TWH F2, "Facility and Exploration Plan." We understand that the site was developed under the 2012 City of Tacoma *Stormwater Management Manual* for design and construction of stormwater facilities and modeled using WWHM2012 with a design infiltration rate of 1.5 inches per hour (in/hr) for the bioretention soil. Land use within the drainage basin consisted of parking lot and associated drive lanes. Per plan sheet C3.14 (Sitts and Hill Engineers, Inc., December 3, 2015), the facility design includes mulch overlying 18 inches of bioretention soil mix overlying a minimum 8-foot-wide rock-filled trench. The rock-filled trench is separated from the overlying bioretention soil mix by a layer of Class A drainage geotextile fabric. The rock-filled trench contains three 6-inch-diameter perforated underdrain pipe bedded in approximately 1.5 feet of "¾-inch to 1½-inch washed rock" which overlies native soil. The three underdrain pipes run along the length of the facility and discharge into the overflow catch basin.

The facility is designed to infiltrate 91 percent of inflow into the subgrade. Stormwater enters the facility through two inlet pipes on the north end, one 12-inch and one 8-inch. The 8-inch pipe was observed in the field but is not marked on plan sheets. If water ponds up on the bioretention soil, the ponded water would discharge into a Type 2 48-inch Catch Basin (CB 203) with a beehive grate located near the southern edge of the cell, and then into the on-site stormwater system. The rim of the Type 2 Catch Basin was designed to be 1 foot higher than the cell base to create 1 foot of ponding depth. Based on review of historic aerial imagery, the facility was constructed after June 2016 and before May 2017.

4.0 SITE OBSERVATIONS

During AESI's site visits, we made notes regarding the physical construction of the bioretention facilities including documenting site inlet/outlet layout relative to site plans and qualitative bioretention soil thickness and compaction. These notes were used to indicate key features of the facility in Figure TWH F2, "Facility and Exploration Plan."

- Level Survey: AESI conducted an elevation survey of the cell using a Leitz C40 automatic level and a stadia rod. An arbitrary project datum was established for this survey, with the rim of the storm manhole south of the cell (CB 205) (identified on the "TWH Level Survey Data" map in Appendix D) defined as project datum elevation 100 feet. All other elevations measured by the survey are relative to this project datum. Key level data is summarized in Table 1. Additional data points are included in Appendix D to this document. This survey was not conducted by a licensed surveyor. Surveyed elevations are expected to be sufficiently accurate for this general assessment of facility construction, but may be inaccurate for purposes requiring greater precision.

- Inflow: Two inflow pipes are present on the eastern side of the northern end of cell TWH.
  - Primary: The primary inflow pipe (Inlet 1) to the facility is a 12-inch polyvinyl chloride (PVC) consistent with project plans, which discharges onto a quarry spall energy dissipation pad approximately 6 feet wide and 8 feet long, which began above the inlet and extended approximately 5 feet past the inlet. No water was discharging at the time of our site visit, but we observed moisture present in the pipe and minor leaf litter and garbage accumulation on the quarry spall.

  - Undocumented inflow: A second inflow pipe (Inlet 2) to the facility is an 8-inch concrete pipe, with a 5-foot-wide, 6-foot-long quarry spall pad which extends 4 feet past the inlet. AESI observed that this pipe is approximately 50 percent blocked with quarry spall, with approximately 1 inch of organic-rich silt present in the pipe. This pipe is not depicted on the project plan sheets. During our field visits, AESI was unable to determine the drainage area from which stormwater would enter this pipe.

- Overflow: The overflow consists of a Type 2 Catch Basin (CB 203) with a beehive grate. The rim of this grate was approximately flush with ground surface in the facility and set into the base of the slope on the southern end of the facility. AESI observed evidence of sediment entering the beehive grate.

- AESI investigated the loose bioretention soil thickness present in cell TWH using a geotechnical soil T-probe. This qualitative data was used in conjunction with the hand-auger observations to understand loose soil thickness and relative potential compactness of the bioretention soils at depth. AESI measured the depth of penetration of the soils probe at locations generally arranged in a 5-foot grid on the facility base.

Penetration of the T-probe generally ranged from approximately 1.1 to 1.7 feet, and averaged 1.5 feet. Probe penetration data is included in Appendix D to this document.

- AESI measured a base area of approximately 1,200 square feet, less than the 2,090 square feet described in the drainage report (Sitts and Hill Engineers, Inc., October 2014).

Table 1
Summary of Cell TWH
Level Survey Data

Location	Elevation (feet, project datum)
Overflow (OF) inner rim (@ outlet pipe)	96.31
OF outer rim corner (N)	96.37
OF outer rim corner (E)	96.33
OF outer rim corner (S)	96.44
OF outer rim corner (W)	96.46
GS @ Ponding tubes#2/ OF (N)	96.32
Ponding Tube TOC (DL#2, S)	97.64
Ponding Tube TOC (Baro#2, S)	97.58
TOC DL, in OF	95.84
TOC Baro, in OF	95.87
Inlet #1, 12", Top/end of green pipe	98.39
Inlet#2, Top/end green pipe	97.05
WP-1 TOC	98.83
WP-1, Ground surface	96.17 to 96.19
Ponding Tube TOC (DL#1, N)	97.48
Ponding Tube TOC (Baro#1, N)	97.44

TOC: top of casing; GS: ground surface. DL: Datalogger;

5.0 SITE SETTING

The text sections below describe our research findings in regards to the topographic, geologic, and hydrogeologic setting of the project site both from regional studies and background site-specific geotechnical and groundwater studies. Our sources of information included the following:

- Site-specific documents cited previously under “Project and Site Description.”
- U.S. Geological Survey (USDA), 2006, *Draft Geologic Map for the Gig Harbor 7.5 Minute Quadrangle*.
- Natural Resource Conservation Service (NRCS), Web Soil Survey, United States Department of Agriculture (USDA), http://websoilsurvey.nrcs.usda.gov/, accessed February 2019.
- Griffin, W.C., Sceva, J.E., Swenson, H.A., and Mundroff, MJ., *Water Resources of the Tacoma Area, Washington*, United States Department of the Interior, Geological Survey, 1962.

5.1 Regional Topography and Project Grading

The project site is situated on an undulating upland. The nearest surface water feature is China Lake, approximately 1 mile south of the site. Elevations on the larger project site range from about 385 feet on the northern edge, to 358 feet on the southern edge of the property.

On a closer scale, the area near Cell TWH is at an elevation of 368 feet, with a previously constructed stormwater detention pond present immediately west of the cell, and parking lot to the east of the cell at an elevation of 371 feet, separated from the cell by a curb, slope, and fence. Tennis courts and fields roughly level with the cell are present to the south, and North 14th Street is present to the north, separated from the cell by a curb, slope, and fence.

The project site was previously developed as Wilson High School with associated sport fields. The nearby stormwater detention pond was added prior to the addition of the bioretention cell and involved excavation of approximately 10 feet. We understand that cell TWH was added later as part of a subsequent phase of work which involved minor cutting (about 3 feet) to achieve design bioretention cell grades based on a review of existing topography compared with built topography.

5.2 Regional Geology and Background Geotechnical Information

According to the current draft U.S. Geological Survey (USGS) *Geologic Map for the Gig Harbor 7.5 Minute Quadrangle* (USGS - Miscellaneous Field Investigation, 2006), the project site is underlain by Vashon lodgement till. Vashon lodgement till is deposited by and directly overridden by the advancing glacial ice sheet, which compacts it to a dense condition

- Vashon lodgement till (Qvt): The Vashon lodgment till was deposited directly from basal, debris-laden, glacial ice during the Vashon Stade of the Fraser Glaciation, approximately 12,500 to 15,000 years ago. The high relative density characteristic of the Vashon lodgement till is due to its consolidation by the massive weight of the glacial ice from which it was deposited.

Background geotechnical information includes exploration log EP-1 from within the footprint of cell TWH dated February 23, 2000, and reached depths of about 5 feet below current grades, and describe material generally consisting of medium dense to dense, gray, moist, sand with gravel and little silt ranging to silty with scattered cobbles with depth, interpreted as Vashon lodgement till. This interpretation is consistent with the geologic mapping in the area.

5.3 Regional Soils and Soil Data Used in Site Stormwater Model

Regional NRCS soils mapping is not available in the project area because it was urbanized prior to NRCS mapping.

As described in the Stormwater Site Plan (Sitts & Hill Engineers, Inc., 2014), the pre-developed condition was modeled as Type C, consistent with the Washington State Department of Ecology

(Ecology) 2014 *Stormwater Management Manual for Western Washington* (2014 Ecology Manual) recommendations for glacial till soils.

5.4 Regional Hydrogeology and Background Groundwater Data

Regional hydrogeology is described in *Water Resources of the Tacoma Area, Washington* (Griffin et al., 1962). Griffin et al. (1962) indicates that recessional and advance outwash are typically productive aquifers, while the Vashon lodgement till typically perches water.

As described in the stormwater site plan, the site is in the Leach Creek watershed. Leach Creek flows generally south, joins Chambers Creek, and ultimately discharges into the Puget Sound. Previous reports inferred based on subsurface exploration data that rainwater perches above the glacial till present at the site (AESI, 2014).

6.0 BIORETENTION CELL SUBSURFACE EXPLORATION

Limited information on subsurface conditions was obtained for this study from hand-auger samples and soil probe penetration measurements at about 2-foot increments in each hand-augered borehole. Four hand-auger borings were performed in the facility bottom and advanced through the bioretention soil and to the underlying aggregate rock, except for hand-auger boring 2 (TWH-HA-2) which was advanced into the underlying subgrade. Representative samples were collected, visually classified in the field, stored in water-tight containers, and transported to AESI's offices for additional classification, geotechnical testing, and study. At the conclusion of the excavation, the boreholes were immediately backfilled with the excavated material or completed as a well point for water level monitoring (described separately below).

The various types of sediments, as well as the depths where characteristics of the sediments changed, are indicated on the exploration logs presented in Appendix B. A detailed record of the observed bioretention soil, subsurface soil, geology, and groundwater conditions was made. The sediments were described by visual and textural examination using the soil classification in general accordance with ASTM D2488, "Standard Recommended Practice for Description of Soils." The depths indicated on the logs where conditions changed may represent gradational variations between sediment types in the field. The exploration logs in Appendix B are based on the field observations, inspection of the samples, and where applicable, laboratory grain-size analysis. Our explorations were approximately located in the field relative to known site features, and are shown on Figure TWH F2, "Facility and Exploration Plan." Global Positioning System (GPS) coordinates for the explorations were taken using a hand-held GPS, and are summarized in Appendix B.

The results presented in this document are based on the explorations completed for this study and review of background data. The number, locations, and depths of the explorations were completed within site and budgetary constraints. Because of the nature of exploratory work below ground, interpolation of subsurface conditions between field explorations is necessary. It should be noted that differing subsurface conditions may sometimes be present due to the random nature of deposition and the alteration of topography by past grading and/or filling.

6.1 Hand-Auger Borings

Hand-auger borings in cell TWH were completed on October 3, 2018. No rainfall was noted at the time of exploration.

Hand-auger boring number 1 (TWH-HA-1), which was completed in the northern portion of the cell, near the inflow, encountered approximately 0.1 feet of organic material and leaf litter, 1 foot of bioretention soil mix, and filter fabric overlying rounded drain rock. Hand-auger boring number 2 (TWH-HA-2), which was completed near the inlets on the edge of the cell, encountered 0.1 feet of organic material and leaf litter, 1.4 feet of bioretention soil mix, and sediments tentatively interpreted as fill to a total depth of 1.9 feet. Hand-auger borings 3 and 4 (THW-HA-3 and TWH-HA-4) encountered 1.4 and 1.3 feet of bioretention soil, respectively, overlying filter fabric. No seepage or caving were observed.

6.2 Well Points

A well point was installed in TWH-HA-1. Key well point dimensions are provided in Table 2, below.

Table 2
Summary of Cell TWH
Well Point Dimensions

Well Point	Exploration in which Well Point was Installed	Total Length of Casing (feet)	Interior Diameter	Stickup Height (feet)	Total Depth Inside Casing Below Ground Surface
TWH-HA-1/WP	TWH-HA-1/WP	7.2	1.25 inch nominal	2.7	4.5

7.0 LABORATORY ANALYSIS

Laboratory testing included mechanical grain-size distribution and percent organic matter by weight in accordance with the ASTM D422 and D2974, respectively. Bioretention soil was first tested for organic matter content and then the burned material was tested for grain-size distribution for comparison with the aggregate fraction of the bioretention soil mix guidance in the 2014 Ecology Manual. One sample of material interpreted as representative of the subgrade was tested for grain-size distribution. The data is summarized in Table 3.

Table 3
Summary of Cell TWH
Organic Content and Grain Size Data

Exploration Number	Depth (feet)	Soil Type	Organic Content (% by weight)	USCS Soil Description	Fines Content (% passing #200)	Cu	Cc	USDA Soil Texture*
TWH-HA-1	0.1-0.5	Bioretention Soil	6.8	SAND, trace silt, trace gravel (SP)	3.6	2.5	1	Sand
TWH-HA-2	1.4-1.9	Fill		Gravelly SAND, some silt (SP-SM)	11.6			Loamy Sand to Sandy Loam
TWH-HA-3	0.1-0.5	Bioretention Soil	8.0	SAND, trace silt, trace gravel (SP)	2.9	2.7	1	Sand

USCS: Unified Soil Classification System; Cu: coefficient of uniformity; Cc: coefficient of curvature; USDA: U.S. Dept. of Agriculture; *No hydrometers were performed. USDA soil texture range assumes fines consist entirely of silt to entirely of clay.

7.1 Bioretention Soil Mix

We compared the organic content and burned fraction gradation against the general guidelines for the bioretention soil mix (Table 4).

The organic content of the tested bioretention soils ranged between 6.8 and 8 percent by weight. This meets the recommended organic content by weight of 5 to 8 percent in the 2014 Ecology Manual.

The grain-size analysis test results on the burned soil fraction indicate that the bioretention soils tested correlate to a “SAND” with trace silt and trace gravel based on ASTM D2487 Unified Soil Classification System (USCS). The respective fines content as measured on the No. 200 sieve was 2.9 to 3.6 percent, within the recommended range of 2 to 5 percent. The coefficient of uniformity ranged from 2.5 to 2.7, lower than the recommended value of equal to or greater than 4. The coefficient of curvature was approximately 1, at the low end of the recommended range of greater than or equal to 1 and less than or equal to 3. The soil mix was generally within the recommended ranges for the sand gradations. The tested bioretention soil was a poorly-graded sand.

7.2 Subgrade

In cell TWH, no samples of the subgrade could be obtained for this study due to the import gravel beneath the bioretention cell and difficulties hand auguring in this material. In TWH-HA-2, a sample was obtained from the lower side slope of the cell was sieved, interpreted tentatively identified as fill, was sieved. The tested material correlates to a gravelly SAND with some silt with 11.6 percent by weight of the material passing the No. 200 sieve.

The grain-size distribution data were also transformed to describe the United States Department of Agriculture (USDA) soil texture. The grain-size distributions were normalized to the No. 10 sieve—

i.e., the coarse sand and gravel fraction of the sample is discounted and the remainder is taken as 100 percent of the sample. The fines were assessed relative to the No. 270 sieve. The respective USDA fines content as measured on the No. 270 sieve after adjusting to remove the weight retained on the #10 sieve was 15.8 percent for the sieved material.

Table 4
General Guidelines for Bioretention Soil Mix (2014 Ecology Manual)
Compared to Averaged Cell TWH Site Data

Parameter	Recommended Range	Cell TWH
Organic Content (by weight)	5 to 8 percent	7.4percent by weight
Cu coefficient of uniformity	4 or greater	2.6
Cc coefficient of curvature	1 to 3	1
Sieve Size	**Percent Passing**	
3/8" (9.51 mm)	100	99.7
#4 (4.76 mm)	95 to 100	97.6
#10 (2.0 mm)	75 to 90	90.5
#40 (0.42 mm)	25 to 40	34
#100 (0.15 mm)	4 to 10	5
#200 (0.074 mm)	2 to 5	3

Note: The general guidelines for mineral aggregate gradation are from Table 7.4.1 of the 2014 Ecology Manual.
mm: millimeters.

8.0 INFILTRATION TESTING

8.1 General Infiltration Test Method

The infiltration test was conducted in general accordance with the 2014 Ecology Manual. The test was conducted by discharging water into the facility for a "soaking period," to allow the receptor soils to become saturated. After completion of the soaking period, water was discharged into the cell at a rate sufficient to maintain a relatively constant head. This constitutes the "constant-head" phase of infiltration testing. Immediately following the constant-head phase of infiltration testing, flow into the facilities was discontinued, and the water level was monitored as it dropped. This constitutes the "falling-head" portion of the infiltration testing.

The water for testing was obtained from an on-site fire hydrant and a water truck, and conveyed to cell TWH with fire hoses. During infiltration testing, the water was conveyed into the bioretention cell via a digital flow meter with gallons per minute (gpm) and total gallon readouts, and discharged through a flow diffuser. Water levels were monitored using a temporary staff gauge (TWH-SG-1) marked in 0.01-foot increments installed adjacent to the well point, within the well point, and with digital pressure transducers. Data from the digital pressure transducers was compensated for barometric response using a separate digital barometer. The area of the pool was measured periodically during testing.

The infiltration test in cell TWH is discussed below, and results are presented in Table 5. Infiltration test data is included in Appendix D to this document.

8.2 Infiltration Test in Cell TWH

AESI performed infiltration testing on November 19, 2018. No rainfall was noted during testing, and no flow from the inflow pipes was present.

During this test, flow from the on-site fire hydrant was limited to 50 gpm, per City of Tacoma requirements. AESI supplemented the flow using a water truck with an approximate 4,000-gallon capacity. Inflow to the facility for the infiltration test was directed, through a diffuser, onto the cell. Flow from the on-site fire hydrant was maintained at approximately 50 gpm for the duration of the test. This 50 gpm initially wetted a portion of the cell totaling approximately 340 square feet in the vicinity of the inflow pipes and staff gauges. The water truck provided an additional approximately 91 gpm (total flow rate approximately 141 gpm average) from approximately 85 to 127 minutes into the test. This higher flow rate led to a total wetted area of approximately 790 square feet, however AESI observed that the wetted area was still growing as the water truck ran out of water, and the wetted area was therefore not stable. The water truck then left the site to refill, and then provided an additional approximately 60 gpm (total flow rate approximately 110 gpm average) from 275 to 345 minutes into the test. During this final period of inflow, the wetted area stabilized with a total wetted area of approximately 850 square feet. No flow into the overflow beehive was observed, however AESI observed that the underdrain pipes were active from approximately 80 minutes into the test, prior to supplemental flow from the water truck, until the end of testing. After approximately 5 and 3/4 hours, the water level in the wetted area was about 0.14 feet as measured on TWH-SG-1. The wetted pool area had been generally stable for about 20 minutes.

Water in the well point was monitored with a data logger during the infiltration test and responded to inflow. Initially, only trapped end-cap water was present in the well point. The water level in the well point responded to inflow within 10 minutes of the start of testing, and rose by up to approximately 0.6 feet during testing. AESI interprets this response to indicate that water from the infiltration test infiltrated rapidly through the bioretention soil and then mounded within the gravel base course beneath the facility, as it discharged primarily through the underdrains.

After about 5 and 3/4 hours, AESI shut off the flow and monitored water level as it fell. AESI observed that the pooled water in the base of the facility infiltrated over the course of approximately 4 minutes.

The constant-head test infiltration rate in Table 5 is calculated based on flow rate from the hoses for infiltration testing, and the wetted area of bioretention soil through which the water infiltrated, and represents the average infiltration rate of the bioretention soil in the wetted area. Infiltration rate calculations for cell TWH are based on the final period of steady discharge, when flow was being supplemented by the water truck to approximately 110 gpm. The falling head infiltration rate is a more localized infiltration rate because the wetted area shrank rapidly after the inflow ceased. AESI observed the discharge from the underdrains, and visually estimated that it was similar to the inflow to the facility during testing, indicating that the majority of inflow was leaving the facility via the underdrains and little to no inflow was infiltrating into the subgrade.

Table 5
Cell TWH
Infiltration Test Results

Test No.	Surface Area (square feet)	Discharge Time (minutes)	Total Volume Discharged (gallons)	Approximate Constant-Head Level (feet)	Field Infiltration Rates	
					Constant-Head Test (in/hr)	Falling-Head Test (in/hr)
TWH (bioretention soil)	850*	345	25,123	0.14	~11	25*
TWH (subgrade)	Perched water response in well point				Unknown, interpreted to be low based on the underdrain outflow	

in/hr: inches per hour
*The falling head infiltration rate is interpreted to represent a more localized area of the cell because the wetted area shrank rapidly once the inflow ceased. The constant head rate is interpreted to an average rate for the wetted are of the cell during testing.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Cell TWH was generally inconsistent with the design shown on the civil plan sheets. Observations on site design, shallow soil and groundwater conditions are discussed below.

- Inflow: A second inflow, not indicated on plan sheets, was observed.

- The overflow is inconsistent with the plans. Site design documents indicate that the ponding level was designed as 1 foot. The overflow was installed approximately flush with ground surface. However, given the high infiltration rate of the bioretention soil and the distance of the overflow from the inflow, it is unlikely that frequent ponding will occur at the overflow.

- Bioretention soil:
    - Thickness: The apparent thickness of loose bioretention soil based on soil probe data was generally about 1.5 feet as indicated on the plan.
    - Composition: The soil tested generally met the recommended guidelines for organic content and grain size.

- Subgrade conditions: The subgrade is interpreted to consist of Vashon lodgement till, as documented in exploration pits prior to construction. Undocumented fill sediments may be present.

- Bioretention soil field infiltration rate:
  - Measured at about 11 to 25 in/hr.
  - Water readily soaked through the bioretention soil mix and the field rate is interpreted to represent the bioretention soil infiltration rate.

- Native subgrade infiltration rate: interpreted to be low. The majority of flow is interpreted to leave the cell via the underdrain.

10.0 CLOSURE

We appreciate the opportunity to be of continued service to you on this project. Should you have any questions regarding this document or other geotechnical/hydrogeologic aspects of the project, please call us at your earliest convenience.

State of Washington
Hydrogeologist
2335
Licensed Geologist
Jennifer H. Saltonstall
6/11/19

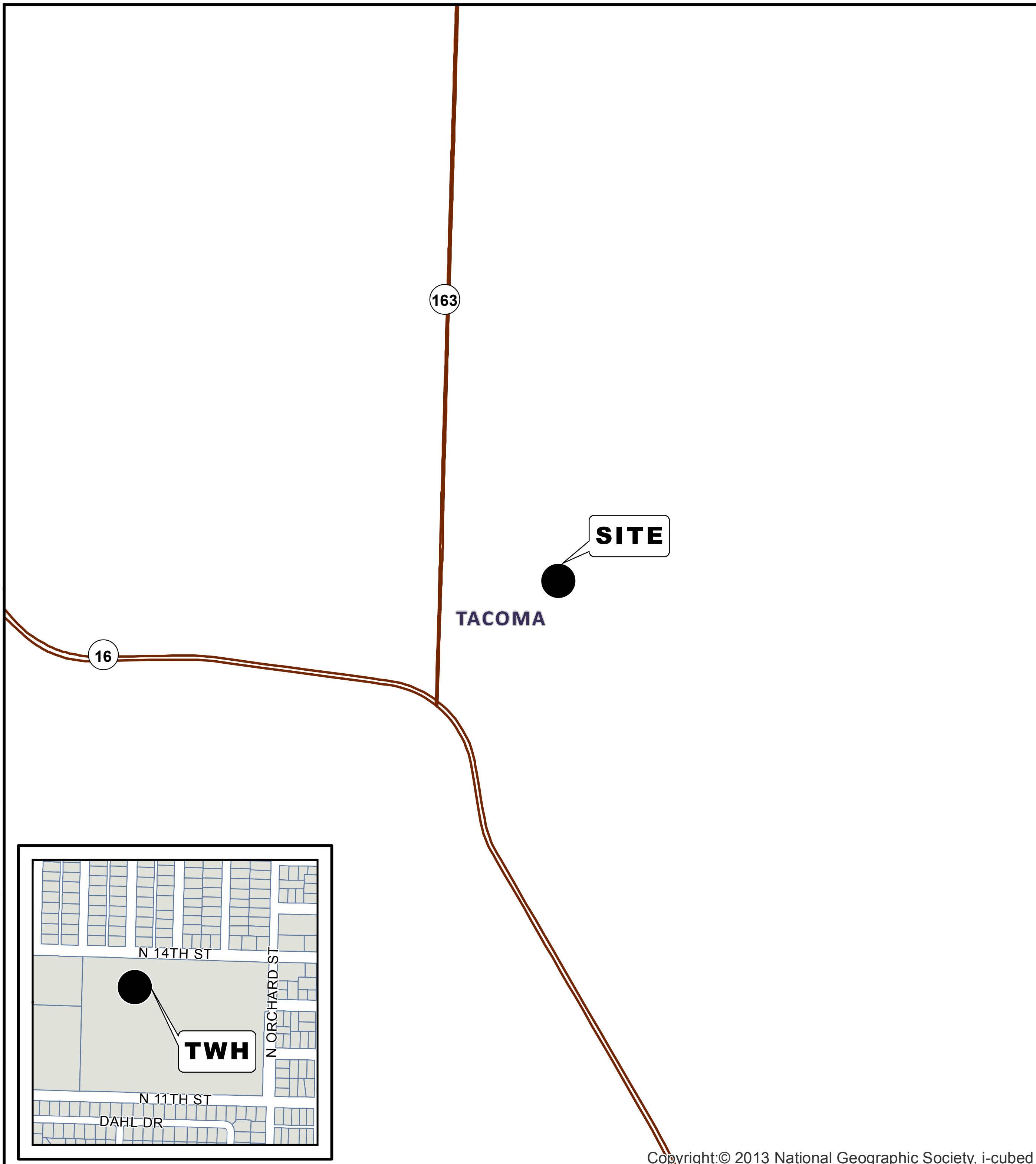
Anton D. Ypma
Staff Geologist

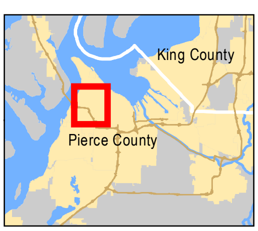
Suzanne S. Cook, L.G.
Senior Project Geologist

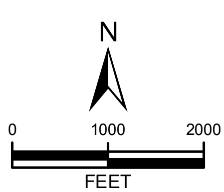
Jennifer H. Saltonstall, L.G., L.Hg.
Principal Geologist/Hydrogeologist

Attachments:	Figure TWH F1:	Vicinity Map
	Figure TWH F2:	Facility and Exploration Plan
	Appendix A:	Project Civil Plans
	Appendix B:	Current Study Exploration Logs and Laboratory Testing Data
	Appendix C:	Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)
	Appendix D:	Soil Probe, Level Survey, and Field Infiltration Testing Data
	Appendix E:	Site Photos

JHS/ld
150387H007-9
Projects\20150387\KH\WP







DATA SOURCES / REFERENCES:
USGS: 7.5' SERIES TOPOGRAPHIC MAPS, ESRI/I-CUBED/NGS 2013
PIERCE CO: STREETS, CITY LIMITS, PARCELS 1/18

LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE

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

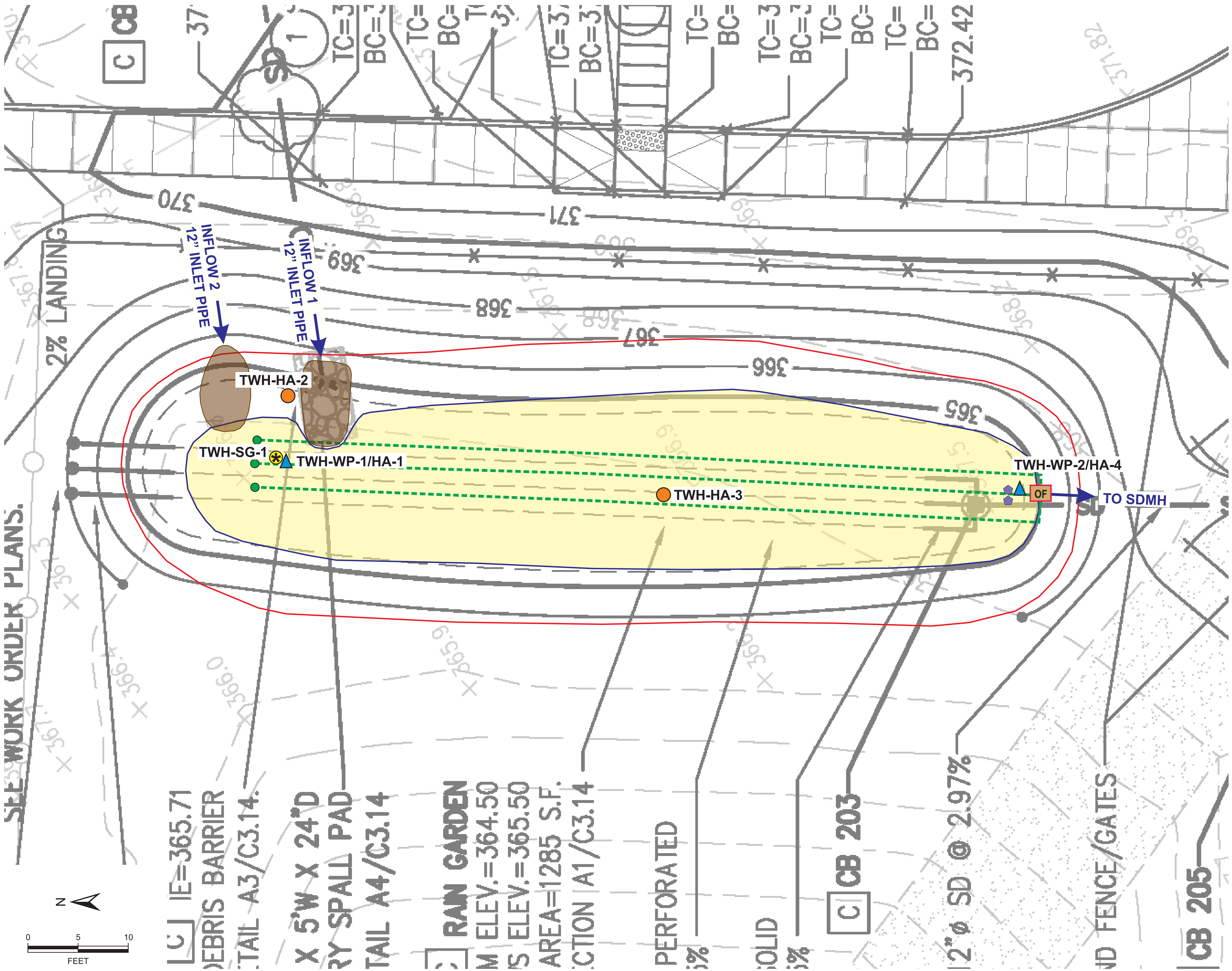
[redacted]

VICINITY MAP

BIORETENTION HYDROLOGIC PERFORMANCE STUDY, TWH SITE
TACOMA, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TWH F1

Document Path: G:\GIS_Projects\aY15post0716\150387 Bioretention Hydro Performance Monitoring\mxd\PhaseII\Fig1s\150387H007 F1 VM_TWH.mxd



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
OF	OVERFLOW GRATE - 24" X 18"
	PVC PONDING TUBE
	UNDERDRAIN
	STORM DRAIN CLEANOUT
	ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: SITTS AND HILL ENGINEERING, INC., TACOMA SCHOOL DISTRICT, WILSON HIGH SCHOOL, GRADING AND DRAINAGE PLAN, SHEET C3.1, 12/10/15

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

associated earth sciences incorporated

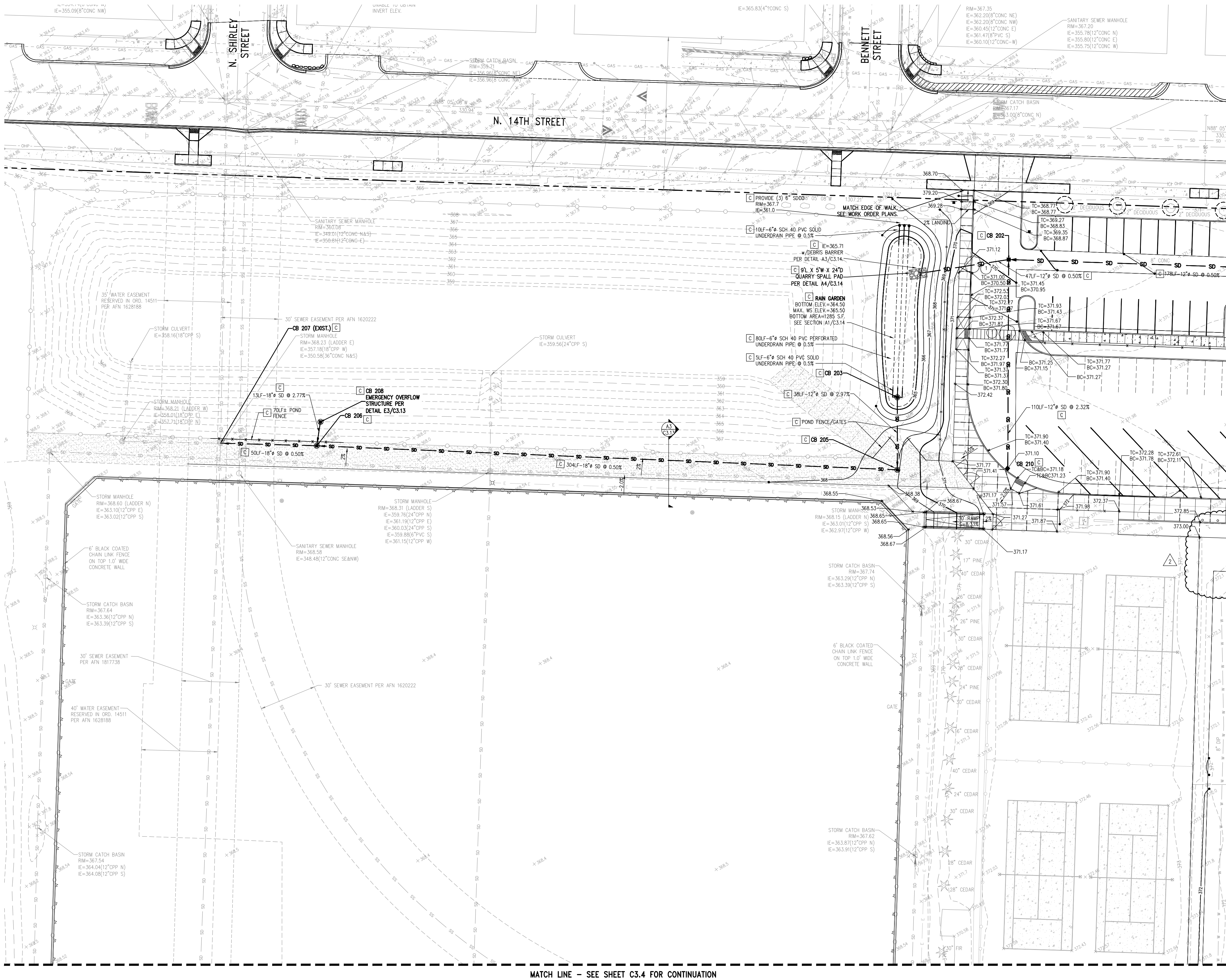
FACILITY AND EXPLORATION PLAN
TWH SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TACOMA, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TWH F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: TWH F2

APPENDIX A

Project Civil Plans



Call 2 Working Days Before You Dig
1-800-424-5555
Utilities Underground Location Center

GENERAL NOTES

1. COMPLY WITH NOTE REQUIREMENTS ON SHEET C3.12.

GRADING AND DRAINAGE KEY NOTES

(1) COORDINATE WITH FIELD DRAWINGS FOR DETAILED FINISHED GRADE ELEVATION AND SURFACING SECTION REQUIREMENTS.

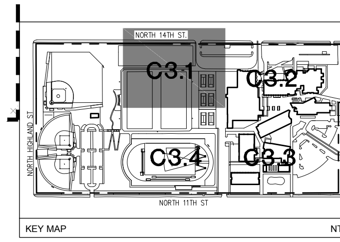
(2) PROVIDE DROP TEE CONNECTION IN 15" SD FOR FIELD SUBDRAINAGE CONNECTIONS. COORDINATE LOCATION AND INSTALLATION REQUIREMENTS WITH FIELD CONTRACTOR AND DRAWINGS.

PROJECT PHASING KEY NOTES

WORK DESIGNATED ON THE PLANS SHALL BE INSTALLED DURING THE NOTED PHASE. COORDINATE PHASE TIMES AND DATES WITH PROJECT PHASING REQUIREMENTS.

- A PHASE A
- B PHASE B
- C PHASE C
- D PHASE D

NORTH
HORIZONTAL SCALE: 1"=20'
20 0 20 40



KEY MAP NTS

REVISIONS
2 PERMIT REVISIONS 09-03-2015

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TACOMA SCHOOL DISTRICT
WILSON HIGH SCHOOL
1202 N. ORCHARD ST., TACOMA, WASHINGTON 98406

NAC | ARCHITECTURE

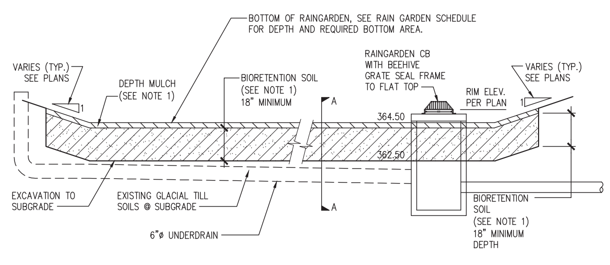
NAC NO	121-13009
DATE	12-10-2015
DRAWN	JMW
CHECKED	RCH

BASE BID - GRADING AND DRAINAGE PLAN

GRADING AND DRAINAGE PLAN
BASE BID

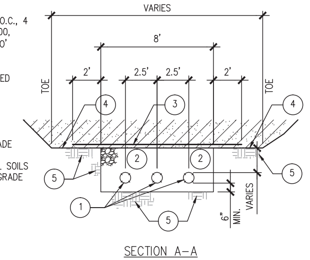
C3.1

NOTES:
1. SEE LANDSCAPE PLAN FOR MULCH AND BIORETENTION SOIL MEDIA MIX.

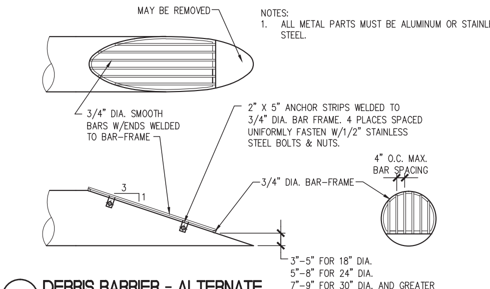


A1 TYPICAL RAIN GARDEN CROSS SECTION - BASE BID
SCALE: N.T.S.

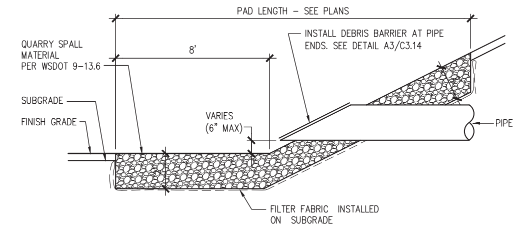
1. 6" SCHEDULE 40 PVC PIPE. PERFORATE W/ 5/8" DIAMETER HOLES, 3" O.C., 4 ROWS- 1 ROW AT 2:00, 4:00, 8:00 & 10:00 O' CLOCK POSITIONS.
2. 3/4" - 1 1/2" WASHED ROCK
3. CLASS A DRAINAGE GEOTEXTILE FABRIC
4. RAIN GARDEN SUBGRADE
5. EXISTING GLACIAL TILL SOILS @ RAIN GARDEN SUBGRADE



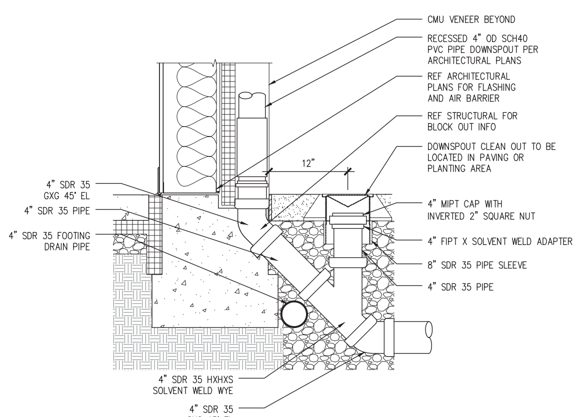
SECTION A-A
N.T.S.



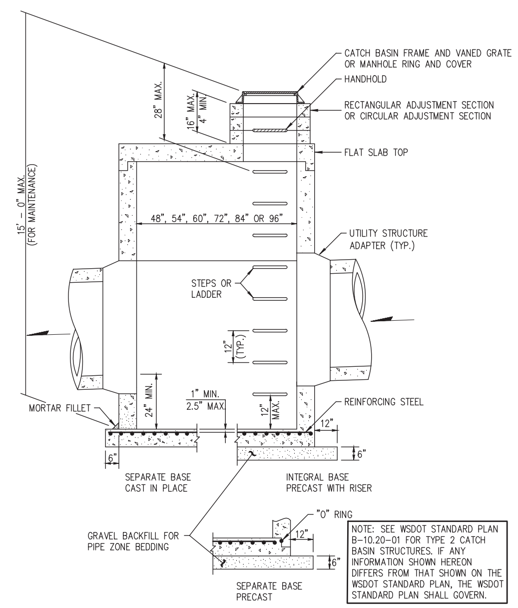
A3 DEBRIS BARRIER - ALTERNATE
SCALE: N.T.S.



A4 QUARRY SPALL PAD SECTION - BASE BID AND ALTERNATE
SCALE: N.T.S.



C1 RECESSED DOWNSPOUT AT FOOTING - BASE BID AND ALTERNATE
SCALE: N.T.S.



NOTE: SEE WSDOT STANDARD PLAN B-10.20-01 FOR TYPE 2 CATCH BASIN STRUCTURES. IF ANY INFORMATION SHOWN HEREON DIFFERS FROM THAT SHOWN ON THE WSDOT STANDARD PLAN, THE WSDOT STANDARD PLAN SHALL GOVERN.

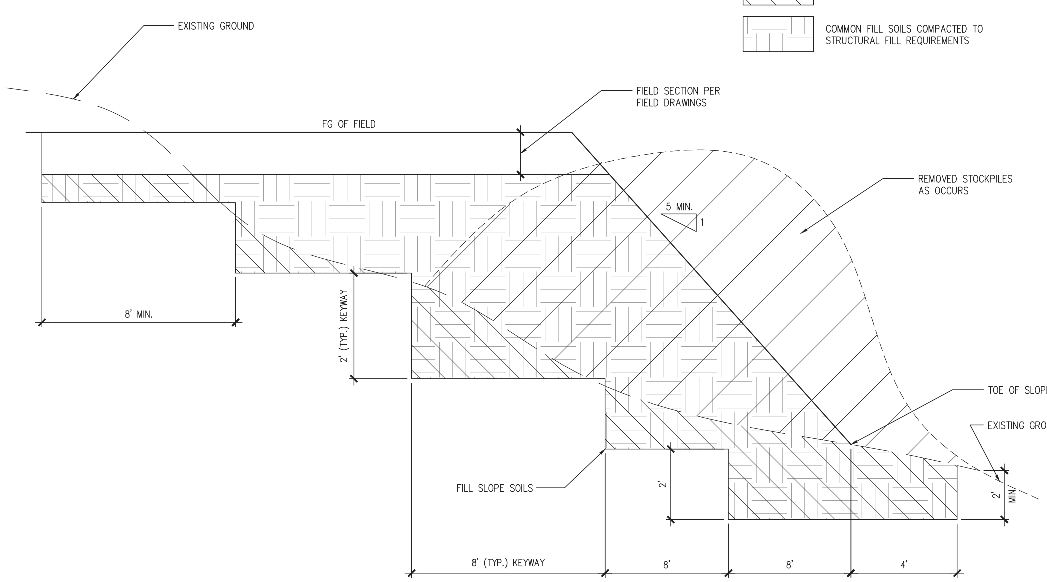
CATCH BASIN DIMENSIONS						
CATCH BASIN DIAMETER	WALL THICKNESS	BASE THICKNESS	MAXIMUM KNOCKOUT SIZE	MINIMUM DISTANCE BETWEEN KNOCKOUTS	BASE REINFORCING STEEL in^2 /ft IN EACH DIRECTION	
					INTEGRAL	SEPARATE
48"	4"	6"	36"	8"	0.15	0.23
54"	4.5"	8"	42"	8"	0.19	0.19
60"	5"	8"	48"	8"	0.25	0.25
72"	6"	8"	60"	12"	0.24	0.35
84"	8"	12"	72"	12"	0.29	0.39
96"	8"	12"	84"	12"	0.29	0.39

PIPE ALLOWANCES					
CATCH BASIN DIAMETER	PIPE MATERIAL WITH MAXIMUM INSIDE DIAMETER				
	CONCRETE	ALL METAL	CPSSP ①	SOLID WALL PVC ②	PROFILE WALL PVC ③
48"	24"	30"	24"	27"	30"
54"	30"	36"	30"	27"	36"
60"	36"	42"	36"	36"	42"
72"	42"	54"	42"	36"	48"
84"	54"	60"	54"	36"	48"
96"	60"	72"	60"	36"	48"

① CORRUGATED POLYETHYLENE STORM SEWER PIPE (Std. Spec. 9-05.20)
② (Std. Spec. 9-05.12(1))
③ (Std. Spec. 9-05.12(2))

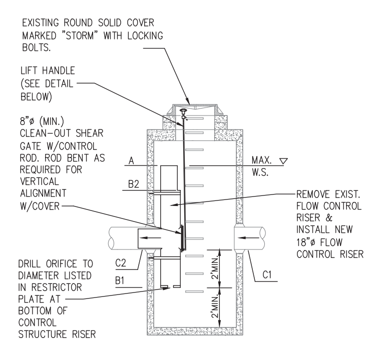
C5 TYPE 2 CATCH BASIN - BASE BID AND ALTERNATE
SCALE: N.T.S.

▨	EXCAVATE EXISTING SOILS TO CONFORM WITH DIMENSIONS SHOWN
▦	COMMON FILL SOILS COMPACTED TO STRUCTURAL FILL REQUIREMENTS

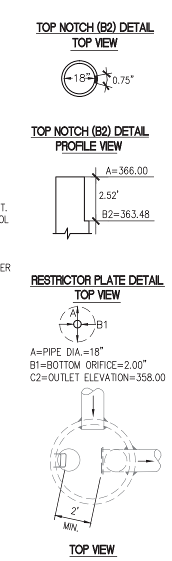


SECTION A-A

E1 EARTHWORK FILL SLOPE CONSTRUCTION - ALTERNATE 5 - FIELDS
SCALE: N.T.S.



PROFILE VIEW
EXISTING CATCH BASIN TYPE 2 W/FLOW RESTRICTOR



CONTROL STRUCTURE											
LOCATION	D (IN.)	B1		B2		A		C1		C2	
		ELEV.	DIAM.	ELEV.		ELEV.	DIAM.	ELEV.	DIAM.	ELEV.	DIAM.
EX. OUTLET CONTROL STRUCTURE	60"	356.00	2"	363.48		366.00	18"	358.00	18"	358.00	18"

NORTH

NOTES:
1. THE PIPE SUPPORTS AND THE CONTROL STRUCTURE RISER SHALL BE CONSTRUCTED OF THE SAME MATERIAL AND BE ANCHORED AT A MAXIMUM SPACING OF 36". ATTACH THE PIPE SUPPORTS TO THE MANHOLE WITH 5/8" STAINLESS STEEL EXPANSION BOLTS OR EMBED THE SUPPORTS INTO THE CATCH BASIN WALL 2".
2. THE CONTROL STRUCTURE RISER SHALL BE THE SAME DIAMETER AS THE HORIZONTAL OUTLET PIPE
3. THE FLOW RESTRICTOR SHALL BE FABRICATED FROM ONE OF THE FOLLOWING MATERIALS: 0.060" CORRUGATED ALUMINUM ALLOY DRAIN PIPE, 0.060" ALUMINUM ALLOY FLAT SHEET, IN ACCORDANCE WITH ASTM B 209, 5052 H32 OR EPS HIGH DENSITY POLYETHYLENE STORM SEWER PIPE.
5. RESTRICTOR PLATE WITH ORIFICE AS SPECIFIED. THE OPENING IS TO BE CUT ROUND AND SMOOTH.
6. THE SHEAR GATE SHALL BE MADE OF ALUMINUM ALLOY IN ACCORDANCE WITH ASTM B 26 AND ASTM B 275 DESIGNATION ZG32A OR CAST IRON IN ACCORDANCE WITH ASTM A48 CLASS 30B.

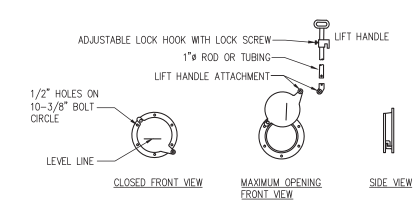
   THE LIFT HANDLE SHALL BE MADE OF A SIMILAR MATERIAL TO THE GATE (TO PREVENT GALVANIC CORROSION). IT MAY BE OF SOLID ROD OR HOLLOW TUBING WITH ADJUSTABLE HOOK AS REQUIRED.

   A NEOPREME RUBBER GASKET IS REQUIRED BETWEEN THE RISER MOUNTING FLANGE AND THE GATE FLANGE.

   INSTALL THE GATE SO THAT THE LEVEL-LINE MARK IS LEVEL WITH THE GATE IS CLOSED.

   THE MATING SURFACES OF THE LID AND THE BODY SHALL BE MACHINED FOR PROPER FIT.

   ALL SHEAR GATE BOLTS SHALL BE STAINLESS STEEL.
7. THE SHEAR GATE MAXIMUM OPENING SHALL BE CONTROLLED BY LIMITED HINGE MOVEMENT, A STOP TAB, OR SOME OTHER DEVICE.
8. ALTERNATIVE SHEAR GATE DESIGNS ARE ACCEPTABLE IF MATERIAL SPECIFICATIONS ARE MET AND FLANGE BOLT PATTERN MATCHES.



SHEAR GATE DETAILS

E3 CONTROL STRUCTURE - ALTERNATE 5 - FIELDS
SCALE: N.T.S.

REVISIONS
3 PR003 MUSIC BUILDING ALTERNATE ACCEPTED

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DATE	12-10-2015
DRAWN	JMW
CHECKED	RCH

BASE BID & ALTERNATE - GRADING AND DRAINAGE DETAILS

DETAILS
BASE BID AND ALTERNATES

ALT
C3.14

APPENDIX B

Current Study Exploration Logs and Laboratory Testing Data

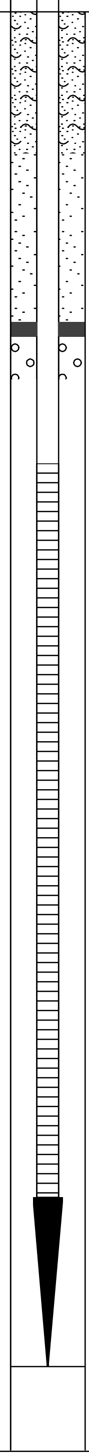
Geologic & Monitoring Well Construction Log

associated earth sciences incorporated

Project Number	Well Number	Sheet
150387H007	TWH-HA-1/WP	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Location	Tacoma, WA
Elevation (Top of Well Casing)	98.8 (Project Datum)	Surface Elevation (ft)	96.1 (Project Datum)
Water Level Elevation	Dry	Date Start/Finish	10/3/18,10/3/18
Drilling/Equipment	Hand Auger	Hole Diameter (in)	4 inches
Hammer Weight/Drop	N/A		

Depth (ft) | Water Level | WELL CONSTRUCTION | S T | Blows/ 6" | Graphic Symbol | DESCRIPTION



Well construction:

Organic material and leaf litter 0 to 0.1 feet

Bioretention soil mix 0.1 to 0.5 feet

Silica sand 0.5 to 1.1 feet

Threaded steel pipe 1.25-inches I.D. with threaded and vented PVC cap -2.7 to 1.6 feet

Layer of filter fabric with extra filter fabric wrapped around well point at 1.1 feet

Rounded gravel 1.1 to 1.3 feet

Stainless steel jacket over stainless steel #60 gauze, welded to perforated steel pipe 1.6 to 4.2 feet

Threaded steel pipe 1.25-inches I.D. and drive point 4.2 to 4.8 feet

Note: ~4 inches of "dead space" below bottom of perforated openings and total inside depth. Total inside depth = 7.2 feet.

Description:

Organic Material and Leaf Litter

Bioretention Soil Mix

Loose, moist, dark brown, medium SAND, trace silt, trace gravel; massive (SP).

Layer of filter fabric at 1.1 feet

Rounded Drain Rock

Loose, slightly moist, rounded GRAVEL, trace silt (GP).

Boring terminated at 1.3 feet
Well completed at 4.1 feet on 10/3/18.
Refusal in gravel. No seepage. Sloughing in gravel.
Steel drive point placed in borehole and hand driven with slide hammer to depth of 4.8 feet.

5

Sampler Type (ST):

2" OD Split Spoon Sampler (SPT)	No Recovery	M - Moisture	**Logged by:**	ADY
3" OD Split Spoon Sampler (D & M)	Ring Sample	Water Level ()	**Approved by:**	JHS
Grab Sample	Shelby Tube Sample	Water Level at time of drilling (ATD)		

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	TWH-HA-2	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Tacoma, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/3/18,10/3/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Organic Material and Leaf Litter					
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace silt, trace gravel; massive (SP).					
		S-2		**Fill ?** Medium dense, moist, brownish gray, silty, gravelly, fine SAND (SM).					
				Bottom of exploration boring at 1.9 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Exploration Log

associated earth sciences incorporated

Project Number	Exploration Number	Sheet
150387H007	TWH-HA-3	1 of 1

Project Name: Bioretention Hydrologic Performance Study
Location: Tacoma, WA
Driller/Equipment: Hand Auger
Hammer Weight/Drop: N/A

Ground Surface Elevation (ft):
Datum: N/A
Date Start/Finish: 10/3/18,10/3/18
Hole Diameter (in): 4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace silt, trace gravel; massive (SP). Filter fabric over rounded drain rock at 1.4 feet.					
				Bottom of exploration boring at 1.4 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

associated earth sciences incorporated

Exploration Log

Project Number	Exploration Number	Sheet
150387H007	TWH-HA-4	1 of 1

Project Name	Bioretention Hydrologic Performance Study	Ground Surface Elevation (ft)	
Location	Tacoma, WA	Datum	N/A
Driller/Equipment	Hand Auger	Date Start/Finish	10/3/18,10/3/18
Hammer Weight/Drop	N/A	Hole Diameter (in)	4 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot 10 20 30 40	Other Tests
		S-1		**Bioretention Soil Mix** Loose, moist, dark brown, medium SAND, trace silt, trace gravel; massive (SP). Filter fabric over rounded drain rock at 1.3 feet.					
				Bottom of exploration boring at 1.3 feet. No seepage. No caving.					
5									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: ADY
Approved by: JHS

Moisture, Ash, and Organic Matter of Peat and Other Organic Soils - ASTM 2974

associated earth sciences incorporated

Date Sampled	Project	Project No.		Soil Description
10/3/2018	Bioretention Hydrologic Performance Monitoring Study	150387 E007		Bioretention soil mix
Tested By	**Location**	**EB/EP No.**	**Depth**	
BN	Onsite- TWH			

Moisture Content

Sample ID	**HA-1 (0.1'-0.5')**	**HA-3 (0.1'-0.5')**
Wet Weight + Pan	**1034.28**	**926.99**
Dry Weight + Pan	**962.62**	**892.96**
Weight of Pan	**467.41**	**426.30**
Weight of Moisture	**71.66**	**34.03**
Dry Weight of Soil	**495.21**	**466.66**
% Moisture	**12.6**	**6.8**

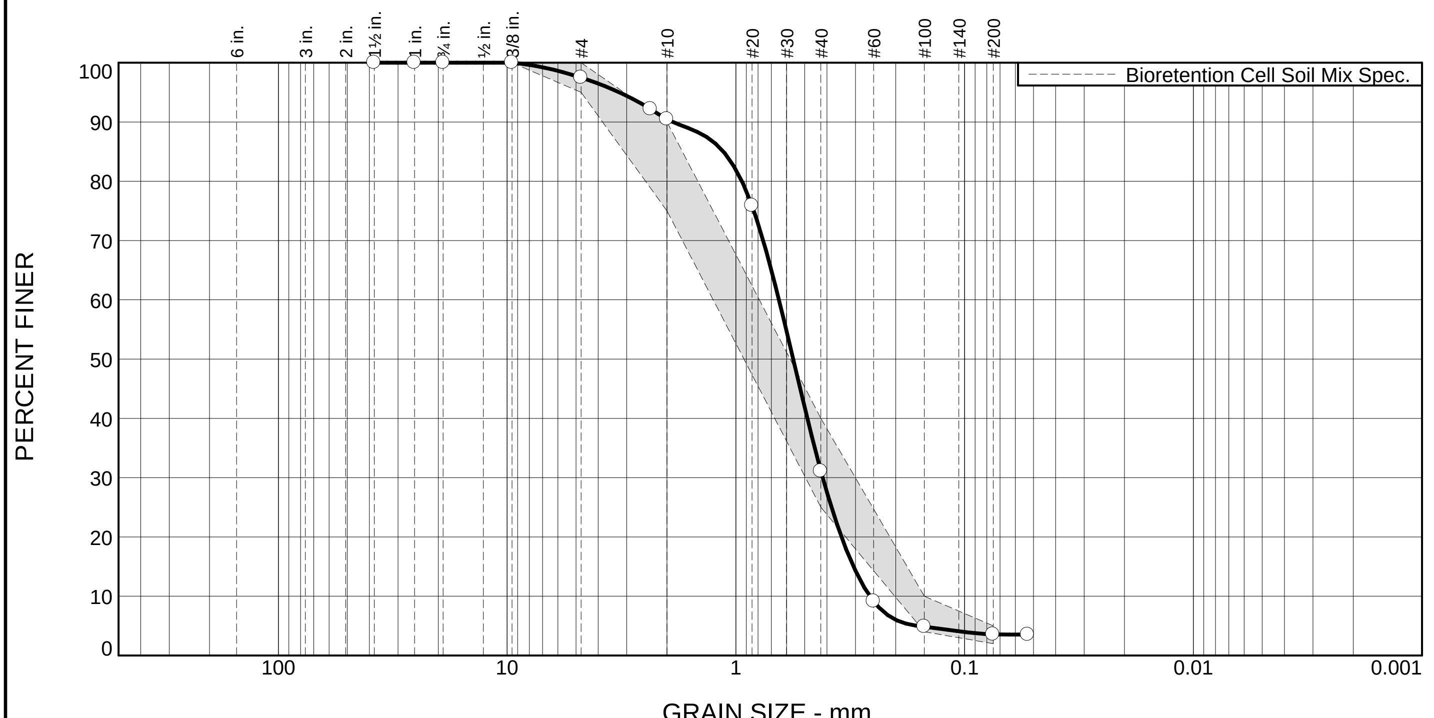
Organic Matter and Ash Content

Dry Soil Befor Burn + Pan	**614.75**	**588.28**
Dry Soil After Burn + Pan	**599.50**	**569.91**
Weight of Pan	**391.92**	**357.91**
Wt. Loss Due to Ignition	**15.25**	**18.37**
Actual Wt. Of Soil After Burr	**207.58**	**212.00**
% Organics	**6.8**	**8.0**

ASSOCIATED EARTH SCIENCES, INC.

911 5th Ave., Suite 100 Kirkland, WA 98033 425-827-7701 FAX 425-827-5424

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.5	7.0	59.4	27.5	3.6	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	100.0	100.0	
#4	97.5	95.0 - 100.0	
#8	92.2		
#10	90.5	75.0 - 90.0	X
#20	75.9		
#40	31.1	25.0 - 40.0	
#60	9.1		
#100	4.9	4.0 - 10.0	
#200	3.6	2.0 - 5.0	
#270	3.5		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 1.8867 D_{85}= 1.1338 D_{60}= 0.6482
D_{50}= 0.5616 D_{30}= 0.4173 D_{15}= 0.3059
D_{10}= 0.2596 C_u= 2.50 C_c= 1.04

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/03/2018 **Date Tested:** 11/01/2018

Tested By: BN

Checked By: JHS

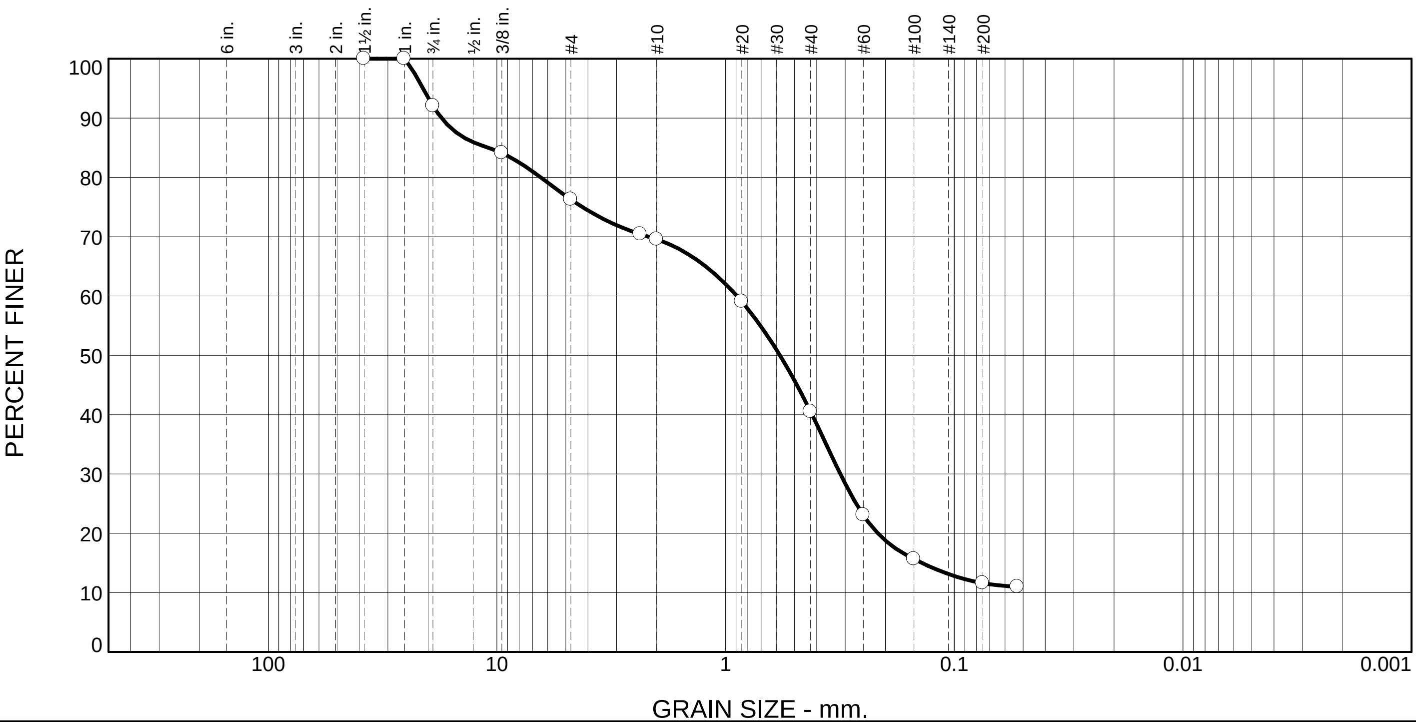
Title:

Source of Sample: (TWH) Tacoma-Wilson High SChool **Depth:** 0.1'-0.5' **Date Sampled:** 10/03/2018
Sample Number: HA-1

associated earth sciences incorporated

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	8.0	15.7	6.7	29.1	28.9	11.6	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	92.0		
.375	84.1		
#4	76.3		
#8	70.4		
#10	69.6		
#20	59.1		
#40	40.5		
#60	23.1		
#100	15.7		
#200	11.6		
#270	11.0		

* (no specification provided)

Material Description

gravelly SAND, some silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 17.4752 D_{85}= 10.9462 D_{60}= 0.8927
D_{50}= 0.5788 D_{30}= 0.3150 D_{15}= 0.1385
D_{10}= C_u= C_c=

Remarks

Collected by: ADY

Date Received: 12/06/2018 **Date Tested:** 12/11/2018

Tested By: BN

Checked By: JHS

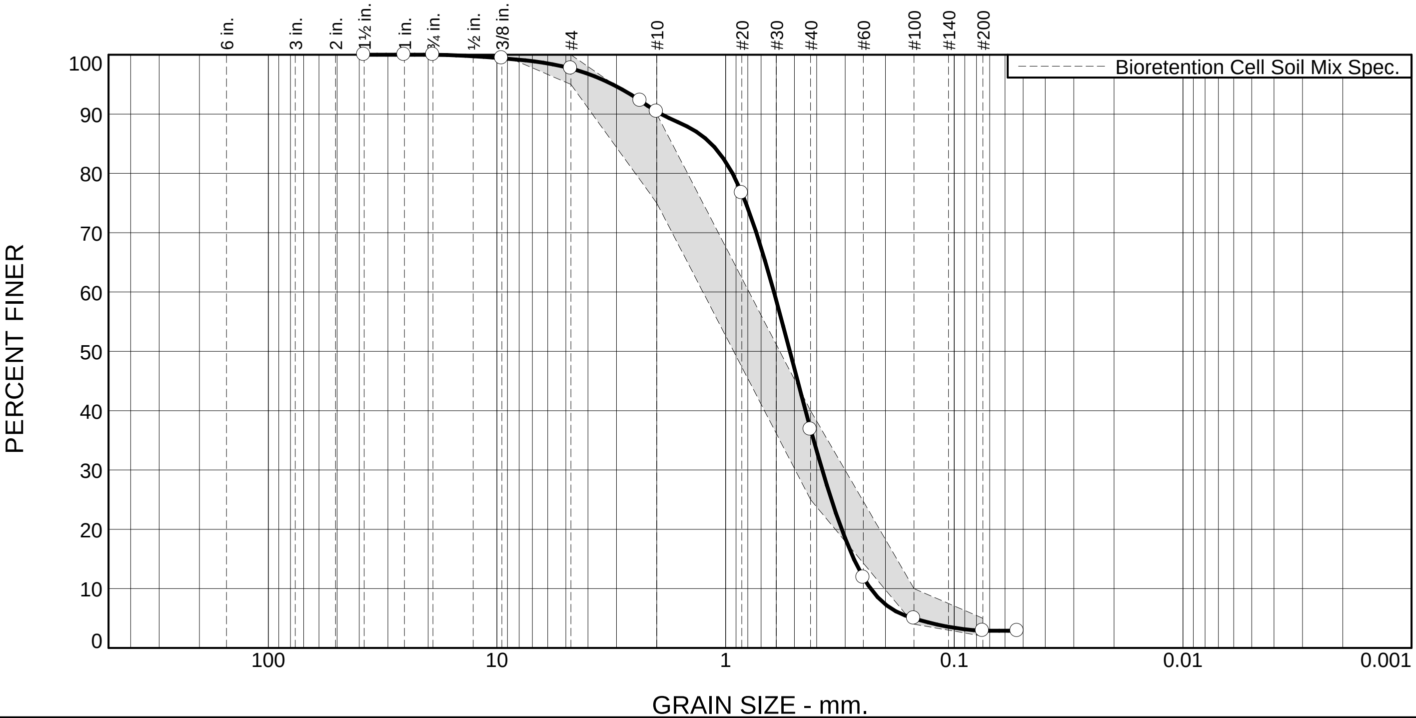
Title:

Source of Sample: (TWH) Tacoma-Wilson High SChool **Depth:** 1.4'-1.9' **Date Sampled:** 10/03/2018
Sample Number: HA-2

a s s o c i a t e d
e a r t h s c i e n c e s
i n c o r p o r a t e d

Client: Clear Creek Solutions
Project: Bioretention Hydrologic Performance Study
Project No: 150387 H004 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.3	7.3	53.5	34.0	2.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1.5	100.0		
1	100.0		
.75	100.0		
.375	99.4	100.0	X
#4	97.7	95.0 - 100.0	
#8	92.3		
#10	90.4	75.0 - 90.0	X
#20	76.7		
#40	36.9	25.0 - 40.0	
#60	11.9		
#100	5.0	4.0 - 10.0	
#200	2.9	2.0 - 5.0	
#270	2.9		

* Bioretention Cell Soil Mix Spec.

Material Description

SAND, trace silt, trace gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 1.9169 D_{85}= 1.1553 D_{60}= 0.6147
D_{50}= 0.5238 D_{30}= 0.3780 D_{15}= 0.2749
D_{10}= 0.2323 C_u= 2.65 C_c= 1.00

Remarks

Collected by: ADY

Bioretention soil mix burned first per ASTM D2974 then sieved.

Date Received: 10/03/2018 **Date Tested:** 11/01/2018

Tested By: BN

Checked By: JHS

Title:

Source of Sample: (TWH) Tacoma-Wilson High SChool **Depth:** 0.1'-0.5' **Date Sampled:** 10/03/2018

Sample Number: HA-3

associated earth sciences incorporated

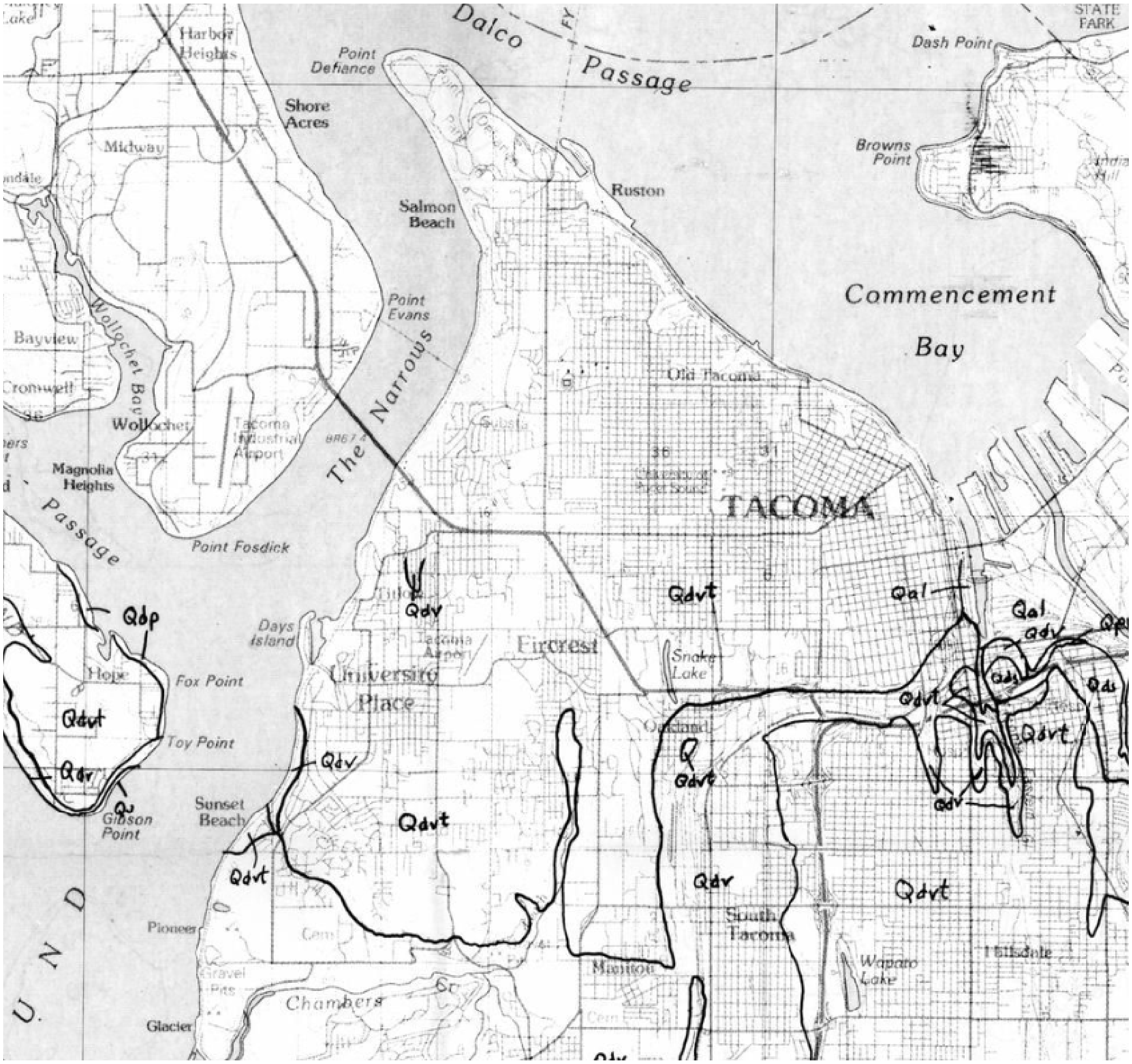
Client: Clear Creek Solutions

Project: Bioretention Hydrologic Performance Study

Project No: 150387 H004 **Figure**

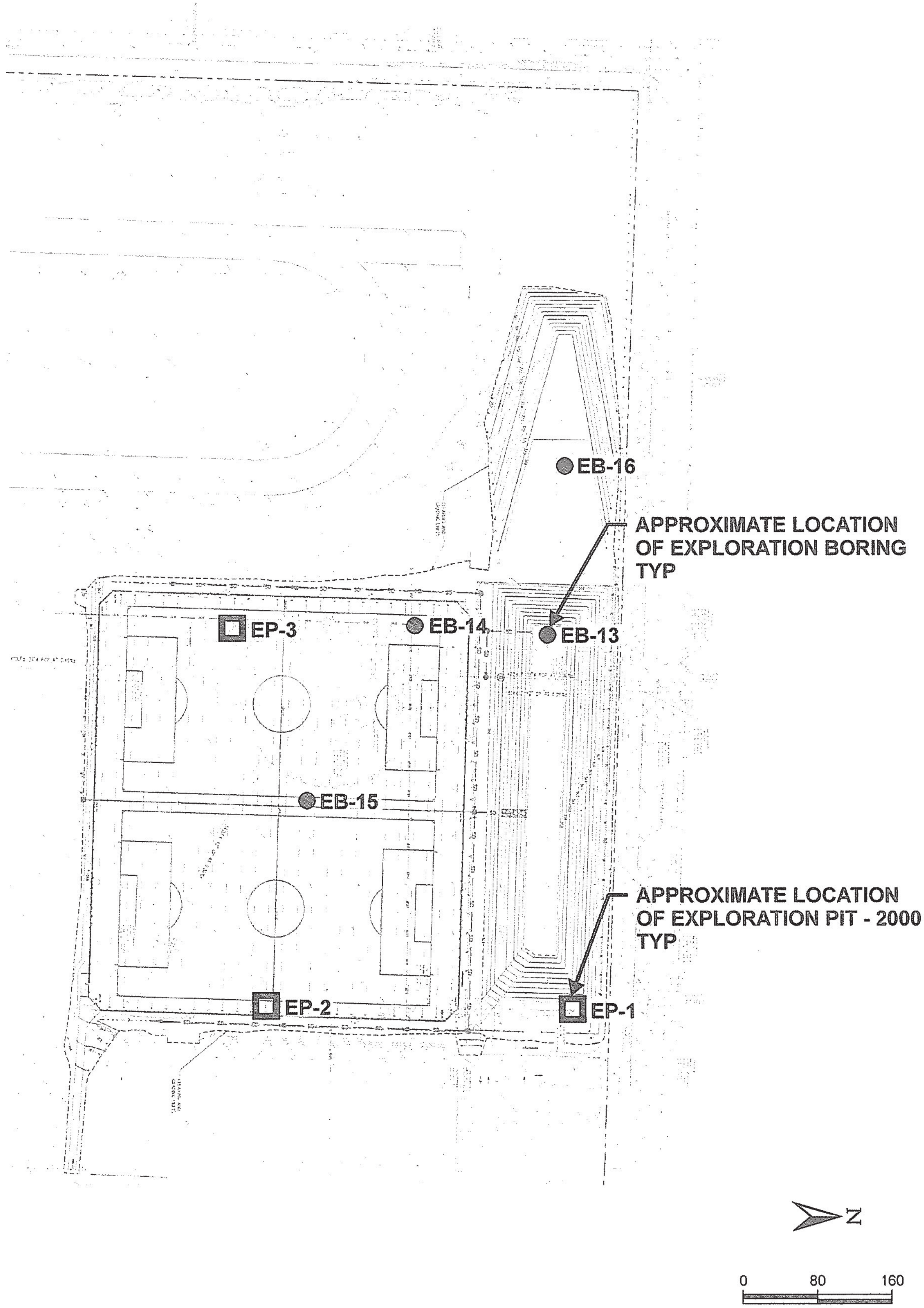
APPENDIX C

Background Soil, Geology, and Groundwater Data (Regional Maps, Previous Studies Exploration Logs and Laboratory Testing Data)



Excerpt from:

Walsh, T. J., 1987, Geologic Map of the south half of the Tacoma quadrangle, Washington, Washington Division of Geology and Earth Resources, Open File Report 87-3, scale 1:100,000.



REFERENCE: NAC ARCHITECTURE / SITTS & HILL ENGINEERS, INC.

Associated Earth Sciences, Inc.

SITE AND EXPLORATION PLAN

WILSON HIGH SCHOOL FIELD RENOVATIONS
TACOMA, WASHINGTON

FIGURE 2
DATE 7/13
PROJ. NO. TE130259A

130259 Wilson HS Field Renovations \ 130259 Site and Explr.cdr

Major Division	Subdivision	Fines	Symbol	Description
Coarse-Grained Soils - More than 50% [1] Retained on No. 200 Sieve	Gravels - More than 50% [1] of Coarse Fraction Retained on No. 4 Sieve	≤5% Fines [5]	GW	Well-graded gravel and gravel with sand, little to no fines
			GP	Poorly-graded gravel and gravel with sand, little to no fines
		≥15% Fines [5]	GM	Silty gravel and silty gravel with sand
			GC	Clayey gravel and clayey gravel with sand
	Sands - 50% [1] or More of Coarse Fraction Passes No. 4 Sieve	≤5% Fines [5]	SW	Well-graded sand and sand with gravel, little to no fines
			SP	Poorly-graded sand and sand with gravel, little to no fines
		≥15% Fines [5]	SM	Silty sand and silty sand with gravel
			SC	Clayey sand and clayey sand with gravel
Fine-Grained Soils - 50% [1] or More Passes No. 200 Sieve	Silts and Clays Liquid Limit Less than 50		ML	Silt, sandy silt, gravelly silt, silt with sand or gravel
			CL	Clay of low to medium plasticity; silty, sandy, or gravelly clay, lean clay
			OL	Organic clay or silt of low plasticity
	Silts and Clays Liquid Limit 50 or More		MH	Elastic silt, clayey silt, silt with micaceous or diatomaceous fine sand or silt
			CH	Clay of high plasticity, sandy or gravelly clay, fat clay with sand or gravel
			OH	Organic clay or silt of medium to high plasticity
Highly Organic Soils			PT	Peat, muck and other highly organic soils

Terms Describing Relative Density and Consistency

	Density	SPT [2] blows/foot
Coarse-Grained Soils	Very Loose	0 to 4
	Loose	4 to 10
	Medium Dense	10 to 30
	Dense	30 to 50
	Very Dense	>50
	Consistency	**SPT [2] blows/foot**
Fine-Grained Soils	Very Soft	0 to 2
	Soft	2 to 4
	Medium Stiff	4 to 8
	Stiff	8 to 15
	Very Stiff	15 to 30
	Hard	>30

Test Symbols

G = Grain Size
M = Moisture Content
A = Atterberg Limits
C = Chemical
DD = Dry Density
K = Permeability

Component Definitions

Descriptive Term	Size Range and Sieve Number
Boulders	Larger than 12"
Cobbles	3" to 12"
Gravel	3" to No. 4 (4.75 mm)
Coarse Gravel	3" to 3/4"
Fine Gravel	3/4" to No. 4 (4.75 mm)
Sand	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse Sand	No. 4 (4.75 mm) to No. 10 (2.00 mm)
Medium Sand	No. 10 (2.00 mm) to No. 40 (0.425 mm)
Fine Sand	No. 40 (0.425 mm) to No. 200 (0.075 mm)
Silt and Clay	Smaller than No. 200 (0.075 mm)

[3] Estimated Percentage

Component	Percentage by Weight
Trace	<5
Few	5 to 10
Little	15 to 25
With	- Non-primary coarse constituents: ≥ 15% - Fines content between 5% and 15%

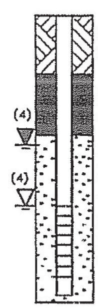
Moisture Content

Dry - Absence of moisture, dusty, dry to the touch
Slightly Moist - Perceptible moisture
Moist - Damp but no visible water
Very Moist - Water visible but not free draining
Wet - Visible free water, usually from below water table

Symbols

Sampler Type
Blows/6" or portion of 6"
2.0" OD Split-Spoon Sampler (SPT)
Bulk sample
Grab Sample

Sampler Type Description
3.0" OD Split-Spoon Sampler
3.25" OD Split-Spoon Ring Sampler
3.0" OD Thin-Wall Tube Sampler (including Shelby tube)
Portion not recovered



Cement grout surface seal
Bentonite seal
Filter pack with blank casing section
Screened casing or Hydrotip with filter pack
End cap

(1) Percentage by dry weight
(2) (SPT) Standard Penetration Test (ASTM D-1586)
(3) In General Accordance with Standard Practice for Description and Identification of Soils (ASTM D-2488)
(4) Depth of ground water
ATD = At time of drilling
Static water level (date)
(5) Combined USCS symbols used for fines between 5% and 15%

Classifications of soils in this report are based on visual field and/or laboratory observations, which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field or laboratory testing unless presented herein. Visual-manual and/or laboratory classification methods of ASTM D-2487 and D-2488 were used as an identification guide for the Unified Soil Classification System.

Associated Earth Sciences, Inc.

EXPLORATION LOG KEY

FIGURE A1

LOG OF EXPLORATION PIT NO. EP-1

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplification of actual conditions encountered.

Depth, ft	DESCRIPTION
	Sod
	Lodgement Till
1	Medium dense to dense, gray, moist, SAND with GRAVEL, little silt (SP); becomes very dense and SILTY with scattered cobbles below 3 1/2' (SM).
2	
3	
4	
5	
6	
7	
8	
9	Bottom of exploration pit at depth 8 feet No seepage, no caving.
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Wilson High School
Tacoma, Washington

Logged by: TJP
Approved by: TJP

ASSOCIATED EARTH SCIENCES, INC

Project No. KE00077G
Feb 23, 2000

LOG OF EXPLORATION PIT NO. EP-2

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplification of actual conditions encountered.

Depth, ft	DESCRIPTION
	Sod
	Lodgement Till
1	Dense, moist, gray SILTY SAND with GRAVEL (SM); contains scattered cobbles, becomes very dense below 4'.
2	
3	
4	
5	
6	
7	
8	
9	Bottom of exploration pit at depth 8 feet No seepage, no caving.
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Wilson High School
Tacoma, Washington

Logged by: TJP
Approved by: TJP

ASSOCIATED EARTH SCIENCES, INC

Project No. KE00077G
Feb 23, 2000

LOG OF EXPLORATION PIT NO. EP-3

This log is part of the report prepared by Associated Earth Sciences, Inc. (AESI) for the named project and should be read together with that report for complete interpretation. This summary applies only to the location of this trench at the time of excavation. Subsurface conditions may change at this location with the passage of time. The data presented are a simplification of actual conditions encountered.

Depth, ft	DESCRIPTION
0	Sod
0–3	**Fill** Medium dense, very moist, brown, SILTY SAND with GRAVEL (SM); contains abundant sticks and branches.
3–5	**Weathered Recessional Outwash** Loose, wet, brown, SILTY SAND, little gravel (SM); contains roots.
5–6	**Recessional Outwash** Stiff, gray with rust mottling, SILT, little fine sand, low plasticity (ML); contains abundant rootlets.
6–8	**Lodgement Till** Very dense, moist, grayish-brown, SILTY SAND with GRAVEL (SM).
8	Bottom of exploration pit at depth 8 feet Slow seepage 3'-5', no caving.

Depth scale: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

KCTF3 00077.GPJ February 23, 2000

Wilson High School
Tacoma, Washington

ASSOCIATED EARTH SCIENCES, INC

Logged by: TJP
Approved by: TJP

Project No. KE00077G
Feb 23, 2000

Associated Earth Sciences, Inc.

Exploration Log

Project Number	Exploration Number	Sheet
TE130259A	EB-13	1 of 1

Project Name	Wilson High School Field Renovations	Ground Surface Elevation (ft)	370
Location	Tacoma, WA	Datum	N/A
Driller/Equipment	Geologic Drill / Mini-Track Rig	Date Start/Finish	6/27/13,6/27/13
Hammer Weight/Drop	140# / 30"	Hole Diameter (in)	6 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Sod					
				Fill					
				Loose, moist, gray to brown, fine to medium SAND, with fine gravel, trace silt (SM).					
		S-1		Medium dense, moist, gray to brown, fine to medium SAND, with fine gravel, few silt, rootlets and moderate organics (SM).			7 10 10	20	
5		S-2		Loose, moist, brown, fine to medium SAND, with silt, few gravel, abundant organics (SM).			5 3 4	7	
				Old Topsoil Horizon					
				Loose, moist, brown to dark brown, fine to medium SAND, with silt, few gravel, moderate rootlets (SM).					
				Vashon Recessional Outwash					
		S-3		Soft, moist to very moist, brown to gray, SILT, few fine sand; weathered (ML).			3 2 2	4	
10		S-4		Medium dense, moist, gray, fine to medium SAND, trace silt; stratified (SM).			7 8 9	17	
				Vashon Lodgement Till					
				Harder drilling.					
15		S-5		Very dense, moist, gray, fine to medium SAND, with silt and gravel (SM).			22 50/6"	72/12"	
				Bottom of exploration boring at 16 5 feet No ground water encountered.					

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: MIL
Approved by:

Associated Earth Sciences, Inc.

Exploration Log

Project Number	Exploration Number	Sheet
TE130259A	EB-14	1 of 1

Project Name	Wilson High School Field Renovations	Ground Surface Elevation (ft)	370
Location	Tacoma, WA	Datum	N/A
Driller/Equipment	Geologic Drill / Mini-Track Rig	Date Start/Finish	6/27/13,6/27/13
Hammer Weight/Drop	140# / 30"	Hole Diameter (in)	6 inches

Depth (ft)	ST	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Sod					
				Fill					
				Loose, moist, gray to brown, fine to medium SAND, with fine gravel, trace silt (SM).					
				Loose to medium dense, moist, brown to dark brown, fine to medium SAND, few silt, trace gravel, moderate rootlets and organics (SM).					
		S-1					12 8 5	▲13	
5				**Old Topsoil Horizon**					
		S-2		Loose, moist, brown, fine to medium SAND, with fine gravel, few silt, minor rootlets (SM).			4 9 14	▲23	
				Vashon Lodgement Till					
				Medium dense, moist, gray, fine to medium SAND, with silt (SM). Cobbles.					
		S-3		Dense, moist, gray, fine to medium SAND, with silt and gravel, trace cobbles; blowcounts overstated due to obstruction (SM).			50/6"	▲50/6"	
10				Dense, moist, gray, fine to medium SAND, with silt and gravel, trace cobbles (SM).					
		S-4					9 19 26	▲45	
				Bottom of exploration boring at 11 5 feet No ground water encountered					
15									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- ▽ Water Level ()
- ▼ Water Level at time of drilling (ATD)

Logged by: MIL
Approved by:

Associated Earth Sciences, Inc.

Exploration Log

Project Number	Exploration Number	Sheet
TE130259A	EB-15	1 of 1

Project Name	Wilson High School Field Renovations	Ground Surface Elevation (ft)	370
Location	Tacoma, WA	Datum	N/A
Driller/Equipment	Geologic Drill / Mini-Track Rig	Date Start/Finish	6/27/13,6/27/13
Hammer Weight/Drop	140# / 30"	Hole Diameter (in)	6 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Sod					
				Fill					
				Loose, moist, gray to brown, fine to medium SAND, with fine gravel, trace silt (SM).					
		S-1		Medium dense, moist, gray, fine to medium SAND, with silt, few gravel (SM).			9 10 11	21	
				Rootlets.					
5		S-2		Medium dense, moist, orang brown to gray, fine to medium SAND, with silt and gravel, minor organics (SM).			3 3 7	10	
				Vashon Lodgement Till					
		S-3		Harder drilling. Very dense, moist, gray, fine to medium SAND, with silt and gravel (SM).			28 30 29	59	
				Bottom of exploration boring at 9 feet No ground water encountered					
10									
15									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- Water Level ()
- Water Level at time of drilling (ATD)

Logged by: MIL
Approved by:

Associated Earth Sciences, Inc.

Exploration Log

Project Number	Exploration Number	Sheet
TE130259A	EB-16	1 of 1

Project Name: Wilson High School Field Renovations
Location: Tacoma, WA
Driller/Equipment: Geologic Drill / Mini-Track Rig
Hammer Weight/Drop: 140# / 30"

Ground Surface Elevation (ft): 382
Datum: N/A
Date Start/Finish: 6/27/13,6/27/13
Hole Diameter (in): 6 inches

Depth (ft)	S T	Samples	Graphic Symbol	DESCRIPTION	Well Completion	Water Level	Blows/6"	Blows/Foot (10 20 30 40)	Other Tests
				Fill					
				Medium dense, moist, brown, fine to medium SAND, with fine gravel, trace silt (SM).					
				Medium dense, moist, brown, fine to medium SAND, with gravel, few cobbles and silt (SM).					
				Vashon Lodgement Till					
		S-1		Dense, moist, gray, fine to medium SAND, with silt and gravel (SM).			3 18 26	▲44	
5				Very dense, moist, gray, fine to medium SAND, with silt and gravel (SM).					
		S-2					9 25 34	▲59	
		S-3		Very dense, moist, gray, fine to medium SAND, with silt and gravel, few cobbles; blowcount overstated due to cobbles (SM).			50/6"	▲50/6"	
				Bottom of exploration boring at 9 feet No ground water encountered					
10									
15									

Sampler Type (ST):

- 2" OD Split Spoon Sampler (SPT)
- 3" OD Split Spoon Sampler (D & M)
- Grab Sample
- No Recovery
- Ring Sample
- Shelby Tube Sample
- M - Moisture
- ▽ Water Level ()
- ▼ Water Level at time of drilling (ATD)

Logged by: MIL
Approved by:

APPENDIX D

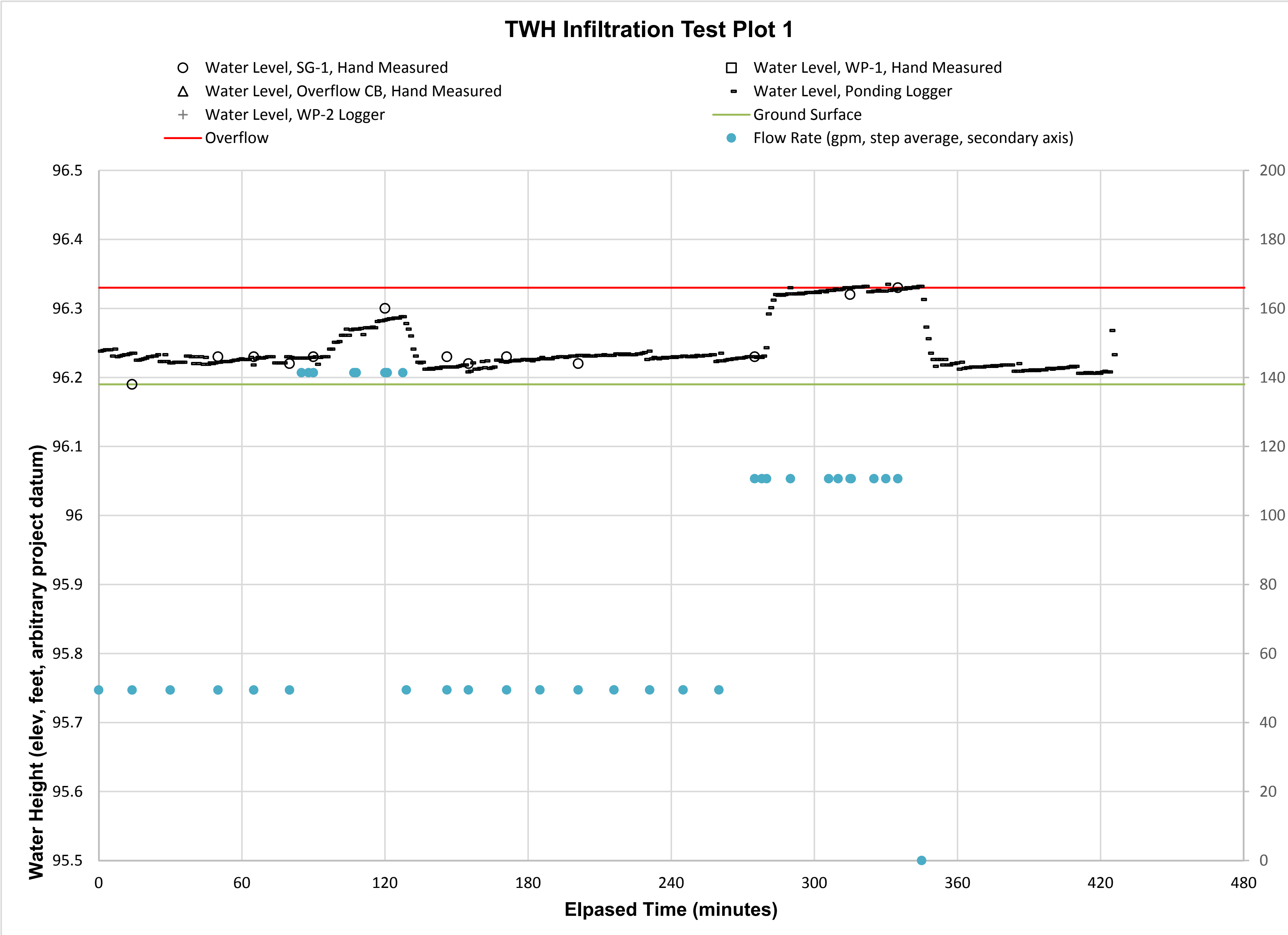
Soil Probe, Level Survey, and Field Infiltration Testing Data

Project Name:	BHPS	**Water Source:**	Hydrant
Project Number:	150387H007	**Meter:**	AESI FM5, 9
Date:	11/19/2018	**Base Area (sq.ft.):**	NA
Weather:	Partly cloudy, 60's	**Ponded Area(sq.ft.):**	850.0
Test No.:	TWH	**Test Depth (feet):**	NA
Performed By:	ADY, SC	**Receptor Soils:**	Vashon lodgment till

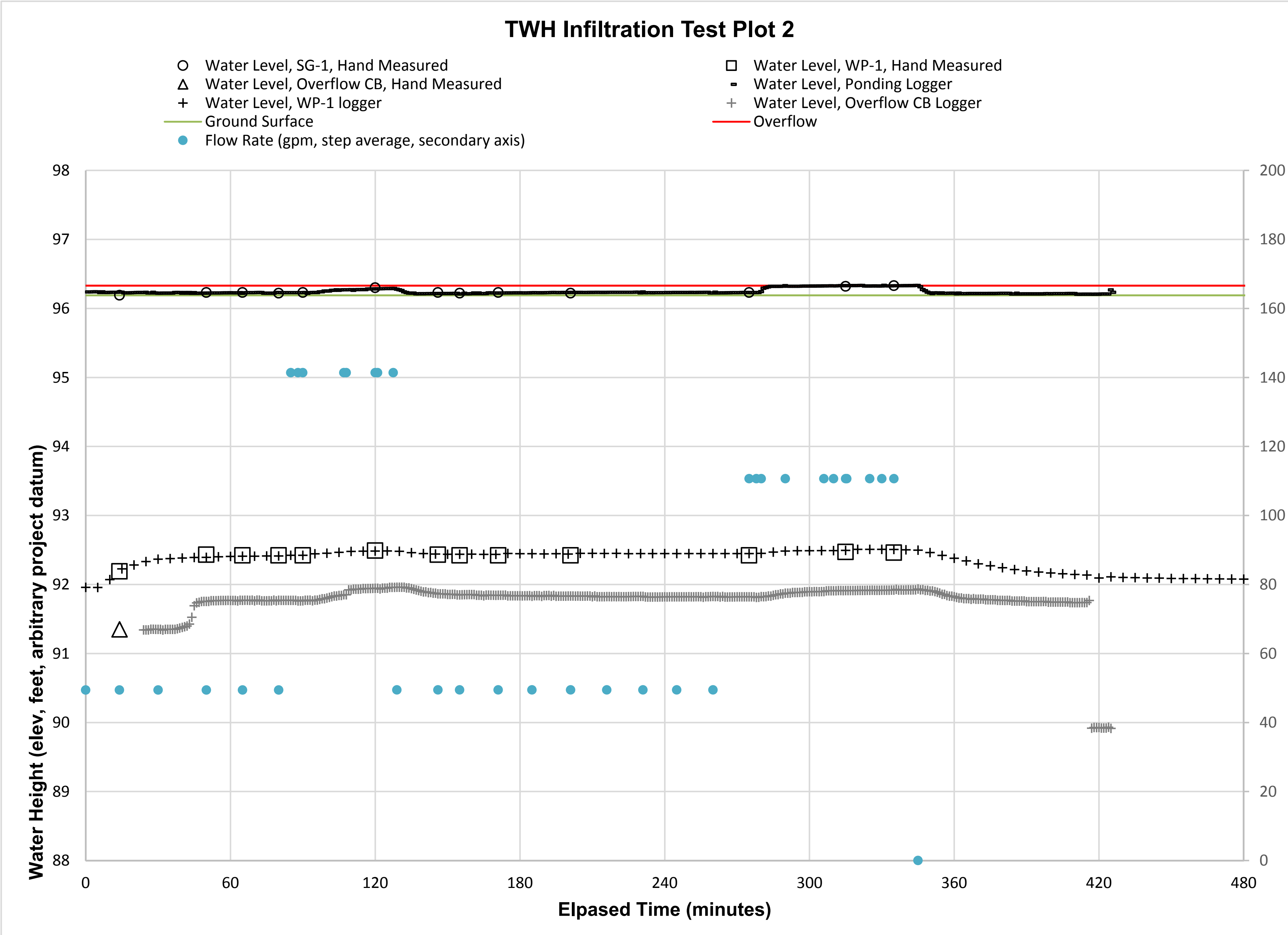
Time (24-hr)	Flow Rate (gpm)	Stage (feet)	Totalizer (gallons)	Comments
8:55	49.7	0	0	Flow on from hydrant.
9:09	49.3	0	693.86	
9:25	49.3	0	1458	FM9 discharge located by SG-1/WP-1
9:45	49.4	0.04	2460	
10:00	49.5	0.04	3220	
10:15	49.2	0.03	3936	Flow observed from underdrain pipes.
10:20	135.7			Flow on FM5 from water truck at approx 98 gpm, discharge near center of facility.
10:23	147.1			No observed discharge into detention pond.
10:25		0.04		
10:42		0.05		
10:43				
10:55		0.11		
10:56				
11:02				Water truck empty. Leaves site to refill.
11:04	49.4	0.09		
11:21	49.2	0.04		
11:30	49.7	0.03		
11:46	49.5	0.04		
12:00	49.5	0.03		Only West underdrain pipe active.
12:16	49.2	0.03		
12:31	49.6	0.04		
12:46	49.4	0.04		
13:00	49.6	0.04		
13:15	49.5	0.04		
13:30		0.04	17547	Water truck returned, flow on from water truck at approx 60 gpm. Discharge near SG-1/WP-1.
13:33	108.9			
13:35	109.4			
13:45	112.5	0.08		No observed flow into detention pond.
14:01	111.7	0.13		

14:05				
14:10	111.2	0.13		
14:10				
14:20	110.9	0.14	22979	
14:25	110.4	0.14	23544	
14:30	110.3	0.14	24137	
14:35		0.14		No observed flow into detention pond.
14:40	0.0	0.14	25123	Water truck empty. All flow off.
14:40:20		0.11		
14:40:45		0.1		
14:41:00		0.09		
14:41:15		0.08		
14:41:35		0.07		
14:41:50		0.06		
14:42:20		0.05		
14:43:30		0.02		
14:44:30		dry		
15:01:00				
15:51:00				
15:57:00				

Average Infiltration Rate (in/hr) during last hour of inflow:	11
Average Infiltration Rate (in/hr) during falling head:	25



TWH Infiltration Test Plot 1
Water Level, SG-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, WP-2 Logger
Overflow
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Ground Surface
Flow Rate (gpm, step average, secondary axis)
Water Height (elev, feet, arbitrary project datum)
96.5
96.4
96.3
96.2
96.1
96
95.9
95.8
95.7
95.6
95.5
200
180
160
140
120
100
80
60
40
20
0
0
60
120
180
240
300
360
420
480
Elpased Time (minutes)



TWH Infiltration Test Plot 2
Water Level, SG-1, Hand Measured
Water Level, Overflow CB, Hand Measured
Water Level, WP-1 logger
Ground Surface
Flow Rate (gpm, step average, secondary axis)
Water Level, WP-1, Hand Measured
Water Level, Ponding Logger
Water Level, Overflow CB Logger
Overflow
Water Height (elev, feet, arbitrary project datum)
Elpased Time (minutes)
98
97
96
95
94
93
92
91
90
89
88
0
60
120
180
240
300
360
420
480
200
180
160
140
120
100
80
60
40
20
0

APPENDIX E

Site Photos

Above photo is overview of cell TWH prior to start of infiltration test.
Lower photo shows the energy dispersion pads for the two inlets and the well point.

Above photo: TWH, underdrain cleanouts and well point.
Lower Photo: overflow structure.

APPENDIX 13

Bioretention Hydrologic Performance Study Phase II - Hydrologic Monitoring Results. Aspect Consulting. 11/5/2020

BIORETENTION HYDROLOGIC PERFORMANCE STUDY II

Hydrologic Monitoring Results

Prepared for: City of Olympia

Project No. 170214 • November 5, 2020

e a r t h + w a t e r

Aspect CONSULTING

BIORETENTION HYDROLOGIC PERFORMANCE STUDY II

Hydrologic Monitoring Results

Prepared for: City of Olympia

Project No. 170214 • November 5, 2020

Aspect Consulting, LLC

Bryan E. Berkompas
Associate Hydrologist
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1 Introduction

Aspect Consulting, LLC (Aspect) prepared this memorandum to summarize the methods and results of the hydrologic data monitoring portion of the Bioretention Hydrologic Performance Study II. Additional information on the soils, vegetation, and modeling portions of the larger study are summarized in other memorandums and the final report. Further details on the project background, site characteristics, and methods are included in the Quality Assurance Project Plan (Taylor and Clear Creek, 2019).

This memorandum presents the equipment and procedures used to collect a continuous data set, which is comprised of inflow, outflow, ponding depth, shallow groundwater depth, and rainfall at 10 bioretention facilities over a 9-month period. A brief discussion of data quality and any anomalies at each facility is also discussed.

2 Summary of Findings

The hydrologic data collection for the Bioretention Hydrologic Performance Study II was successful due to a partnership between staff from Aspect and the City of Bellingham for field data collection. In addition, precipitation data from City of Tacoma, City of Marysville, Snohomish County, King County, and the National Weather Service reduced the need to install project-specific rain gauges and improved efficiency. Over 4.23 million continuous water level, rainfall, and flow data points were collected over a 9-month study period from October 2018 through July2019. Overall, the continuous data and field observations revealed some commonality between the 10 bioretention facilities.

1. The facilities without underdrains did not discharge throughout this study. The five facilities with underdrains all discharged, largely due to the underdrain collecting water and routing it to the outlet.

2. It appears that site constraints may have affected the overall performance of some sites. Retrofits along streets are often constrained in size, slope, and elevation by right-of-way or the need to tie into existing storm drain infrastructure. This led to one site (BCK) with an inlet pipe that likely also discharged from the facility at times and some overflow structures that were barely above the bottom elevation of the facility. This made the sites difficult to monitor accurately, but also indicates that the site constraints limit the effectiveness of the facility.

3. Sustained periods of snow and below-freezing temperatures affected the monitoring equipment for a month or more at most sites.

4. The monitored facilities were generally effective at infiltrating the stormwater they received. Four of the facilities did overflow but only during the most intense events.

3 Site Descriptions

The Bioretention Hydrologic Performance Study II monitored 10 bioretention facilities spread across the Puget Sound region. Table 1 shows a summary of the site names and locations. More detail on each facility and the monitoring approach for each are described in Section 4.

Table 1. Bioretention Monitoring Sites

Site Name	Site Location
BCK	Corner of Cornwall and Kentucky Bellingham, WA – cell 2
BUW	Corner of Utter and Washington, Bellingham, WA – cell 5
FWI	Wainwright Intermediate School, Fircrest, WA – cell 4
M1C	1st Street, Marysville, WA – cell S-1
M3Q	3rd Street and Quinn, Marysville, WA – NE cell
MPP	Park Place Middle School, Monroe, WA – cell 6
RSH	Harrington Avenue NE, Renton, WA – cell E2
SSW	Salem Woods Elementary School, Monroe, WA – cell 2
TBM	Bush Middle School, Tumwater. WA
TWH	Wilson High School, Tacoma, WA

4 Methods

This section describes the equipment and methods used to measure water level, flow, and rainfall at the bioretention facilities.

4.1 Hydrologic Monitoring Equipment

The hydrologic monitoring equipment consisted of pressure transducers, weirs, and rain gauges. Each bioretention facility had unique requirements, and the equipment was tailored to meet the constraints of each facility. Table 2 summarizes the location and monitoring site names for all the monitoring equipment. Drawings showing the installation locations of the equipment for each facility are shown in Appendix A.

Table 2. Summary of Monitoring Equipment

Site	Inlet	Outlet	Ponding	Subsurface Water/ Groundwater	Rain
BCK	BCK_IN1 6-inch Thel-Mar weir connected to curb cut BCK_IN2 installed in 6-inch pipe with Thel-Mar weir	BCK_OUT installed in overflow structure - 8-inch outlet pipe with Thel-Mar weir	BCK_PD1 installed near groundwater well	BCK_WP installed in groundwater well near center of facility	BCK_RN City of Bellingham rain gauge at City Hall
BUW	BUW_IN1 8-inch Thel-Mar weir connected to curb cut BUW_IN2 8-inch Thel-Mar weir connected to curb cut	BUW_OUT installed in overflow structure - 8-inch outlet pipe with Thel-Mar weir	BUW_PD installed near groundwater well	BUW_WP installed in groundwater well in center of facility	BUW_RN City of Bellingham rain gauge at City Hall
FWI	FWI_IN1 8-inch Thel-Mar weir connected to curb cut FWI_IN2 6-inch Thel-Mar weir connected to curb cut	FWI_OUT installed in 12-inch outlet pipe	FWI_PD installed near groundwater well	FWI_WP installed in groundwater well in center of facility	FWI_RN City of Tacoma rain gauge at Tacoma Community College
M1C	M1C_IN 8-inch Thel-Mar weir connected to curb cut	N/A	M1C_PD installed near Groundwater well	M1C_WP1 installed in deep groundwater well near center of cell M1C_WP2 Installed in shallow groundwater well near center of cell	M1C_RN City of Marysville rain gauge at Public Works Building
M3Q	M3Q_IN 6-inch Thel-Mar weir connected to curb cut	M3Q_OUT 8-inch Thel-Mar weir connected to outlet pipe	M3Q_PD installed near groundwater well	M3Q_WP1 installed in deep groundwater well near center of cell M3Q_WP2 Installed in shallow groundwater well near center of cell	M3Q_RN City of Marysville rain gauge at Public Works Building

Site	Inlet	Outlet	Ponding	Subsurface Water/ Groundwater	Rain
MPP	MPP_IN 6-inch Thel-Mar connected to curb cut	NA	MPP_PD installed adjacent to groundwater well	MPP_WP installed in groundwater well near center of facility	MPP_RN Snohomish County rain gauge at Snohomish County Fairgrounds
RSH	RSH_IN1 8-inch Thel-Mar weir connected to curb cut RSH_IN2 6-inch Thel-Mar weir connected to curb cut	RSH_OUT 8-inch Thel-Mar installed in outlet pipe	RSH_PD installed adjacent to groundwater well	RSH_WP install in groundwater well near center of facility RSH_UD installed in existing underdrain riser	RSH_RN King County rain gauge 31UN
SSW	SSW_IN 12-inch Thel-Mar weir connected to curb cut	N/A	SSW_PD installed adjacent to groundwater well	SSW_WP installed in groundwater well near center of facility	SSW_RN installed on SSW building roof
TBM	TBM_IN 6-inch Thel-Mar weir connected to curb cut	N/A	TBM_PD installed in facility near groundwater well	TBM_WP1 installed in deep groundwater well near center of cell TBM_WP2 Installed in shallow groundwater well near center of cell	TBM_RN NWS rain gauge at Olympia Regional Airport (KOLM)
TWH	TWH_IN1 12-inch Thel-Mar weir connected to inlet pipe TWH_IN2 8-inch Thel-Mar weir connected to inlet pipe	TWH_OUT 12-inch Thel-Mar weir install in outlet pipe	TWH_PD1 installed adjacent to GW well near inlets TSH_PD2 installed adjacent to outlet overflow structure	TWH_WP installed in groundwater well near inlets	TWH_RN City of Tacoma rain gauge at Tacoma Community College

4.1.1 Rainfall

Precipitation data is an important part of the modeling and inlet flow verification analysis. The data collection at each site included a nearby or on-site rain gauge. The Bellingham sites at Cornwall Avenue and Kentucky Street (BCK), and Utter Street and Washington Street (BUW), utilized an existing City of Bellingham rain gauge located on top of City Hall. The Fircrest Wainwright Intermediate School (FWI) and Tacoma Wilson High School (TWH) sites utilized an existing City of Tacoma rain gauge located at Tacoma Community College. The Marysville sites at 1st Street near Cedar Avenue (M1C), and at 3rd Street and Quinn Avenue (M3Q), utilized an existing City of Marysville rain gauge located on top of the city's Public Works building. A National Weather Service (NWS) rain gauge at Olympia Regional Airport (KOLM) was used for the Bush Middle School (TBM) site in Tumwater. The Renton site on Harrington Avenue (RSH) utilized an existing King County rain gauge (31UN) located at the Renton Roads facility. An existing Snohomish County rain gauge located at the Snohomish County Fairgrounds was used for Park Place Middle School (MPP) in Monroe. The Salem Woods Elementary School (SSW) site used a Solinst Rainlogger datalogger connected to a Hydrological Services America TB-6 rain gauge (Figure 1) that was installed on the site as part of this study. Each rain gauge reported rainfall in increments of 0.01 inches. The BCK, BUW, M1C, M3Q, and RSH gauges recorded rain in 15-minute increments. The NWS rain gauge near TBM recorded rainfall in 5-minute increments, in general, but was somewhat irregular with periods of no data during dry periods or more frequent measurements during periods of higher-intensity rainfall. The other rain gauges recorded rain in 5-minute increments.

Figure 1. Rain Gauge Installed on Salem Woods Elementary School Roof (SSW)

4.1.2 Inflow

Bioretention facilities in this study had two types of inlets: pipes and curb cuts. The sites at TWH and the second inlet at BCK were built with piped inlets, and the inflow was measured using Thel-Mar weir inserts sized to fit the inlet pipes (Figure 2).

The sites at BUW, FWI, M3Q, MPP, RSH, SSW, TBM, and the first inlet at BCK were built with curb-cut inlets. Curb cuts required adaptation, as the flow through the cut was too shallow to measure directly under all but the most extreme storm conditions. A rubber sheet was used to line the curb cut and funnel the flow into a section of pipe with a Thel-Mar weir inserted at the downstream end of the pipe (Figure 3).

The M1C site had one curb-cut inlet from 1st Street and four very small curb-cut inlets from the adjacent sidewalk. Inflow from 1st Street was measured using a Thel-Mar weir like the other curb-cut sites, but the inflow from the sidewalk inlets was modeled to estimate the total flow into the bioretention cell.

The water level behind each weir was measured using Solinst Levelogger and Barologger pressure transducers. Leveloggers are not vented, so a Barologger was installed in a “dry” well adjacent to each Levelogger and used to compensate for changes in atmospheric pressure.

Figure 2. Inflow Monitoring in the Inlet Pipe at TWH_IN1

Figure 3. Inflow Monitoring in Curb Cut at FWI_IN2

4.1.3 Outflow / Overflow

The bioretention facilities at BCK, BUW, FWI, M1C, M3Q, RSH, SSW, and TWH all have an outlet overflow structure. In addition, the outlets at BCK, BUW, FWI, RSH, and TWH, are connected to underdrains. The underdrain at RSH is installed 1.13 feet below a lateral connecting pipe to the overflow structure and will not contribute to discharge unless the facility is fully saturated up to the invert of the lateral pipe. If the underdrain at RSH does discharge, the flow rate is controlled by a 1-inch orifice that discharges into the outlet structure. Discharge from BCK, BUW, RSH, and TWH was measured using a Thel-Mar weir inserted into the outlet pipe of each overflow structure, and Levelogger and Barologger pressure transducers were installed in the sump of the structure to measure the water level acting on the weir (Figure 4a). Discharge from FWI and M3Q was measured using a Thel-Mar weir inserted into the outlet pipe where it connected to the storm drain system and the Levelogger and Barologger pressure transducers were installed in a stilling well that is hydraulically connected to the upstream side of the weir with a PVC connector pipe. (Figure 4b). Discharge from M3Q and SSW could not be measured directly as their overflow structures were directly connected to drains from other bioretention cells and any discharge would be comingled with discharge from other facilities. Discharge would have been estimated from the ponding depths at the overflow structure but neither site overflowed during this study. The bioretention facilities at MPP and TBM did not have outlets and were not monitored for discharge.

Figure 4. a) Outflow Monitoring in Catch Basin at BUW and b) Outflow Monitoring in Outlet Structure with a Stilling Well at FWI

4.1.4 Groundwater

A monitoring well was installed at each facility to measure the groundwater surface elevations within the facility (Figure 5). A Levelogger pressure transducer was installed in the bottom of each well, paired with a Barologger pressure transducer installed near the top of each well. The M1C, M3Q, and TBM facilities had an additional pressure transducer installed in a deeper groundwater well designed to monitor groundwater levels in the native soil underneath the facility. The RSH facility had an additional pressure transducer installed in the bottom of the underdrain pipes. The water level in the underdrain can provide insight into the infiltration rates within the facility, as well as a broader understanding of the groundwater levels within the facility, as the underdrain extends across almost the entire length of the facility. A more detailed analysis of subsurface water and groundwater was completed by Associated Earth Sciences, Inc. (AESI; 2019), and their reports are referenced below (AESI, 2019a–2019j).

Figure 5. Groundwater Monitoring Wells at TBM

4.1.5 Ponding

A monitoring well was installed at each facility to measure ponding depth and to corroborate any overflow bypass events that may occur (Figure 6a and 6b). TWH had two ponding wells installed due to its length and the anticipated infiltration rate. The first

TWH ponding well was installed near the inlets, and the second ponding well was installed adjacent to the overflow structure.

Figure 6. a) Ponding Wells at Overflow of TWH and b) Near Center of BCK

Ponding water levels were measured using paired Levelogger and Barologger pressure transducers. The ponding depth was used in the analysis of both infiltration rates of the bioretention soil mix and overflow events (where applicable) at each facility.

4.2 Hydrologic Data Collection

Each site was visited at regular intervals throughout the 9-month data-collection period. During each site visit, all monitoring equipment was examined and maintained as needed. Maintenance activities included removing debris from the weirs, stilling well, and pipes; cleaning and downloading the Solinst pressure transducers; cleaning project rain gauges and ensuring the rain gauges remained level; and measuring and recording water levels at each monitoring point.

The hydrologic data set was collected by a monitoring team consisting of Aspect and municipal staff. City of Bellingham staff downloaded and maintained the monitoring equipment at BCK and BUW. City, county, and federal rain gauges were maintained and operated by their respective staff. All other sites were maintained and downloaded by Aspect staff.

4.3 Hydrologic Data QA/QC

Hydrologic data were initially graphed and reviewed visually to identify data gaps, data spikes, anomalies, etc. All water levels were also graphed with rainfall data to ensure changes in water levels corresponded with rainfall events. All potential issues were identified and addressed, where possible, and the procedures for these corrections are described below.

Data gaps were difficult to address, because the sites were far apart and subject to different weather conditions, and because variable rainfall intensities and antecedent conditions at each site limited opportunities for regression analysis between sites or even between monitoring points within a site. Data gaps that could not be filled were noted in the data set.

Data spikes refer to a short duration (often a single data point) where the water level was much greater or less than the water levels that precede or follow it. Data spikes were generally smoothed by interpolating between the data points that preceded and followed the spike.

All water level data for this study required adjustment. The field teams manually measured the water levels (or noted dry conditions) during each site visit. The transducers could not be calibrated in place, so corrections were applied during the data quality assurance/quality control (QA/QC) process to align the water level data with the water levels measured in the field. Each field visit was used as the endpoint for the data period that preceded it and as the beginning point for the following data period. The field water level measurements were used to determine an offset at the start and end of each data period. If the offsets were the same, then the offset was applied to the entire data period. If the offsets at the start and end of the data period did not match, then the data were adjusted by applying the smaller offset to the data and then adjusting the water level across the data period using linear interpolation. Overall, the data required 1,346 adjustment periods for the study period.

Flow in and out (where applicable) of each facility was calculated using the adjusted water level and the appropriate Thel-Mar weir equation.

Once the data were adjusted to match the field observations, the water levels were then tied into temporary datums based on surveys performed by the consultant team. Water levels for each site were adjusted based on the relative elevation of each monitoring point. Tying the water levels into a common datum at each site allowed for direct comparisons of ponding water depth with overflow conditions and comparing shallow groundwater and ponding water levels.

5 Hydrologic Results and Data Analysis

Approximately 9 months of continuous hydrologic data were collected at each site for this study. The results from each bioretention facility are discussed below

5.1 BCK

The monitoring equipment was installed at BCK on October 22, 2018, and removed on July 25, 2019. Most of the monitoring equipment functioned well throughout the study period, but the curb-cut inlet (BCK_IN1) was often clogged with leaves and appears to underreport inflow for significant periods of time. Field notes show that both inlets were often full of leaves with the overall effect on inflow unknown. Freezing temperatures affected between 3.7 and 9.9 percent of the inflow and ponding data during the study with BCK_IN2 being less affected due to the inlet pipe being mostly underground.

During the monitoring period, 24.91 inches of rain fell and produced a total inflow volume of 18,185 cubic feet. The rainfall-runoff relationship was not consistent across a range of events, as shown on Figure 7. This is likely due to a couple of factors. First, as described above, the inflow values for BCK_IN1 were often measured as zero even when there should have been sufficient rain to generate flow. Second, during larger events the ponding depth could partially submerge the weir for BCK_IN2 which would cause it to measure more flow than was actually coming into the facility. The rainfall event shown on Figure 8 demonstrates the issues that were present at BCK during the study. The rainfall event of 1.61 inches was intense enough to sustain ponding depths that affect the water levels at BCK_IN2, yet it did not generate any measured inflow at BCK_IN1. It should be noted that the 2012 Western Washington Hydrology Model (WWHM2012) modeled inflows were consistently higher than the measured inflows.

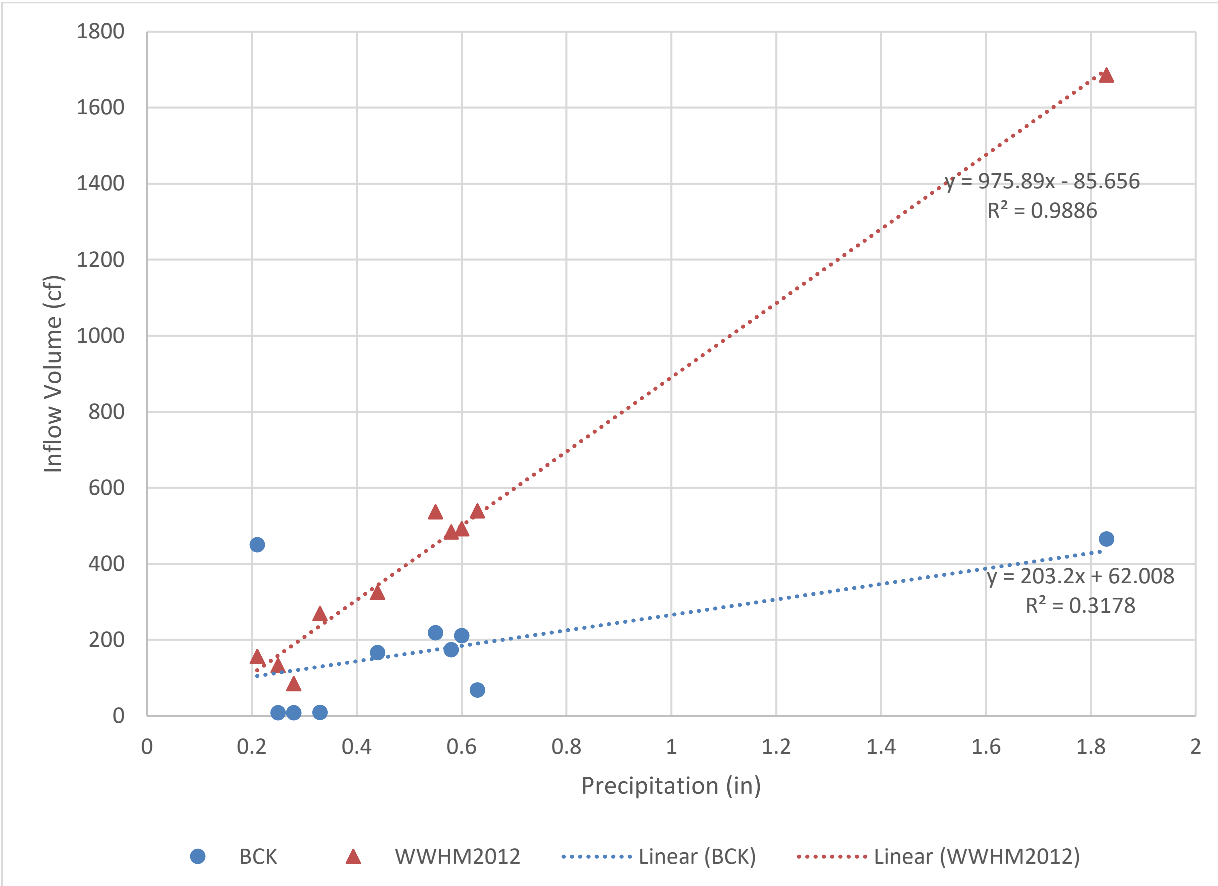

Figure 7. Rainfall-Runoff Relationship for BCK

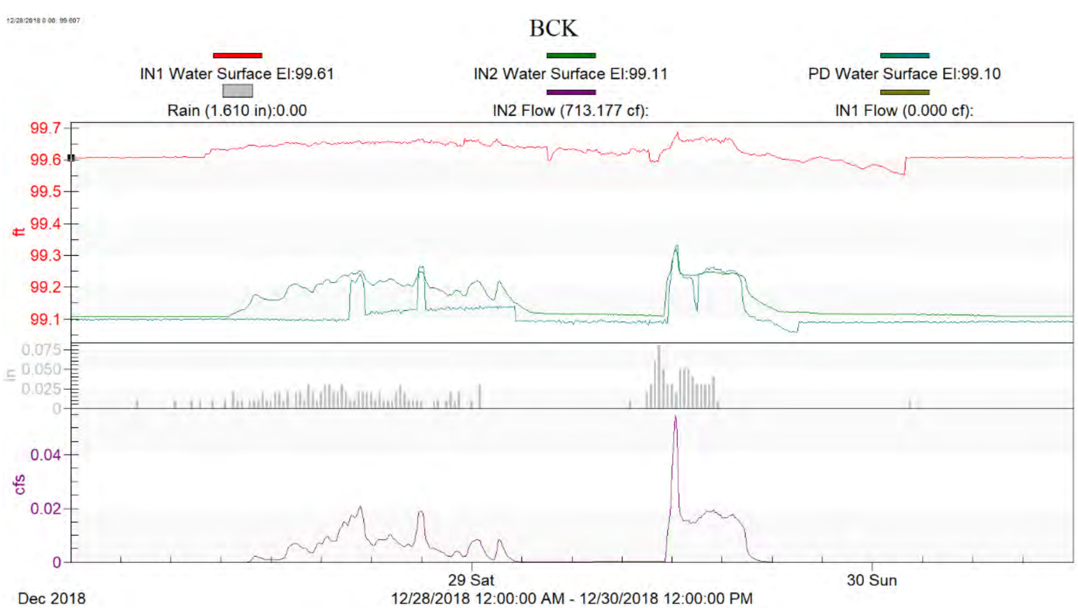

Figure 8. BCK Water Level Elevations and Flow

Discharge occurred throughout the study period due to the underdrain and the overall slope of the facility, which set the overflow elevation at ground level in the lowest portion of the bioretention cell.

Data and field observations from the ponding station at BCK indicate that the facility is filtering water effectively into the bioretention soil and only ponding during the most intense rainfall events. Most of the filtered water appears to be collected by the underdrain and discharged.

5.2 BUW

The monitoring equipment was installed at BUW on October 22, 2018, and removed on July 25, 2019, but BUW_IN2 did not start data collection until November 6, 2018, due to waiting for a Thel-Mar weir to arrive. Local site conditions proved challenging at this site and the monitoring system may have restricted flow into the facility. Field notes also indicate that the inlet weirs were frequently clogged with leaves, likely further reducing inflow.

During the infiltration testing on November 15, 2018, it was noted that when inflow rates exceeded about 40 gallons per minute (gpm), the inlet weirs caused water levels to back up into the roadside gutter and bypass the facility. The infiltration testing also indicated that once the inlet-weir restriction was removed the water entering the facility was relatively quickly infiltrated into the soil, collected by the underdrain, and discharged from the facility. Outside of the infiltration test, the outlet water levels are barely responsive to inflow and do not show any real inputs from the underdrain. This is further shown in the well point data, which shows shallow groundwater in the facility was not responsive to rainfall. The large difference in facility response during the infiltration test and the rest of the data collection period indicates that the inlets restrictions likely reduced inflow to the point of masking the true facility performance. BUW is a shallow facility and even with some excavation the inlet weirs were only just below the street gutter elevation and this, combined with leaf clogging, likely caused the observed data problems.

5.3 FWI

The monitoring equipment was installed at FWI on October 12, 2018, and removed on July 17, 2019. In general, the monitoring equipment performed well. Maintenance crews pushed snow into the facility and buried the inlet stations for an extended period in February. Freezing temperatures affected 9 percent of the FWI_IN1 data, 9.4 percent of the FWI _IN2 data, and roughly 15 percent of the FWI _PD data during the study period.

During the monitoring period, 25.73 inches of rain fell and produced a total inflow volume of 19,527 cubic feet, with FWI_IN1 producing 17,024 cubic feet and FWI _IN2 producing 2,503 cubic feet during the nonfreeze-affected periods. The rainfall-runoff relationship was relatively consistent and exceeded the modeled runoff for all events (Figure 9). This suggests that the actual contributing drainage area may be larger than the intended design.

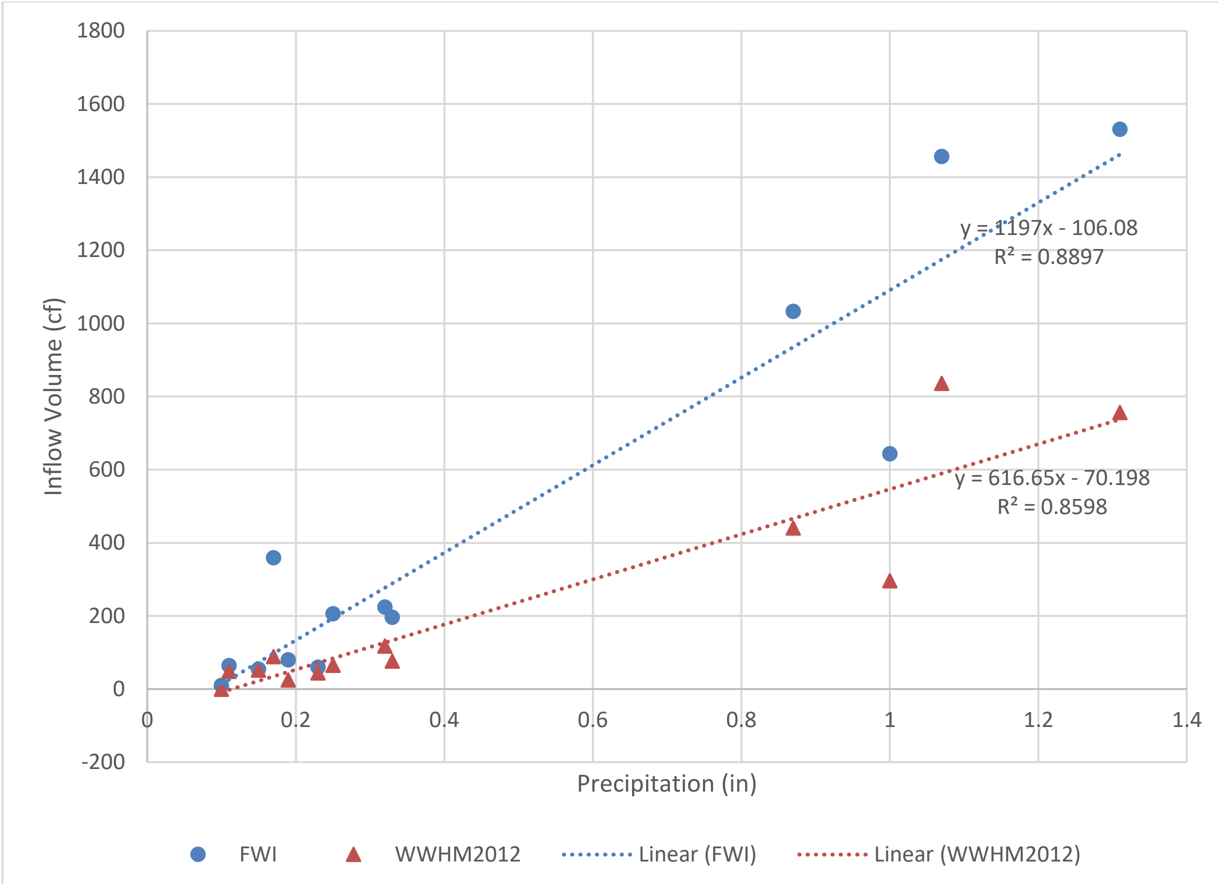

Figure 9. Rainfall-Runoff Relationship for FWI

Total outflow volume from the facility was 6,150 cubic feet. Ponding data from FWI_PD show that no overflows occurred during the study period, but the facility has an underdrain that allowed the facility to discharge. The FWI facility did have some brief surface ponding, but only during periods with active inflow. The ponding depth never exceeded 0.16 feet and ponded water quickly infiltrated into the soil after inflow ceased.

5.4 M1C

Monitoring equipment was installed at M1C on October 19, 2018, and removed on July 16, 2019. The monitoring equipment functioned well with only minor clogging in the inlet weir noted in the field sheets. Freezing temperatures affected 16.7 percent of the data at the inlet and 7.2 percent of the data at the ponding station.

During the monitoring period, 49.80 inches of rain fell and produced a total inflow volume of 18,700 cubic feet during the nonfreeze-affected periods. Figure 10 shows that the rainfall-runoff relationship for M1C was inconsistent and usually exceeded the modeled flow volumes. Rainfall recorded at the City of Marysville rain gauge shows a wide range of rainfall intensities including a March 11, 2019, event totaling more than 6 inches with sustained intensities exceeding 0.5 inches/hour. This rainfall variability between the facility and the city rain gauge may have contributed to the inconsistency of the rainfall-runoff relationship. It should be noted that the ponding depth at M1C never exceeded the overflow riser height and the facility did not discharge.

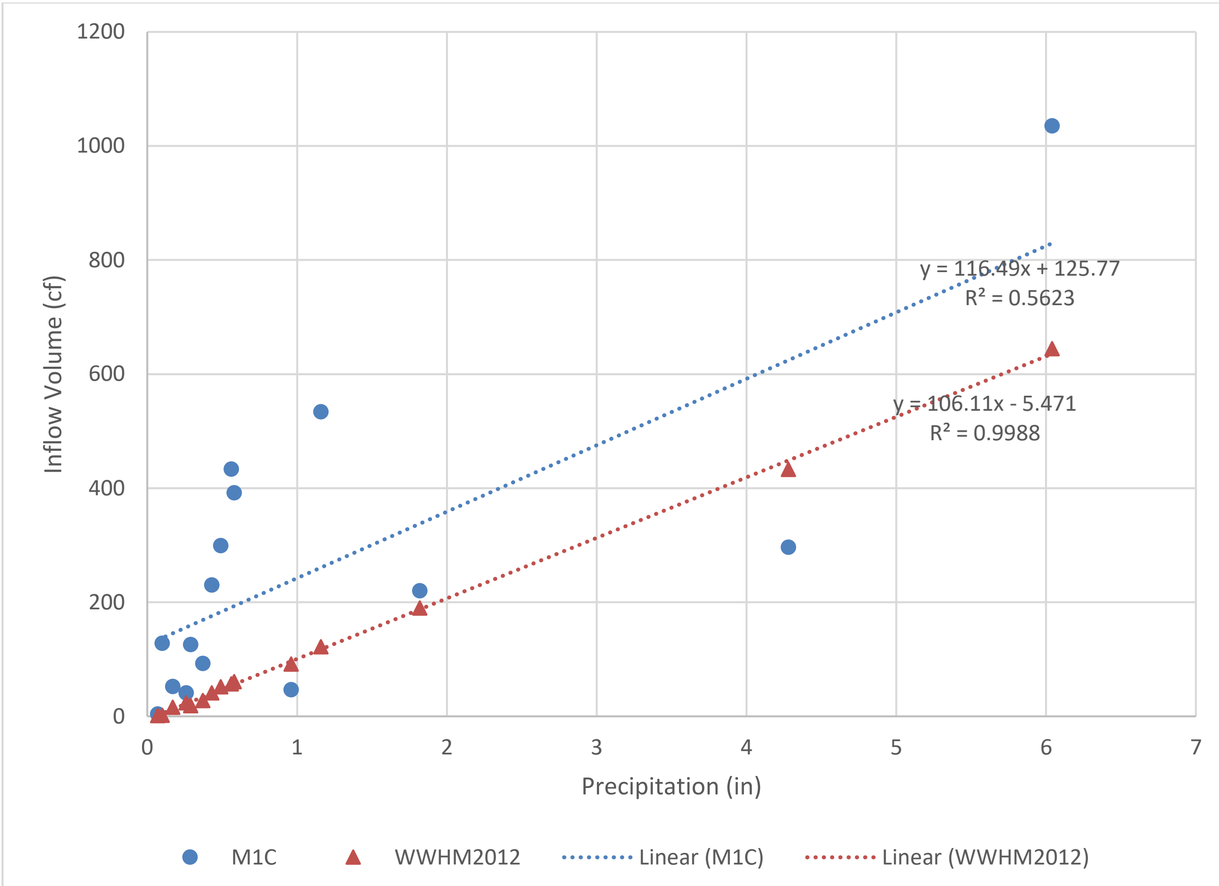

Figure 10. Rainfall-Runoff Relationship for M1C

5.5 M3Q

Monitoring equipment was installed at M3Q on October 19, 2018, and removed on July 16, 2019. The monitoring equipment functioned well throughout the study. The inlet pipe and weir were often noted as partially filled with sediment. A persistent upstream source of sand consistently flowed down the gutter and into the inlet (and facility). The sediment was not noted to exceed the weir notch, but did require cleaning during each maintenance visit. Freezing temperatures affected 10.5 percent of the inlet data and 8.2 percent of the ponding data during the study.

M3Q received 49.80 inches of rainfall over the study period with a total inflow volume was 27,400 cubic feet. Data from M3Q_PD and M3Q_OUT show that the site never discharged during the data collection period, even during some relatively large events.

M3Q used the same City of Marysville rain gauge as M1C and the rainfall runoff curve is even more inconsistent (Figure 11). The runoff volumes from the two largest rain events are particularly low and drag the rainfall-runoff relationship into a negative slope.

Ponding depths at M3Q_PD are also fairly minor during the larger events. This could indicate that the intense rainfall events were localized around M1C and the Marysville maintenance yard. but less representative of the M3Q area. It could also indicate that under higher runoff velocities during larger events cause flow in the gutters to bypass the inlet curb cut for M3Q.

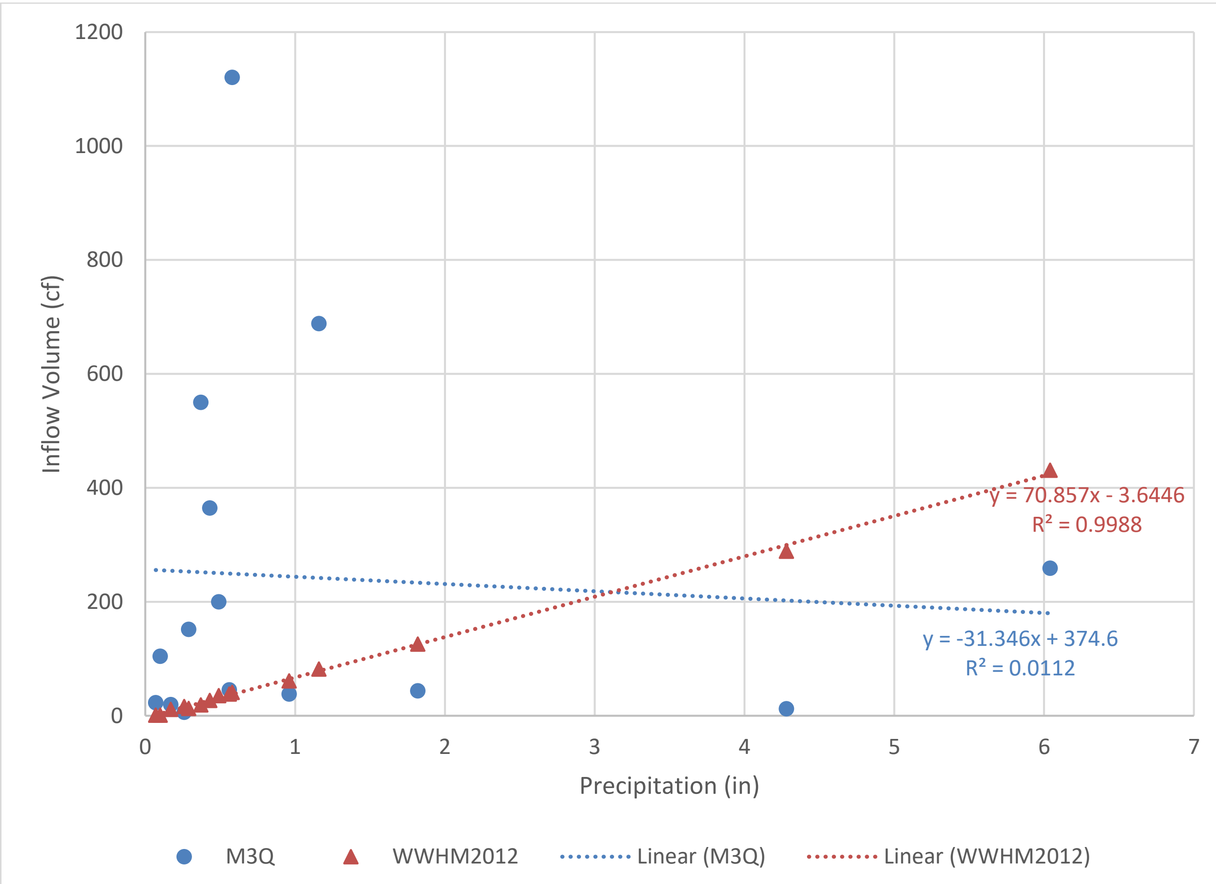

Figure 11. Rainfall-Runoff Relationship for M3Q

5.6 MPP

The monitoring equipment at MPP was installed on October 15, 2018, and removed on July 16, 2019. The monitoring equipment functioned well throughout the study period with only minor sediment accumulation noted during a couple of site visits. Freezing temperatures affected 9.7 percent of the inflow and 13.6 percent of the ponding measurements at MPP.

The measured rainfall at MPP_RN was 27.95 inches during the study period. This produced a measured inflow of 32,820 cubic feet. MPP does not have an overflow or outlet structure and never ponded to the point of submerging the inlet or flowing out into the adjacent football field. Data from MPP_PD indicate that the facility only ponded slightly during periods of active inflow and quickly infiltrated any ponded water once inflow ceased. Data from MPP_WP corroborate with the ponding data and show brief rises in subsurface water level during active inflow, but the level drops below the wellpoint level within hours of inflow ceasing. The April 11, 2019, rain event shows this typical pattern for the facility (Figure 12).

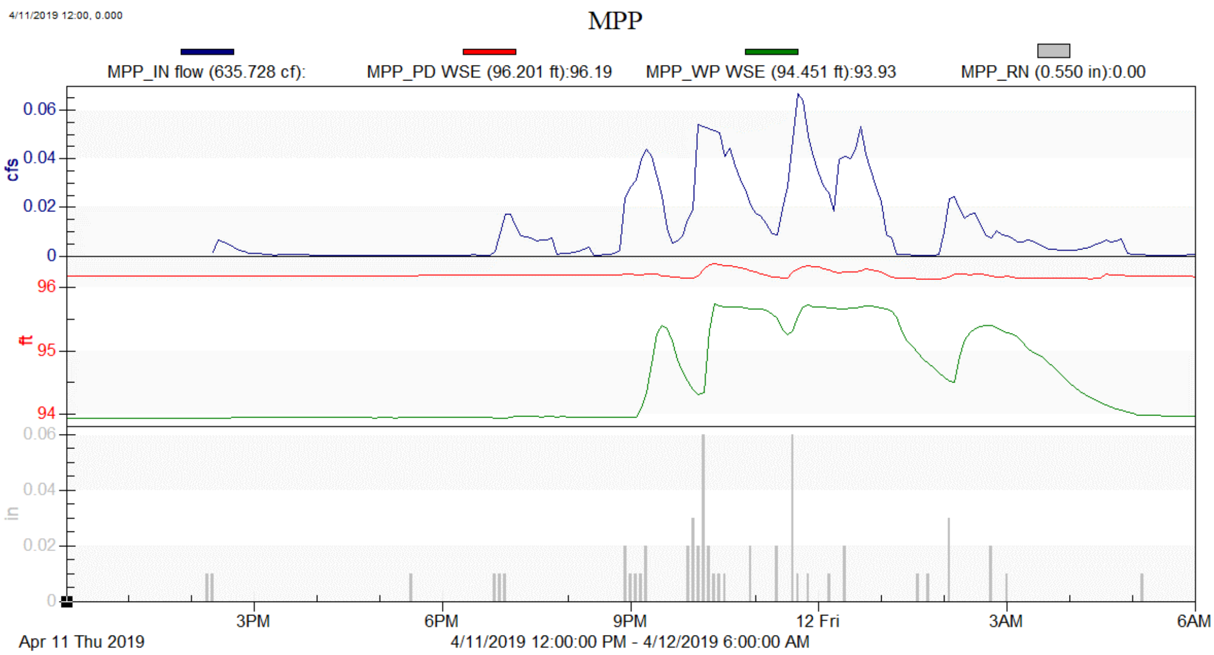

Figure 12. MPP Inflow, Ponding, and Groundwater from April 11, 2019

The rainfall-runoff relationship was somewhat variable at MPP, but trended pretty close to the modeled inflow overall (Figure 13).

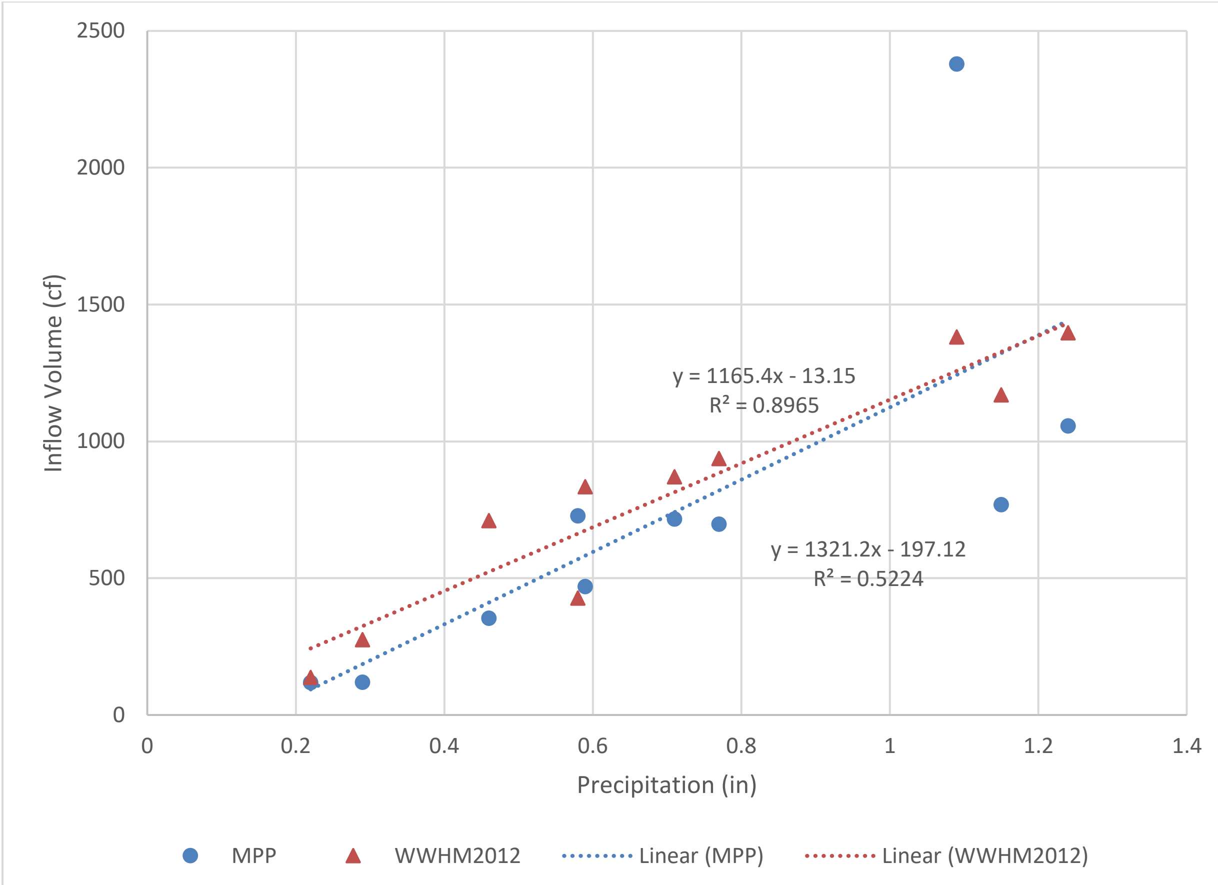

Figure 13. Rainfall-Runoff Relationship for MPP

5.7 RSH

The monitoring equipment at RSH was installed on October 10, 2018, and removed on July 16, 2019. The monitoring equipment functioned well, with some minor issues with leaf debris clogging the inlet weirs. Freezing temperatures affected 3.5 percent of the data at RSH_IN1 and 9.5 percent data at RSH_IN2. RSH_IN2 often drained faster than RSH_IN1, and the additional freeze-affected data are likely due to the sensor being exposed to ambient air more often. Freezing also affected 4.3 percent of the ponding data at RSH_PD.

The total rainfall during the monitoring period was 27.00 inches. The measured inflow at RSH_IN1 was 56,760 cubic feet and RSH_IN2 measured 13,884 cubic feet for a total inflow volume of 70, 644 cubic feet. Total discharge from the facility was 8,045 cubic feet. Discharge was a combination of ponding depth overtopping the overflow structure rim (4.1 percent of measured levels) and the underdrain riser pipe filling enough to discharge into the outlet structure (5.7 percent of measured levels). Shallow groundwater levels at RSH_WP appear to be limited by the elevation of the underdrain overflow pipe. As an example, the October 27, 2018, event (Figure 14) shows the shallow groundwater and underdrain water surface elevations rising rapidly as water flows into the facility, but topping out near the overflow point of the underdrain and never saturating fully up to the ground surface.

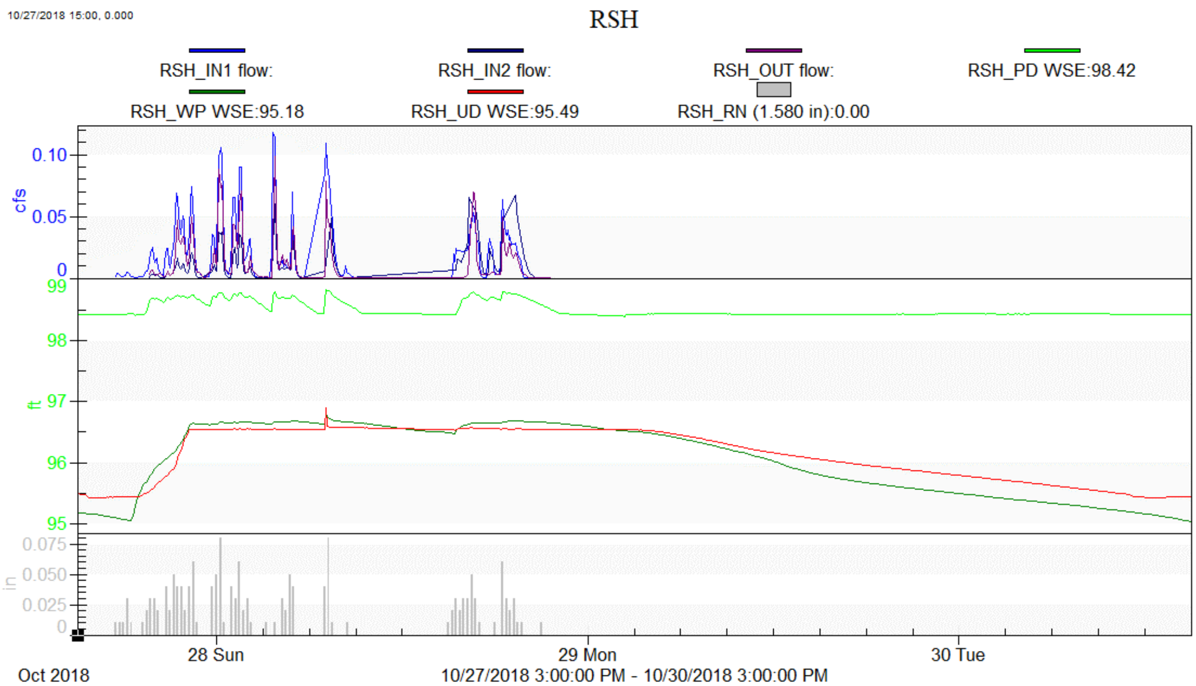

Figure 14. RSH Flow and Water Surface Elevations during October 27, 2018, Event

The rainfall-runoff relationship was inconsistent during the study period (Figure 15), but typically exceeds the modeled runoff.

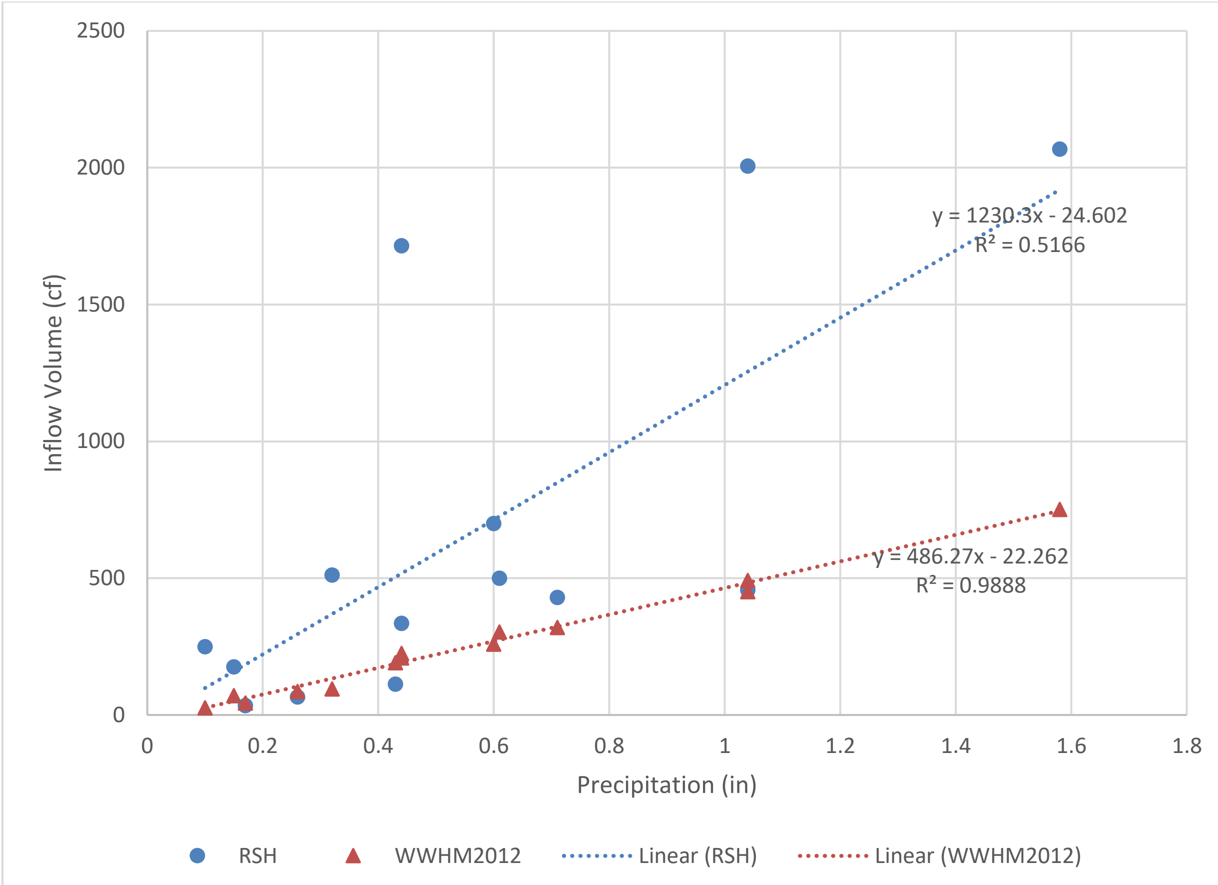

Figure 15. Rainfall-Runoff Relationship for RSH

5.8 SSW

The monitoring equipment at SSW was installed on October 17, 2018, and removed on July 16, 2019. The monitoring equipment functioned well during the study period; however, soon after the monitoring equipment was installed, a contractor placed a wattle across the curb cut at SSW_IN as a sediment treatment measure. This wattle caused water to flow around SSW_IN and spill into the facility at another point causing some erosion on the facility side slope (Figure 16). The wattle was installed during a rainfall event on November 1, 2018, and was still present during the November 20, 2018, maintenance visit. The exact date that the wattle was removed is not known, but it was no longer present during the December 21, 2018, site visit. Inflow data between November 1 and December 21, 2018, were not included in the rainfall-runoff analysis. Freezing temperatures affected 9 percent of the data collected at SSW_IN and 15.9 percent of the data collected at SSW_PD.

Figure 16. SSW_IN with Construction Wattle on November 6, 2018

The total rainfall during the monitoring period was 33.74 inches. The measured inflow at SSW_IN was 39,900 cubic feet. SSW does not have an underdrain and the ponding water level was never close to overflowing, and the facility did not discharge during the study. Data from SSW_PD show that ponding only occurred during active inflow and infiltrated quickly once inflow ceased.

The rainfall-runoff relationship at SSW was relatively consistent (Figure 17), which is likely due, in part, to the small drainage area and the on-site location of the rain gauge.

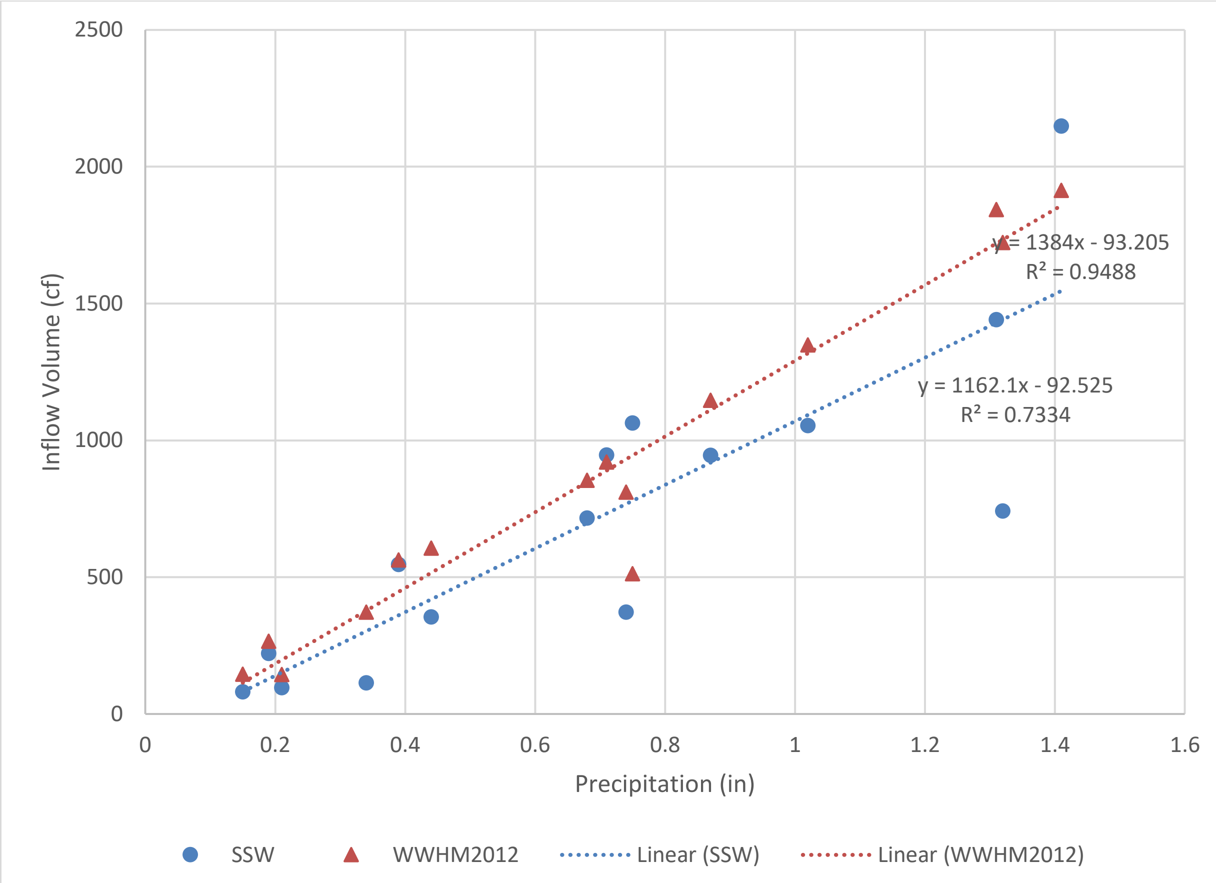

Figure 17. Rainfall-Runoff Relationship at SSW

5.9 TBM

The monitoring equipment at TBM was installed on October 10, 2018, and removed on July 17, 2019. The monitoring equipment performed well throughout the study. Field notes indicate that the pipe for TBM_IN often contained sand or leaves, but not to the point of clogging the weir. Field notes also indicate that TBM_IN was full of snow during the February 19, 2019, site visit (Figure 18). Overall, freezing temperatures affected 7.8 percent of the data collected at TBM_IN and 7.5 percent of the data collected at TBM_PD.

Figure 18. Snow Covering TBM_IN on February 19, 2019

The total rainfall during the monitoring period was 33.30 inches. The measured inflow at TBM_IN was 47,910 cubic feet. TBM does not have an overflow or outlet structure and never ponded to the point of submerging the inlet or flowing out into the adjacent field. Data from TBM_PD indicate that the facility only ponded slightly during periods of active inflow and quickly infiltrated any ponded water once inflow ceased. Data from TBM_WP2 corroborate with the ponding data and show brief rises in subsurface ponding during active inflow, but the level drops below the bottom of TBM_WP2 within hours of inflow ceasing. Data from TBM_WP1 shows that the deeper well is not generally affected by inflow into the facility. Figure 19 exemplifies these trends showing the rain event from January 18, 2019, and the water surface elevations of the ponding and well points .

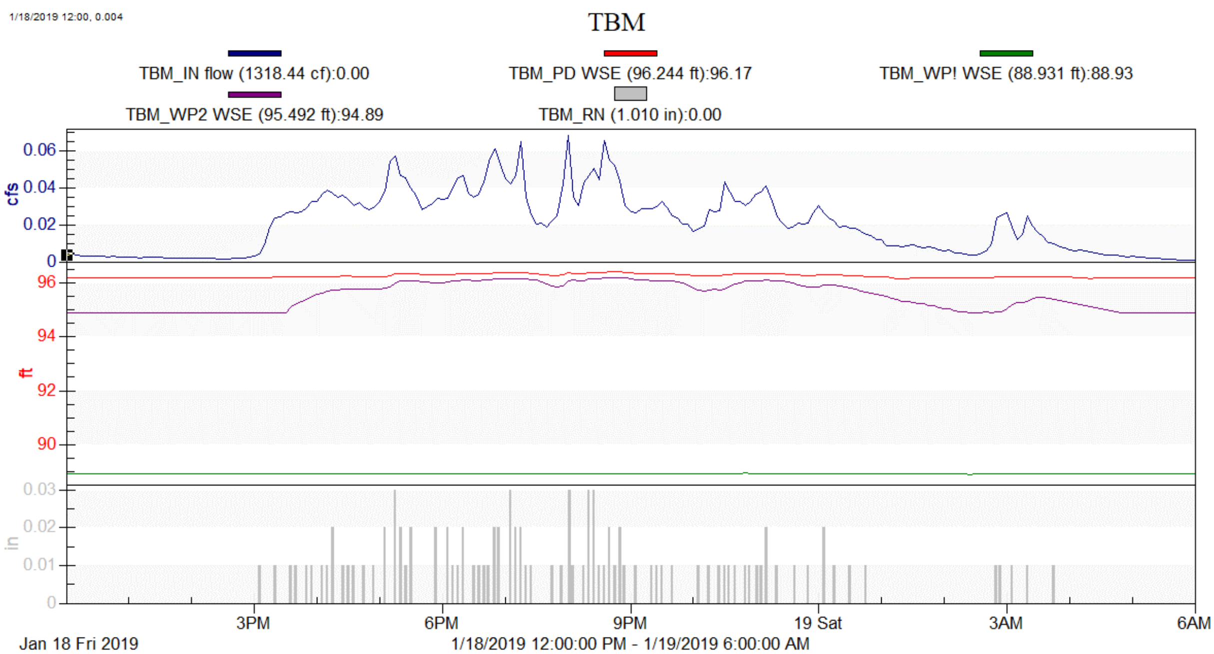

Figure 19. TBM Inflow, Rain, Ponding and Wellpoint water Surface Elevations for January 18, 2019, Rain Event

The rainfall-runoff relationship for TBM was fairly consistent and, overall, trended higher than the modeled inflow (Figure 20).

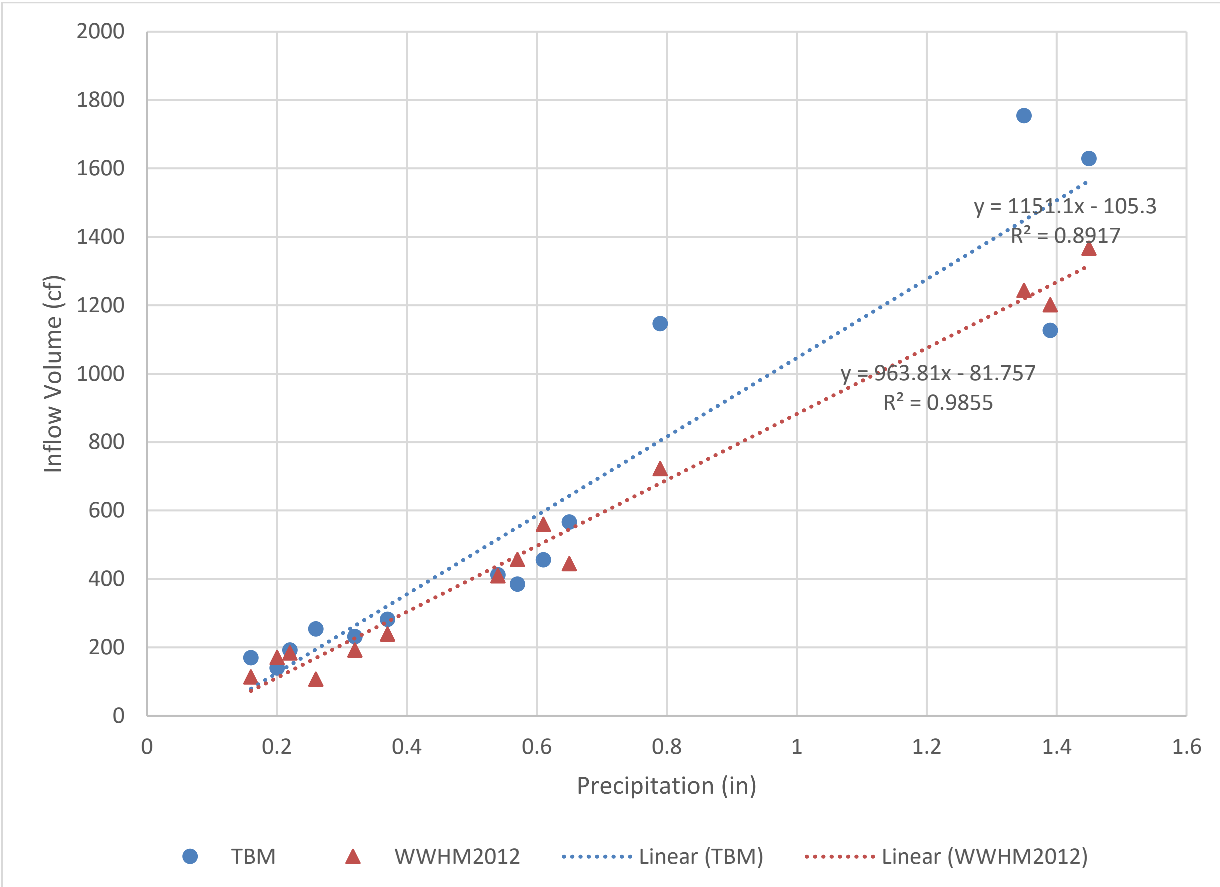

Figure 20. Rainfall-Runoff Relationship for TBM

5.10 TWH

The monitoring equipment at TWH was installed on October 12, 2018, and removed on July 17, 2019. The monitoring equipment functioned well overall, but both inlets were subject to inundation at times during intense events. This was evidenced by field notes that the Barologger "dry" wells were full of water during the November and December 2018 site visits. These wells were revised and, after the December 20, 2018, site visit, all inlet Barologger wells remained dry. Freezing temperatures affected 1.6 percent of the data collected at TWH_IN1 and 5.2 percent of the data from TWH_IN2. Freezing temperatures also affected 10.2 percent of the data at TWH_PD1 and 8 percent of the data from TWH_PD2.

The total rainfall during the monitoring period was 25.73 inches. The measured inflow at TWH_IN1 was 84,640 cubic feet and TWH_IN2 measured 52,310 cubic feet for a total inflow volume of 136,950 cubic feet. Total discharge from the facility was 83,350 cubic feet. Discharge was largely driven by underdrain flow, but the facility did overflow into the outflow structure during a few of the more intense events.

The rainfall-runoff relationship for TWH was consistent across a broad range of events and, overall, trended slightly lower than the modeled inflow (Figure 21).

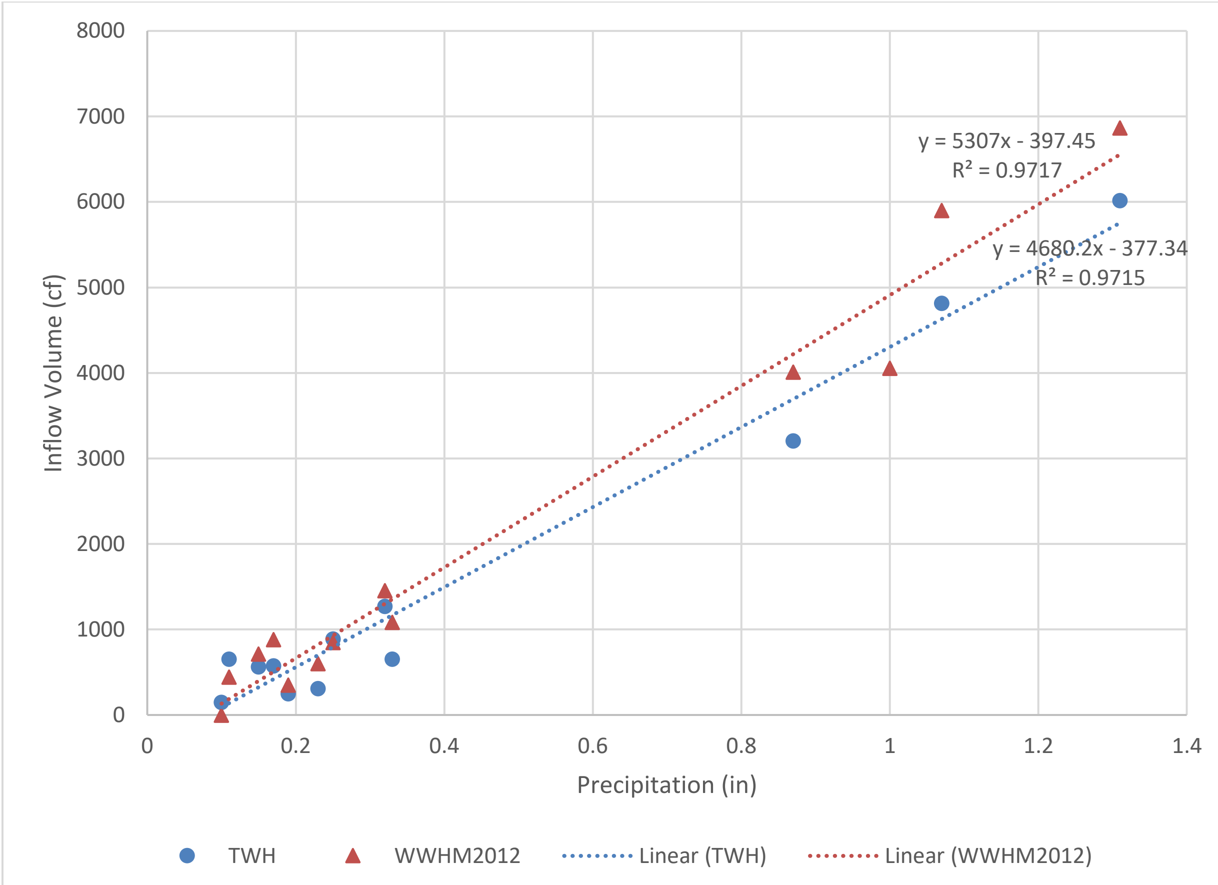

Figure 21. Rainfall-Runoff Relationship at TWH

References

Associated Earth Sciences, Inc. (AESI), 2019a, Deliverable Task 4.5, Site BCK, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Cornwall Avenue and Kentucky Street, Bellingham, Washington, June 11, 2019.

Associated Earth Sciences, Inc. (AESI), 2019b, Deliverable Task 4.5, Site BUW, Geotechnical/Soils Assessment Design Data and Current Conditions, Bellingham Utter Street and Washington Street, Bellingham, Washington, June 11, 2019.

Associated Earth Sciences, Inc. (AESI), 2019c, Deliverable Task 4.5, Site FWI Geotechnical/Soils Assessment Design Data and Current Conditions, Wainwright Intermediate School, Fircrest, Washington, June 11, 2019.

Associated Earth Sciences, Inc. (AESI), 2019d, Deliverable Task 4.5, Site M1C, Geotechnical/Soils Assessment Design Data and Current Conditions, 1st Street Low Impact Development Project, Marysville, Washington, June 14, 2019.

Associated Earth Sciences, Inc. (AESI), 2019e, Deliverable Task 4.5, Site M3Q, Geotechnical/Soils Assessment Design Data and Current Conditions, 3rd Street Low Impact Development, Marysville, Washington, June 14, 2020.

Associated Earth Sciences, Inc. (AESI), 2019f, Deliverable Task 4.5, Site MPP, Geotechnical/Soils Assessment Design Data and Current Conditions, Monroe Park Place Middle School, Monroe, Washington, June 14, 2020.

Associated Earth Sciences, Inc. (AESI), 2019g, Deliverable Task 4.5, Site RSH, Geotechnical/Soils Assessment Design Data and Current Conditions, Renton Sunset Community at Harrington Avenue NE, Renton, Washington, June 14, 2020.

Associated Earth Sciences, Inc. (AESI), 2019h, Deliverable Task 4.5, Site SSW, Geotechnical/Soils Assessment Design Data and Current Conditions, Salem Woods Elementary School, Snohomish County, Washington, June 14, 2020.

Associated Earth Sciences, Inc. (AESI), 2019i, Deliverable Task 4.5, Site TBM, Geotechnical/Soils Assessment Design Data and Current Conditions, George W. Bush Middle School, Tumwater, Washington, June 14, 2020.

Associated Earth Sciences, Inc. (AESI), 2019j, Deliverable Task 4.5, Site TWH, Geotechnical/Soils Assessment Design Data and Current Conditions, Wilson High School, Tacoma, Washington, June 11, 2019.

Taylor Aquatic Science and Clear Creek Solutions, Inc. (Taylor and Clear Creek), 2019, Quality Assurance Project Plan, Bioretention Hydrologic Performance Study II, Prepared for City of Olympia, April 2019. https://www.ezview.wa.gov/Portals/_1962/Documents/SAM/BHP_II%20D3-2%20Final%20QAPP.pdf

Limitations

Work for this project was performed for City of Olympia (City), and this memorandum was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

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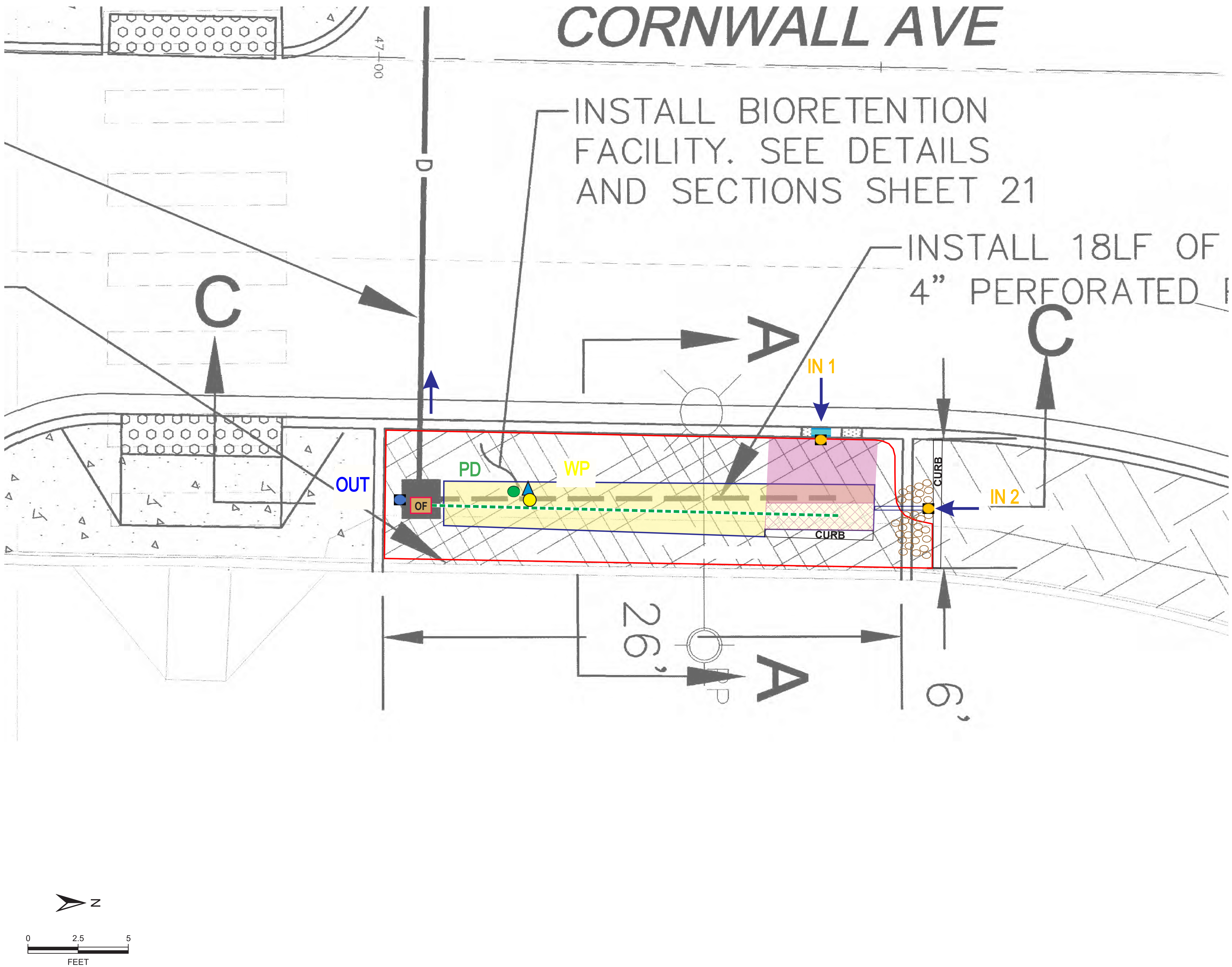
APPENDIX A

Bioretention Facility Maps and Monitoring Locations (by Associated Earth Sciences Incorporated [AESI])



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
OF	OVERFLOW GRATE - 24" X 18"
	PVC PONDING TUBE
	UNDERDRAIN
	CURB CUT
	CONCRETE SPLASH PAD
	COBBLES SET IN CONCRETE
	AREA OF BURIED ROCKS

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: CITY OF BELLINGHAM PUBLIC WORKS DEPT, ES-0512 NEVADA KENTUCKY BIKE BLVD, BIORETENTION FACILITIES PLAN, SHEET 21 OF 26, 5/2015

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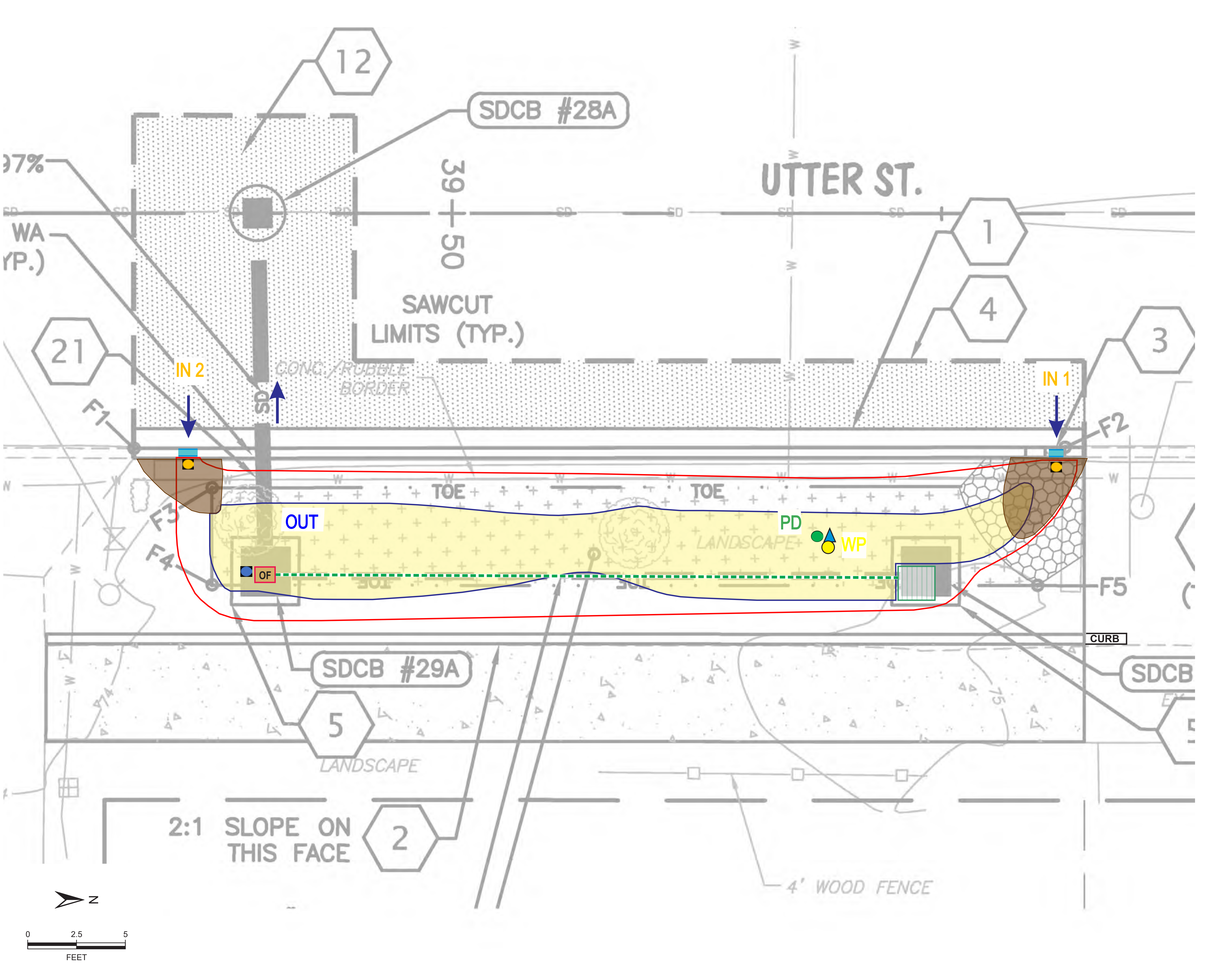
FACILITY AND EXPLORATION PLAN
BCK SITE
BIORETENTION HYDROLOGIC PERFORMANCE
BELLINGHAM, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BCK F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- ENERGY DISSIPATER
- UNDERDRAIN CLEANOUT

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:

1. BASE MAP REFERENCE: CITY OF BELLINGHAM PUBLIC WORKS DEPT, COLUMBIA WATER QUALITY IMPROVEMENTS, DRAINAGE IMPROVEMENTS, UTTER STREET 2, SHEET C16 OF C32, 10/30/17

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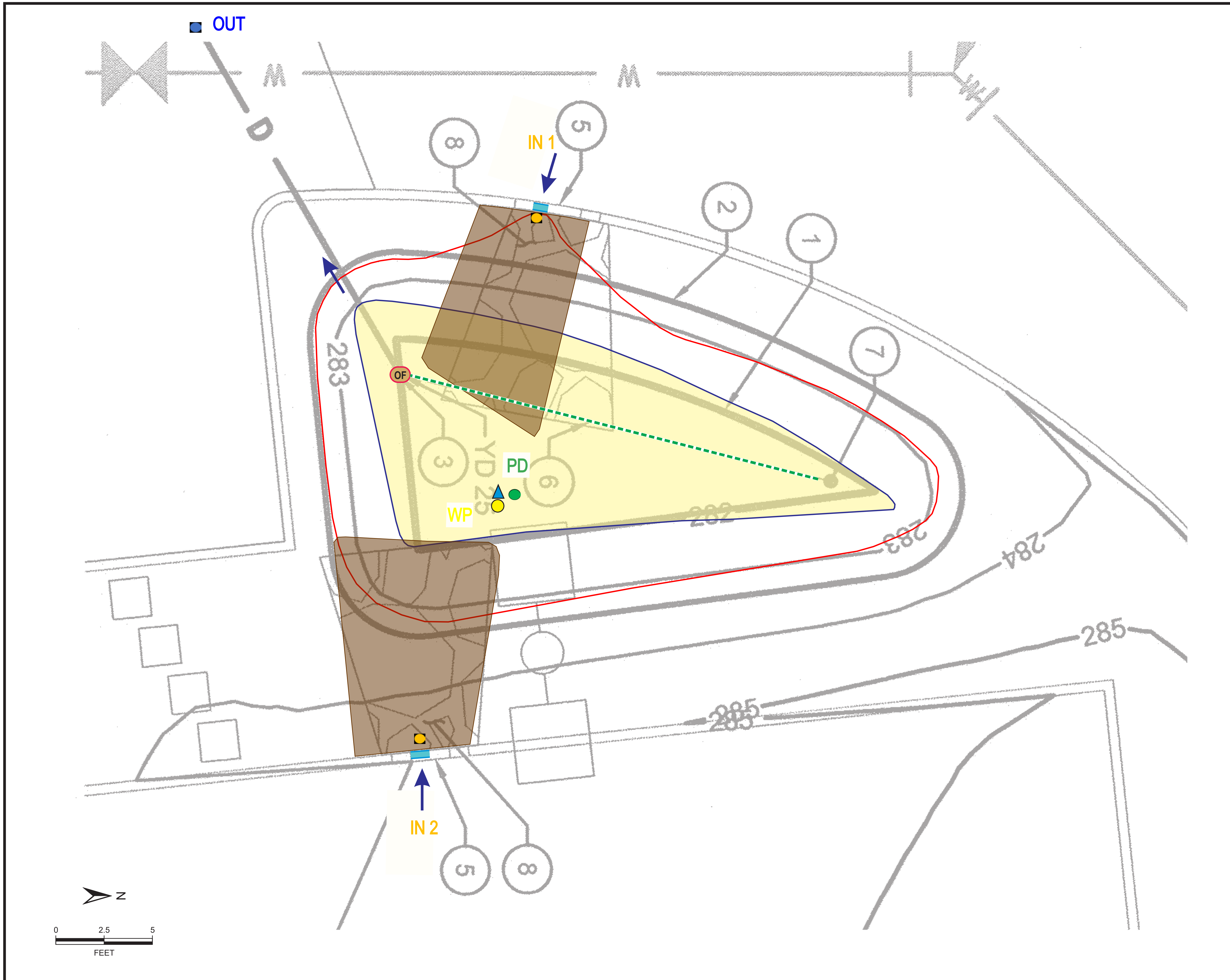
FACILITY AND EXPLORATION PLAN
BUW SITE
BIORETENTION HYDROLOGIC PERFORMANCE
BELLINGHAM, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	BUW F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: BUW F2



LEGEND:

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- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 12" PVC YARD DRAIN
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: AHBL, DLR GROUP, WAINWRIGHT INTERMEDIATE SCHOOL , TACOMA PUBLIC SCHOOLS, STORM DRAINAGE NOTES AND DETAILS, SHEET C4.3, 5/29/15

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

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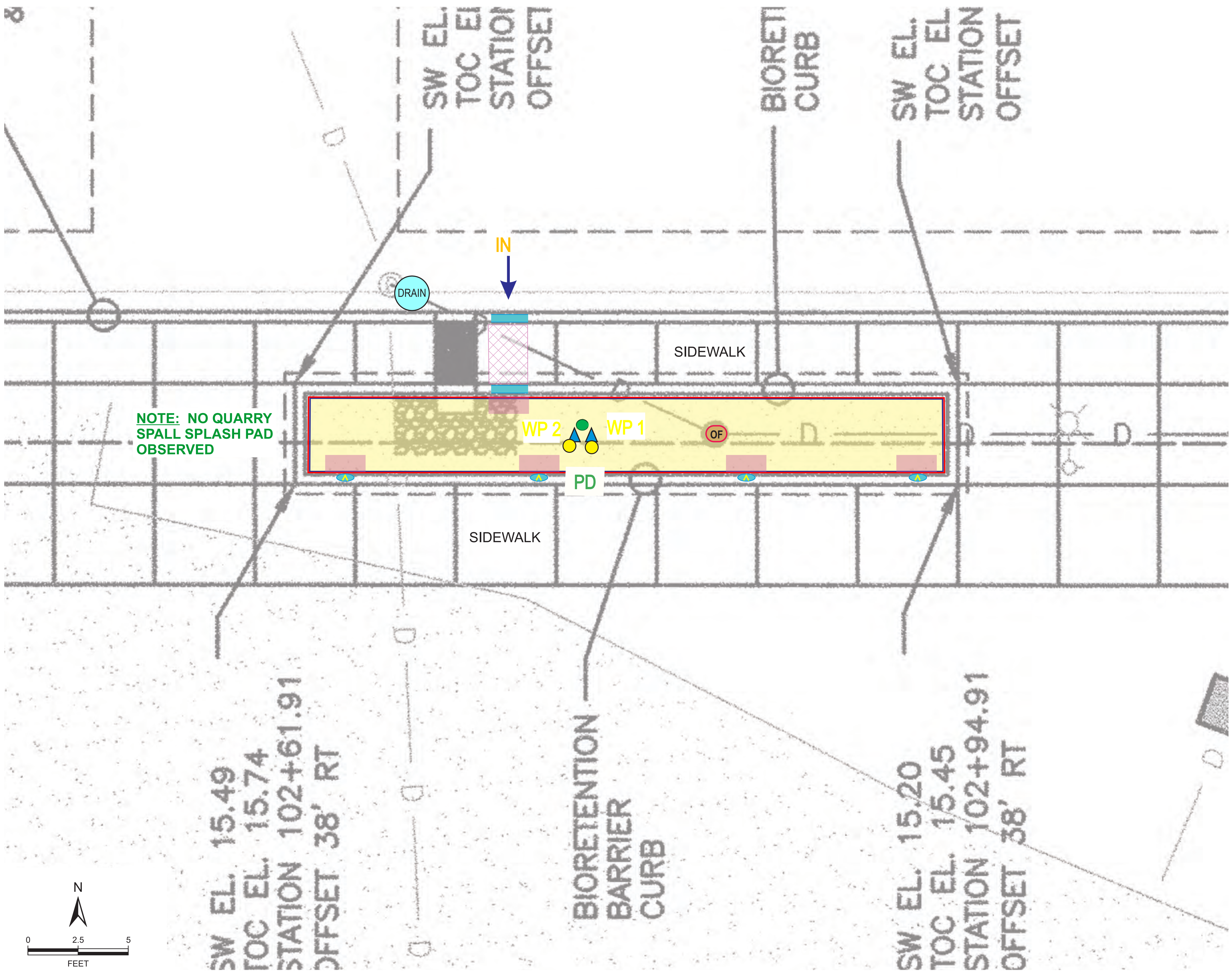
FACILITY AND EXPLORATION PLAN
FWI SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TACOMA, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	FWI F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: FWI F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW - 8" PVC
- PVC PONDING TUBE
- CURB CUT
- CONCRETE SPLASH PAD
- METAL GRATE
- SMALL CURB NOTCH

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: GRAY AND OSBORNE, INC., CITY OF MARYSVILLE, 1ST STREET LOW IMPACT DEVELOPMENT, BIORETENTION PLAN, SHEET 14 OF 25 6/19/17

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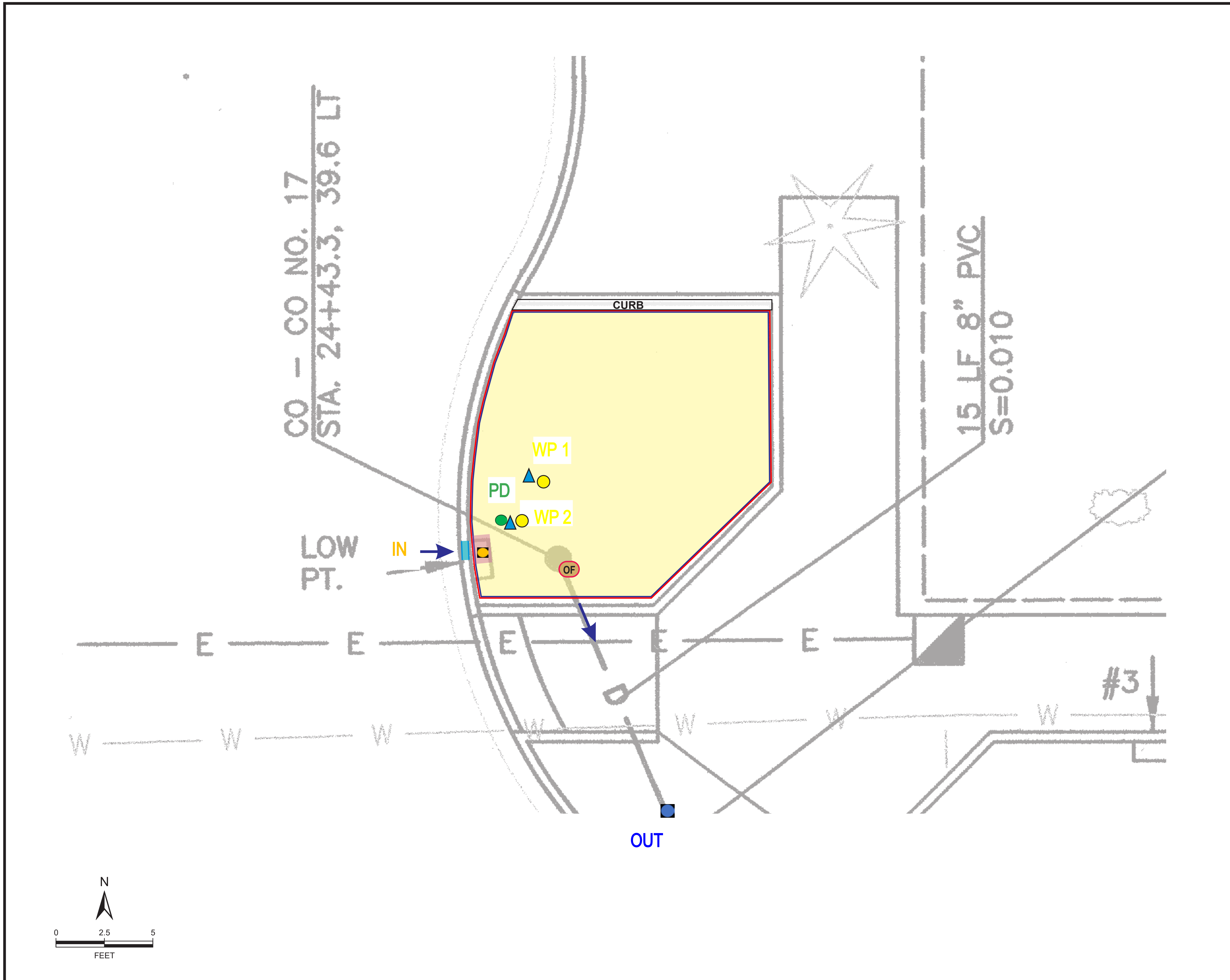
FACILITY AND EXPLORATION PLAN
M1C SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MARYSVILLE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M1C F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: M1C F2



LEGEND:

- HA — HAND AUGER
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- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW - 8" PVC
- PVC PONDING TUBE
- CURB CUT
- CONCRETE SPLASH PAD

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: GRAY AND OSBORNE, INC., CITY OF MARYSVILLE 3RD STREET LOW IMPACT DEVELOPMENT AND ROADWAY IMPROVEMENT PROJECT, STORMWATER PLAN AND PROFILE, SHEET 21 OF 68, 8/12/16

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

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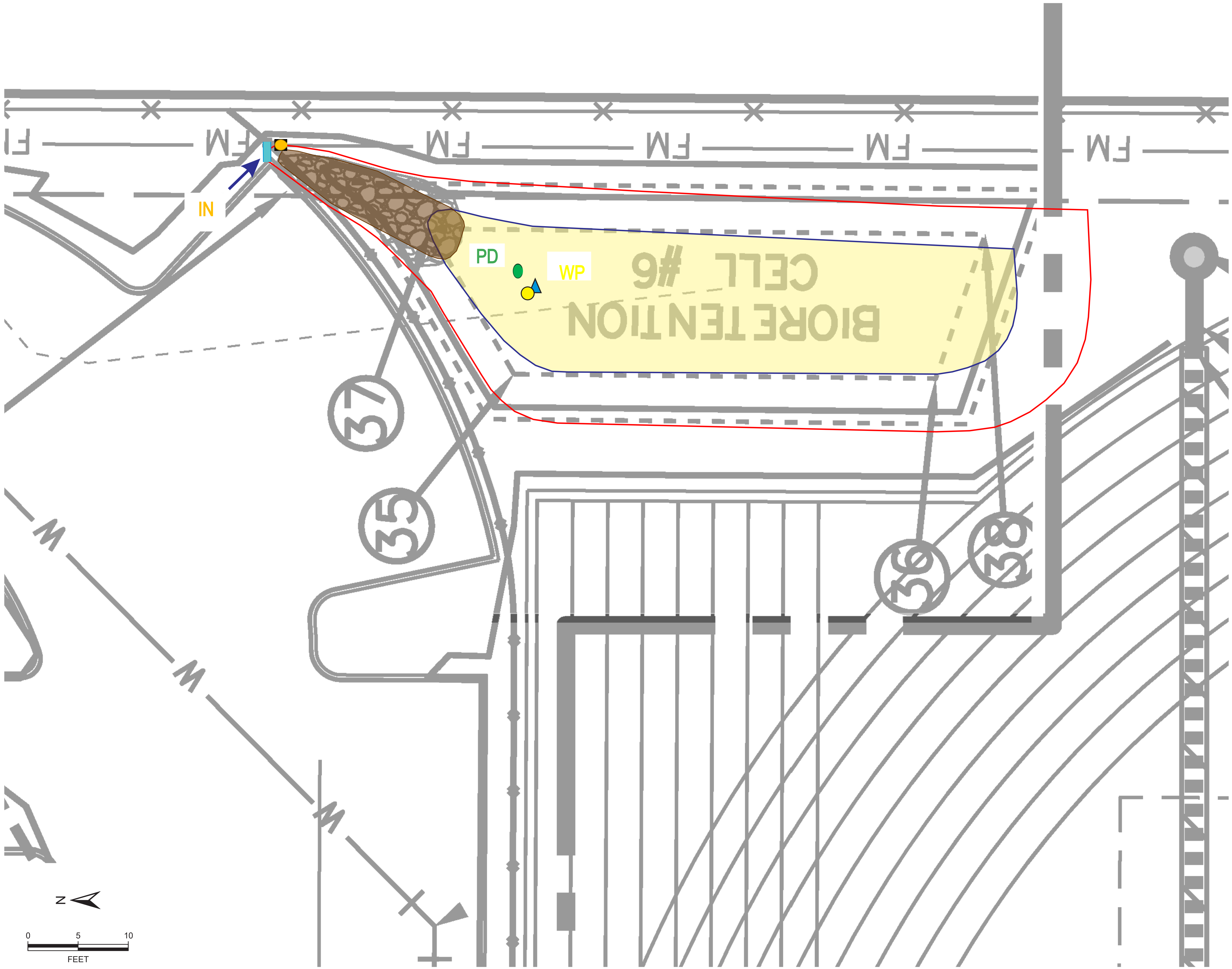
FACILITY AND EXPLORATION PLAN
M3Q SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MARYSVILLE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	M3Q F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: M3Q F2



LEGEND:

HA	HAND AUGER
WP	WELL POINT
	TEMPORARY STAFF GAUGE
	BASE OF FACILITY
	TOP OF FACILITY SLOPE
	INFLOW / OVERFLOW DIRECTION
	PVC PONDING TUBE
	CURB CUT
	ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: INTEGRUS ARCHITECTURE, MONROE SCHOOL DISTRICT, PARK PLACE MIDDLE SCHOOL, STORM DRAINAGE PLAN, SHEETS C300 AND C301, 6/6/16

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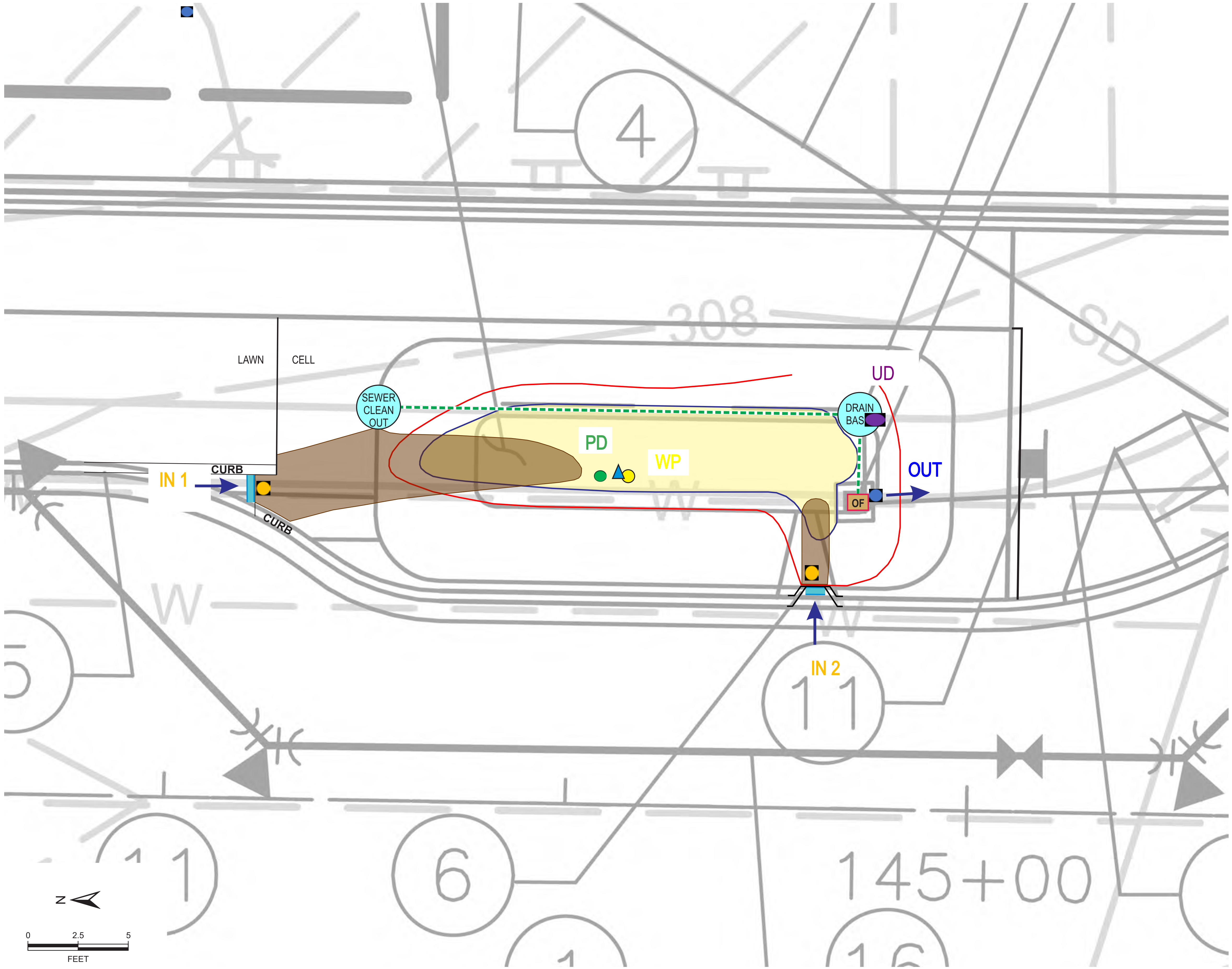
FACILITY AND EXPLORATION PLAN
MPP SITE
BIORETENTION HYDROLOGIC PERFORMANCE
MONROE, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	MPP F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- UNDERDRAIN
- CURB CUT
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: CH2MHILL, HARRINGTON AVENUE NE PHASE II SUNSET COMMUNITY GREEN CONNECTOR, DRW C-2, SHEET 6 OF 24, 5/5/17

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

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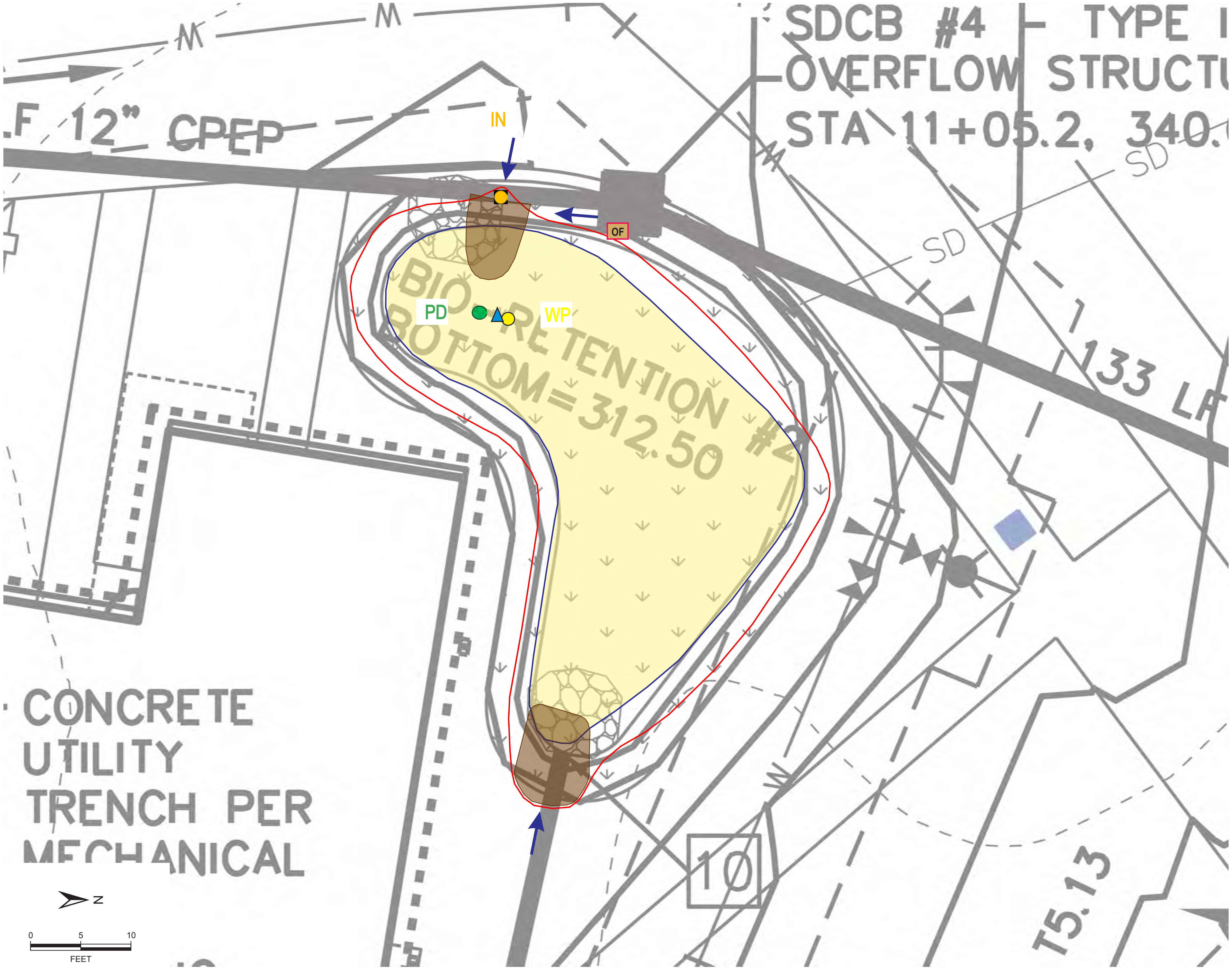
FACILITY AND EXPLORATION PLAN
RSH SITE
BIORETENTION HYDROLOGIC PERFORMANCE
RENTON, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	RSH F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: RSH F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: DLR GROUP, SALEM WOODS ELEMENTARY SCHOOL CONSTRUCTIONS DOCUMENTS, FULL DRAINAGE PLAN, SHEET C3.00, CONFORMED SET, 5/16/17

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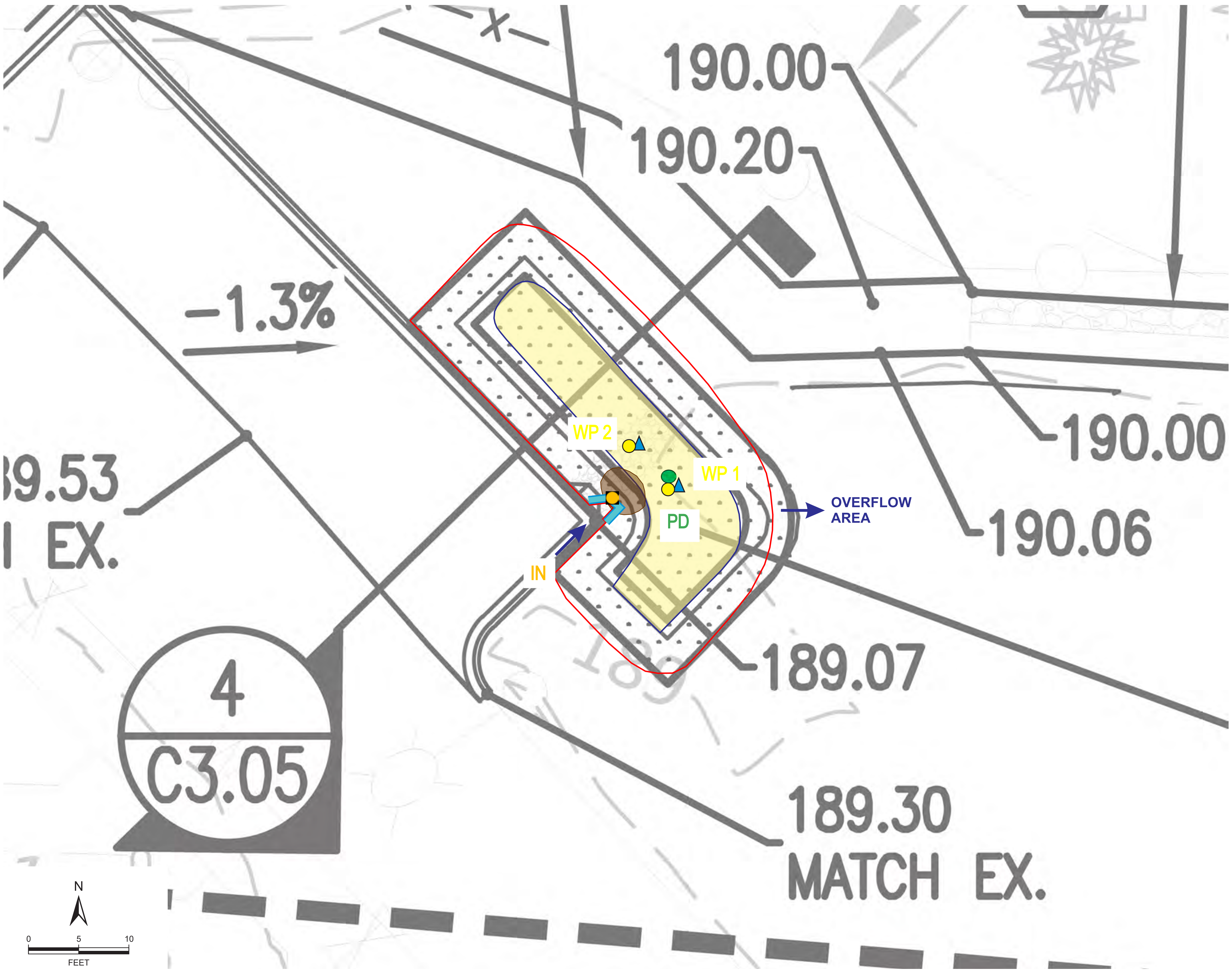
FACILITY AND EXPLORATION PLAN
SSW SITE
BIORETENTION HYDROLOGIC PERFORMANCE
SNOHOMISH COUNTY, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	SSW F2

150387 BHPS MCCA \ 150387H007 Site-Explr ALL.cdr PAGE x: SSW F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- PVC PONDING TUBE
- CURB CUT
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: BCRA, TUMWATER SCHOOL DISTRICT, GEORGE W. BUSH MIDDLE SCHOOL RENOVATION AND ADDITIONS, GRADING PLAN, SHEET C3.01, 12/29/07

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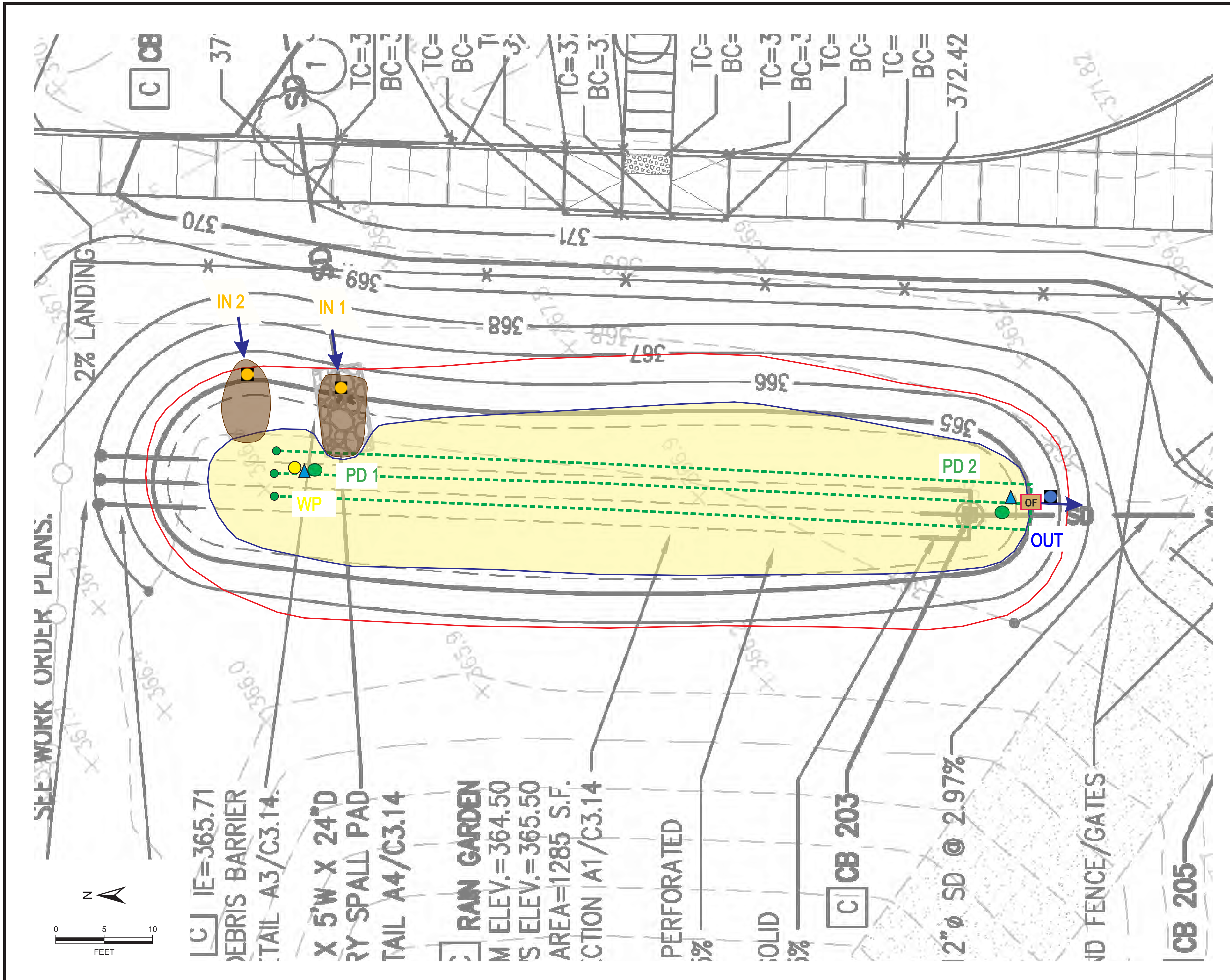
FACILITY AND EXPLORATION PLAN
TBM SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TUMWATER, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TBM F2

150387 BHPS MCCA \ 150387H007 Site-Expl ALL.cdr PAGE x: TBM F2



LEGEND:

- HA — HAND AUGER
- WP — WELL POINT
- TEMPORARY STAFF GAUGE
- BASE OF FACILITY
- TOP OF FACILITY SLOPE
- INFLOW / OVERFLOW DIRECTION
- OF — OVERFLOW GRATE - 24" X 18"
- PVC PONDING TUBE
- UNDERDRAIN
- STORM DRAIN CLEANOUT
- ENERGY DISSIPATER

CONTOUR INTERVAL = N/A

NOTE: LOCATION AND DISTANCES SHOWN ARE APPROXIMATE.

NOTES:
1. BASE MAP REFERENCE: SITTS AND HILL ENGINEERING, INC., TACOMA SCHOOL DISTRICT, WILSON HIGH SCHOOL, GRADING AND DRAINAGE PLAN, SHEET C3.1, 12/10/15

associated earth sciences incorporated

FACILITY AND EXPLORATION PLAN
TWH SITE
BIORETENTION HYDROLOGIC PERFORMANCE
TACOMA, WASHINGTON

PROJ NO.	DATE:	FIGURE:
150387H007	3/19	TWH F2

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APPENDIX 14

Olympia Bioretention Study - Vegetation Results Summary. Raedeke Associates, Inc. 8/21/2019

Raedeke Associates, Inc.

Wetland & Aquatic Sciences
Wildlife Ecology
Landscape Architecture

TECHNICAL MEMORANDUM

August 21, 2019

To:	Mr. Doug Beyerlein Clear Creek Solutions, Inc.
From	Anne Cline, PLA, Raedeke Associates, Inc. Chris Wright, BS, Raedeke Associates, Inc.
RE:	Olympia Bioretention Hydrologic Performance Study Vegetation Results Summary (RAI-2017-114)

A portion of the Olympia Bioretention Hydrologic Performance Study is to measure and describe the vegetation communities within each of the monitored bioretention cells. The purpose of describing the vegetation community composition and percent basal cover is to determine if specific vegetation types have an influence on the ability of the bioretention cell to perform hydrologic control functions.

The following memorandum describes the vegetation conditions observed at each of the monitored cells. Attached are individual tables for each monitored cell listing the vegetation species observed, their percent cover within the monitored area, and the number of individual stems of woody plants growing within the cells.

METHODS

Bioretention facility plant composition and density was 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 was sampled for vegetation.

1. For bioretention units that had only woody vegetation (shrubs and trees), the number of stems were 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 less than 50 centimeters above ground level (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 was made. Cover is the proportion of the ground obscured by a species's aboveground leaves and stems. The genus and species of the woody plants was recorded, as well as the wetland indicator status (WIS) of the species observed. WIS assignment to plant species is described below.

2. For bioretention units with only herbaceous plant species, a quadrat along pre-determined points along a transect line(s) was used to estimate percent basal vegetation cover. Basal cover is the proportion of the plant that extends into the soil. A 25 cm x 25 cm quadrat was used to record the percentage of herbaceous vegetation at ground level versus the percentage of bare ground that covers each quadrat. Species were identified to genus and species and note made of the wetland indicator status of the observed species. A minimum 25% of the unit was sampled.

3. For bioretetion units with woody and herbaceous species, both sampling methods were used. Stem density was counted for the woody species and quadrats were used to estimate coverage of herbaceous vegetation.

Wetland Indicator status (WIS)

Native Plants

Wetland Indicator Status (WIS) is a status (Reed 1998) used to designate a plant species' preference for occurrence in a wetland or in upland based on qualitative descriptions. The WIS for a given species will vary based upon region. Western Washington is in the Western Mountains, Valleys and Coast region. The WIS of plants within our region can be found on the USDA, Natural Conservation Service, Plants Database (USDA 2019a). Below are the categories and definitions for characterizing a plants preference for growing conditions:

OBL	Obligate Wetland	Hydrophyte	Almost always occur in wetlands
FACW	Facultative Wetland	Hydrophyte	Usually occur in wetlands, but may occur in non-wetlands
FAC	Facultative	Hydrophyte	Occur in wetlands and non-wetlands
FACU	Facultative Upland	Nonhydrophyte	Usually occur in non-wetlands, but may occur in wetlands
UPL	Obligate Upland	Nonhydrophyte	Almost never occur in wetlands

Ornamental Plants

The USDA assigns WIS to native plants and nonnative plants that occur frequently in the natural environment, such as Himalayan blackberry. In the bioretention cells, we found ornamental plant species, as well as native plants, had been installed. Since ornamental plants frequently do not have a WIS, we looked for an equivalent native plant, so we could assign the plant with a WIS where possible. For example, multiple varieties of red-twig dogwood (*Cornus alba, previously known as sericea*) were recorded in bioretention cells, varieties such as Kelsey's, or the variegated dogwood. Since these varieties do not have a WIS, we assigned the varieties the same WIS as the native red-twig dogwood (FACW).

RESULTS

Corner of Utter & Washington, Cell #5, Bellingham (Site BUW)

Vegetative cover was measured on May 16, 2019 at Bellingham Cell #5 located at the northwest corner of Utter Street and Washington Street in Bellingham. According to our field measurements, the bottom of this cell is approximately 88 square feet (sf). The cell was constructed in July of 2017. The cell contains both woody and herbaceous vegetation; therefore, both sampling methods were used to collect vegetation data. Cell #5 contains 33 woody plants and approximately 945 woody stems. Woody cover was estimated at 60%. Percent cover of herbaceous vegetation was estimated in 31 quadrats in the cell. Herbaceous species in the sampled area averaged 19% basal cover.

Woody vegetation within the cell was composed of 25 shiny-leaf spirea (*Spiraea betufolia var. lucida)* and 8 Kelsey's dwarf red-twig dogwood (*Cornus sericea 'Kelseyi;*). The planting plan specified 81 spirea and 29 dwarf red-twig dogwoods. However, installing the specified quantity of shrubs would put the shrubs at less than one foot on center. Plant spacing was not listed in the plant schedule. We assume the cell was smaller than originally planned. The stem count for the dogwood was estimated at 320 and the stem count for the spirea was estimated at 625. Spirea has a tentative WIS of FAC (Native Plants PNW 2019). The dwarf red-twig dog was assigned the same WIS as the native red-twig dogwood of FACW.

Per the approved plan, this cell was planted with thick-headed sedge (*Carex pachystachya*) (FAC), tufted hair grass (*Deschampsia caespitosa*) (FACW), golden and blue-eyed grass (*Sisyrinchium californicum*, *S. idahoense*) (FACW) Oregon iris (*Iris* *tenax*) (UPL), and common rush (*Juncus effusus)*(FACW). We recorded all the specified herbaceous species growing in the bottom of the cell. Hairy cat's ear *(Hypochaeris radicata)* (FACU) was the one species recorded in the quadrats that was not per plan, and most likely volunteered in the cell.

Common rush was the dominant herbaceous vegetation and occurred in 45.2% of the quadrats. Plants rated FACW occurred in 80.6% of the quadrats, and included common rush, golden and blue-eyed grass, and tufted hairgrass. Plants rated FAC occurred in 22.6% of the quadrats, and 16.1% of the quadrats contained plants that have a WIS rating of UPL.

This Bellingham cell is located on a native outwash soil. Natural Resource Conservation Service (USDA NRCS 2019b) mapped soils in the area as Urban Land. The native soil is considered well-draining, and the cell has an underdrain. An infiltration test was conducted by the geologists. The bioretention soil infiltrated at approximately 310 inches/hour. The subgrade infiltration was low, but most of the water is interpreted to leave through the underdrain. See the Geotechnical Soils Assessment prepared by AESI (2019) for more information on the soils and the infiltration tests.

Corner of Kentucky St. and Cornwall Ave., Site 2, Bellingham (Site BCK)

Vegetative cover was measured on May 16, 2019 at Site 2, located at the southeast corner of Kentucky Street and Cornwall Avenue in Bellingham. According to our measurements, the bottom or footprint of the cell totaled approximately 34 square feet, an additional 9 square feet of the cell is unvegetated where the inlet is located. This cell was constructed in August 2016. This cell contains only herbaceous vegetation in the bottom of the cell. Percent cover of herbaceous vegetation was estimated in 17 quadrats.

Per the approved plan, this cell was planted with slough sedge (*Carex obnupta*) (OBL) and blue elk spreading rush (*Juncus patens 'Blue Elk'*) (FACW). We recorded both the specified plants in addition to a few volunteers, such as oxeye daisy (*Leucanthemum vulgare*) (FACU) and similar weedy species.

Slough sedge is the only obligate plant growing in the cell and was recorded in 47% of the quadrats. The blue elk spreading rush occurred in 17.6% of the quadrats. Six of the quadrats contained plants that are FACU. All the FACU plants were volunteers within the cell, such as oxeye daisy and English plantain (*Plantago lanceolata*) (FACU). An upland plant, garden vetch (*Vicia sativa*) (UPL), also a volunteer, was found in two quadrats. Herbaceous species in the sampled area averaged 27% basal cover.

The Kentucky/ Cornwall cell is located on glaciomarine drift. The Natural Resource Conservation Service (USDA NRCS 2019b) maps the soils in the area of the cell as Urban Land. The cell has an underdrain surrounded by 16 inches of drain rock. The cell was designed to primarily discharge through the underdrain. An infiltration test was conducted by the geologists. The bioretention soil infiltrated at approximately 6.6 inches/hour. See the Geotechnical Soils Assessment prepared by AESI (2019) for more information on the soils and the infiltration tests.

3rd & Quinn, Marysville (Site M3Q)

Vegetative cover was measured on May 16, 2019 at the northeast corner of Quinn Avenue and 3rd Street in Marysville. This cell was constructed in the spring of 2018. According to our field measurements the cell bottom totaled approximately 162 square feet. The cell contains both woody and herbaceous vegetation; therefore, both sampling methods were used to collect vegetation data. This cell contains 7 woody plants and approximately 62 woody stems. Woody cover was estimated at 30%. Herbaceous vegetation was measured in 47 quadrats.

The planting plan for the cell at the corner of 3rd St. and Quinn Ave. is reflective of the woody plants that were present at the time of our survey. We recorded mid-winter fire red-twig dogwood (*Cornus sanguinea 'Midwinter fire'*)(FACW), yellow twig dogwood (*Cornus sericea 'Flaviramea')* (FACW), evergreen huckleberry (*Vaccinium ovatum*) (FACU), and a sweet bay magnolia (*Magnolia Virginiana*). Sweet bay magnolia is native to the east coast (FACW) and great plains (OBL). We counted 62 stems for seven woody plants.

The herbaceous vegetation recorded in the cell differed in quantities from the approved plan but most of the plant species specified on the planting plan were installed within the cell. Per the approved plan we observed slough sedge, Western swordfern (*Polystichum munitum*) (UPL), Japanese silver grass (*Miscanthus sinensis 'Morning light'*) (FAC), tufted hairgrass (*Deschampsia cespitosa*) (FACW), and sneezeweed (*Helenium 'Sahin's early flowerer*) (FACW). Common sneezeweed (*Helenium autumnale*) (FACW) is native to all but three states and tends to grow in wet areas. The plan specified approximately 100 golden variegated sweet flag (*Acorus granimeus*) (FACW) were to be installed in the footprint of the cell. We observed a few sweet flag plants and only one quadrat contained a sweet flag. Since this cell was installed recently, it is not likely that the sweet flag perished due to conditions, so we assume that is was not planted. We did not observe the seven cinnamon fern (*Osmundastrum cinnamomeum*) (FACW) or the crimson flag (*Hesperantha coccinea*) (FAC) specified on the plans. Oregon iris (UPL) was noted in the cell and is not on the plan.

Slough sedge, the only OBL plant within the cell occurred in 34% of the quadrats. Plants rated as FACW occurred in 23% of the quadrats, FAC plants occurred in 10% of the quadrats and 15% contained upland (UPL) plants. Herbaceous species in the sampled area averaged 21% basal cover.

The 3rd and Quinn cell is located on an outwash soil. The Natural Resource Conservation Service (USDA NRCS 2019b) maps the soils in the area of the cell as Ragnar fine sandy loam. The soil is considered well-draining. The cell does not have an underdrain and relies on 100% infiltration. An infiltration test was conducted by the geologists. The subgrade infiltrates at approximately 15 inches/ hour and the bioretention soil mix infiltrates more rapidly than 15 inches/ hour. (AESI 2019).

Marysville 1st Street LID, Cell S-1 (Site M1C)

Vegetative cover was measured on May 16, 2019 on 1st Street in Cell S-1 located in Marysville. This cell is the third cell from the west. It was installed in the spring of 2018. According to our field measurements, the bottom of this cell totals approximately 133 square feet. The cell contains both woody and herbaceous vegetation; therefore, both sampling methods were used to collect vegetation data. Cell S1 contains ten Kelsey's red-twig dogwood, and an estimated 300 stems (approximately 30 stems per shrub). Woody cover was estimated at 30%. Herbaceous vegetation in the cell was recorded within 33 quadrats.

The shrubs were installed per plan.

Per plan, the cell was planted with evercolor everillo sedge (*Carex oshimensis* Everillo) (FAC), Jakob Cline's bee balm (*Monarda didyma* 'Jakob Cline') (FAC), and Japanese iris (*Iris ensata*) (FAC). Ornamental sedges, such as evercolor everillo, prefer moist, well drained soils. The Japanese Iris was also assigned a WIS of FAC. According to the Missouri Botanical Garden website, the plants will grow in standing water and require constant moist soils, however, are intolerant of standing water in the winter, which may cause the rhizomes to rot.

Plants with a WIS of FAC occurred in 100% of the quadrats. One quadrat contained a willow herb (*Epilobium ciliatum*) (FACW). Herbaceous species in the sampled area averaged 24% basal cover.

The 1st Street cell is located on a native outwash soil. Natural Resource Conservation Service (USDA NRCS 2019b) mapped soils in the area as Ragnar fine sandy loam. The soil is considered well-draining. The cell does not have an underdrain and relies only on infiltration. An infiltration test was conducted by the geologists. The subgrade infiltrates at approximately 17 inches/ hour and the bioretention soil mix infiltrates more quickly rapidly than 17 inches/ hour. (AESI 2019).

Salem Woods Middle School, Cell 2, Monroe (Site SSW)

Vegetative cover was measured on May 16, 2019 at Salem Woods Middle School Cell #2. According to our field measurements, the bottom of Cell 2 totaled approximately 1,638 square feet. This cell was constructed in November 2018. The cell contains primarily herbaceous vegetation, except eight Kelsey's red-twig dogwoods installed around the inlets. Both sampling methods were used to collect vegetation data. Cell 2 contains eight woody plants and approximately 240 woody stems. Woody cover was estimated at 2.0%. Herbaceous vegetation in the cell was recorded within 192 quadrats.

Per plan, Kelsey's red-twig dogwood were installed around inlets of the bioretention cell. The cell was designed to have 11 salmonberry (*Rubus spectabilis*) (FAC) shrubs installed in the footprint. We did not observe salmonberry shrubs growing within the cell.

Herbaceous vegetation in Cell 2 consisted of slough sedge, small fruited bulrush (*Scirpus microcarpus*) (OBL), tapered bulrush (*Juncus acuminatus*) (OBL), iris tenax (UPL), and common spike rush (*Eleocharis palustris*) (OBL). The plan also includes hardstem bulrush (*Scirpus acutus*) (OBL), but we did not observe any growing in the bottom of the cell. Per the plan, slough sedge was to comprise 40% of the installed plants, while the five other herbaceous plants made up the remaining 60% of the plants. Slough sedge was only recorded in 12 quadrats and the other plants were recorded in greater quantities, so the plants do not appear to be installed in the specified quantities.

Within this bioretention cell 97.3% of the sampled area contained OBL plants, and 12.6% contained upland plants. Oregon iris and garden vetch comprised the upland plants. Herbaceous species in the sampled area averaged 6.0% basal cover.

The Salem Woods cell is located on a native outwash soil. USDA NRCS (2019b) mapped soils in the area as Tokul and Tokul Wiston gravelly loams. The native soil is considered well-draining. The cell does not have an underdrain and relies only on infiltration. An infiltration test was conducted by the geologists. Water accumulated on the underlying subgrade. The biorention soil mix infiltrated at a field rate of 16 inches per hour (AESI 2019).

This cell is irrigated and mulched with a large shredded wood mulch.

Park Place Middle School, Monroe (Site MPP)

Vegetative cover was measured on May 16, 2019 in Cell #6 adjacent to the football field at Park Place Middle School. According to our field measurements, the bottom of this cell totaled approximately 336 square feet. This cell was constructed in the summer of 2017. The cell contains both woody and herbaceous vegetation; therefore, both sampling methods were used to collect vegetation data. The cell contains 14 woody plants and 14 woody stems. Overall woody cover was estimated at 5%. Herbaceous vegetation in the cell was recorded within 80 quadrats.

The plan specifies twenty salmonberry for installation in the bottom of the cell near the inlet. We counted twelve salmonberry and two red alder (*Alnus rubra*) (FAC) saplings within the bottom of the cell.

The planting plan and plant densities for herbaceous species at Park Place is the same as the Salem Woods School described above. This cell is approximately a year older than the Salem Woods cell. We did not record bulrush, iris tenax, or common spike rush growing in the bottom of the cell. Several plant species had volunteered in the cell including willow herb, hairy cats' ear, and garden vetch. We recorded OBL plants in 69% of the quadrats. All OBL plants were installed in the cell. Based on the results for Salem Woods where 97% of the quadrats contained installed plant material, approximately 25% of the installed plants have died within this cell, if it was installed per plan. The "weedy" plants comprised the other wetland indicator statuses. Plants rated as FACW (willow herb) were observed in 13.8% of the cells, plants rated as FACU occurred in 3.8% of the quadrats, and UPL species were counted in 8.8% of the cells. Herbaceous species in the sampled area averaged 9.2% basal cover.

The Park Place cell is located on a native alluvium soil. Natural Resource Conservation Service (USDA NRCS 2019b) mapped soils in the area as Sultan silt loam. The native soil is considered well-draining. The cell does not have an underdrain and relies only on infiltration. An infiltration test was conducted by the geologists. The subgrade infiltrates at approximately 3 inches/ hour and the bioretention soil mix infiltrates more quickly rapidly than 3 inches/ hour. (AESI 2019).

This cell is irrigated and is mulched with a large shredded wood mulch.

Wilson High School, Tacoma (Site TWH)

Vegetative cover was measured on May 30, 2019 at Wilson High School in a large bioretention cell located between a storm water pond and a parking lot in the vicinity of the sports fields. According to our field measurements, the bottom of this cell totaled approximately 1,260 square feet. This cell was constructed sometime between June 2016 and May 2017. The cell contains only herbaceous vegetation. Herbaceous vegetation in the cell was recorded with 222 quadrats.

We were unable to obtain a planting plan for this cell. Based on our observation of what was present in the cell, we assume the cell was planted with slough sedge (OBL), common rush (FACW), and tapered rush (*Juncus acuminatus*) (OBL). We observed many dead and drought-stressed slough sedge at the south end of the cell. Much of the herbaceous vegetation was comprised of plants that would be considered weeds, such as prickly sow thistle (*Sonchus asper*) (FACU), perennial ryegrass (*Lolium perenne*) (FAC), hairy cat's ear (FACU), and several other weedy plant species. Plants with a status of OBL occurred in 43% of the quadrats. The most common within the OBL plants was the slough sedge. The installed common rush, volunteer willow herb, reed canarygrass (*Phalaris arundinacea*), and field mint (*Mentha arvensis*), all FACW plants, occurred in 9.0% of the cells. The remaining plants, which we assume are volunteers, have a WIS of FAC or drier. Plants with a WIS of FAC occurred in 55% of the quadrats. Plants with a WIS of FACU occurred in 32% of the quadrats, and upland plants occurred in 6.0% of the quadrats. Herbaceous species in the sampled area averaged 17% basal cover. The installed herbaceous plants averaged 19% basal cover, while the volunteer plants only average 6.8% cover. The installed plants provide greater basal cover, and probably root mass, than the volunteer plants.

This cell is located on a Vashon Lodgment till. The Natural Resource Conservation Service (USDA NRCS 2019b) does not have data for soil in this area. This cell has three underdrains. When doing the infiltration test, the geologists were unable to get the entire footprint of the cell wetted. The cell drains through the underdrains prior to the cell filling with water, and the bioretention soil mix infiltrates at 11 to 25 inches/ hour (AESI 2019). The hydrology in the cell explains why much of the assumed installed vegetation is dead, and weedy plants that prefer growing in uplands are growing in the bottom of the cell.

This cell is not irrigated. This cell is probably not maintained since it is not located in an area that is highly visible.

Bush Middle School, Tumwater (Site TBM)

Vegetative cover was measured on May 30, 2019 at Bush Middle School in a cell located in the back of the building adjacent to a small parking area. This cell was constructed in the summer of 2016 based on a review of aerial photography (Google Earth 2019). According to our field measurements, the bottom of this cell totaled approximately 110 square feet. The cell contains both woody and herbaceous vegetation; therefore, both sampling methods were used to collect vegetation data. The cell contains 9 woody plants and stems. Overall woody cover was estimated at 15%. Herbaceous vegetation was recorded in 64 quadrats.

We counted four dwarf arctic willow (*Salix purpurea 'nana'*) (FACW), and five dogwood shrubs. Per the as-built plans, four willows, thirteen red-twig dogwoods, and 13 yellow-twig dogwoods (*Cornus sericea 'flavireamea'*) (FACW) were installed. The dogwoods were very small, and it appears the shrubs are browsed heavily by deer. We did not observe any deer on site, but deer are known to eat dogwood shrubs.

According to the planting plan, seven slender rush (*Juncus tenuis*) were supposed to be installed in the cell. However, we identified the rush as common rush. Much of the herbaceous vegetation was comprised of plants that would be considered weeds, such as

mare's tale (*Conyza canadensis*) (UPL), spiny sowthistle (FACU), Kentucky bluegrass (*Poa pratensis*) (FAC), along with other common garden weeds. Plants rated as FACW occurred in 37.5% of the quadrats, this accounts for the installed rush and volunteer willow herb. Plants rated as FAC, primarily Kentucky bluegrass, occurred in 25% of the quadrats. Plants rated as FACU occurred in 100% of the quadrats, and UPL plants, primarily mare's tale, occurred in 33% of the quadrats. No plants rated as OBL were recorded in this cell. Herbaceous species in the sampled area averaged 14.5% basal cover. The installed herbaceous plants averaged 24% basal cover, and the volunteer plants averaged 10.2% cover. Volunteer plants have a greater density overall in the cell, but on a plant by plant basis provide less basal cover than the installed species.

The Bush Middle School cell is located on a native outwash soil. Natural Resource Conservation Service (USDA NRCS 2019b) mapped soils in the area as Cagey loamy sand. The native soil is considered well-draining. The cell does not have an underdrain and relies only on infiltration. An infiltration test was conducted by the geologists. The subgrade infiltrates at approximately 8 inches/ hour and the bioretention soil mix infiltrates more quickly rapidly than 8 inches/ hour. (AESI 2019).

Due to the quantity of weeds growing in the cell, we assume it is not maintained, at least not regularly. The cell did not appear to be irrigated.

Wainwright Intermediate School, Fircrest (Site FWI)

Vegetative cover was measured on June 5, 2019 in Cell #4, located in the middle of the parking lot, at Wainwright Intermediate School. According to our field measurements, the bottom of Cell #4 totaled approximately 170 square feet. The plan specified only herbaceous vegetation for installation. However, two river birch (*Betula nigra*) (FACW) have volunteered within the cell. The birch saplings provide 5% woody cover.

Herbaceous vegetation was measured with 44 quadrats in the bottom of the cell. Per plan, twenty-seven small-fruited bulrush and eighteen brown sedge (*Carex testacea*) (FAC) were installed in the cell; however, we did not observe either of those plants within the bottom of the cell. It appears slough sedge was installed at the bottom of the cell instead of the two specified plants. Similar to the cell at Bush Middle School, most of the plants growing within the cell would be considered weeds. The most prevalent weed growing was bull thistle (*Cirsium vulgare*) (FACU). Plants rated as FACU, primarily bull thistle, occurred in 100% of the quadrats. Kentucky bluegrass (FAC) was the most dominant plant with that rating, and FAC plants occurred in 70% of the quadrats. Plants with a WIS of FACW occurred in 38% of the quadrats, and the installed slough sedge occurred in 34% of the quadrats. The slough sedge was more robust at the north end of the cell; most likely the water pools at that end of the cell. Herbaceous species in the sampled area averaged 5.5% basal cover.

This cell is located on a native outwash soil. The Natural Resource Conservation Service (USDA NRCS 2019b) mapped the soil in this location as Alderwood gravelly sandy loam. The native soil is considered well-draining. This cell has an underdrain. An infiltration test was conducted by the geologists. The bioretention soil mix infiltrates at about 66 inches/ hour. (AESI 2019).

Harrington Avenue NE, Renton (Site RSH)

Vegetative cover was measured on June 5, 2019 in Cell E2 located at the northwest corner of NE 8th St. and Harrington Ave. NE. According to our field measurements, the bottom of this cell totaled approximately 60 square feet. The cell contained only herbaceous vegetation, which was recorded in 21 quadrats.

The plants observed growing in the cell are per plan. The plan lists a variety of native and non-native rush species including elk blue rush, common rush, and slender rush. Both native rushes have a WIS of FACW, therefore the non-native elk blue rush was assigned a WIS of FACW. Pacific coast iris (*Iris douglasiana*) (UPL) was also listed on the plan, which was recorded in one quadrat. Four quadrats contained no plants. We recorded a rush species or multiple rush species in 100%

of the cells, therefore the dominant vegetation in the cell has a WIS of FACW. Herbaceous species in the sampled area averaged 25.5% basal cover.

The Harrington cell is located on an outwash soil. The Natural Resource Conservation Service (USDA NRCS 2019b) mapped the soil in this location as Ragnar-Indianola Association soils. This cell has a rock trench under the bioretention mix and an underdrain. An infiltration test was conducted by the geologists. The bioretention soil mix infiltrates at than 2 inches/ hour, which is a relatively low infiltration rate. However, do to flaws in the design or execution the geologist believe the cell will experience more frequent bypass overflows. Essentially, the cell will dump water as opposed to filling and infiltrating the water (AESI 2019).

CONCLUSIONS

Many of these cells have only been planted in the past year or two. Drawing conclusions on the overall health and survival of the plants is difficult since the plants have not had much time to establish and adjust to the hydrologic conditions in the cells. Also, many of the cells we looked at only contained herbaceous plant material, which makes it difficult to draw conclusions about woody material. However, it appears that the use of the dwarf red-twig dogwood is becoming more common in the bioretention cells. We do not know yet whether the dwarf versions will be as successful as the native and full-size dogwoods which grow well in seasonal standing water and are somewhat drought tolerant.

The herbaceous plants specified in the planting plans tend toward plants with a WIS of OBL and FACW. However, most of the cells are very well draining, and plants that need a consistent hydrologic regime either do not survive or struggle to survive. The cells with underdrains infiltrated most rapidly (AESI 2019). The cells with underdrains probably drain better than most residential gardens. We found that most of the volunteer (weedy) plants in the cells have a WIS of FACU, and these plants are growing well in the cells. If the cell has underdrains, drought tolerant plants installed further from the inlet may be a better option than installing wetland-like plants throughout the bottom of the cell. In cells located on well-draining soil without underdrains, plants with a rating of FAC would be a better option than obligate plants. From the previous study, we found the exception is slough sedge (OBL), which seems to tolerate well-draining soils if irrigation is present.

Weedy plants have readily volunteered in the cells where the installed plant material had died. Weedy plants provide tilth and root mass; however, they provide less basal cover than many of the installed plants. The basal cover provided by plants may play a long-term role in creating space for water to infiltrate as sediments accumulate.

In the long run, we expect shrubs will provide more tilth and therefore help keep the water draining more effectively as the cells begin to age and sediments accumulate.

Shrubs also seem to adapt to a variety of hydrologic regimes better than many herbaceous species, and they help minimize the weeds in the cell by providing shade and competition. Shrubs can be problematic due to their large size if site lines are needed; however, it appears that many designers are using smaller shrubs in the cells, like the Kelsey red-twig dogwood, and shiny spirea. Although herbaceous vegetation is more difficult to establish in bioretention cells, herbaceous vegetation plays an important role in maintaining the tilth of the soil with the roots and adding organic matter as the plants senesce. The herbaceous plants also add visual interest to bioretention cells.

The engineering of the bio-retention cells takes a team of people. It is important to understand the soils under the cells and the models for the cells and their drainage patterns prior to choosing a plant pallet.

LITERATURE CITED

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2017-114 Olympia Bioretention Study
Spring 2019

BELLINGHAM - CORNER OF UTTER AND WASHINGTON
Plot Size: 39.25 x 2.75

Woody Cover:
60%

Woody Shrub

Species	Plant Count	Stems
SPBE	25	625
COSE-KE	8	320
	33	**945**

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	0	0	0
2	JUEF	10	FACW
3	CAPA	25	FAC
3	JUEF	10	FACW
4	JUEF	20	FACW
5	CAPA	50	FAC
7	JUEF	40	FACW
7	CAPA	25	FAC
9	JUEF	25	FACW
10	SPBE	25	
10	CAPA	1	FAC
11	JUEF	20	FACW
14	IRTE	15	UPL
15	IRTE	30	UPL
15	JUEF	10	FACW
16	IRTE	25	UPL
16	DECE	25	FACW
17	JUEF	50	FACW
18	SISP	15	FACW
19	JUEF	30	FACW
19	SISP	10	FACW
20	SISP	5	FACW
21	JUEF	35	FACW
21	SISP	7	FACW
22	SISP	7	FACW
23	JUEF	15	FACW
23	SISP	7	FACW
24	SISP	1	FACW
25	JUEF	10	FACW
25	SISP	4	FACW
25	Grass sp	3	FAC
27	SISP	50	FACW

Plant List

Code	Name
JUEF	*Juncus effusus*
CAPA	*Carex pachystachya*
SPBE	*Spiraea betulifolia*
COSE	*Cornus sericea*
IRTE	*Iris tenax*
DECE	*Deschampsia caespitosa*
HYRA	*Hypochaeris radicata*

27	JUEF	3	FACW
28	HYRA	1	FACU
29	IRTE	50	UPL
30	CAPA	20	FAC
30	IRTE	15	UPL
30	SISP	3	FACW
31	CAPA	50	FAC
31	JUEF	10	FACW

2017-114 Olympia Bioretention Study
Spring 2019

BELLINGHAM CORNER OF CORNWALL & KENTUCKY
Plot Size: 17 x 2

Woody Cover:
0%

Woody Shrub

Species	Plant Count	Stem Count
SPDO		
COSE-FL		

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	LASE	2	FACU
1	LEVU	2	FACU
2	Vetch	2	UPL
2	LEVU	1	FACU
2	0		
2	TAOF	1	FACU
3	0		
4	PLLA	1	FACU
4	Vetch	1	UPL
5	0		
6	JUPA	80	FACW
7	JUEF	25	FACW
8	CAOB	50	OBL
9	CAOB	30	OBL
10	JUEF	50	FACW
10	TAOF	2	FACU
11	CAOB	50	OBL
12	0		
13	CAOB	60	OBL
14	CAOB	40	OBL
15	CAOB	25	OBL
16	CAOB	75	OBL
17	CAOB	15	OBL

Plant List

Code	Name
JUPA	*Juncus patens-BLUE ELK*
CAPA	*Carex pachystachya*
SPBE	*Spiraea betulifolia*
COSE	*Cornus sericea*
IRTE	*Iris tenax*
DECE	*Deschampsia caespitosa*
SI SP	*Sisyrinchium species*
HYRA	*Hypochaeris radicata*
LEVU	*Leucanthemum vulgare*
PLLA	*Plantago lanceolata*
CAOB	*Carex obnupta*
LASE	*Lactuca serriola*
Vetch	*Vichia sativa*

2017-114 Olympia Bioretention Study
Spring 2019

MARYSVILLE 3RD & QUINN

Woody Cover:

30%

Woody Shrub

Species	Plant Count	Stem Count
COSE	2	17
COEL	2	16
VAOV	2	16
Magnolia Tree	1	13

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	CAOB	50	OBL
2	CAOB	20	OBL
3	CAOB	50	OBL
4	CAOB	7	OBL
5	COSE	100	
6	POMU	15	UPL
6	VAOV	5	
7	0		
8	0		
9	Woody		
10	CAOB	1	OBL
11	ACGR	15	FACW
11	MISI	5	FAC
12	CAOB	20	OBL
13	CAOB	10	OBL
13	TAOF	1	FACU
14	CAOB	5	OBL
15	CAOB	1	OBL
16	HESA	10	FACW
16	MISI	7	FAC
17	COSE	0	
18	MISI	50	FAC
19	0		
20	0		
21	Woody		
22	0		
23	0		
24	0		
25	MISI	75	FAC
26	HESA	80	FACW
27	HESA	50	FACW
27	POMU	25	UPL
28	CAOB	10	OBL
29	POMU	30	UPL
30	CAOB	10	OBL
31	IRTE	3	UPL

Plant List

Code	Name
JUEF	*Juncus effusus*
CAPA	*Carex pachystachya*
SPBE	*Spiraea betulifolia*
COSE	*Cornus sericea*
IRTE	*Iris tenax*
DECE	*Deschampsia caespitosa*
SI SP	*Sisyrinchium species*
	CALIFORNICUM OR IDAHOENSIS
HYRA	*Hypochaeris radicata*
LEVU	*Leucanthemum vulgare*
PLLA	*Plantago lanceolata*
CAOB	*Carex obnupta*
Rud	*Rudbeckia*
VAOV	*Vaccinium ovatum*
ACGR	*Acorus gramineus*
MISI	*Miscanthus sinensis*
EQAR	*Equisetum arvense*
POMU	*Polystichum munitum*
HESA	*Helenium 'Sahin's early flowerer*

32	IRTE	30	UPL
33	IRTE	25	UPL
33	HESA	10	FACW
34	HESA	10	FACW
34	CAOB	8	OBL
35	HESA	15	FACW
35	CAOB	1	OBL
36	COSE		
36	EQAR	3	FAC
37	Woody		
38	0		
39	0		
40	POMU	25	UPL
41	Woody		
42	CAOB	10	OBL
43	HESA	50	FACW
44	HESA	25	FACW
44	CAOB	5	OBL
45	HESA	15	FACW
46	DECE	10	FACW
47	CAOB	15	OBL

2017-114 Olympia Bioretention Study
Spring 2019

MARYSVILLE 1ST & STATE
Plot Size: 33.2 x 4

Woody Cover:
20%

Woody Shrub

Species	Plant Count	Stem Count
COKE	10	30

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	MODI	25	FAC
2	MODI	18	FAC
3	IRSE	75	FAC
4	IRSE	15	FAC
4	MODI	6	FAC
5	MODI	10	FAC
6	Woody		
6	MODI	16	FAC
7	Woody		
7	MODI	10	FAC
8	CAOS	50	FAC
9	COSE	75	
9	CAOS	15	FAC
10	Woody		
11	Woody		
12	Woody		
12	EPAN	1	FACW
13	IRSE	25	FAC
14	IRSE	50	FAC
15	MODI	20	FAC
15	IRSE	15	FAC
16	IRSE	30	FAC
16	MODI	6	FAC
17	IRSE	40	FAC
17	MODI	4	FAC
18	Woody		
18	MODI	4	FAC
19	CAOS	15	FAC
20	CAOS	30	FAC
21	CAOS	15	FAC
22	CAOS	30	FAC
23	CAOS	30	FAC
24	CAOS	50	FAC
25	COSE	0	
26	CAOS	30	FAC
27	CAOS	10	FAC
28	CAOS	20	FAC
28	Woody		FAC
29	0		
30	CAOS	25	FAC

Plant List

Code	Name
CAOS	*Carex oshimensis*
COSE	*Cornus sericea*
MODI	*Monarda didyma 'Jakob Cline'*
IRSE	*Iris ensata*
EPAN	*EPILOBIUM ANGUSTI (CHAMERION)*

30	MODI	4	FAC
31	IRSE	50	FAC
32	MODI	25	FAC
33	IRSE	30	FAC

2017-114 Olympia Bioretention Study
Spring 2019

SALEM WOODS
Plot Size: 43 x 29

Woody Cover:
2%

Woody Shrub

Species	Plant Count	Stem Count
COKE	8	

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	SCMI	2	OBL
2	SCMI	2	OBL
2	JUAC	1	OBL
3	JUAC	2	OBL
4	JUAC	2	OBL
5	JUAC	2	OBL
6	ViSA	1	UPL
6	JUAC	1	OBL
7	JUAC	6	OBL
8	SCMI	5	OBL
8	ELPA	2	OBL
9	ELPA	3	OBL
9	SCMI	2	OBL
10	ELPA	2	OBL
11	IRTE	3	UNK.
12	IRTE	2	UNK.
12	ELPA	1	OBL
13	IRTE	3	UNK.
14	IRTE	1	UNK.
15	ELPA	3	OBL
16	ELPA	6	OBL
17	SCMI	4	OBL
18	SCMI	2	OBL
19	SCMI	10	OBL
20	SCMI	10	OBL
20	IRTE	2	UNK.
21	SCMI	10	OBL
21	ELPA	2	OBL
22	SCMI	5	OBL
22	ELPA	2	OBL
23	ELPA	6	OBL
24	ELPA	4	OBL

Plant List

Code	Name
CAOS	*Carex oshimensis*
COSE	*Cornus sericea*
MODI	*Monarda*
IRTE	*Iris tenax*
ELPA	*Eleocharis palustris*
SCMI	*Scirpus microcarpos*
JUAC	*Juncus acuminatus*
VISA	*Vichia sativa*

25	ELPA	8	OBL
26	IRTE	6	UNK.
27	IRTE	10	UNK.
28	IRTE	10	UNK.
29	IRTE	6	UNK.
29	ELPA	4	OBL
30	SCMI	4	OBL
31	SCMI	10	OBL
32	IRTE	3	UNK.
33	SCMI	10	OBL
34	IRTE	2	UNK.
35	SCMI	5	OBL
36	ELPA	5	OBL
37	ELPA	5	OBL
38	ELPA	1	OBL
39	ELPA	1	OBL
40	ELPA	1	OBL
41	SCMI	5	OBL
42	SCMI	10	OBL
43	SCMI	10	OBL
44	SCMI	12	OBL
45	SCMI	12	OBL
46	ELPA	10	OBL
47	SCMI	5	OBL
47	ELPA	2	OBL
48	SCMI	10	OBL
49	SCMI	15	OBL
50	SCMI	7	OBL
51	SCMI	7	OBL
52	SCMI	10	OBL
53	SCMI	7	OBL
54	ELPA	5	OBL
54	SCMI	5	OBL
55	ELPA	6	OBL
56	ELPA	7	OBL
57	ELPA	8	OBL
58	ELPA	5	OBL
59	SCMI	7	OBL
60	SCMI	5	OBL
61	SCMI	15	OBL
62	0		
63	ELPA	1	OBL
64	ELPA	1	OBL
65	SCMI	7	OBL
66	SCMI	8	OBL
67	SCMI	5	OBL
68	SCMI	12	OBL

69	ELPA	3	OBL
70	SCMI	12	OBL
71	ELPA	3	OBL
72	ELPA	7	OBL
73	ELPA	3	OBL
74	ELPA	3	OBL
75	ELPA	2	OBL
76	0		
77	ELPA	2	OBL
78	ELPA	3	OBL
79	SCMI	10	OBL
79	ELPA	2	OBL
80	ELPA	4	OBL
80	IRTE	1	UNK.
81	ELPA	3	OBL
82	ELPA	5	OBL
83	ELPA	5	OBL
84	SCMI	12	OBL
85	SCMI	15	OBL
86	SCMI	10	OBL
87	SCMI	7	OBL
88	SCMI	7	OBL
88	ELPA	2	OBL
89	ELPA	6	OBL
90	SCMI	10	OBL
91	SCMI	12	OBL
92	ELPA	10	OBL
93	ELPA	3	OBL
94	ELPA	10	OBL
95	ELPA	6	OBL
95	IRTE	2	UNK.
96	SCMI	8	OBL
97	SCMI	8	OBL
98	ELPA	9	OBL
99	ELPA	9	OBL
100	ELPA	3	OBL
101	ELPA	6	OBL
102	ELPA	3	OBL
103	ELPA	6	OBL
104	ELPA	2	OBL
105	SCMI	10	OBL
106	SCMI	20	OBL
107	SCMI	10	OBL
108	ELPA	6	OBL
108	SCMI	5	OBL
109	SCMI	5	OBL
109	IRTE	2	UNK.

110	SCMI	7	OBL
111	SCMI	3	OBL
112	SCMI	5	OBL
113	SCMI	6	OBL
114	SCMI	4	OBL
115	ELPA	6	OBL
115	SCMI	4	OBL
116	SCMI	15	OBL
116	ViSA	1	UPL
117	SCMI	7	OBL
117	ELPA	5	OBL
118	ELPA	5	OBL
119	JUAC	5	OBL
120	JUAC	10	OBL
121	JUAC	3	OBL
122	0		
123	0		
124	JUAC	10	OBL
125	IRTE	2	UNK.
126	CAOB	7	OBL
126	IRTE	2	UNK.
127	IRTE	4	UNK.
128	CAOB	12	OBL
129	CAOB	10	OBL
130	CAOB	25	OBL
131	CAOB	10	OBL
132	CAOB	10	OBL
133	SCMI	7	OBL
134	SCMI	10	OBL
135	SCMI	7	OBL
136	ELPA	3	OBL
136	VISA	1	UPL
137	ELPA	9	OBL
138	ELPA	7	OBL
139	ELPA	9	OBL
140	ELPA	3	OBL
141	SCMI	5	OBL
142	0		
143	0		
144	SCMI	5	OBL
145	IRTE	3	UNK.
146	IRTE	5	UNK.
147	IRTE	2	UNK.
148	SCMI	5	OBL
149	SCMI	10	OBL
150	SCMI	12	OBL
151	SCMI	9	OBL

152	SCMI	7	OBL
153	SCMI	8	OBL
154	SCMI	7	OBL
155	SCMI	10	OBL
156	SCMI	1	OBL
157	SCMI	7	OBL
158	SCMI	10	OBL
159	SCMI	4	OBL
160	SCMI	7	OBL
161	IRTE	2	UNK.
162	SCMI	6	OBL
163	SCMI	10	OBL
164	SCMI	10	OBL
165	SCMI	3	OBL
166	0		
167	JUAC	1	OBL
168	JUAC	1	OBL
169	SCMI	5	OBL
170	SCMI	7	OBL
171	SCMI	10	OBL
172	JUAC	3	OBL
172	ELPA	2	OBL
173	JUAC	5	OBL
174	JUAC	5	OBL
174	vetch	1	UPL
175	JUAC	7	OBL
175	ELPA	3	OBL
176	SCMI	10	OBL
177	SCMI	5	OBL
178	SCMI	5	OBL
179	SCMI	12	OBL
180	SCMI	5	OBL
181	IRTE	3	UNK.
182	IRTE	3	UNK.
182	SCMI	3	OBL
183	IRTE	3	UNK.
184	CAOB	5	OBL
185	CAOB	12	OBL
186	CAOB	10	OBL
187	CAOB	12	OBL
188	CAOB	10	OBL
189	CAOB	8	OBL
190	CAOB	9	OBL

2017-114 Olympia Bioretention Study
Spring 2019

PARK PLACE MIDDLE SCHOOL
Plots Size: 32 x 10.5, 52 x 22

Woody Cover:

Woody Shrub

Species	Plant Count	Stem Count
RUSP	12	
ALRU	2	

Herb Quadrats

Quad. #	Species	% Cover	
1	EPCI	1	FACW
1	vetch	1	UPL
2	EPCI	25	FACW
3	HYRA	5	FACU
4	TAOF	5	FACU
4	EPCI	1	FACW
4	VISA	1	UPL
5	VISA	1	UPL
6	EPCI	5	FACW
7	VISA	1	UPL
8	SCMI	4	OBL
8	vetch	1	UPL
10	0		
11	SCMI	5	OBL
11	vetch	1	UPL
12	SCMI	1	OBL
13	SCMI	5	OBL
14	SCMI	6	OBL
14	HYRA	5	FACU
14	EPCI	2	FACW
15	SCMI	5	OBL
16	SCMI	6	OBL
17	SCMI	15	OBL
18	SCMI	5	OBL
19	SCMI	10	OBL
19	vetch	1	UPL
20	SCMI	5	OBL
21	SCMI	9	OBL
22	SCMI	6	OBL
22	HOLA	1	FAC
23	JUAC	7	OBL

Plant List

Code	Name
CAOS	*Carex oshimensis*
COSE	*Cornus sericea*
MODI	*Monarda*
IRTE	*Iris tenax*
ELPA	*Eleocharis palustris*
SCMI	*Scirpus microcarpos*
JUAC	*Juncus acuminatus*
EPCI	*Epilobium ciliatum*
HYRA	*Hypochaeris radicata*
TAOF	*Taraxacum officinale*
JUEF	*Juncus effusus*
RUAR	*Rubus armeniacus*
RARE	*Ranunculus repens*
HODI	*Holodiscus discolor*
VISA	*Vichia sativa*

24	JUAC	25	OBL
25	JUAC	9	OBL
26	JUAC	5	OBL
26	SCMI	1	OBL
27	JUAC	20	OBL
28	JUAC	1	OBL
28	SCMI	1	OBL
29	CAOB	6	OBL
29	SCMI	5	OBL
30	CAOB	50	OBL
31	CAOB	5	OBL
31	SCMI	5	OBL
32	CAOB	20	OBL
33	CAOB	10	OBL
34	CAOB	25	OBL
35	CAOB	20	OBL
35	JUEF	5	OBL
36	0		
37	CAOB	25	OBL
38	CAOB	1	OBL
39	CAOB	20	OBL
40	CAOB	30	OBL
41	0		
42	CAOB	30	OBL
43	SCMI	2	OBL
44	SCMI	3	OBL
45	SCMI	15	OBL
46	CAOB	25	OBL
47	CAOB	40	OBL
48	CAOB	40	OBL
49	CAOB	25	OBL
50	CAOB	5	OBL
51	CAOB	10	OBL
51	JUAC	2	OBL
52	0		
53	CAOB	5	OBL
54	SCMI	2	OBL
55	CAOB	30	OBL
56	0		
57	CAOB	25	OBL
58	0		
59	0		
60	0		
61	SCMI	1	OBL
62	0		
63	0		
64	EPCI	7	FACW

65	EPCI	5	FACW
65	TAOF	1	FACU
65	RUAR	1	FAC
66	EPCI	1	FACW
67	RARE	10	FAC
68	EPCI	10	FACW
69	EPCI	5	FACW
70	HOLA	1	FAC
70	EPCI	1	FACW
71	0		
72	SCMI	1	OBL
73	0		
74	0		
75	0		
76	0		
77	CAOB	2	OBL
78	JUAC	3	OBL
79	JUAC	2	OBL
80	0		

2017-114 Olympia Bioretention Study
Spring 2019

WILSON HIGH SCHOOL TACOMA
Plot Size: 84 x 15

Woody Cover:
No shrubs

Woody Shrub

Species	Plant Count	Stem Count
	No shrubs	

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	HOLA	15	FAC
2	HYRA	5	FACU
3	HOLA	10	FAC
3	CHJU	10	UPL
4	HOLA	15	FAC
4	CHJU	15	UPL
5	CHJU	25	UPL
6	HOLA	3	FAC
6	MYMU	3	UPL
7	PHAR	25	FACW
8	PHAR	25	FACW
8	LOPE	15	FAC
9	PHAR	25	FACW
9	LOPE	5	FAC
10	LOPE	50	FAC
11	PLLA	20	FACU
11	HYRA	15	FACU
11	LOPE	10	FAC
11	MEAR	1	FACW
12	LOPE	50	FAC
12	CAOB	5	OBL
12	PLLA	5	FACU
13	FERU	15	FAC
13	LOPE	15	FAC
13	PLLA	5	FACU
14	LOPE	50	FAC
14	PLLA	3	FACU
15	SOAS	3	FACU
16	LOPE	15	FAC
16	PLLA	7	FACU
17	LOPE	10	FAC
18	LOPE	10	FAC

Plant List

Code	Name
HOLA	*Holcus lanatus*
HYRA	*Hypochaeris radicata*
LOPE	*Lolium perenne*
FERU	*Festuca rubra*
FEAR	*Festuca arundinacea*
SOAS	*Sonchus asper*
CAEX	*Castilleja exserta*
SIAL	*Sisymbrium altissimum*
MYMU	*Mycelis muralis*
PHAR	*Phalaris arundinacea*
PLLA	*Plantago lanceolata*
CAOB	*Carex obnupta*
TAOF	*Taraxacum officinale*
VIAM	*Vicia americana*
EPCI	*Epilobium ciliatum*
LEVU	*Leucanthemum vulgare*
TAVU	*Tanacetum vulgare*
CEGL	*Cerastium glomeratum*
JUAC	*Juncus acuminatus*
CIHO	*Cirsium horridulum*
JUEF	*Juncus effesus*
CHJU	*Chondrilla juncea*
CAEX	*Castilleja exserta*
TRRE	*Trifolium repens*
TRPR	*Trifolium pratense*
VISA	*Vicia sativa*

18	PLLA	5	FACU
18	SOAS	3	FACU
19	PLLA	15	FACU
20	LOPE	1	FAC
21	LOPE	50	FAC
22	LOPE	50	FAC
22	FERU	3	FAC
23	LOPE	30	FAC
23	SOAS	3	FACU
24	PLLA	10	FACU
25	LOPE	10	FAC
25	SOAS	2	FACU
26	LOPE	50	FAC
27	LOPE	10	FAC
27	TRPR	3	FACU
27	SOAS	3	FACU
27	VISA	1	UPL
28	LOPE	50	FAC
29	FERU	50	FAC
30	FERU	25	FAC
31	LOPE	10	FAC
31	PLLA	3	FACU
31	SOAS	3	FACU
32	FERU	75	FAC
33	PLLA	15	FACU
34	FERU	60	FAC
35	FERU	50	FAC
36	FERU	10	FAC
36	VISA	5	UPL
36	CAOB	5	OBL
37	HYRA	15	FACU
38	HYRA	25	FACU
38	CAOB	15	OBL
39	HYRA	25	FACU
39	CAOB	10	OBL
40	HYRA	10	FACU
40	FEAR	2	FAC
40	TAOF	2	FACU
41	CAOB	15	OBL
41	LOPE	5	FAC
42	HYRA	15	FACU
42	CAOB	5	OBL
43	HYRA	15	FACU
44	PLLA	20	FACU
45	CAOB	20	OBL
46	CAOB	10	OBL
46	HYRA	3	FACU

47	TAOF	5	FACU
47	LOPE	3	FAC
48	CAOB	25	OBL
48	VISA	5	UPL
49	CAOB	5	OBL
49	FEAR	3	FAC
50	CAOB	25	OBL
50	VISA	2	UPL
51	CAOB	5	OBL
52	CAOB	25	OBL
53	CAOB	25	OBL
54	CAOB	25	OBL
55	CAOB	50	OBL
56	CAOB	20	OBL
57	0		
58	CAOB	25	OBL
59	CAOB	10	OBL
59	JUEF	5	FACW
59	EPCI	1	FACW
60	CAOB	25	OBL
61	CAOB	10	OBL
62	JUEF	15	FACW
62	CAOB	5	OBL
63	JUEF	50	FACW
64	JUEF	50	FACW
65	JUEF	50	FACW
66	CAOB	10	OBL
66	CAEX	10	UPL
66	JUEF	5	FACW
67	CAEX	10	UPL
67	CAOB	3	UPL
68	CAEX	40	UPL
68	LOPE	40	FAC
69	ROCK		
70	CAEX	40	UPL
71	CAEX	60	UPL
72	CAEX	50	UPL
72	CAOB	3	OBL
73	CAEX	60	UPL
73	JUEF	3	FACW
74	JUEF	80	FACW
74	EPCI	1	FACW
75	CAOB	50	OBL
76	CAOB	50	OBL
77	CAOB	20	OBL
78	CAOB	25	OBL
79	VISA	3	UPL

80	CAOB	25	OBL
81	CAOB	50	OBL
82	CAOB	20	OBL
83	LOPE	50	FAC
84	PLLA	10	FACU
84	LOPE	10	FAC
84	CAOB	3	OBL
85	LOPE	25	FAC
85	PLLA	3	FACU
86	LOPE	10	FAC
86	PLLA	5	FACU
87	LOPE	3	FAC
88	LOPE	20	FAC
89	LOPE	10	FAC
90	LOPE	20	FAC
91	PLLA	5	FACU
92	LOPE	40	FAC
93	LOPE	60	FAC
94	LOPE	10	FAC
94	PLLA	7	FACU
94	HYRA	1	FACU
95	CAOB	10	OBL
95	PLLA	10	FACU
95	LOPE	5	FAC
96	PLLA	5	FACU
96	CAOB	5	OBL
97	LOPE	50	FAC
97	PLLA	7	FACU
98	FERU	10	FAC
98	CAOB	5	OBL
99	HYRA	10	FACU
99	FERU	10	FAC
100	CAOB	25	OBL
100	LOPE	5	FAC
101	FERU	25	FAC
101	TAOF	3	FACU
102	LOPE	25	FAC
102	LEVU	7	FACU
103	LOPE	20	FAC
103	LEVU	7	FACU
104	CAOB	25	OBL
104	LEVU	5	FACU
105	LEVU	10	FACU
105	VISA	3	FACU
106	CAOB	20	OBL
106	HYRA	3	FACU
107	HYRA	25	FACU

107	CAOB	3	OBL
107	VISA	3	FACU
108	HYRA	15	FACU
108	CAOB	5	OBL
108	JUEF	5	FACW
109	LEVU	20	FACU
109	JUEF	15	FACW
109	SOAS	2	FACU
110	CAOB	15	OBL
110	LEVU	10	FACU
111	LEVU	25	FACU
111	VIAM	10	FACU
112	CAOB	30	OBL
113	LEVU	10	FACU
113	CAOB	10	OBL
114	CAOB	25	OBL
115	LOPE	10	FAC
116	CAOB	25	OBL
116	HYRA	7	FACU
117	CAOB	50	OBL
118	CAOB	10	OBL
119	CAOB	20	OBL
119	LOPE	15	FAC
120	CAOB	10	OBL
121	CAOB	15	OBL
122	CAOB	25	OBL
123	CAOB	15	OBL
123	LEVU	3	FACU
124	CAOB	10	OBL
125	CAOB	25	OBL
125	HYRA	5	FACU
126	CAOB	15	OBL
127	CAOB	30	OBL
128	CAOB	25	OBL
129	CAOB	10	OBL
130	FERU	15	FAC
130	CAOB	10	OBL
131	CAOB	25	OBL
132	CAOB	30	OBL
132	SOAS	8	FACU
133	CAOB	20	OBL
134	CAOB	15	OBL
135	CAOB	5	OBL
136	CAOB	30	OBL
137	CAOB	15	OBL
138	CAOB	20	OBL
138	EPCI	1	FACW

139	CAOB	25	OBL
139	SOAS	3	FACU
140	CAOB	15	OBL
140	EPCI	1	FACW
141	CAOB	10	OBL
142	CAOB	25	OBL
143	CAOB	25	OBL
144	CAOB	30	OBL
144	EPCI	2	FACW
145	CAOB	5	OBL
146	CAOB	50	OBL
147	CAOB	25	OBL
148	CAOB	25	OBL
149	0		
150	CAOB	50	OBL
151	RARE	10	FAC
151	CAOB	5	OBL
152	CAOB	10	OBL
153	CAOB	10	OBL
153	RARE	3	FAC
154	LOPE	5	FAC
155	PLLA	10	FACU
155	LOPE	5	FAC
156	PLLA	25	FACU
156	LOPE	5	FAC
157	PLLA	50	FACU
157	LOPE	3	FAC
158	LOPE	60	FAC
159	LOPE	25	FAC
159	PLLA	10	FAC
160	LOPE	50	FAC
160	PLLA	10	FACU
161	LOPE	30	FAC
161	PLLA	5	FACU
162	LOPE	15	FAC
162	PLLA	5	FACU
163	FERU	10	FAC
163	PLLA	5	FACU
163	SOAS	2	FACU
164	FERU	20	FAC
165	FERU	25	FAC
166	LOPE	25	FAC
167	LOPE	5	FAC
167	VISA	3	UPL
167	SOAS	3	FACU
168	LOPE	20	FAC
168	PLLA	5	FACU

169	FERU	20	FAC
169	PLLA	5	FACU
170	FERU	25	FAC
170	PLLA	5	FACU
172	HYRA	10	FACU
172	FERU	5	FAC
173	PLLA	15	FACU
173	SOAS	3	FACU
174	FERU	50	FAC
175	PLLA	10	FACU
175	FERU	5	FAC
176	FERU	20	FAC
176	PLLA	10	FACU
177	LOPE	30	FAC
178	LOPE	25	FAC
179	TAOF	5	FACU
179	TAVU	3	FACU
179	HOLA	3	FAC
181	HOLA	20	FAC
181	VISA	1	UPL
182	HOLA	5	FAC
182	SOAS	6	FACU
183	HOLA	15	FAC
183	TAOF	5	FACU
183	LOPE	5	FAC
184	HYRA	5	FACU
184	FERU	5	FAC
185	HOLA	15	FAC
185	FERU	15	FAC
186	LOPE	50	FAC
187	JUEF	15	FACW
187	TAOF	5	FACU
189	LOPE	40	FAC
189	HOLA	5	FAC
190	HOLA	13	FAC
190	TAOF	5	FACU
191	LOPE	30	FAC
191	HOLA	3	FAC
192	LOPE	50	FAC
193	LOPE	50	FAC
194	LOPE	50	FAC
195	LOPE	50	FAC
196	LOPE	50	FAC
197	LOPE	50	FAC
198	LOPE	10	FAC
198	TAOF	5	FACU
198	VISA	3	UPL

199	LOPE	50	FAC
200	LOPE	20	FAC
200	HYRA	3	FACU
200	VISA	1	UPL
201	CEGL	20	FACU
201	VISA	10	UPL
201	LOPE	5	FAC
202	CEGL	20	FACU
202	LOPE	5	FAC
203	CEGL	20	FACU
203	LOPE	5	FAC
204	CEGL	20	FACU
204	LOPE	5	FAC
205	CEGL	20	FACU
205	LOPE	5	FAC
206	HOLA	10	FAC
206	TAOF	5	FACU
206	VISA	5	UPL
207	HYRA	15	FACU
208	TRPR	15	FAC
208	HYRA	3	FACU
209	SOAS	10	FACU
209	TRPR	10	FACU
209	EPCI	3	FACW
210	SOAS	14	FACU
210	JUAC	5	OBL
210	HOLA	1	FAC
211	FERU	10	FACU
211	TRRE	10	FAC
211	JUAC	3	OBL
212	LOPE	50	FAC
212	TRPA	3	FACU
212	HYRA	3	FACU
213	LOPE	10	FAC
213	SOAS	5	FACU
213	TRRE	3	FAC
214	TRRE	5	FAC
214	SOAS	1	FACU
215	SOAS	20	FACU
216	FEAR	50	FAC
217	SOAS	20	FACU
218	FEAR	50	FAC
219	FEAR	50	FAC
220	FEAR	50	FAC
221	CAOB	25	OBL
222	CAOB	25	OBL

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Spring 2019

BUSH MIDDLE SCHOOL
Plot Size: 8.7 x 12.6, 24.6 x 5.6

Woody Cover:
15%

Woody Shrub

Species	Plant Count	Stem Count
SAPU	4	
COSE	5	

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	COCA	3	UPL
1	POPR	1	FAC
1	LASE	1	FACU
2	Woody		
2	COCA	1	UPL
3	Woody		
3	LASE	4	FACU
3	SOAS	1	FACU
4	LASE	3	FACU
4	COCA	1	UPL
4	EPCI	1	FACW
5	COCA	3	UPL
6	COCA	6	UPL
6	SOAS	5	FACU
6	UNK.	2	
7	Woody		
7	EPCI	2	FACW
8	EPCI	6	FACW
8	COCA	3	UPL
8	TAOF	2	FACU
9	LASE	15	FACU
10	LASE	6	FACU
10	COCA	1	FACU
10	EPCI	1	FACW
11	COCA	15	FACU
11	LASE	5	FACU
12	COCA	5	FACU
12	SOAS	2	FACU
13	COCA	10	FACU
13	LASE	5	FACU
13	SOAS	1	UPL

Plant List

Code	Name
HOLA	*Holcus lanatus*
HYRA	*Hypochaeris radicata*
LOPE	*Lolium perenne*
FERU	*Festuca rubra*
FEAR	*Festuca arundinacea*
SOAS	*Sonchus asper*
CAEX	*Castilleja exserta*
SIAL	*Sisymbrium altissimum*
MYMU	*Mycelis muralis*
PHAR	*Phalaris arundinacea*
PLLA	*Plantago lanceolata*
CAOB	*Carex obnupta*
TAOF	*Taraxacum officinale*
VIAM	*Vicia americana*
EPCI	*Epilobium ciliatum*
LEVU	*Leucanthemum vulgare*
TAVU	*Tanacetum vulgare*
CEGL	*Cerastium glomeratum*
JUAC	*Juncus acuminatus*
POPR	*Poa pratensis*
COCA	*Conyza canadensis*
LASE	*Lactuca serriola*
MATA	*Mare's Tail*

14	LASE	10	FACU
14	COCA	10	FACU
15	EPCI	8	FACW
15	COCA	6	FACU
15	LASE	3	FACU
16	JUEF	40	FACW
17	POPR	40	FAC
17	JUEF	10	FACW
17	COCA	10	FACU
18	POPR	30	FAC
18	EPCI	20	FACW
18	JUEF	10	FACW
19	POPR	50	FAC
19	HYRA	10	FACU
19	MATA	10	FACU
20	JUEF	40	FACW
20	POPR	20	FAC
21	POPR	50	FAC
21	HYRA	20	FACU
21	COCA	1	FACU
22	JUEF	25	FACW
22	EPCI	2	FACW
23	JUEF	25	FACW
24	POPR	15	FAC
24	EPCI	1	FACW
25	JUEF	25	FACW
25	EPCI	10	FACW
25	HYRA	1	FACU
26	POPR	15	FAC
26	HYRA	9	FACU
27	Woody		
28	HYRA	80	FACU
29	POPR	10	FAC
29	TRRE	5	FAC
29	HYRA	5	FACU
30	HYRA	25	FACU
30	unkn.	16	
30	SOAS	1	UPL
31	POPR	30	FAC
31	SOAS	10	UPL
31	RUCR	3	FAC
32	Woody		
33	FERU	10	UPL
33	LASE	2	FACU
33	COCA	1	FACU
34	CEFO	10	FACU
34	UNK.	6	

35	FERU	70	UPL
36	FERU	50	UPL
36	CEFO	30	FACU
37	Woody		
38	COCA	15	UPL
38	SEJA	2	FACU
38	HYRA	1	FACU
39	COCA	10	UPL
39	LASE	10	FACU
39	SOAS	8	FACU
40	LASE	20	FACU
40	COCA	10	UPL
40	SOAS	2	FACU
41	HYRA	50	FACU
41	TRRE	5	FACU
42	HYRA	10	FACU
42	POPR	10	FAC
42	EPCI	1	FACW
43	POPR	25	FAC
43	HYRA	10	FACU
44	JUEF	25	FACW
45	POPR	25	FAC
45	SOAS	3	FACU
45	EPCI	2	FACW
46	HYRA	25	FACU
47	JUEF	25	FACW
47	HYRA	3	FACU
47	LASE	3	FACU
48	SOAS	8	FACU
49	JUEF	15	FACW
49	SOAS	10	FACU
50	SOAS	15	FACU
50	LASE	7	FACU
51	SOAS	10	FACU
51	LASE	5	FACU
52	SOAS	15	FACU
52	unkn.	12	
53	COCA	6	UPL
53	LASE	6	FACU
53	SOAS	1	FACU
54	COCA	20	UPL
54	LASE	6	FACU
54	EPCI	1	FACW
55	COCA	25	UPL
55	LASE	4	FACU
55	LASE	2	FACU
56	COCA	12	UPL

56	LASE	10	FACU
57	Woody		
58	COCA	10	UPL
58	HYRA	6	FACU
58	LASE	3	FACU
59	EPCI	10	FACW
59	COCA	5	UPL
59	HYRA	1	FACU
60	TAOF	4	FACU
60	COCA	4	UPL
61	POPR	15	FAC
61	COCA	6	UPL
62	HYRA	25	FACU
63	Woody		
63	EPCI	3	FACW
63	COCA	2	UPL
64	HYRA	25	FACU

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Spring 2019

WAINWRIGHT INTERMEDIATE SCHOOL
Plot Size: 24' x 7'

Woody Cover:

	5%	Betula

Woody Shrub

Species	Plant Count	Stem Count
Betula	2	

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	LASE	15	FACU
1	SOTH	6	FACU
1	EPCI	3	FACW
2	CAOB	3	OBL
2	SOTH	2	FACU
2	VIAM	2	FAC
3	CIVU	10	FACU
3	EPCI	3	FACW
3	HYRA	2	FACU
3	POPR	2	FAC
4	SOTH	12	FACU
4	EPCI	7	FACW
5	POPR	15	FAC
5	CIVU	6	FACU
5	HYRA	2	FACU
5	CIVU	1	FACU
6	POPR	10	FAC
6	CIVU	10	FACU
7	CIVU	10	FACU
7	POPR	5	FAC
7	SOTH	1	FACU
7	VIAM	1	UPL
8	CIVU	16	FACU
8	POPR	3	FAC
8	GER	1	UPL
9	CIVU	20	FACU
9	POPR	2	FAC
10	CIVU	25	FACU
10	POPR	3	FAC
10	GER	1	UPL
11	CIVU	25	FACU

Plant List

Code	Name
CAOB	*Carex obnupta*
CIVU	*Cirsium vulgare*
EPCI	*Epilobium ciliatum*
GER	*Geranium*
HYRA	*Hypochaeris radicata*
LASE	*Lactuca serriola*
POPR	*Poa pratensis*
SOTH	*Sow Thistle*
VIAM	*Vicia americana*
COCA	*Conyza canadensis*
HOLA	*Holcus lanatus*
MATA	*Mare's Tail*
LOPE	*Lolium perenne*
FERU	*Festuca rubra*
FEAR	*Festuca arundinacea*
SOAS	*Sonchus asper*
CAEX	*Castilleja exserta*
SIAL	*Sisymbrium altissimum*
MYMU	*Mycelis muralis*
PHAR	*Phalaris arundinacea*
PLLA	*Plantago lanceolata*
OXAL	*Oxalis*
TAOF	*Taraxacum officinale*
GAAP	*Galium aparine*
LEVU	*Leucanthemum vulgare*
TAVU	*Tanacetum vulgare*
CEGL	*Cerastium glomeratum*
JUAC	*Juncus acuminatus*

11	POPR	1	FAC
12	CIVU	25	FACU
12	POPR	5	FAC
13	CIVU	6	FACU
13	POPR	2	FAC
13	HOLA	1	FAC
14	CIVU	10	FACU
14	POPR	3	FAC
15	CIVU	6	FACU
15	POPR	5	FAC
15	HYRA	3	FACU
16	CIVU	10	FACU
16	POPR	5	FAC
17	VIAM	2	UPL
17	POPR	2	FAC
17	CAOB	1	OBL
17	OXAL	1	FACU
18	CIVU	10	FACU
18	HYRA	6	FACU
19	CAOB	15	OBL
19	HYRA	3	FACU
20	CAOB	5	OBL
20	HYRA	4	FACU
20	CIVU	2	FACU
21	SOTH	6	FACU
21	CAOB	2	OBL
22	EPCI	10	FACW
22	SOTH	2	FACU
22	TAOF	1	FACU
23	EPCI	15	FACW
23	HYRA	1	FACU
24	EPCI	20	FACW
24	CAOB	4	OBL
24	SOTH	2	FACU
25	EPCI	3	FACW
25	CIVU	2	FACU
25	POPR	2	FAC
25	HOLA	1	FACU
26	SOMI	6	
26	POPR	3	FAC
26	CAOB	2	OBL
26	TAOF	2	FACU
26	VIAM	1	UPL
27	EPCI	5	FACW
27	HYRA	2	FACU
27	CAOB	2	OBL
27	CIVU	2	facu

27	PLMA	2	FAC
27	TANSY	2	UPL
27	SOTH	1	facu
28	Grass	5	FAC
28	EPCI	3	FACW
28	CAOB	2	OBL
28	CIVU	2	facu
29	JUEF	15	FACW
29	CAOB	5	OBL
29	HYRA	2	FACU
29	EPCI	2	FACW
31	POPR	12	FAC
31	CIVU	2	facu
31	CAOB	2	OBL
32	CAOB	10	OBL
32	EPCI	10	FACW
32	HYRA	4	FACU
32	GAAP	3	FACW
33	SOTH	5	facu
33	HYRA	5	FACU
33	Grass	5	FAC
33	EPCI	3	FACW
33	VIAM	2	UPL
34	EPCI	25	FACW
34	CIVU	12	facu
34	PLMA	2	FAC
35	CIVU	4	facu
35	HYRA	2	FACU
35	EPCI	2	FACW
35	CAOB	1	OBL
36	POPR	5	FAC
36	Grass	3	FAC
36	HYRA	3	FACU
36	CAOB	3	OBL
37	CIVU	10	facu
37	POPR	3	FAC
38	CIVU	10	FACU
38	POPR	3	FAC
39	CIVU	8	facu
39	HYRA	3	FACU
39	POPR	3	FAC
40	POPR	10	FAC
40	HYRA	8	FACU
40	EPCI	2	FACW
41	CIVU	12	facu
41	TAOF	2	FACU
41	EPCI	1	FACW

41	POPR	1	FAC
42	CIVU	20	facu
42	TAOF	4	FACU
43	SOTH	8	facu
43	CIVU	6	facu
43	CAOB	2	OBL
43	HYRA	2	FACU
43	POPR	1	FAC
44	EPCI	8	FACW
44	SOTH	4	facu
44	CIVU	4	facu
44	POPR	3	FAC

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Spring 2019

HARRINGTON AVENUE RENTON
Plot Size: 20' x 3'

Woody Cover:
Zero

Woody Shrub

Species	Plant Count	Stem Count
	Zero	

Herb Quadrats

Quad. #	Species	% Cover	WIS
1	0		
2	0		
3	0		
4	JUEF	30	FACW
5	JUEF	20	FACW
6	JUSP	20	FACW
7	JUEF	35	FACW
8	JUEF	25	FACW
9	JUEF	25	FACW
10	JUEF	30	FACW
11	JUEF	30	FACW
11	JUSP	10	FACW
12	JUEF	40	FACW
13	JUEF	5	FACW
13	JUSP	5	FACW
14	JUEF	40	FACW
15	JUEF	40	FACW
16	JUEF	50	FACW
16	JUSP	10	FACW
17	JUEF	25	FACW
18	JUEF	30	FACW
19	IRDO	25	UPL
19	JUEF	15	FACW
19	JUSP	10	FACW
20	JUEF	40	FACW
21	0		

Plant List

Code	Name
JUEF	*Juncus effusus*
JUSP	*Juncus species*
IRTE	*Iris tenax*

APPENDIX 15

Bioretention Hydrologic Performance Study Phase II Deliverable 4.6 Hydrologic Design Report. Clear Creek Solutions, Inc. 7/23/2019

CLEAR CREEK SOLUTIONS, INC.

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425-225-5997
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MEMORANDUM

DATE: 23 July 2019

TO: Eric Christensen, Water Resources Director, City of Olympia

CC: Bill Taylor, Principal Investigator

FROM: Doug Beyerlein, P.E., Hydrology Lead and Project Manager

SUBJECT: Bioretention Hydrologic Performance Study II Deliverable 4.6 Hydrologic Design Report

For Task 4 of the Bioretention Hydrologic Performance Study II we have completed Deliverable 4.6 – Hydrologic Design Report.

The hydrologic design report consists of compiling drainage area-related information for use in the WWHM2012 modeling that will be conducted as part of Task 5 (Data Analysis). Where possible, the following drainage area-related information has been compiled from documentation (drainage reports and/or plan drawings) for the project site. In cases where the drainage reports and the WWHM Report files differ in details the WWHM Report information has been used, as this is information directly from the model input.

Where drainage area and bioretention site information were not available we have substituted our field collection information.

In Task 5 we will be comparing the previously documented hydrologic design information with our field collected information and will be noting where there are significant differences. The purpose of this technical memo is to provide a baseline against which field-collected information can be compared.

<u>Site: Bellingham, Utter & Washington, Bioretention Cell #5, (BUW)</u>

The hydrologic design information provided for this site is from the “Columbia Neighborhood Storm Water Quality Improvements Design Report” produced by Pacific Surveying & Engineering, dated November 10, 2016.

The original hydrologic design was based on the 2012 Ecology manual and used WWHM2012 to do the runoff calculations.

The hydrologic design is based on a total contributing area of the 0.93 acres. The contributing area consisted of 0.49 acres of landscape (C soil, lawn vegetation, flat slope), 0.26 acres of roofs, and 0.18 acres of roads (flat slope).

The bioretention facility was designed to have a bottom area of 210 square feet. The maximum ponding depth is 0.5 feet with a riser at 0.2 feet. The amended soil was to be 1.75 feet deep with a design amended soil based on the Ecology standard soil mix (SMMWW 12). Below the Ecology soil mix is 0.5 feet of gravel.

The site was designed for no infiltration. A 4-inch diameter underdrain (with no orifice control) is located 1 inch above the bottom of the gravel layer.

Site: Bellingham, Kentucky & Cornwall, Site #2, (BCK)

This bioretention site was designed and constructed by the City of Bellingham. There is no stormwater or hydrologic design report for this facility, but the City did provide a WWHM project file and a WWHM2012 project report dated 5/16/2016.

The original hydrologic design was based on the 2012/2014 Ecology manual and apparently used WWHM12 to do the runoff calculations. In the model input the Site #2 bioretention facility is designated as "Kentucky South Bioswale".

The hydrologic design is based on a total contributing area of the 0.27 acres. The contributing area consisted of 0.27 acres of impervious surfaces (roads, flat slope).

The bioretention facility was designed to have a bottom area of 169 square feet with 3 to 1 side slopes (H:V). The bottom slope is flat. The maximum ponding depth is 3.827 feet with a riser at 0.167 feet. The amended soil was to be 1.50 feet deep with an amended soil mix of 15 inches per hour soil mix (Amended 15 in/hr). The Ksat safety factor is 1. Below the amended soil mix is 1.83 feet of gravel.

The site was designed for 100% infiltration and actually infiltrated 99.99%. The design infiltration rate is 12.3 inches per hour. The infiltration reduction factor is 1.0 (no reduction). Infiltration through the side walls was allowed.

A 4-inch diameter underdrain (with a 0.26-inch diameter orifice control) is located 17 inches above the bottom of the gravel layer.

Site: Marysville, 3rd & Quinn, NE Corner North Cell, (M3Q)

The hydrologic design information provided for this site is from the document "1st and 3rd Street Stormwater Retrofit Project Predesign Report, City of Marysville, Snohomish County, Washington" produced by Gray & Osbourne, Inc., dated January 2014.

The original hydrologic design was based on the 2012 Ecology manual and used WWHM12 to do the runoff calculations. Note that WWHM3 is incorrectly mentioned second page of Appendix B as the stormwater sizing software; the model input screenshots are actually of WWHM2012.

The hydrologic design is based on a total contributing area of the 0.08 acres. The contributing area consisted of 0.08 acres of impervious surfaces (roads, flat slope).

The bioretention facility was designed to have a bottom area of 500 square feet with vertical side slopes (0 to 1 (H:V)). The bottom slope is flat. The maximum ponding depth is 1.5 feet with a riser at 1.0 foot. The amended soil was to be 1.50 feet deep with the Ecology 6 inch per hour soil mix (SMMWW). The Ksat safety factor is 1. Below the Ecology soil mix is native soil.

The site was designed for 100% infiltration. The design infiltration rate is 1.0 inches per hour. The infiltration reduction factor is 1.0 (no reduction). There is no underdrain.

<u>Site: Marysville, 1st & Cedar, LID Site #S-1, (M1C)</u>

The hydrologic design information provided for this site is from the document "1st and 3rd Street Stormwater Retrofit Project Predesign Report, City of Marysville, Snohomish County, Washington" produced by Gray & Osbourne, Inc., dated January 2014.

The original hydrologic design was based on the 2012 Ecology manual and used WWHM12 to do the runoff calculations. Note that WWHM3 is incorrectly mentioned second page of Appendix B as the stormwater sizing software; the model input screenshots are actually of WWHM2012.

The hydrologic design is based on a total contributing area of the 0.03 acres. The contributing area consisted of 0.03 acres of impervious surfaces (roads, flat slope).

The bioretention facility was designed to have a bottom area of 193 square feet with vertical side slopes (0 to 1 (H:V)). The bottom slope is flat. The maximum ponding depth is 1.5 feet with a riser at 1.0 foot. The amended soil was to be 1.50 feet deep with the Ecology 6 inch per hour soil mix (SMMWW). The Ksat safety factor is 1. Below the Ecology soil mix is native soil.

The site was designed for 100% infiltration. The design infiltration rate is 2.0 inches per hour. The infiltration reduction factor is 1.0 (no reduction). There is no underdrain.

<u>Site: Monroe School District, Park Place Middle School, Cell #6, (MPP)</u>

The hydrologic design information provided for this site is from the document "Stormwater Site Plan for Park Place Middle School, Monroe, Washington" produced by Harmsen Associates, Inc., dated February 4, 2016.

The original hydrologic design was based on the 2005 Ecology manual as adopted by the City of Monroe and used WWHM3 to do the runoff calculations.

The hydrologic design is based on a total contributing area of the 0.48 acres. The contributing area consisted of 0.19 acres of landscape (C soil, lawn vegetation, flat slope) and 0.29 acres of pavement and walkways (roads, flat slope).

WWHM3 did not have a bioretention element to represent Cell #6. Instead the design engineers used the SSD Table element. Input to the SSD Table element consists of a user-defined table of stage, surface area, storage volume, surface discharge, and infiltration. There is no documentation on how the data in this table was calculated.

The stormwater site plan report states that the Cell #6 bioretention facility was designed to have a bottom area of 684 square feet with 3 to 1 (H:V) side slopes. The bottom slope is assumed to be flat. The maximum ponding depth is 1.5 feet with a riser at 1.0 foot. The amended soil was to be 1.50 feet deep with a bioretention soil mix (soil mix infiltration rate of 2 inches per hour). Below the bioretention soil mix is native soil.

The site was designed for 100% infiltration. The design infiltration rate is 4 inches per hour. The infiltration reduction factor is 1.0 (no reduction). Infiltration through the side walls was allowed. There is no underdrain.

Site: Monroe School District, Salem Woods Elementary School, Cell #2, (SSW)

The hydrologic design information provided for this site is from the document "Full Drainage Report for Salem Woods Elementary School, Snohomish County, Washington" produced by Harmsen Associates, Inc., dated January 19, 2017.

The original hydrologic design was based on the 2016 Snohomish County Drainage Manual and used WWHM12 to do the runoff calculations. Note that WWHM3 is incorrectly mentioned on page 2 of the drainage report as the stormwater sizing software; the actual WWHM2012 summary documentation is provided in Appendix B.

The hydrologic design is based on a total contributing area of the 0.71 acres. The contributing area consisted of 0.22 acres of landscape (C soil, lawn vegetation, moderate slope), 0.03 acres of roofs, and 0.46 acres of pavement and walkways (parking, moderate slope).

The bioretention facility was designed to have a bottom area of 1158 square feet with 3 to 1 (H:V) side slopes. The bottom slope is unknown. The maximum ponding depth is 1.5 feet with a riser at 1.0 foot. The amended soil was to be 1.50 feet deep with the Ecology standard soil mix (SMMWW 12). The Ksat safety factor is unknown. Below the Ecology soil mix is native soil.

The site was designed for 100% infiltration. The design infiltration rate is 11.5 inches per hour. The infiltration reduction factor is 1.0 (no reduction). Infiltration through the side walls was allowed. There is no underdrain.

Site: Renton, Harrington & NE 8th, Cell #E2, (RSH)

The hydrologic design information provided for this site is from the document "Technical Information Report: Green Connections – Harrington Avenue NE Phase II, NE 8th Place to NE 7th Street – Stormwater Retrofit Project" produced by CH2M, dated April 2017.

The original hydrologic design was based on the 2012 Ecology manual and used WWHM4 to do the runoff calculations.

The hydrologic design is based on a total contributing area of the 0.17 acres. The contributing area consisted of 0.0283 acres of landscape (A/B soil, lawn vegetation, moderate slope) and 0.1417 acres of impervious (roads, moderate slope).

The bioretention facility was designed to have a bottom area of 64.2 square feet with 3 to 1 (H:V) side slopes. The facility bottom slope is shown as 0.50, but it is assumed that this is an error and should be 0.005 feet/foot. The maximum ponding depth is 0.70 feet with a riser at 0.45 feet. The amended soil was to be 1.50 feet deep with a design amended soil infiltration rate of 5 inches per hour (Amended 5 in/hr). No Ksat safety factor was included. Below the Ecology soil mix is 0.5 feet of gravel.

The site was designed for infiltration and an underdrain. The long-term native soil infiltration rate was 1.2 inches per hour with an infiltration reduction factor of 1.0 (the long-term infiltration rate included a safety factor of 8).

A 6-inch diameter underdrain (with a 1-inch diameter orifice control) is located at the bottom of the gravel layer. The amended soil layer treated 94.9% of the stormwater flowing into the facility.

<u>Site: Tacoma School District, Wainwright Intermediate School, Fircrest, Cell #4, (FWI)</u>

The hydrologic design information provided for this site is from the document "Stormwater Site Plan" produced by AHBL, dated March 2015, revised May 2015.

The original hydrologic design was based on the 2012 Ecology manual and used WWHM2012 to do the runoff calculations.

The hydrologic design is based on a total contributing area of the 0.33 acres. The contributing area consisted of 0.23 acres of landscape (C soil, lawn vegetation, flat slope) and 0.10 acres of parking (roads, flat slope).

The bioretention facility was designed to have a bottom area of 159 square feet with 3 to 1 (H:V) side slopes. The facility bottom slope is zero. The maximum ponding depth is 1.5 feet with a riser at 1.0 feet. The amended soil was to be 1.50 feet deep with a design amended soil based on the Ecology standard soil mix 6-inch infiltration rate (SMMWW). A Ksat safety factor of 4 was included. Below the Ecology soil mix is 1.0 foot of gravel.

The site was designed for no infiltration. A 6-inch diameter underdrain (with no orifice control) is located at the bottom of the gravel layer. The amended soil layer treated 96.25% of the stormwater flowing into the facility.

<u>Site: Tacoma School District, Wilson High School, Rain Garden, (TWH)</u>

The hydrologic design information provided for this site is from the document "Wilson High School Phase 2 Stormwater Site Plan" produced by Sitts & Hill Engineers, dated October 2014.

The original hydrologic design was based on the 2012 City of Tacoma manual and used WWHM2012 to do the runoff calculations. However, the bioretention site (labeled "Rain Garden" in the report) was modeled using the WWHM2012 gravel trench element instead of the bioretention element.

The hydrologic design is based on a total contributing area of the 1.62 acres. The contributing area consisted of 0.19 acres of landscape (C soil, lawn vegetation, flat slope) and 1.43 acres of parking (flat slope).

The bioretention facility was designed to have a bottom area of 992 square feet with 3 to 1 (H:V) side slopes. The bottom slope is 0.00001. The maximum ponding depth is 1.0 foot with a riser at the surface of the soil. The amended soil was to be 1.5 feet deep. The gravel trench element input used a porosity of 0.4 for the top layer. This implies a soil with the consistency of gravel (no specific soil mix was stated). A second soil layer of 1.0 foot was included; it had a porosity of 1.0 (implying no soil), which appears to be an error.

The site was designed for 91% infiltration. The design infiltration rate is 1.5 inches per hour. The infiltration reduction factor is 1.0 (no reduction). Infiltration through the side walls was allowed. There is no underdrain.

Site: Tumwater School District, Bush Middle School, Bioretenion Area, (TBM)

The hydrologic design information provided for this site is from the document "Drainage Report: Tumwater Middle School Renovations and Additions" produced by BCRA, dated May 27, 2016.

The original hydrologic design was based on the 2005 Ecology manual and used WWHM2012 to do the runoff calculations.

The hydrologic design is based on a total contributing area of the 0.18 acres. The contributing area consisted of 0.05 acres of landscape (A/B soil, lawn vegetation, flat slope) and 0.13 acres of roads (flat slope).

The bioretention facility was designed to have a bottom area of 280 square feet with 3 to 1 (H:V) side slopes. The bottom slope is zero. The maximum ponding depth is 1.5 feet with a riser at 1.0 foot. The amended soil was to be 1.75 feet deep with a design amended soil based on the Ecology standard soil mix (SMMWW 6). The Ksat safety factor is 4. Below the Ecology soil mix is native soil.

The site was designed for 100% infiltration. The design infiltration rate is 0.9 inches per hour. The infiltration reduction factor is 1.0 (no reduction). Infiltration through the side walls was allowed. There is no underdrain.

APPENDIX 16

Bioretention Hydrologic Performance Study Phase II Deliverable 5.2 Hydrologic Model Development and Results. Clear Creek Solutions, Inc. 6/19/2020

CLEAR CREEK SOLUTIONS

CLEAR CREEK SOLUTIONS, INC.

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MEMORANDUM

DATE: 19 June 2020

TO: Eric Christensen, P.E., Water Resources Director, City of Olympia

CC: Bill Taylor, Principal Investigator

FROM: Doug Beyerlein, P.E., Hydrology Lead and Project Manager

SUBJECT: Deliverable 5.2 Hydrologic Model Development and Results FINAL

For Task 5 of the Bioretention Hydrologic Performance Study II we have completed Deliverable 5.2 – Hydrologic Model Development and Results. Deliverable 5.2 summarizes the development of the models for each bioretention based on as-built construction, confirmed drainage area, and site field conditions (depth of soil mix, groundwater, native soil infiltration, etc.). The memo also provides analysis and recommendations for inclusion in Deliverable 5.4.

This deliverable has been internally reviewed by the BHP Study project team and comments received from team members have been incorporated into this final deliverable memo, as appropriate. The City of Olympia and the Washington Department of Ecology staff have also reviewed this deliverable and have provided valuable suggestions and comments. This final deliverable has been updated to include their input to the model development and results discussion.

Modeling Procedures

The field monitoring provided information that was used as part of the WWHM2012 model input for each of the ten bioretention sites.

The hydrologic monitoring data collection (previously discussed) provided time series data for rainfall, inflow, overflow, groundwater, and ponding at 5-minute intervals for use in the individual site models. Each data time series was copied into (imported into) the individual site model's WWHM2012 data base for later use in either the model's calculations (rainfall data or inflow data) or comparison with the model's results (inflow, overflow, groundwater, and ponding data).

The geotechnical data collection provided information about the bioretention soil mix found at each of the ten bioretention sites and the native soil infiltration rate, as measured on-site. Some of these bioretention sites were constructed without using the standard bioretention soil mix specified by Ecology. Accordingly, we did not expect that all of the soil mixes would meet that specific standard. When it was the case that their general soil characteristics, as they related to water movement, did not match Ecology's standard bioretention soil mix the geotechnical data provided guidance in the selection of appropriate engineered soil mix for the bioretention site in question. The measured native soil infiltration rate was used to determine the appropriate infiltration value to include in each model. As will later be discussed, there were sites where groundwater mounding influenced the native soil infiltration rate during the winter months. These specific sites will be noted in the individual site results section of this memo.

The vegetation data collection was not used directly in the input to the individual site models. However, its potential impact on the hydrologic performance of each site was considered in terms of leaf litter impact on ponding and water infiltrating into the top bioretention soil layer. Also, vegetation influences evapotranspiration from the soil layer. WWHM2012 assumes a standard evapotranspiration rate from the soil that may be dependent based on the type and amount of vegetation.

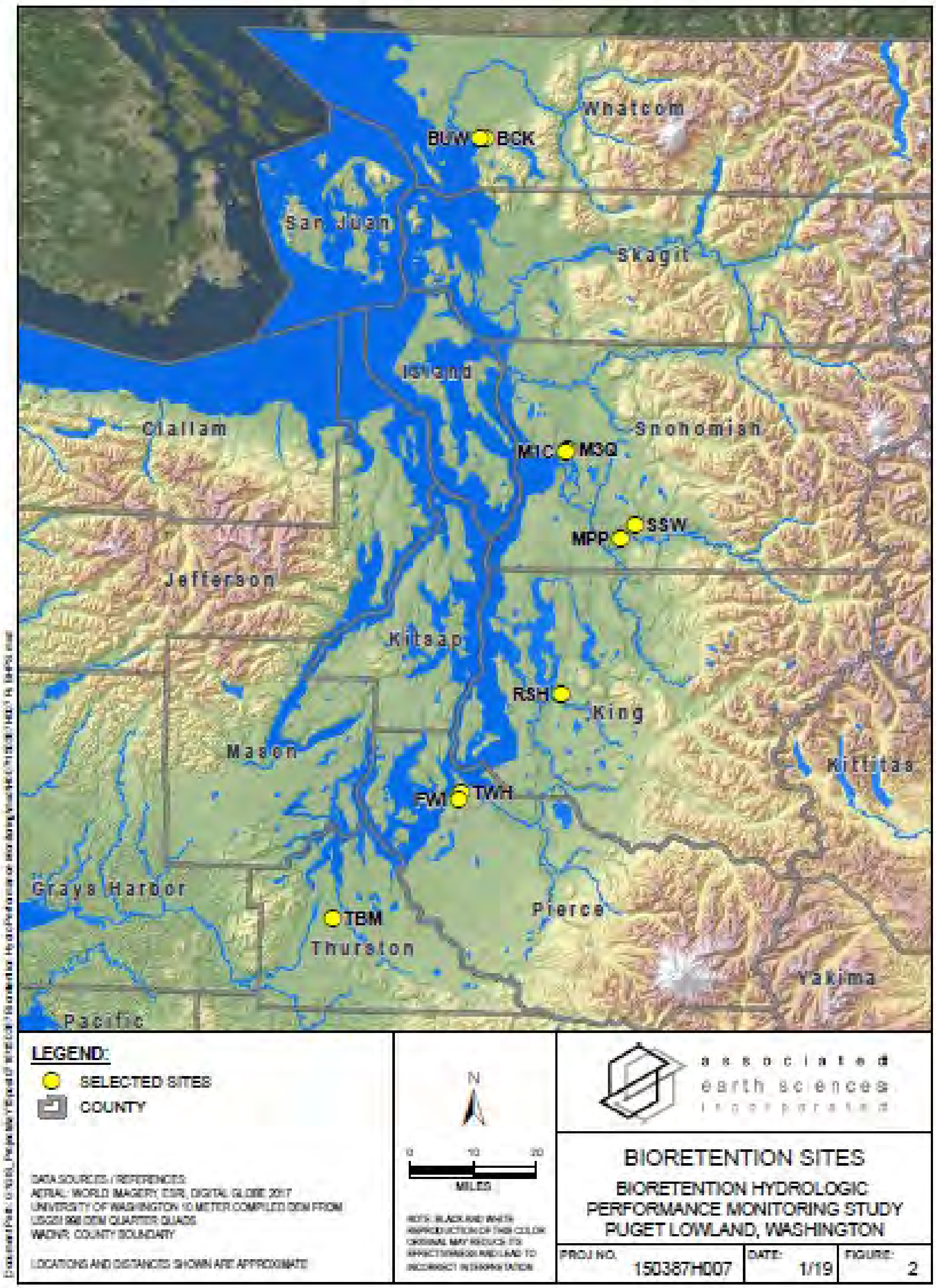
The other field monitoring data collected for use in the individual bioretention site models were the dimensions of the bioretention facility (length, width, maximum depth of ponding) and the outlet control structure(s), if any. The size of each facility was field measured and compared with design drawings, if available. The elevation of the inlets, outlet riser or weir, and the top of the facility were surveyed. The underdrain elevation and outlet diameter was also measured for the sites that have an active underdrain.

All of the above field data were used in one way or another in either the WWHM2012 model input for each of the ten bioretention sites or evaluating the model output.

As described in Deliverable 2.2, the ten bioretention sites are:

Site Name	**Jurisdiction**	**Project Name**
BUW	Bellingham	Columbia WQ Improvements
BCK	Bellingham	Nevada-Kentucky Bike Boulevard
FWI	Tacoma S.D.	Wainwright Intermediate School
M1C	Marysville	1st and 3rd Street SW Retrofit
M3Q	Marysville	1st and 3rd Street SW Retrofit
MPP	Monroe S.D.	Park Place Middle School
RSH	Renton	Green Connections
SSW	Monroe S.D.	Salem Woods Elementary School
TBM	Tumwater S.D.	Bush Middle School
TWH	Tacoma S.D.	Wilson High School

The locations of the ten sites in the Puget Sound Basin are shown in the figure below.


Whatcom
BUW
BCK
San Juan
Skagit
Island
Clallam
Snohomish
M1C
M3Q
SSW
MPP
Jefferson
Kitsap
RSH
King
Mason
Kittitas
FWI
TWH
Grays Harbor
TBM
Pierce
Thurston
Yakima
Pacific
LEGEND:
SELECTED SITES
COUNTY
DATA SOURCES / REFERENCES:
AERIAL: WORLD IMAGERY, ESRI, DIGITAL GLOBE 2017
UNIVERSITY OF WASHINGTON 10 METER COMPILED DEM FROM
USGS 1:24,000 DEM QUARTER QUADS
WADNR, COUNTY BOUNDARY
LOCATIONS AND DISTANCES SHOWN ARE APPROXIMATE
N
0
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20
MILES
associated
earth sciences
incorporated
BIORETENTION SITES
BIORETENTION HYDROLOGIC
PERFORMANCE MONITORING STUDY
PUGET LOWLAND, WASHINGTON
PROJ NO.
150387H007
DATE:
1/19
FIGURE:
2

After collection, analysis, and input of the field data into the WWHM2012 models it became apparent that the severe cold weather experienced in the winter of 2018-2019 adversely affected the ability to accurately model this time period. Freezing temperatures and snow were the major problems. Freezing temperatures made all of the monitored rainfall, inflow, overflow, groundwater, and ponding data suspect for this period (see Table 1 for summary of number of days of freezing temperatures by site).

Table 1. Number of days of freezing temperatures per month

Site	Nov 2018	Dec 2018	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	Jun 2019
BCK	1	4	5	19	8	0	0	0
BUW	0	5	5	22	8	0	0	0
FWI	12	12	17	26	21	1	0	0
M1C	0	5	7	22	10	0	0	0
M3Q	4	7	7	21	9	0	0	0
MPP	5	13	15	26	25	6	0	0
RSH	0	4	4	11	9	0	0	0
SSW	8	11	14	26	18	0	0	0
TBM	5	7	10	21	12	0	0	0
TWH	12	8	15	21	24	1	0	0

In particular, precipitation that fell as snow instead of rain could not be modeled correctly in WWHM2012, inflow and overflow were constricted (if not totally blocked) by ice formation on the ponding surfaces of the bioretention sites, and ponding depths (as measured) were not accurate. To further complicate the monitoring work, we observed some local city and school district maintenance staff using the bioretention facilities for snow storage when plowing the adjacent impervious road and parking lot surfaces. This meant that piles of snow covered the monitoring equipment and affected the monitored readings for days after the surrounding land temperatures had warmed up and the non-piled snow had melted.

There was no way to adjust the monitored field data to compensate for these problems. As a result, a decision was made to limit the model result comparisons to the months of April, May, and June 2019.

Data Analysis and Results

Modeling Comparison of Observed versus Design Results

Summary

In general the hydrologic performance of the ten bioretention facilities was well represented by WWHM2012. The range in performance in terms of ponding depths and well point elevations met or exceeded the expected WWHM2012 model graphical results comparison with the monitored data for many of the sites, although there was a frustrating lack of consistency from one site to another. This lack of consistency was observed when two fairly identical sites produced very different monitored data (for example, M1C and M3Q well point data).

In general, the WWHM2012 models of the ten bioretention sites reproduced the monitored bioretention hydrologic performance data with accurate results when viewing the long-term graphical trends. Accurate results are defined as periods where the simulated results match closely with the recorded (monitored) data and other periods where the simulated results are sometimes high and sometimes low. Overall there is no obvious bias high or low.

As noted in our earlier study, it appears that there are two major model inputs that may be influencing the results. The vegetative litter cover can, at some sites, reduce the infiltration rate of the ponded water into the bioretention soil mix. At sites MPP, RSH, SSW, and TWM this vegetative litter cover was modeled using a limiting soil type (ASTM 1, ASTM 2, or ASTM 3). At the other six sites no vegetative litter cover was modeled.

The other major model input that may be influencing the results is the evapotranspiration (ET) from the bioretention soil mix. It is set in WWHM2012 to equal 0.5*PET (Potential ET). There is evidence from the well point data that the 0.5 multiplier factor should be higher. That will help to remove water faster from the bioretention soil mix layer.

<u>Site Characteristics</u>

The field collected data, described in the previous section, was used to provide input data in the construction of the individual WWHM2012 models of each bioretention site. These data are summarized in Table 2 below.

Table 2. Site General Information

Site	Drainage Area (ac)	Top Area (ft2)	Bottom Area (ft2)	Top Area to Drainage Percentage	Overflow Height (ft)	Modeled Depth (ft)	Native Soil Infiltration (in/hr)	Underdrain
BCK	0.27	71	60	0.6%	0.05	3.8	0.5	Yes
BUW	0.93*	38.5	38.5	0.1%	0.05	2.8	0.05	Yes
FWI	0.33	250	159	1.7%	1.0	2.45	0.05	Yes
M1C	0.03	132	132	10.1%	0.6	1.3	17	No
M3Q	0.02	200	200	23.0%	0.95	6.25	15	No
MPP	0.48	1320	684	6.3%	3.6	2.15	3	No
RSH	0.17	68	64	0.9%	0.3	3.6	0.5	Yes
SSW	0.40	1022	735	5.9%	1.4	2.8	16	No
TBM	0.31	366	280	2.7%	1.1	3.85	8	No
TWH	1.62	1269	1200	1.8%	0.12	4.1	0.05	Yes

Notes:

* Only a portion of the stormwater runoff from the drainage area actually enters the bioretention site due to inflow inlet restrictions.

The drainage area is the area that contributes runoff to the bioretention site. For each bioretention facility this information was taken from design reports and drawings, if available. The drainage area inflow restriction to BUW is discussed in detail in the BUW site results section of this memo.

The bottom area is the bottom footprint of each of the bioretention cells. The bottom area is calculated from the field survey information. Most of the bioretention sites had a flat bottom area and sloping sides. The side slopes were calculated based on the difference in bottom and top lengths and widths and bioretention cell heights.

The top area is the surface area footprint of each of the bioretention cells at their individual overflow height above the bottom surface. The top area was not measured but was calculated based on the bottom area dimensions, side slopes, and the overflow height.

The top area to drainage percentage is the relative size of the bioretention top area (as defined above) to the contributing drainage area. The larger the percentage the larger the relative size of the bioretention area is to the surrounding area that drains to it. Many of the sites have percentages in the 1-5% rate. According to the 2019 Ecology manual, for design on projects subject to MR#5 (On-Site Stormwater Management) and choosing to use The List Approach for that requirement, the bioretention BMP shall have a horizontally projected surface area below the overflow which is at least 5% of the area draining to it. As shown in Table 2, some of these sites (BCK, BUW, FWI, RSH, TBM, and TWH) do not meet this 5% standard. Sites BCK, BUW, and RSH were field-fit retrofits and were not necessarily designed to meet Ecology's minimum stormwater requirements. As discussed below, FWI, TBM, and TWH either relied on infiltration (TBM) or an underdrain (FWI and TWH) to prevent site flooding, but none of these three sites met MR#5 standards.

The overflow height is the height (depth) from the bioretention soil surface to an overflow. The overflow may be a riser inlet, weir, or lowest spot on the side of the bioretention facility. When the ponding depth reaches this height then water can flow out of the bioretention cell via surface discharge (the other ways that water can flow out are by infiltrating into the native soil or discharging through an underground underdrain).

The modeled depth is the total soil depth modeled in the individual WWHM2012 models. This modeled depth typically includes two modeled soil layers. The top modeled soil layer (Layer 1) is the bioretention soil mix (BSM). The second modeled soil layer (Layer 2) is the soil layer below the BSM soil mix (Layer 1) and above the bottom of the monitored well point. Layer 2 was included in each model to provide a subsurface water depth/height that can be compared with the monitored well point data. The second layer soil is typically gravel or sand and is imported as part of the site design. For the sites with a top leaf litter layer a third modeled soil layer was added. For these sites a top layer (Layer 1) was added above the BSM layer to represent the effect of leaf litter in reducing the water movement into the BSM layer (which in these models is Layer 2). Details of the composition of the modeled depth in each bioretention site are presented in Table 3 below.

Native soil infiltration (inches per hour) for each site was initially based on the infiltration tests conducted as part of the geotechnical field measurements. After discussions with the geotech experts who conducted the infiltration tests, some of the native soil infiltration rates were reduced to compensate for the limiting geology of the underlying native soils.

An underdrain is a set of pipes in the bottom of the bioretention facility that collect water and discharge it through an outlet control structure. Typically underdrains are connected to a storm sewer system. Underdrains are used where it appears that the native soil infiltration rate is insufficient to remove all of the water from the bioretention cell and there is a potential for surface ponding to overtop the facility and flood surrounding properties. Underdrains can prevent this from happening. Five of the ten sites have an underdrain. For each of these sites water can also infiltrate into the native soil. As discussed below, in general underdrain flows were difficult to accurately monitor and usually were connected to the riser surface discharge outflow. They were modeled accordingly.

Table 3 provides information on the modeled soil layers in each bioretention model.

Table 3. Modeled Soil Layer Information

Site	Layer 1 Soil	Layer 1 Depth (ft)	Layer 2 Soil	Layer 2 Depth (ft)	Layer 3 Soil	Layer 3 Depth (ft)	Native Soil Infiltration (in/hr)
BCK	SMMWW 12	1.5	Gravel	2.3	none	0	0.5
BUW	ASTM100	1.5	Gravel	1.3	none	0	0.05
FWI	ASTM60	1.5	Gravel	1.4	none	0	0.05
M1C	SMMWW 12	1.3	none	0	none	0	17
M3Q	SMMWW 12	1.0	Sand	5.25	none	0	15
MPP	ASTM1	0.2	SMMWW 12	1.7	Sand	0.25	3
RSH	ASTM2	1.3	Gravel	2.3	none	0	0.5
SSW	ASTM2	0.1	SMMWW 12	1.4	Sand	1.3	16
TBM	SMMWW 12	1.5	Sand	2.35	none	0	8
TWH	ASTM3	0.1	SMMWW 12	1.4	Gravel	2.6	0.05

As described above, the modeled depth is the total soil depth modeled in the individual WWHM2012 models. The modeled soil depth is composed two or more individual soil layers.

For BCK, M1C, M3Q, and TBM, Layer 1 represents the bioretention soil mix (BSM) type and depth. The Layer 1 depth is the depth or thickness of the BSM, as measured in the geotechnical field work. For some sites, the actual Layer 1 soil mix was initially unknown, but could be determined by comparing the monitored and modeled surface pond depths and well point depths. WWHM2012 provides the soil input parameter values for the Ecology-standard bioretention soil mix. WWHM2012 also provides soil input parameter values for a range of ASTM (American Society for Testing and Materials) soils. For the purposes of hydrologic modeling the ASTM number specification (for example, ASTM1) refers to the saturated conductivity value (1 inch per hour for ASTM1).

For BUW, FWI, and RSH the soil mix found on site does not meet Ecology's bioretention soil specifications. Water quality treatment is not provided by these soil mixes due to their excessive infiltration rates. It should be noted that for the purpose of the long-term simulation to evaluate compliance with MR#5 and MR#6 that these inappropriate soil mixes were replaced with the Ecology-standard bioretention soil mix. All three sites still failed MR#5, and BUW and RSH failed MR#6.

Layer 2 is not necessarily an engineered bioretention soil mix soil. Layer 2 is the soil layer below the BSM soil mix (Layer 1) and above the bottom of the monitored well point. Layer 2 was included in each model to provide a subsurface water depth/height that can be compared with the monitored well point data. When there was an underdrain, it was located in Layer 2.

For the four sites with infiltration constricted by leaf litter a third modeled soil layer was added. For these sites only a top layer (Layer 1) was added above the BSM layer to represent the effect of leaf litter in reducing the water movement into the BSM layer (which in these models is Layer 2).

<u>WWHM2012 Model Construction</u>

A separate WWHM2012 model was constructed for each of the ten bioretention sites. The bioretention site was located on the appropriate WWHM2012 project site map (see Figure 1 for an example).

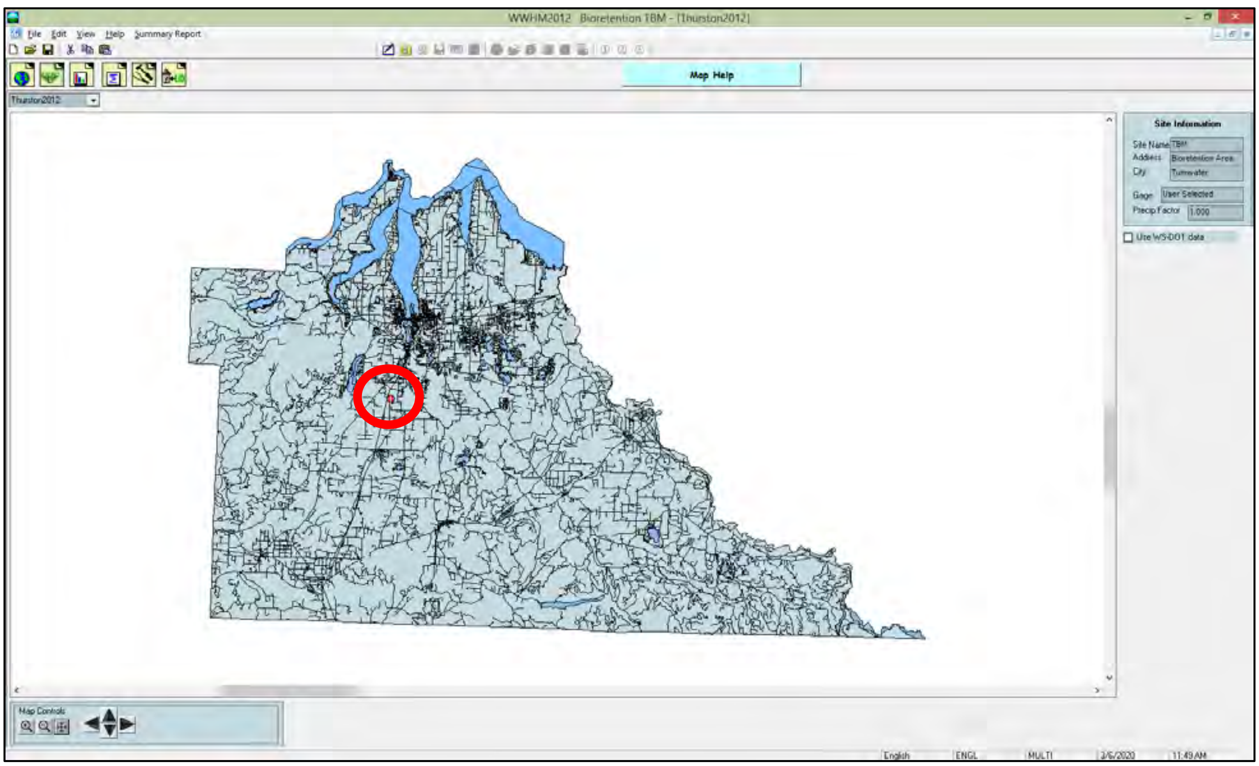


Figure 1. WWHM2012 Project Site (TBM) in Thurston County

The TBM bioretention site is located at the red dot in the center of the red circle in Thurston County.

For each model the corresponding monitored 5-minute data were imported into the specific model's data base file (HSPF WDM file), as shown in Figure 2.

Figure 2. WWHM2012 Time Series Data

Each monitored data set is given a unique data set number (DSN), as shown in Figure 2.

For TBM the monitored 5-minute precipitation time series is data set number 101; the monitored inflow is DSN 131; the pond depth is DSN 111; and the two well point depth time series are DSN 121 and 122. For this site there is no monitored outflow data.

The above monitored time series will be used to compare and evaluate the model results.

The model simulation period time step and start and end dates were changed from the default WWHM2012 simulation values. These changes were made by going to View, Options, Timestep (see Figure 3). The WWHM2012 default time step was changed from 15 minutes to 5 minutes because all of the monitored data were collected in 5-minute intervals. The WWHM2012 simulation start and end dates were changed to run from 12 October 2018 through the end of the data collection period (typically mid-July 2019). Because of above-mentioned freezing condition problems in the winter months the simulation started in October 2018, but the model results were only compared with the monitored data only for the period of April through the end of June 2019. This provided a consistent analysis period for all ten sites.

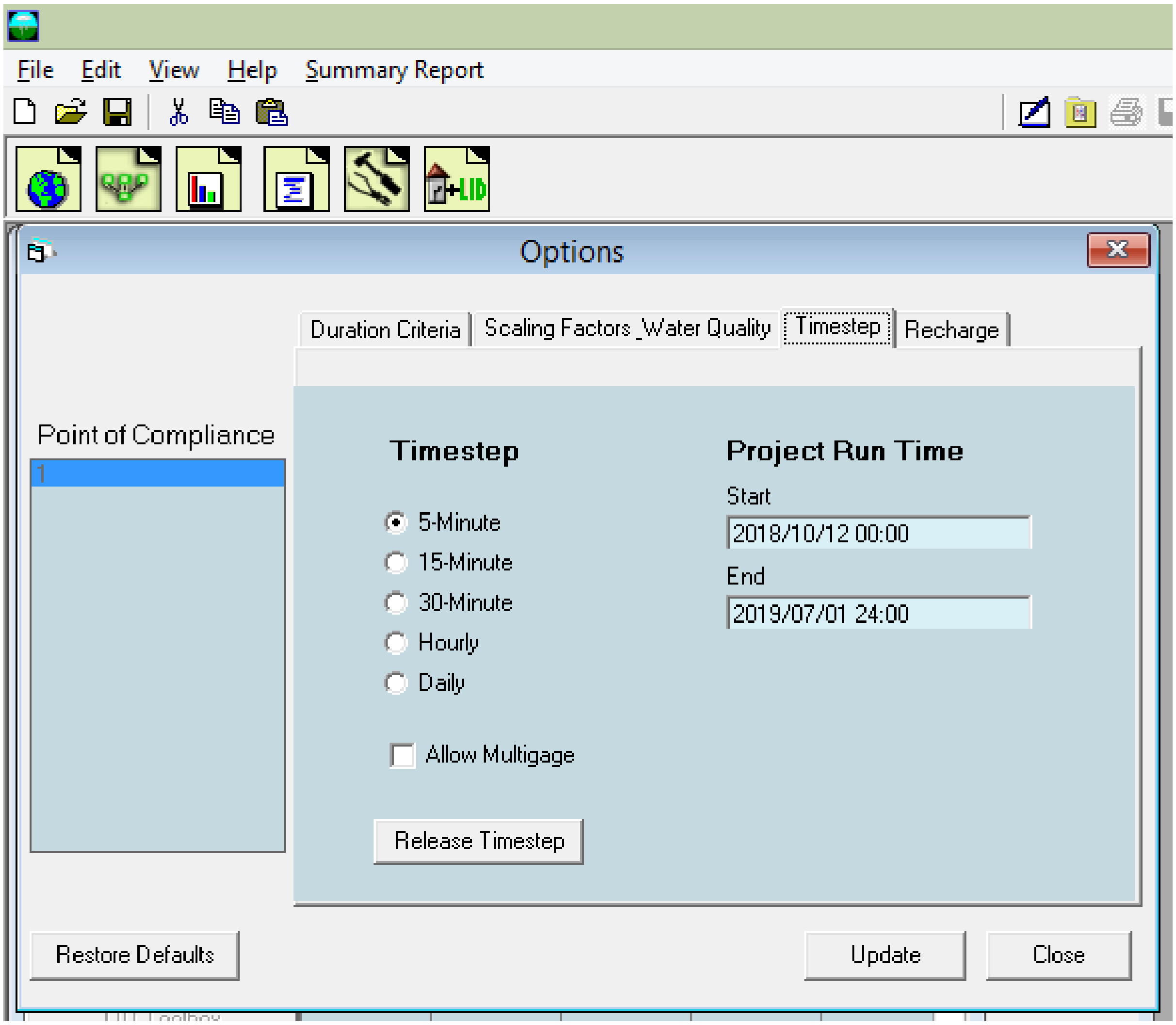


Figure 3. WWHM2012 Simulation Time Step and Start and End Dates (for TBM)

The contributing drainage area for each bioretention facility was determined from design reports and drawings, if available. Where there was a question about the drainage area it was field checked, as described above. The specific acreages were input to each WWHM2012 model using the WWHM2012 Land-use element (see Figure 4).

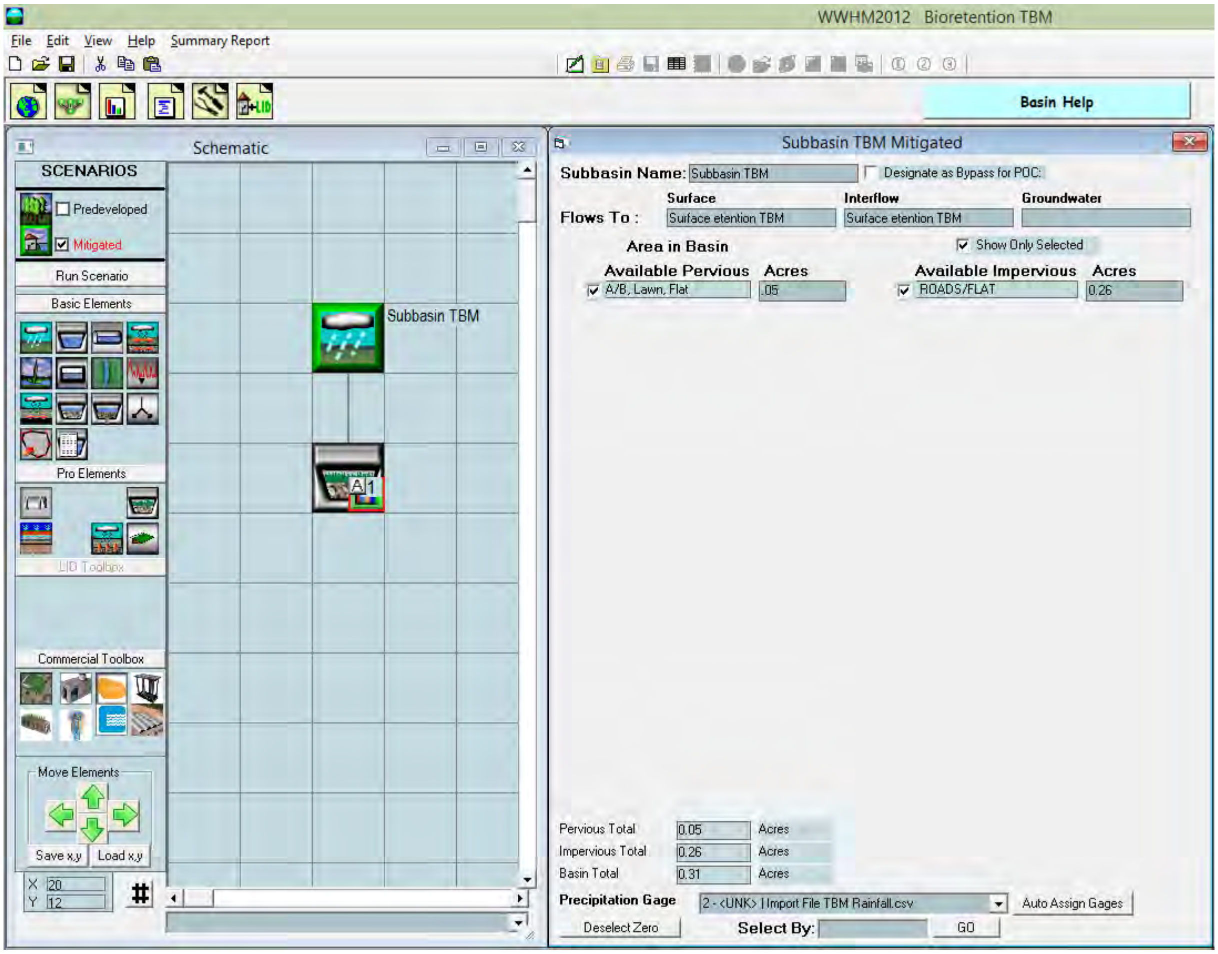


Figure 4. WWHM2012 Land-use Element

The specific bioretention facility is represented in WWHM2012 by the Bioretention element and contains all of the user input for defining the dimensions and characteristics of the bioretention site. The reader is referred to the *WWHM2012 User Manual* for more details about the Bioretention element input and model calculations. The TBM Bioretention element is shown in Figure 5.

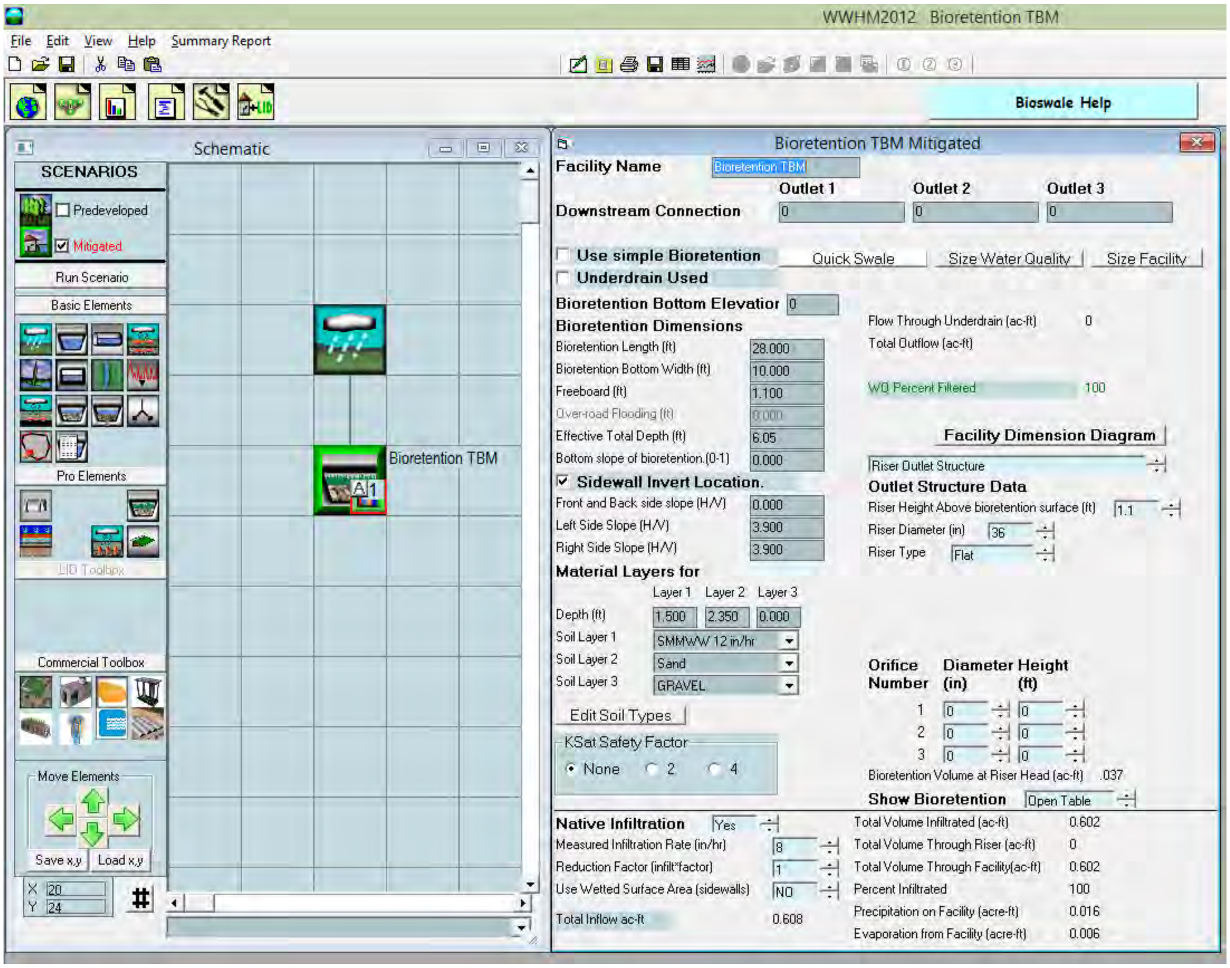


Figure 5. WWHM2012 Bioretention Element (for TBM)

WWHM2012 Model Results

Two sets of WWHM2012 model results were generated and evaluated. For each site WWHM2012 was first set up to compare the model results with the monitored data. For the comparison of the model simulation results with the monitored/recorded data the primary focus was trying to match the simulated and recorded ponding depths and the simulated and recorded well point data. The ponding depths showed how the water ponded on the surface of the bioretention facility. The well point data showed how the water filled up the bioretention soil column. The ponding and well point data are linked. If the well point data shows that the bioretention soil column is completely saturated then water cannot drain from the surface into the bioretention soil and this causes water to pond on the surface. Water can also pond on the surface even if the soil column is not completely saturated if the inflow of water into the bioretention facility is greater than the infiltration into the top layer (Layer 1) of the bioretention soil mix.

Each model was set up with a specific bioretention soil mix for each soil layer and an infiltration rate. These model inputs were then adjusted to produce the best match of the simulated ponding and well point results with the recorded data. Those final model inputs are shown in Table 3. The ponding depth plots and the well point plots are shown for each site in the Individual Bioretention Site Results discussion below.

The model inflow and outflow simulation results were also compared with the monitored inflow and outflow data, where available. A number of issues were found with the monitored inflow data. Specifically, there were numerous periods in December 2018 and January through March 2019 where because of freezing conditions and/or snow the monitored inflow data matched poorly with the monitored rainfall data. For this reason the results comparison was limited to the months of April, May, and June 2019. This decision eliminated the possibility of error in the monitored/recorded inflow data affecting the bioretention results. The simulated inflow volumes were plotted together with the recorded inflow data to identify inconsistencies. The comparison plot for each site is shown in in the Individual Bioretention Site Results discussion below.

For many of the bioretention sites there was no outflow. This was because all of the inflow to the bioretention site infiltrated into the native soil. Also as noted below, outflow, when it did occur, was difficult to measure due to the outlet conditions.

Model results are presented in both statistical and graphical formats. The statistical format compares the model simulated versus recorded/monitored inflow data, pond depths, soil layer water content depths, and underdrain discharge volumes for the ten sites in terms of maximum values, minimum, mean, and standard deviation of the 5-minute data for the data collection period. The statistical comparison periods were limited to the period of April through June 2019 (primarily due to freezing conditions and/or snow in the winter months).

The statistical results are shown in tables 4 through 8 below. Table 4 shows the maximum, minimum, mean, and standard deviation of the 5-minute data for monitored/recorded (R) and model simulated (S) bioretention site inflow results for the period of April, May, and June 2019.

It should be noted that some of the statistical values (particularly the mean values) are very small and are, for all practical purposes, equal to zero due to long periods when the facilities were dry.

Table 4. Bioretention Site Inflow (cfs)

Site	MAX-R	MAX-S	MIN-R	MIN-S	MEAN-R	MEAN-S	STD DEV-R	STD DEV-S
BCK	0.03	0.07	0.00	0.00	0.0002	0.0006	0.002	0.003
BUW	0.12	0.10	0.00	0.00	0.0006	0.0013	0.006	0.006
FWI	0.10	0.01	0.00	0.00	0.0005	0.0001	0.004	0.001
M1C	0.11	0.15	0.00	0.00	0.0014	0.0006	0.006	0.005
M3Q	0.04	0.10	0.00	0.00	0.0002	0.0004	0.001	0.003
MPP	0.07	0.07	0.00	0.00	0.0016	0.0011	0.007	0.005
RSH	0.23	0.05	0.00	0.00	0.0006	0.0003	0.007	0.002
SSW	0.35	0.11	0.00	0.00	0.0022	0.0016	0.014	0.009
TBM	0.06	0.08	0.00	0.00	0.0006	0.0004	0.003	0.003
TWH	0.44	0.17	0.00	0.00	0.0024	0.0013	0.018	0.010

Table 5. Bioretention Site Pond Depth (feet)

Site	MAX-R	MAX-S	MIN-R	MIN-S	MEAN-R	MEAN-S	STD DEV-R	STD DEV-S
BCK	0.08	0.06	0.00	0.00	0.001	0.002	0.003	0.009
BUW	0.03	0.04	0.00	0.00	0.012	0.0005	0.007	0.002
FWI	0.05	0.002	0.00	0.00	0.009	0.00003	0.008	0.0002
M1C	0.14	0.62	0.00	0.00	0.007	0.002	0.012	0.023
M3Q	0.12	0.21	0.00	0.00	0.007	0.001	0.008	0.007
MPP	0.39	0.22	0.00	0.00	0.027	0.005	0.034	0.020
RSH	0.42	0.33	0.00	0.00	0.007	0.007	0.030	0.039
SSW	0.17	0.16	0.00	0.00	0.007	0.002	0.019	0.012
TBM	0.21	0.05	0.00	0.00	0.005	0.0003	0.013	0.002
TWH	0.20	0.10	0.00	0.00	0.005	0.001	0.010	0.006

Table 6. Bioretention Site Well Point Depth (feet)

Site	MAX-R	MAX-S	MIN-R	MIN-S	MEAN-R	MEAN-S	STD DEV-R	STD DEV-S
BCK	1.76	3.79	0.00	0.00	0.22	0.43	0.27	0.91
BUW	0.42	2.17	0.00	0.00	0.001	0.145	0.01	0.27
FWI	0.46	0.54	0.00	0.00	0.004	0.06	0.03	0.08
M1C	1.15	1.29	0.00	0.00	0.06	0.09	0.18	0.16
M3Q	0.19	2.87	0.00	0.00	0.00	0.52	0.01	0.49
MPP	1.98	0.98	0.00	0.00	0.04	0.32	0.22	0.29
RSH	1.73	2.58	0.00	0.00	0.15	0.36	0.35	0.54
SSW	0.00	1.59	0.00	0.00	0.00	0.30	0.00	0.20
TBM	1.22	2.50	0.00	0.00	0.02	0.21	0.09	0.28
TWH	0.44	1.44	0.00	0.00	0.01	0.11	0.05	0.17

Table 7. Bioretention Underdrain Discharge (cfs)

Site	MAX-R	MAX-S	MIN-R	MIN-S	MEAN-R	MEAN-S	STD DEV-R	STD DEV-S
BCK*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BUW*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FWI**	0.002	0.01	0.00	0.00	0.000003	0.00011	0.00006	0.0006
M1C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M3Q	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MPP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RSH*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SSW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TBM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWH*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note:
* could not be measured
** same as outflow

Table 8. Bioretention Site Outflow (cfs)

Site	MAX-R	MAX-S	MIN-R	MIN-S	MEAN-R	MEAN-S	STD DEV-R	STD DEV-S
BCK	0.049	0.057	0.00	0.00	0.0001	0.0004	0.0017	0.0029
BUW	0.045	0.100	0.00	0.00	0.00002	0.0012	0.0010	0.0059
FWI**	0.002	0.01	0.00	0.00	0.000003	0.00011	0.00006	0.0006
M1C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
M3Q	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MPP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RSH*	0.14	0.05	0.00	0.00	0.0005	0.0002	0.004	0.002
SSW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TBM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TWH	0.09	0.11	0.00	0.00	0.0003	0.001	0.003	0.006

Note:
* surface plus underdrain
** underdrain flow (no surface discharge)

The statistical comparisons do not necessarily match well. This can be for a number of reasons, as discussed in the individual site results below. As such, the statistical comparison of results can be misleading. What is more important is the ability to match trends rather than statistics. By looking at graphical trends we can visually see if the model provides the same trends in terms of inflow, ponding, and well point data as the monitored info. The statistics cannot show trends and therefore are less useful in evaluating the modeling results than the graphical comparisons.

A summary of the model graphical comparisons is presented in Table 9. The table presents a comparison of the model simulated versus recorded/monitored inflow data, pond depths, soil layer water content depths, and underdrain discharge volumes for the ten sites.

Table 9. Comparison of Model (S) versus Monitored (R) Results

Site	S vs R Inflow	S vs R Pond	S vs R Soil Layer	S vs R Outflow	S vs R Underdrain
BCK	High	Mixed	High	Mixed	Undeterminable
BUW	Mixed	High	High	High	Undeterminable
FWI	Accurate	Low	Mixed	High	High
M1C	Mixed	High	Mixed	N/A	N/A
M3Q	High	Mixed	High	N/A	N/A
MPP	Mixed	Low	Low	N/A	N/A
RSH	Mixed	Accurate	Mixed	Low	Undeterminable
SSW	High	Accurate	High	N/A	N/A
TBM	Mixed	Low	Mixed	N/A	N/A
TWH	Mixed	Low	High	Mixed	Undeterminable

S vs R Inflow is the comparison of the simulated (S) inflow volume to the bioretention site compared to the monitored or recorded (R) inflow volume. The simulated inflow volume is calculated from the rainfall on the contributing drainage area to the bioretention site. The monitored inflow volume is calculated from the inflow measurements collected at specific input locations entering the bioretention site.

S vs R Pond is the comparison of the simulated (S) bioretention site surface ponding depths compared to the monitored or recorded (R) ponding depths.

S vs R Soil Layer is the comparison of the simulated (S) bioretention site subsurface soil layer water elevations compared to the monitored or recorded (R) well point data.

S vs R Outflow is the comparison of the simulated (S) outflow volume to the bioretention site compared to the monitored or recorded (R) outflow volume.

S vs R Underdrain is the comparison of the simulated (S) bioretention site underdrain outflow compared to the monitored or recorded (R) underdrain outflow.

The comparison categories of “Accurate”, “Mixed”, “High”, and “Low” are somewhat subjective, but are based on a total view of the comparison plot for each type of data. There is no statistical measure or test that can adequately represent the ability of the model results to reproduce the monitored data, due to missing data periods, weather problems, and timing issues. An evaluation of the results by a modeling professional takes these issues into account and allows for an unbiased opinion.

For purposes of this comparison, "Accurate" is defined as a good overall match of the simulated and recorded data. Even if there is not an exact match, both sets of data follow the same trends and magnitudes.

"Mixed" is similar to "Accurate" but shows more variability. With "Mixed" some periods match well while other periods match poorly, but the simulated results are neither consistently high or low.

"High" means that the simulated results are consistently high. There may be a valid reason for this different between the simulated and recorded results, but regardless the difference is noticeable. "Low" is similar, but in the opposite direction (the simulated results are consistently low).

"Undeterminable" means that the monitored data were unable to determine the contribution of the underdrain flow to the total outflow.

Further discussion of these graphical results and the comparison plots from which they were determined is presented below in the individual site modeling section of this report.

The second set of model results were generated based the Ecology-approved design conditions.

The second set of model results was based on the long-term county precipitation data. For each site the long-term (50 years or longer) precipitation record was used to generate long-term simulated ponding and outflow data. For sites that were found not to have the required bioretention soil mix as the top layer the long-term models were adjusted to provide this soil mix as the standard top layer, as per Ecology requirements. In addition, the Ksat Safety Factor was added in accordance with Ecology's requirements related to the contributing drainage area to each site.

These simulated data were not compared against the monitored data, but were used to evaluate the individual bioretention's site ability to meet Ecology minimum requirements #5 and #6.

Minimum Requirement #5 (MR#5) is the LID flow duration performance standard. MR#5 requires that flow durations between 8 percent of the 2-year flow (0.08Q2) and 50 percent of the 2-year flow (0.50Q2) do not increase above the predevelopment land use conditions. For each of these models the predevelopment land use was defined as forested. WWHM2012 provides the appropriate calculations to demonstrate compliance with MR#5.

Minimum Requirement #6 (MR#6) is the water quality performance standard. MR#6 requires that at least 91 percent of the total runoff volume be treated. Treatment in a bioretention facility consists of water movement through the bioretention soil mix. This treated water can then either infiltrated into the native soil or exit via an underdrain or both. Water that discharges through the surface outlet (riser or weir) is not treated. WWHM2012 provides the appropriate calculations to demonstrate compliance with MR#6.

Compliance with MR#5 and MR#6 is shown in Table 10.

Table 10. Minimum Requirement Compliance

Site	Long-Term Precip Record	Multiplication Factor	MR#5	MR#6
BCK	Blaine	0.857	No	No
BUW	Blaine	0.857	No	No
FWI	38-in Central*	1.000	No	Yes
M1C	Everett	1.000	Yes	Yes
M3Q	Everett	1.000	Yes	Yes
MPP	Everett	1.200	Yes	Yes
RSH	Sea Tac	1.000	No	No
SSW	Everett	1.200	Yes**	Yes
TBM	Olympia Airport	1.000	No	Yes
TWH	38-in Central*	1.000	No	No

* WSDOT precipitation time series used by Pierce County
** after overflow to an infiltration trench

M1C, M3Q, MPP, and SSW pass the MR#5 LID flow duration criterion. The other sites (BCK, BUW, FWI, RSH, RSH, and TWH) do not pass – either because the site is undersized and excessive uncontrolled surface discharge occurs (see Table 2) or because the water moves through the soil column then discharges through the underdrain with no outlet control.

The same sites that fail MR#5 also fail the MR#6 water quality standard, except FWI and TBM, both which pass MR#6. The sites that fail the MR#6 standard fail because they have too much surface discharge (often due to the overflow riser height set too low on the surface) and do not filter at least 91% of the flow through the bioretention soil mix.

Bioretention facilities are not required to meet Minimum Requirement #7 (MR#7) and many do not. MR#7 is the stream protection flow control standard. MR#7 requires that flow durations between 50 percent of the 2-year flow (0.50Q2) and the 50-year flow (Q50) do not increase above the predevelopment land use conditions. While WWHM2012 provides the appropriate calculations to demonstrate compliance with MR#7, we did not evaluate the bioretention facilities for this compliance. This is because they did not have to be designed to meet this standard and to test them for compliance would be potentially misleading as to the effectiveness of their hydrologic performance.

Individual Bioretention Site Results

Individual bioretention model results are discussed below. Each bioretention site has a unique set of characteristics that influenced the model set up and the comparison of model (simulation) results with the monitored (recorded) field data.

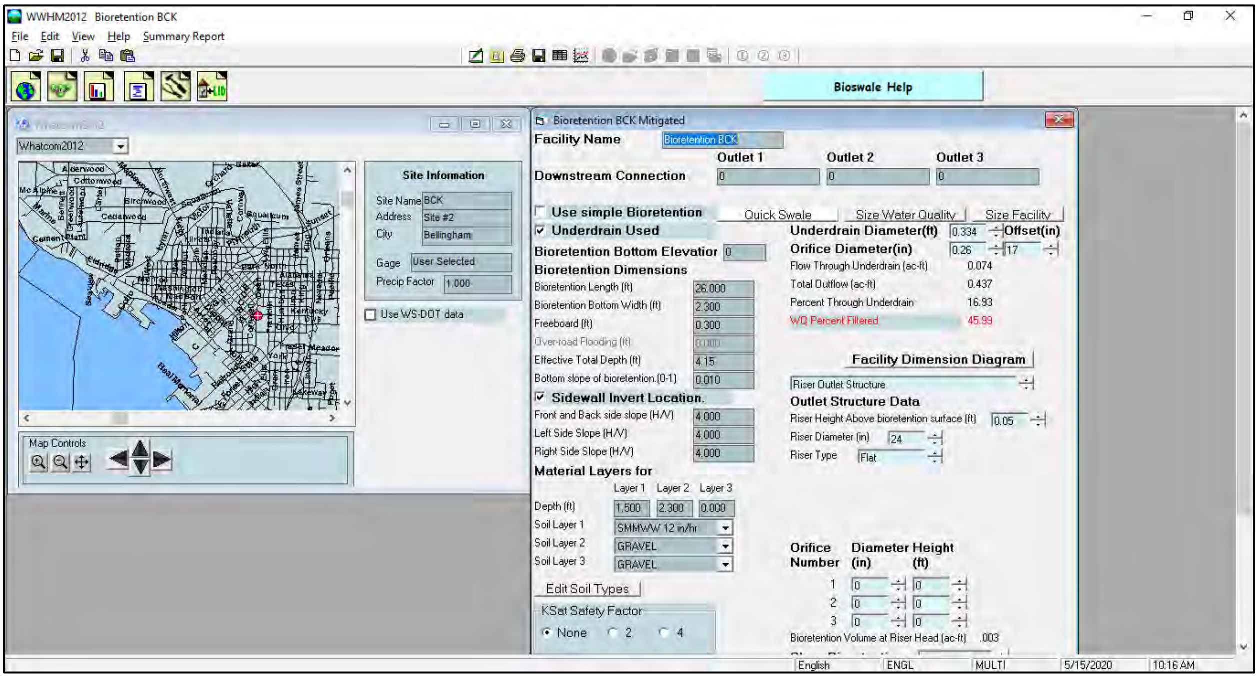
At each site the simulated and recorded daily inflow volumes are plotted and compared. The purpose of this comparison is to identify any potential errors in either the simulated or recorded inflow volumes. The simulated inflow volumes are calculated by WWHM2012 using the monitored rainfall data and the contributing drainage area to the bioretention site. It is possible that either one of those model inputs contains errors. The recorded/monitored inflow volumes are field measured values. These recorded values also may contain errors due to weather conditions (snow and/or freezing temperatures) and/or not recording all of the inflow sources to the bioretention site. By comparing the two sets of daily inflow volumes it is possible to identify problems that can and will affect the ability of WWHM2012 to correctly reproduce the surface ponding and soil layer elevations measured in the field.

At each site the simulated and recorded bioretention surface ponding depths are plotted and compared. The purpose of this comparison is to see how well WWHM2012 can reproduce the recorded/monitored ponding data. Surface ponding is a critical measure of the bioretention site's hydrologic performance. Excessive surface ponding can result in surface discharge via riser or weir that does not provide any water quality treatment or LID flow control.

At each site the simulated and recorded bioretention well point data are also plotted and compared. The well point data shows how the water fills up the bioretention soil column. The ponding and well point data are linked. If the well point data shows that the bioretention soil column is completely saturated then water cannot drain from the surface into the bioretention soil layer and this causes water to pond on the surface. Water can also pond on the surface even if the soil column is not completely saturated if the inflow of water into the bioretention facility is greater than the infiltration into the top layer (Layer 1) of the bioretention soil mix.

It should be noted that the monitored well point data is not a perfect match for the WWHM2012 soil layer moisture calculations. The monitored well point data is a measure of the "free" water in the soil column. This is water that freely drains to the well and fluctuates up and down depending on inflow to the soil from above and infiltration to the native soil below. The WWHM2012 simulated soil layer data is calculated based on the soil's hydraulic conductivity and wilting point (and other factors). Included in these simulated soil moisture calculates is both the "free" water measured in the monitored wells (well point data) and water that cannot freely flow, but remains trapped in the void spaces between soil particles. In WWHM2012 this "trapped" water is removed by evapotranspiration. The "trapped" water is not included in the well point monitored data. This is often the reason for the discrepancy between the simulated and recorded soil layer plotted results.

BCK: Bellingham, Whatcom County



The BCK bioretention site is located in Bellingham, Whatcom County, Washington. The drainage area to BCK consists of 0.27 acres of roads on a flat slope (0-5%).

The BCK surface area footprint is 71 square feet at top of overflow. This equals 0.6% of the tributary drainage area to BCK.

BCK has a surface discharge via riser outlet set at only 0.05 feet above the surface bottom. Most of the inflow to BCK is infiltrated into the native soil beneath the bioretention soil layers. An elevated underdrain is included in the bioretention site, but according to on-site visual inspection and the modeling results, most of the stormwater runoff bypasses the underdrain and either drains laterally, flows into the adjacent underground utility conduit corridor, or infiltrates into the native soil under the bioretention site.

The native soil infiltration rate could not be accurately measured but based on the underlaying geology appears to be low. As such, a native soil infiltration rate of 0.5 inches per hour together with a bioretention top soil layer of Ecology soil mix 12 in/hr and a second soil layer of gravel-like soil best reproduced the monitored soil moisture and surface ponding conditions.

Figure BCK-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the BCK site monitored daily rainfall data. The simulated inflow volumes are considerably larger than recorded daily inflow volumes. It was observed in the field that there may be more inflow to the bioretention site than originally expected and recorded. The comparison of simulated and recorded daily inflow volumes appears to support this observation.

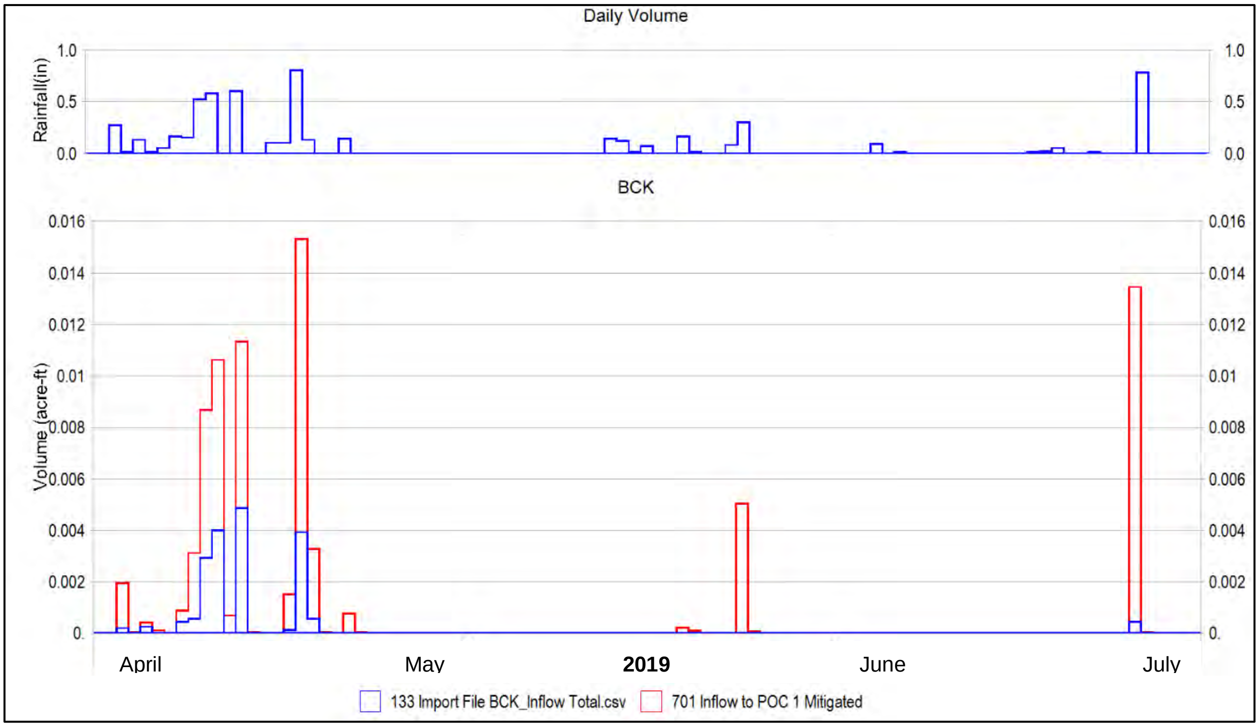


Figure BCK-1. BCK Daily Inflow Volumes

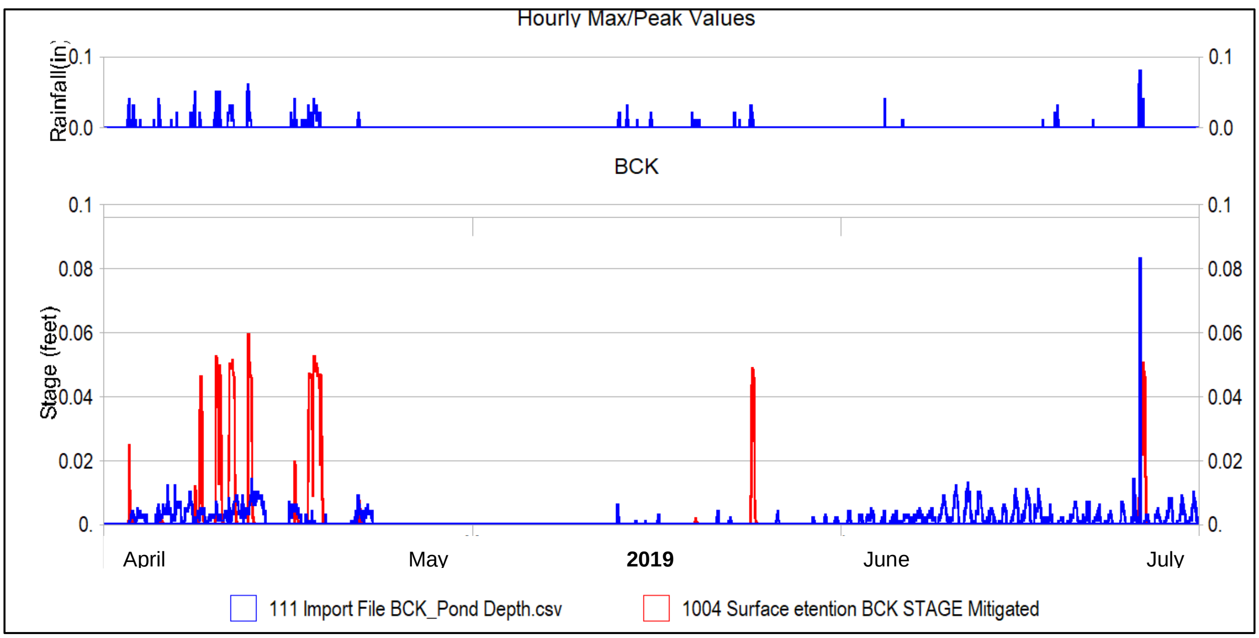


Figure BCK-2. BCK Hourly Surface Ponding Depths

Figure BCK-2 shows the simulated (red) and recorded (blue) hourly maximum 15-minute surface ponding (stage) values and, along the top of the figure, the BCK site monitored hourly maximum 15-minute rainfall data. The simulated and recorded ponding values are mixed. All of the pond depths are very small (less than 0.10 feet). The minor recorded depth fluctuations during the dry periods may either be due to on-site irrigation or monitoring equipment error due to daily air temperature fluctuations. This phenomena was observed at multiple sites.

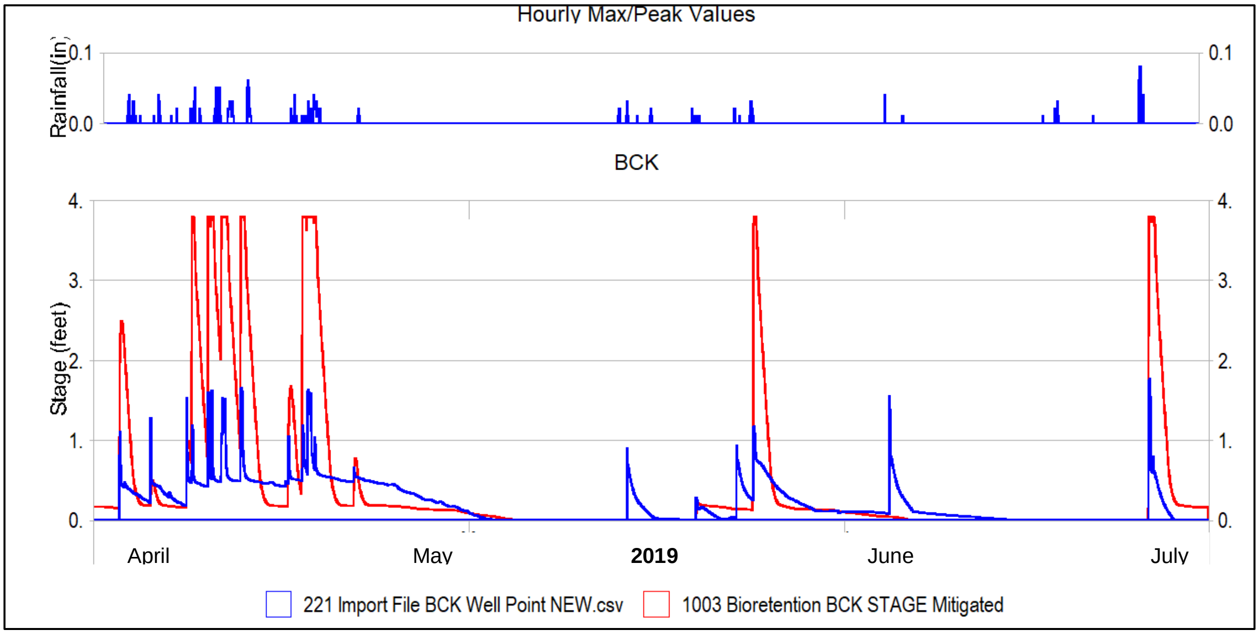


Figure BCK-3. BCK Hourly Soil Layer Well Point Elevations

Figure BCK-3 shows the simulated (red) and recorded (blue) hourly maximum 15-minute soil layer well point elevations (stage) values and, along the top of the figure, the BCK site monitored hourly maximum 15-minute rainfall data. The simulated well point elevations show more fluctuation than the recorded well point data. The recorded well point elevations show less fluctuation. This may be due to stormwater runoff quickly draining laterally into the adjacent underground utility conduit corridor.

BCK has an underdrain, but there was no access to install monitoring equipment to measure the flow exiting the underdrain. As a result of this situation, no underdrain outflow measurements are available. In addition, during the infiltration test conducted by AESI no discharge from the underdrain was observed. The modeling shows that with the designed underdrain outlet configuration that less than 20% of the total discharge exits through the underdrain.

The BCK simulated combined outflow was compared with the measured/recorded outflow to better understand the relative magnitude of the surface discharge and the underdrain outflow.

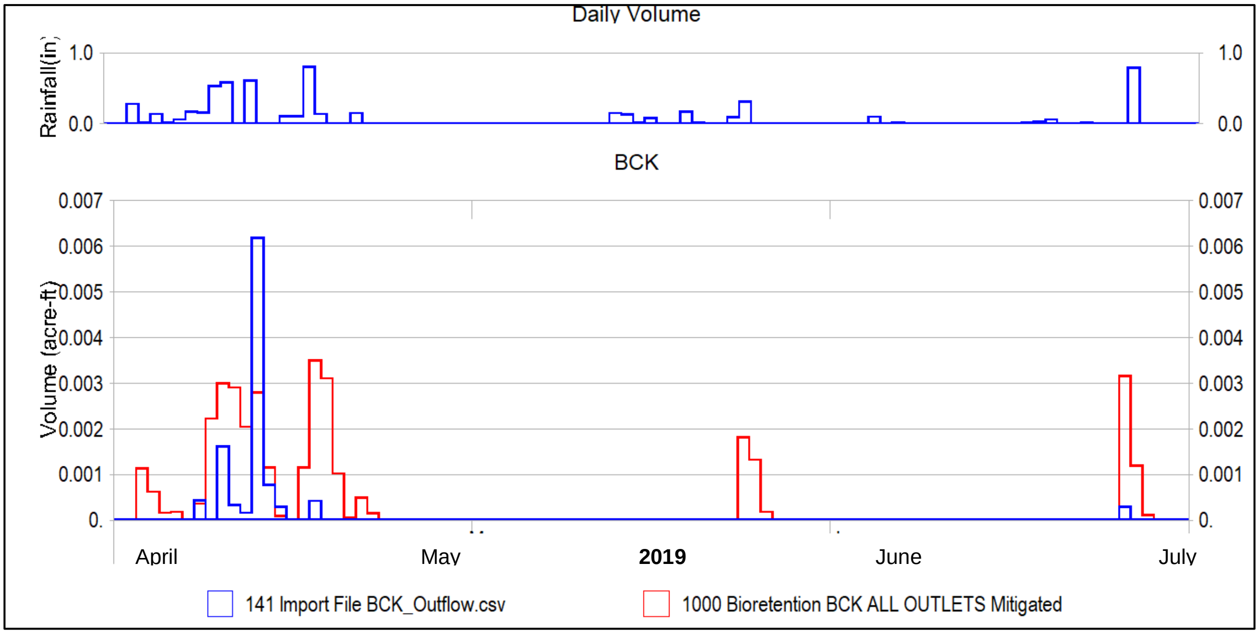


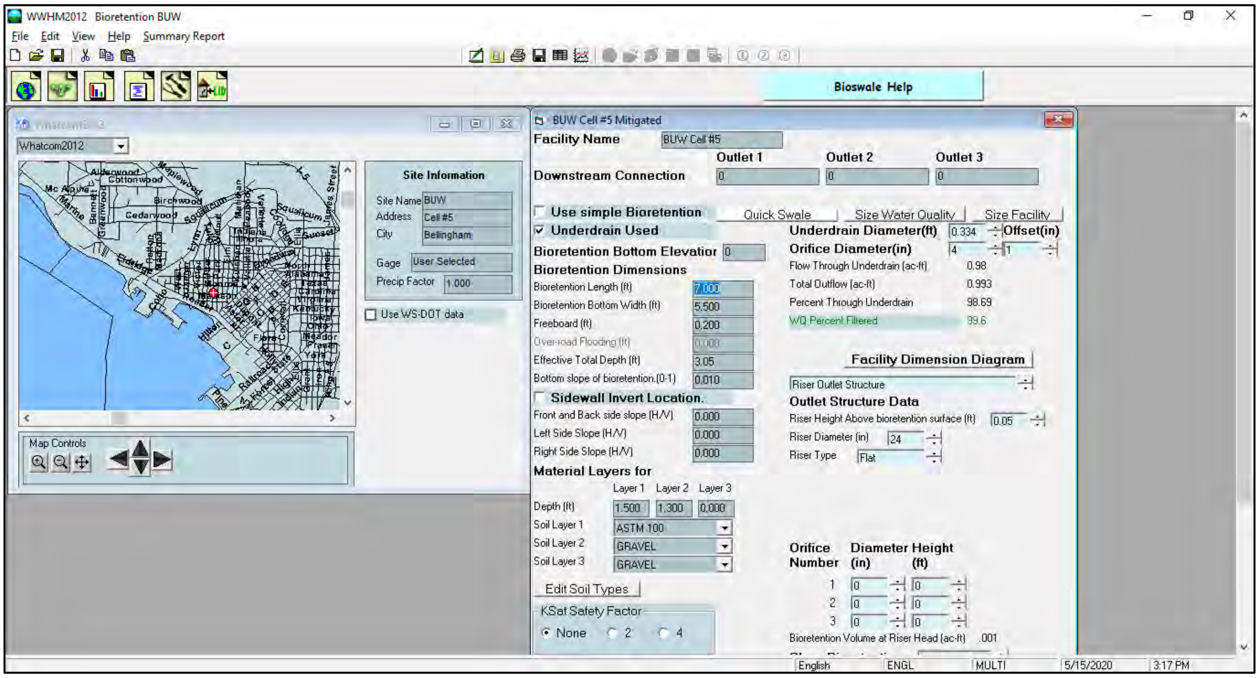
Figure BCK-4. BCK Daily Outflow Volumes

Figure BCK-4 shows the simulated (red) surface discharge and recorded (blue) hourly maximum 15-minute outflow values and, along the top of the figure, the BCK site monitored hourly maximum 15-minute rainfall data.

For most events the combined simulated surface discharge and underdrain outflow volume (red) is greater than the recorded (blue) outflow volume. It is assumed that this is because of the inability to monitor the underdrain flows and subsurface water escaping the site laterally.

The long-term modeling results based on the Whatcom County Blaine rain gage record show that BCK fails both MR #5 and MR #6. BCK's bottom area is only 0.5% of the drainage area to BCK. This site is too small to meet these minimum requirements and is overwhelmed by large runoff events.

BUW: Bellingham, Whatcom County



The BUW bioretention site is located in Bellingham, Whatcom County, Washington. The drainage area to BUW is a neighborhood consisting of 0.49 acres of C soil, lawn vegetation, on a flat slope (0-5%), 0.26 acres of roof, and 0.18 acres of road on a flat slope.

The BUW surface bottom footprint was originally designed to be 210 square feet. Infiltration test monitoring conducted by AESI discovered that due to the bioretention surface slope from north to south that the actual surface area footprint at top of overflow is only approximately 38.5 square feet. This equals 0.1% of the 0.93-acre tributary drainage area to BUW.

Infiltration test monitoring also found that the curb inlets to the BUW bioretention site limit the maximum inflow to 45 gallons per minute. This is equivalent to 0.1 cfs. To represent this inflow limitation situation in the model a flow splitter was added to the model with the flow threshold to the bioretention element set to 0.1 cfs. Flows greater than 0.1 cfs did not enter the bioretention site but continued to flow in the street to a street storm drain inlet downslope.

BUW has a surface discharge via riser set at 0.05 feet (0.5 inch) above the surface bottom. Even with this low riser height, during the spring 2019 monitoring period the majority of the inflow to BUW is infiltrated into the bioretention soil mix and then outflows through an underdrain.

A native soil infiltration rate of 0.05 inches per hour together with a bioretention top soil layer of very high infiltrating soil (estimated at over 100 in/hr) and a second soil layer of gravel best reproduced the monitored soil moisture and surface ponding conditions. The very low native soil permeability creates a perched groundwater lens below the gravel layer.

Figure BUW-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the BUW site monitored daily rainfall data. The simulated inflow volumes are considerably larger than recorded daily inflow volumes, even with the simulated inflow limited to a maximum of 45 gpm (0.1 cfs). It was observed in the field that it was very difficult to measure the inflow at the two inlets to BUW. The comparison of simulated and recorded daily inflow volumes appears to support this observation.

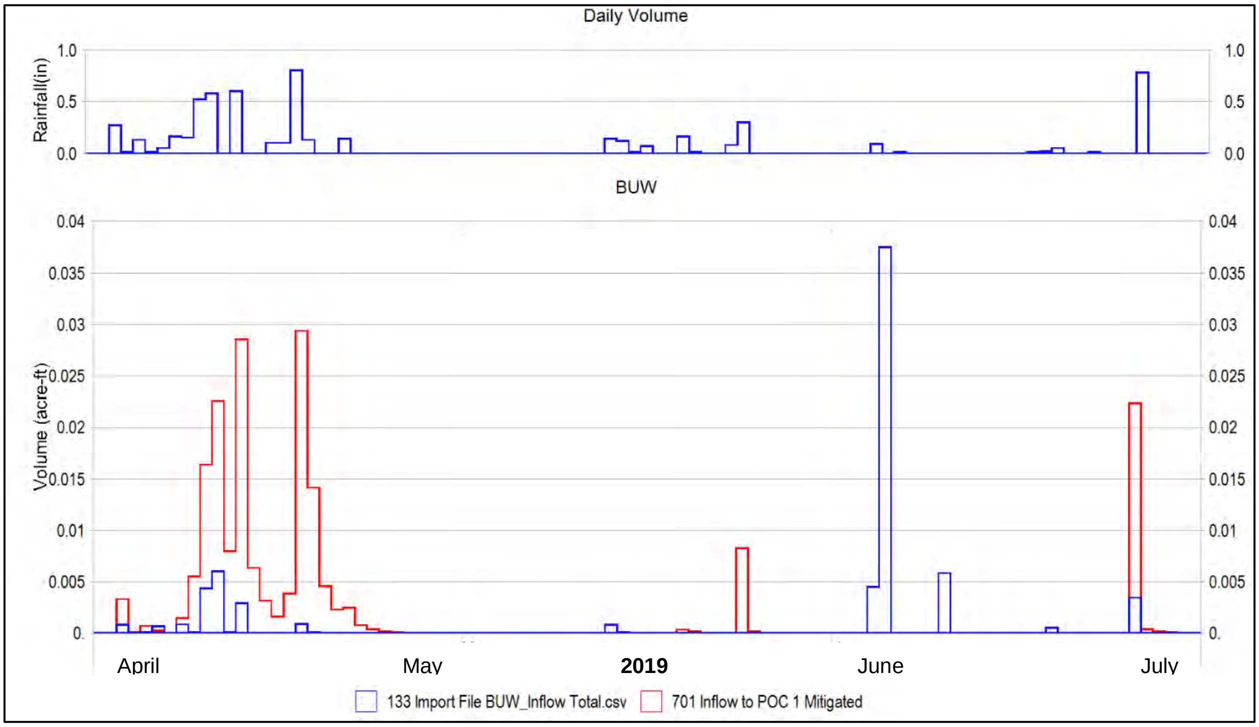


Figure BUW-1. BUW Daily Inflow Volumes

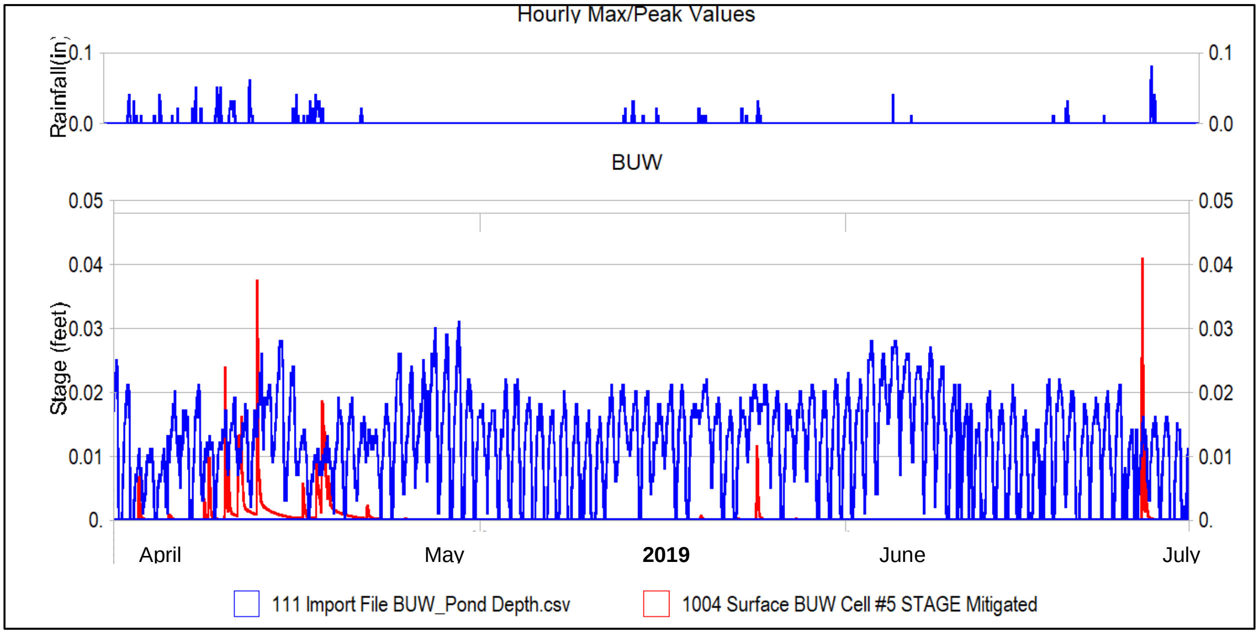


Figure BUW-2. BUW Hourly Surface Ponding Depths

Figure BUW-2 shows the simulated (red) and recorded (blue) hourly maximum 15-minute surface ponding (stage) values and, along the top of the figure, the BUW site monitored hourly maximum 15-minute rainfall data. The simulated and recorded ponding values are mixed. All of the pond depths are very small (less than 0.05 feet). The minor recorded depth fluctuations during the dry periods may be due to monitoring equipment error due to daily air temperature fluctuations. This phenomenon was observed at multiple sites.

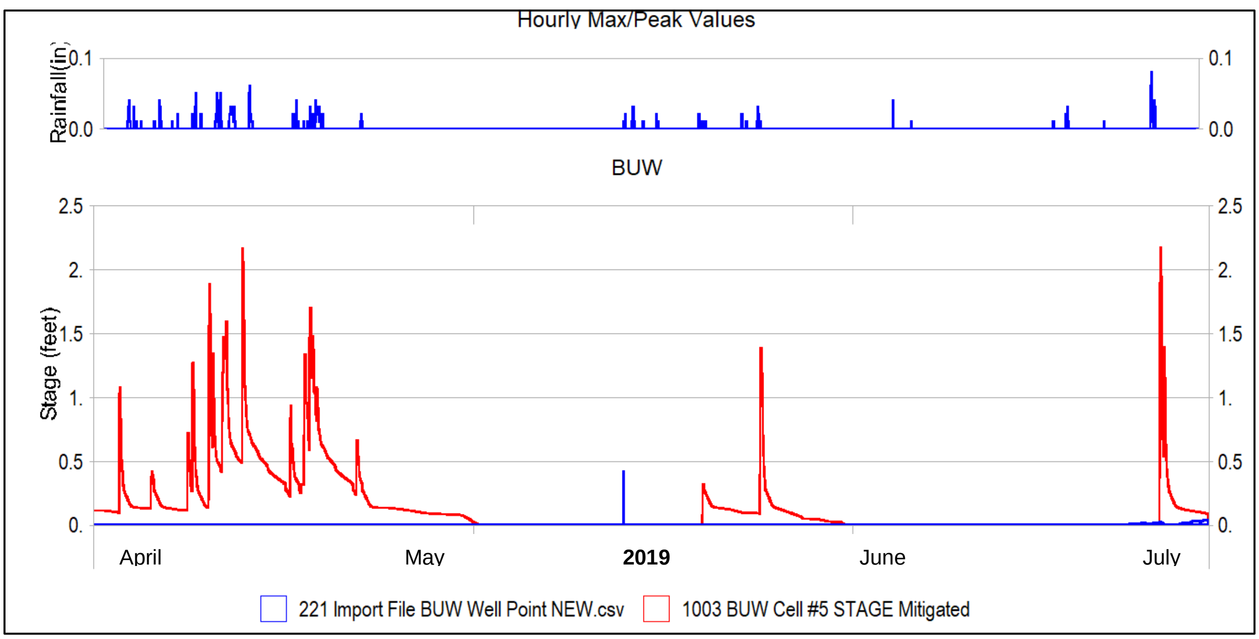


Figure BUW-3. BUW Hourly Soil Layer Well Point Elevations

Figure BUW-3 shows the simulated (red) and recorded (blue) hourly maximum 15-minute soil layer well point elevations (stage) values and, along the top of the figure, the BUW site monitored hourly maximum 15-minute rainfall data. The simulated well point elevations show more fluctuation than the recorded well point data. The recorded well point elevations show almost no fluctuation.

BUW has an underdrain, but there was no access to install monitoring equipment to measure the flow exiting the underdrain. As a result of this situation, no underdrain outflow measurements are available. During the infiltration test conducted by AESI a large amount of discharge from the underdrain was observed. Bryan Berkompas of Aspect, monitoring team leader, noted in an email dated 4/10/20 that:

> "The outflow data show the site almost never discharged which directly contradicts the infiltration testing results. Our data from the infiltration test show that the outlet flow exceeded our weir capacity at times. We have an initial discharge of around 40 gpm and then it spiked to 81 gpm before it exceeded our weir's capacity. I would say 120 gpm is within reason per Jenny's inflow data. But for the rest of the study period, the outfall level almost never rises, despite the underdrain. Either that is the leakiest structure ever or something else is going on. I suspect the relatively shallow and sloping nature of the facility undermined us."

In other words, the monitored outflow data cannot be compared with the simulated results, as seen below.

The BUW simulated combined outflow (riser discharge and underdrain discharge) was compared with the measured/recorded outflow to better understand the problems noted above.

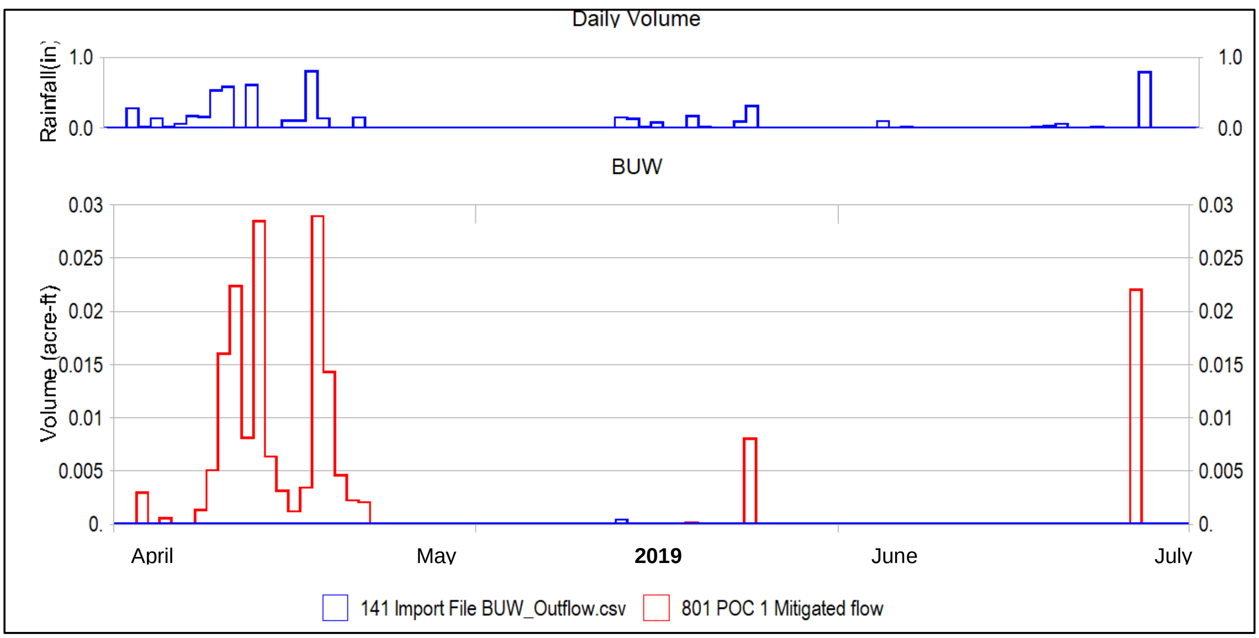


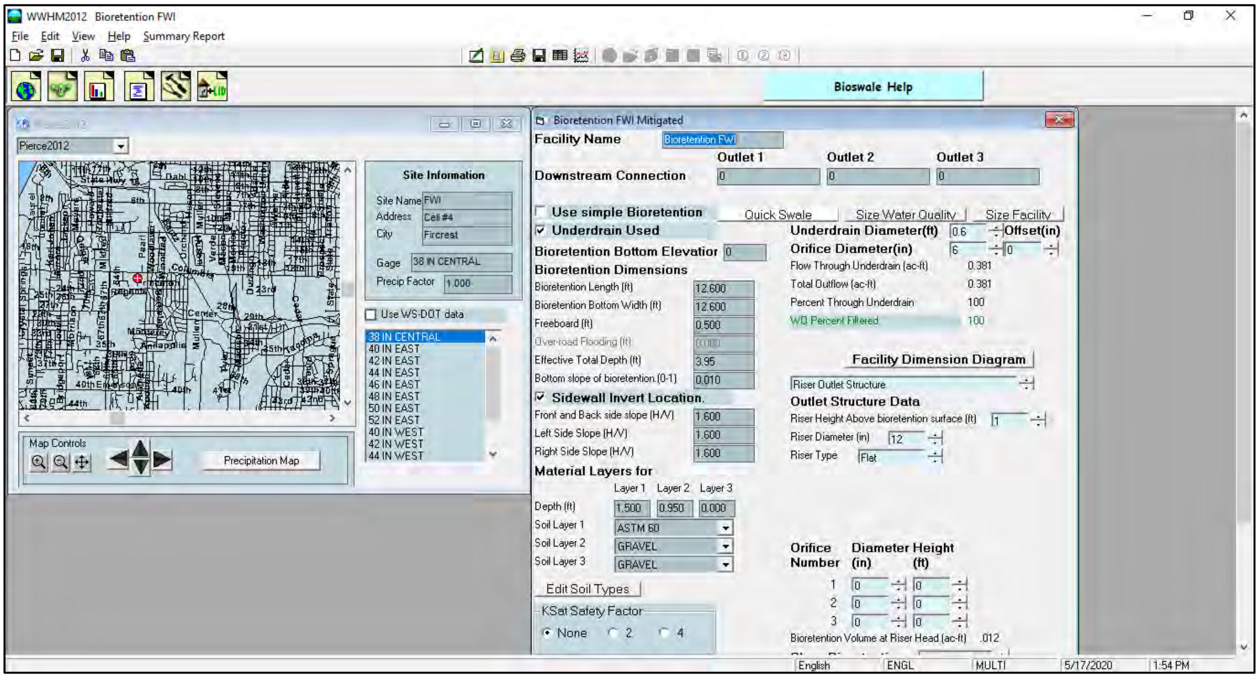
Figure BUW-4. BUW Daily Outflow Volumes

Figure BUW-4 shows the simulated (red) combined surface and underdrain discharge and recorded (blue) hourly maximum 15-minute outflow values and, along the top of the figure, the BUW site monitored hourly maximum 15-minute rainfall data.

There is almost no recorded outflow (blue). The total simulated outflow is much larger than the recorded outflow for the reasons described above, but the simulated outflow results are consistent with the observed rainfall data.

The long-term modeling results based on the Whatcom County Blaine rain gage record show that BUW fails both MR #5 and MR #6. BUW's bottom area is only 0.1% of the drainage area to BUW. This site is too small to meet these minimum requirements and is overwhelmed by large runoff events.

FWI: Fircrest, Pierce County



The FWI bioretention site is located in Fircrest, Pierce County, Washington. The drainage area to FWI consists of 0.23 acres of C soil, lawn vegetation, on a flat slope (0-5%) and 0.10 acres of road on a flat slope (0-5%).

The FWI surface area footprint at top of overflow is 250 square feet. This equals 1.7% of the 0.33-acre tributary drainage area to FWI.

FWI has a surface discharge via riser outlet set at 1.0 feet above the surface bottom. Most of the inflow to FWI is infiltrated into the bioretention soil and then exits via an underdrain.

The original FWI bioretention site modeling assumed no infiltration to groundwater. AESI estimated a lateral infiltration rate of 0.4 in/hr based on historical testing in the weathered zone, but expects that the vertical infiltration rate is near zero. A value of 0.05 in/hr was used in the modeling.

A bioretention top soil layer of very high infiltrating soil (estimated at 60 in/hr) and a second soil layer of gravel best reproduced the monitored soil moisture and surface ponding conditions. The very low native soil permeability soil creates a perched groundwater lens below the gravel layer.

Figure FWI-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the FWI site monitored daily rainfall data. The simulated and recorded daily inflow volumes match well for most storm events.

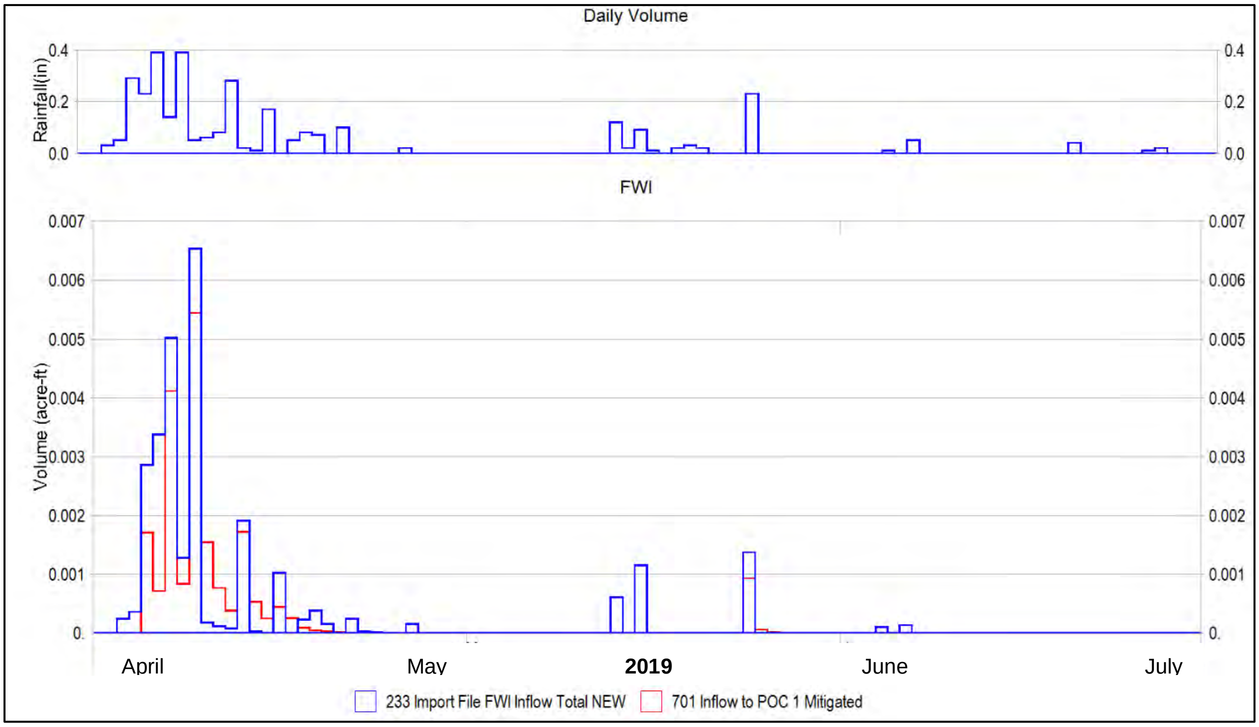


Figure FWI-1. FWI Daily Inflow Volumes

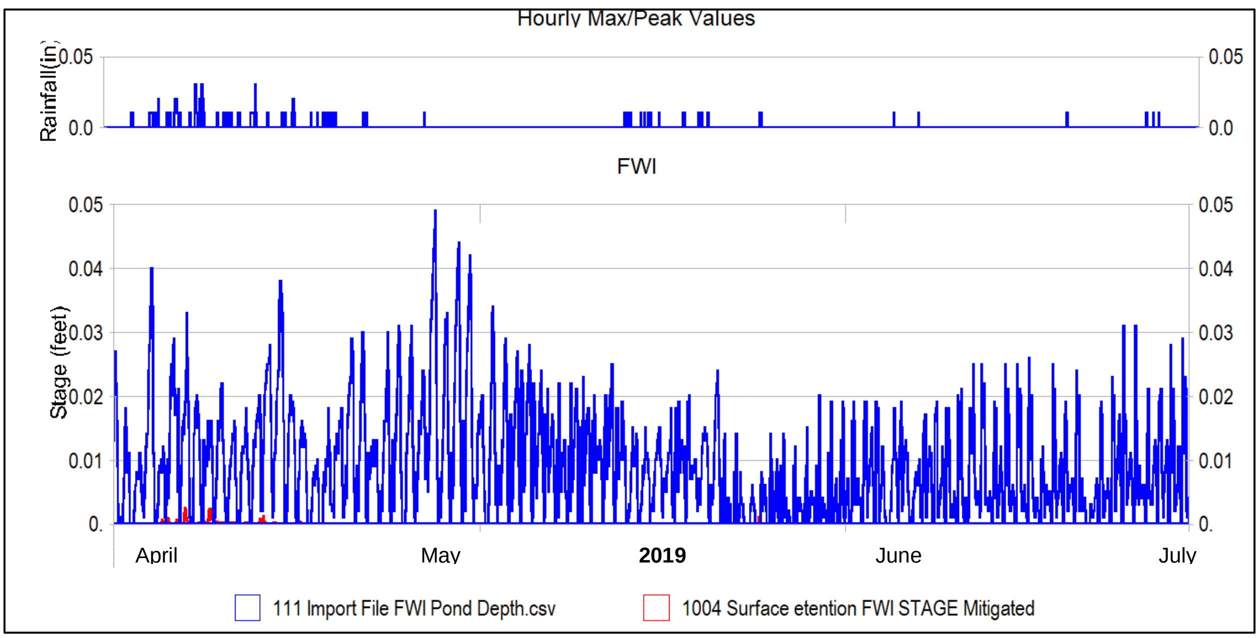


Figure FWI-2. FWI Hourly Surface Ponding Depths

Figure FWI-2 shows the simulated (red) and recorded (blue) hourly maximum 5-minute surface ponding (stage) values and, along the top of the figure, the FWI site monitored hourly maximum 5-minute rainfall data. The simulated pond depths are lower than the recorded ponding values, but all of the pond depths are very small (less than 0.05 feet). The minor recorded depth fluctuations during the dry periods may either be due to on-site irrigation or monitoring equipment error due to daily air temperature fluctuations. This phenomena was observed at multiple sites.

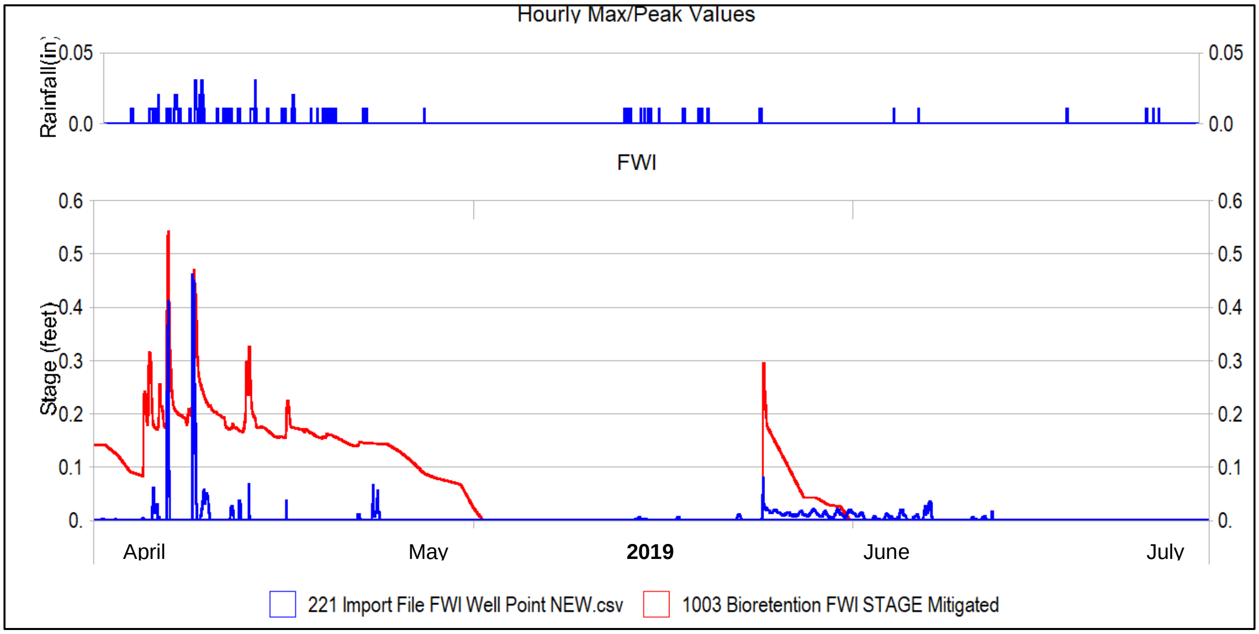


Figure FWI-3. FWI Hourly Soil Layer Well Point Elevations

Figure FWI-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the FWI site monitored hourly maximum 5-minute rainfall data.

The simulated well point elevations show more fluctuation than the recorded well point data. The recorded well point elevations show almost no fluctuation. The simulated and recorded well point values match well for the major events.

FWI has an underdrain, but there was no access to install monitoring equipment to measure the flow exiting the underdrain. As a result of this situation, no underdrain outflow measurements are available.

The FWI simulated underdrain outflow (there was no simulated surface discharge) was compared with the measured/recorded outflow.

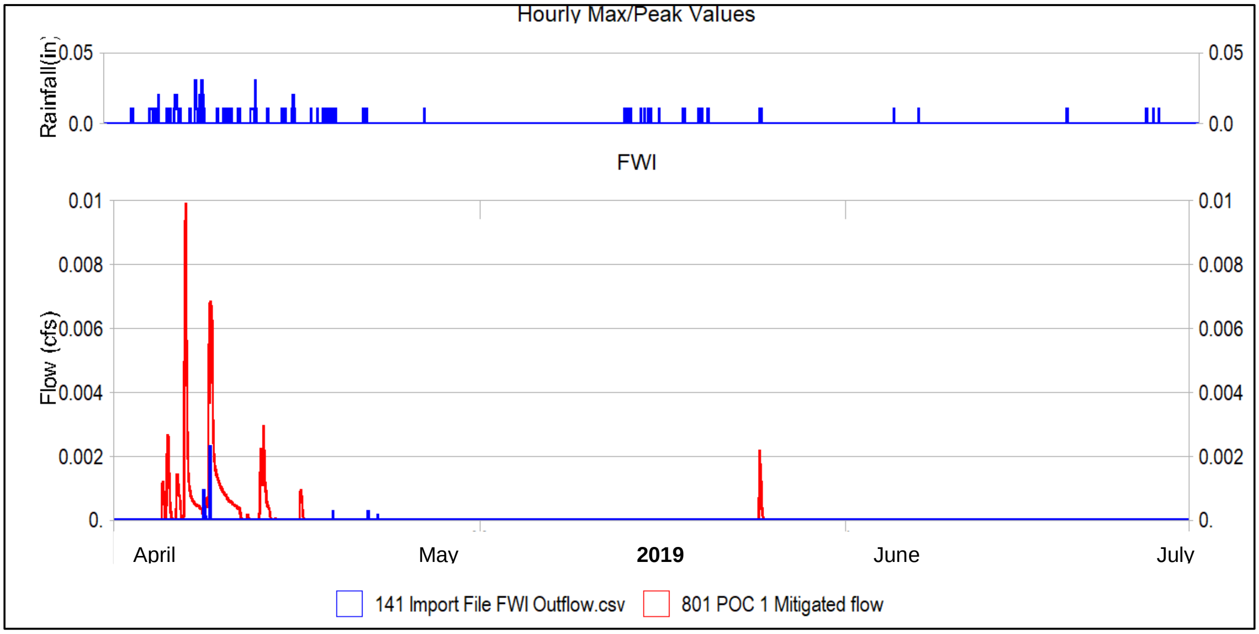


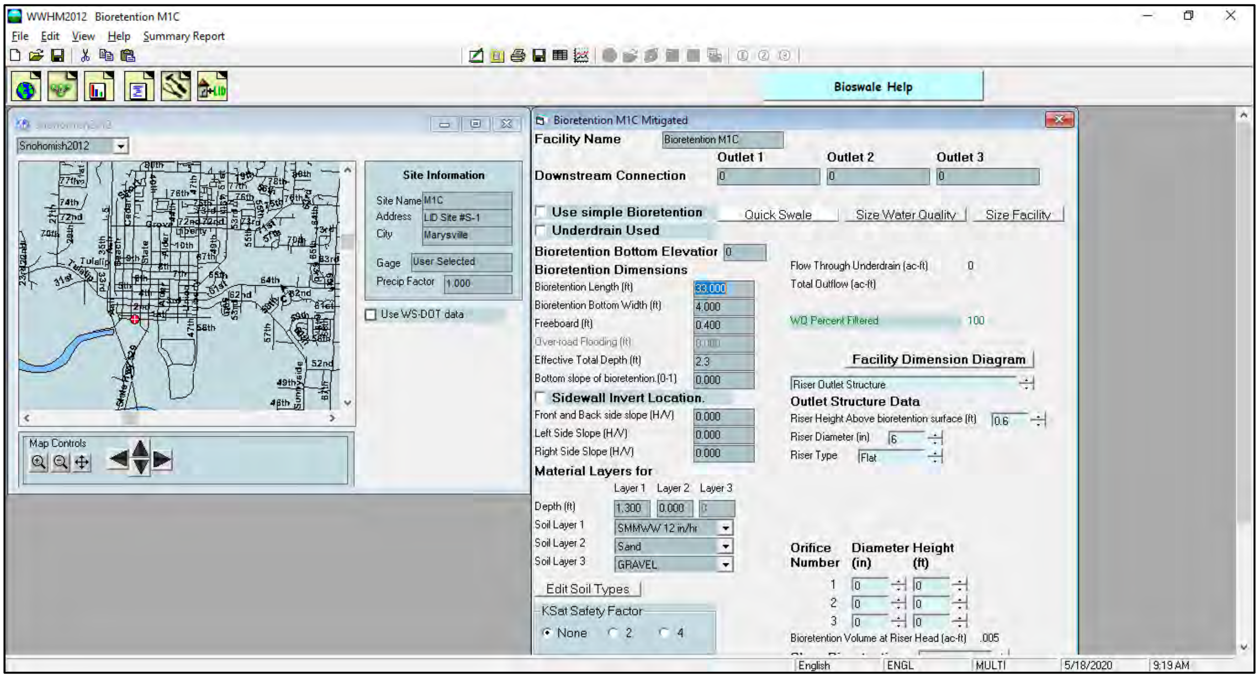
Figure FWI-4. Comparison of FWI Hourly Outflow Simulated and Measured Peak Flows

In Figure FWI-4 the FWI recorded outflow (blue) and the simulated underdrain outflow (red) hourly peak flows are shown. For the measured outflow events the simulated underdrain outflow (red) is greater than the recorded outflow (blue).

For all practical purposes all of the inflow to the FWI bioretention site exits via the underdrain. This was seen in the modeling and this same observation was made by AESI during the infiltration testing. The simulated underdrain outflow is consistent with the simulated inflow. Therefore, it can be assumed that the magnitude of the simulated underdrain outflow peaks is correct and that the recorded peak outflows are actually larger than measured. As noted at some of the other small bioretention sites, this is probably due to the errors inherent with the difficulty of measuring very small outflow rates from this small bioretention facility.

The long-term modeling results based on the Pierce County WSDOT 38-inch Central rainfall record show that FWI passes MR #6 (water quality) but fails MR #5 (LID flow duration). FWI fails MR #5 because the flow out of the underdrain occurs too rapidly and exceeds the flow duration standard for MR #5 (8% of Q2 to 50% of Q2).

M1C: Marysville, Snohomish County



The M1C bioretention site is located in Marysville, Snohomish County, Washington. The drainage area to M1C consists of 0.03 acres of road on a flat slope (0-5%).

The M1C surface area footprint is 132 square feet at top of overflow. This equals 10.1% of the tributary drainage area to M1C.

M1C has a riser for surface discharge set at 0.6 feet above the surface bottom. Most of the inflow to M1C is infiltrated into the native soil beneath the bioretention soil layer.

A native soil infiltration rate of 17 inches per hour is based on the infiltration field test. The bioretention top soil layer of Ecology SMMWW 12 in/hr soil represents the soil found on the site.

Figure M1C-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the M1C-1 site monitored daily rainfall data. The simulated and recorded daily inflow volumes match well, except for periods in late May and late June where inflow was measured but there was no corresponding measured rainfall. It is assumed that this inflow is the product of irrigation of adjacent landscape areas.

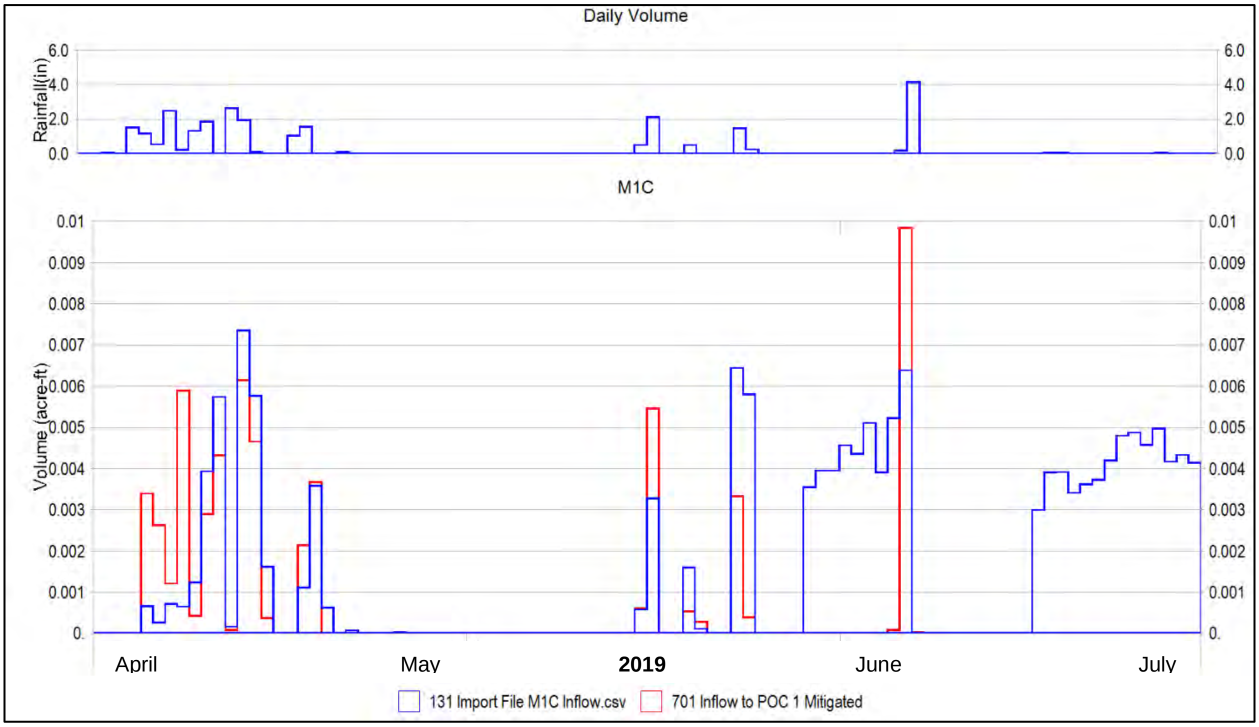


Figure M1C-1. M1C Daily Inflow Volumes

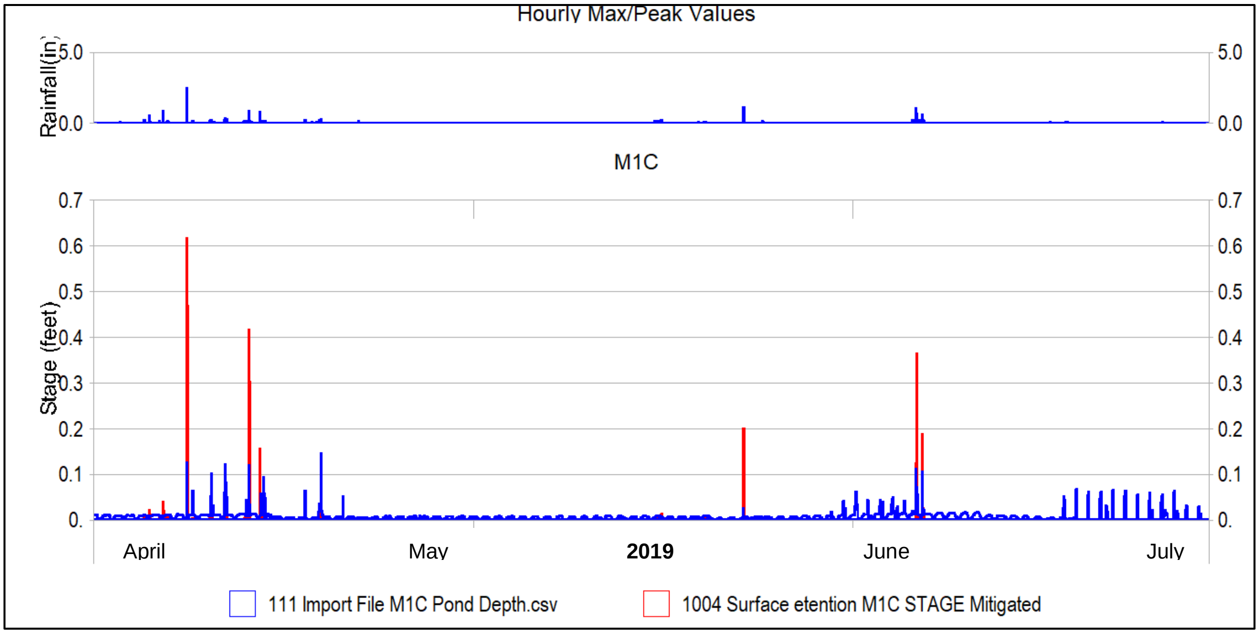


Figure M1C-2. M1C Hourly Surface Ponding Depths

Figure M1C-2 shows the simulated (red) and recorded (blue) hourly maximum 15-minute surface ponding (stage) values and, along the top of the figure, the M1C site monitored hourly maximum 15-minute rainfall data. The simulated ponding depths are larger than the recorded depths except for the periods when the addition of irrigated water produces ponding. This is observed to start in early June. The stormwater runoff onto the bioretention site appears to infiltrate better than the Ecology soil mix would indicate.

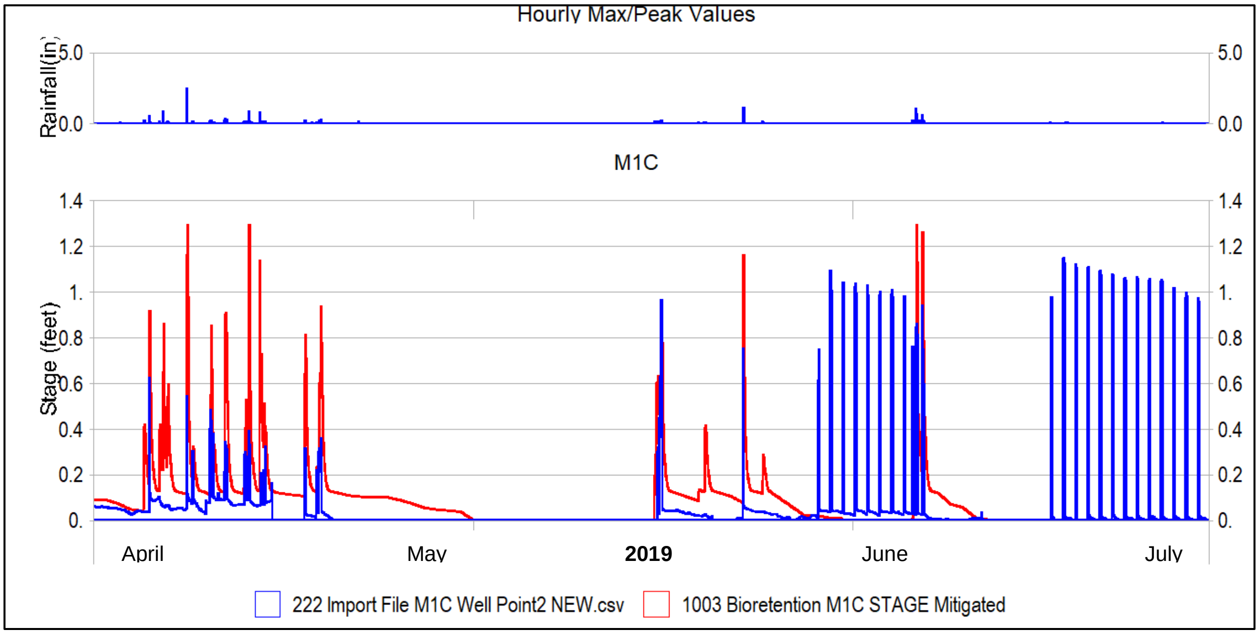
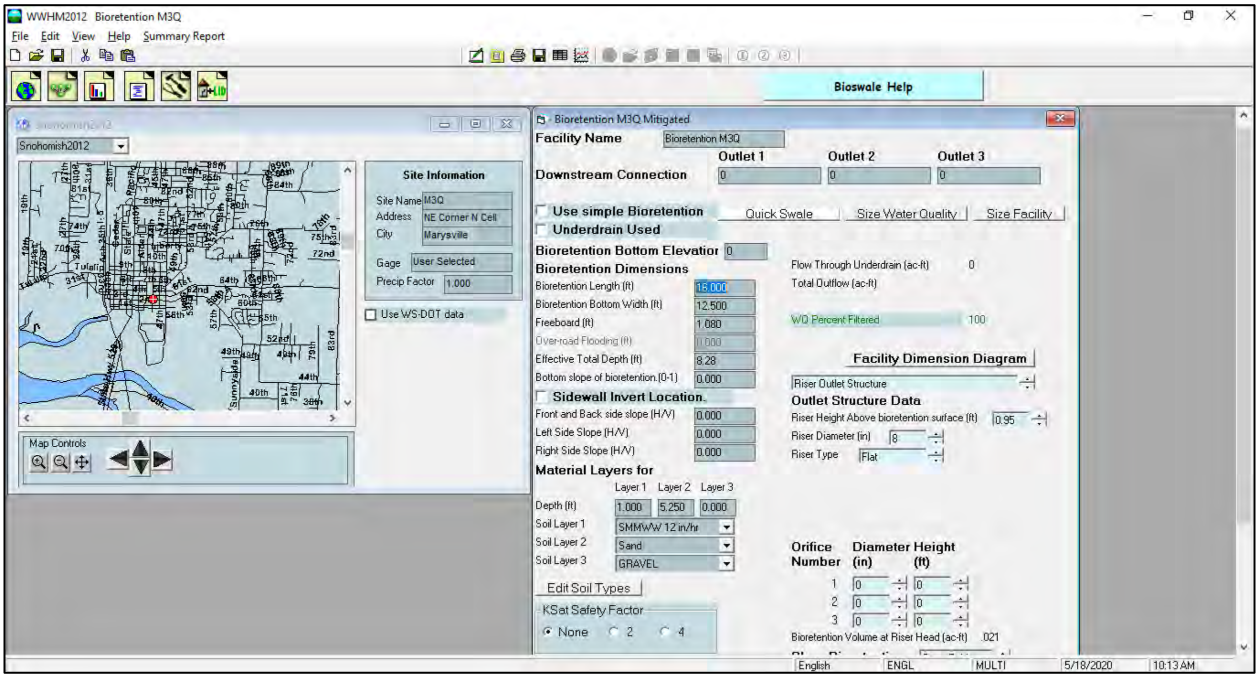


Figure M1C-3. M1C Hourly Soil Layer Well Point Elevations

Figure M1C-3 shows the simulated (red) and recorded (blue) hourly maximum 15-minute soil layer well point elevations (stage) values and, along the top of the figure, the M1C site monitored hourly maximum 15-minute rainfall data. The simulated and recorded ponding values match well when there is measured rainfall data. The simulated values show more fluctuation and faster drainage times than the recorded well point data. The recorded spikes in well point elevations starting in late May/early June appear to be the result of on-site irrigation of the bioretention facility. This is often done to water the bioretention plant community during dry periods. This artificial addition of water to the site is not included in the model results.

The long-term modeling results based on the Snohomish County Everett rain gage record show that M1C passes both MR #5 and MR #6. Ability to pass these two minimum requirements is due to infiltration of almost 100% of the total runoff volume. This was also true for the nearby M3Q site.

M3Q: Marysville, Snohomish County



The M3Q bioretention site is located in Marysville, Snohomish County, Washington. The drainage area to M3Q consists of 0.02 acres of road on a flat slope (0-5%). As discussed below, the design drainage area was specified as 0.08 acres of road, but the modeling results showed that that size of a drainage area to the bioretention site was highly unlikely due to the very large inflows and resulting pond depths that are computed using a drainage area of 0.08 acres of impervious surfaces when compared to the recorded (monitored) data. A drainage area of 0.02 acres produces more realistic results.

The M3Q surface area footprint is 200 square feet at top of overflow. This equals 23% of the 0.02-acre tributary drainage area to M3Q.

M3Q has a riser for surface discharge set at 0.95 feet above the surface bottom. All of the inflow to M3Q is infiltrated into the native soil beneath the bioretention soil layer.

A native soil infiltration rate of 15 inches per hour is based on the infiltration field test. The bioretention top soil layer of Ecology SMMWW 12 in/hr soil represents the soil found on the site.

Figure M3Q-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the M3Q -1 site monitored daily rainfall data. Even with the reduction in drainage area from 0.08 acres to 0.02 acres the simulated daily inflow volumes exceed the recorded inflow volumes. The error may be in the difficulty to accurately measure very small flow values that enter M3Q through the 12-inch curb cut on Quinn Avenue. Also, the June rainfall event that measured 4 inches at the rain gage does not appear to be representative of the actual amount that fell on the M3Q drainage area.

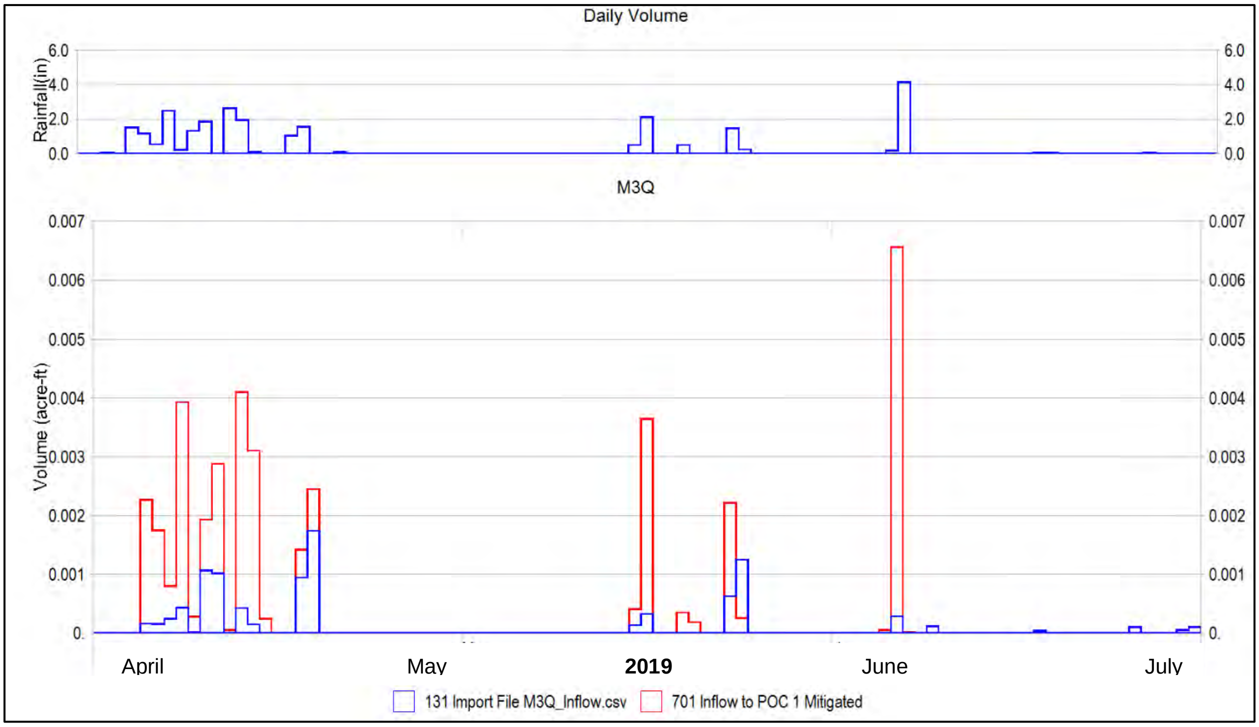


Figure M3Q-1. M3Q Daily Inflow Volumes

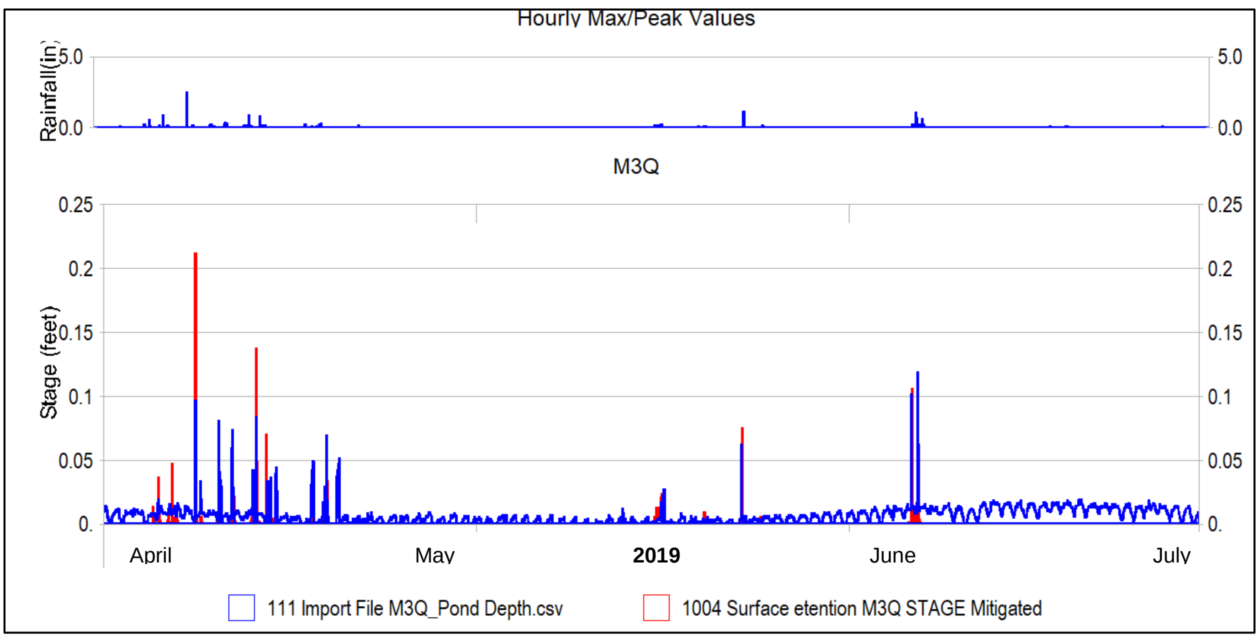


Figure M3Q-2. M3Q Hourly Surface Ponding Depths

Figure M3Q-2 shows the simulated (red) and recorded (blue) hourly maximum 15-minute surface ponding (stage) values and, along the top of the figure, the M3Q site monitored hourly maximum 15-minute rainfall data. The simulated ponding depths are close to the recorded depths for most of the storm events, although they are mixed (some higher and some lower) overall. The minor recorded depth fluctuations during the dry periods may either be due to monitoring equipment error resulting from daily air temperature fluctuations confusing the sensor. This phenomenon was observed at multiple sites.

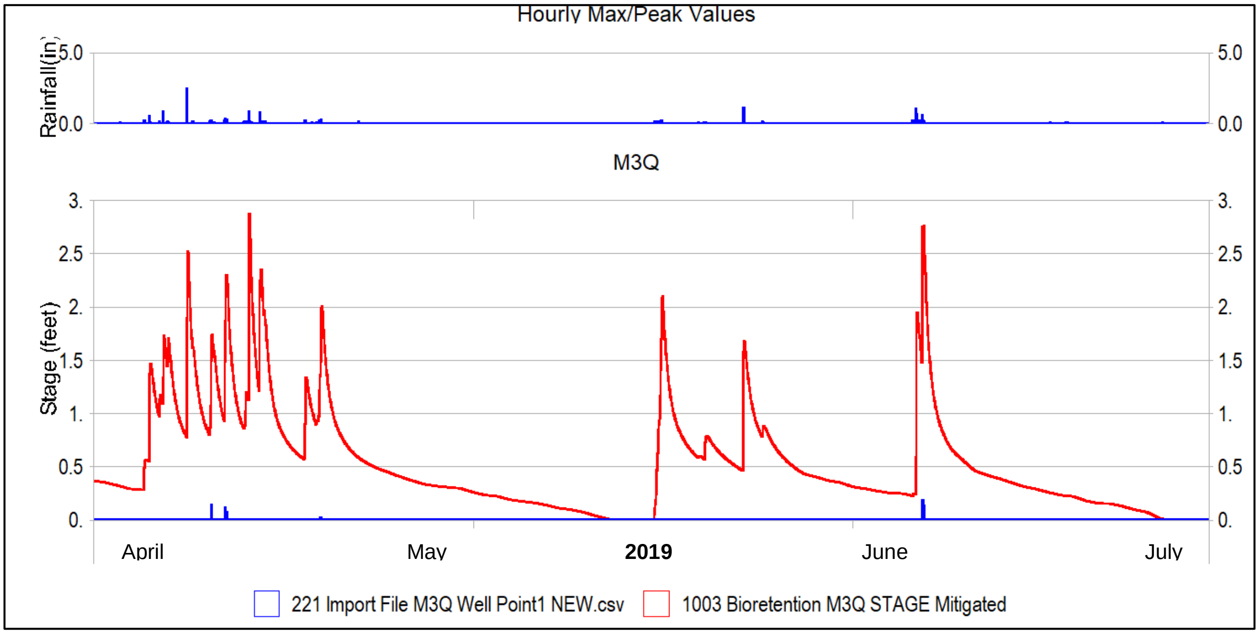
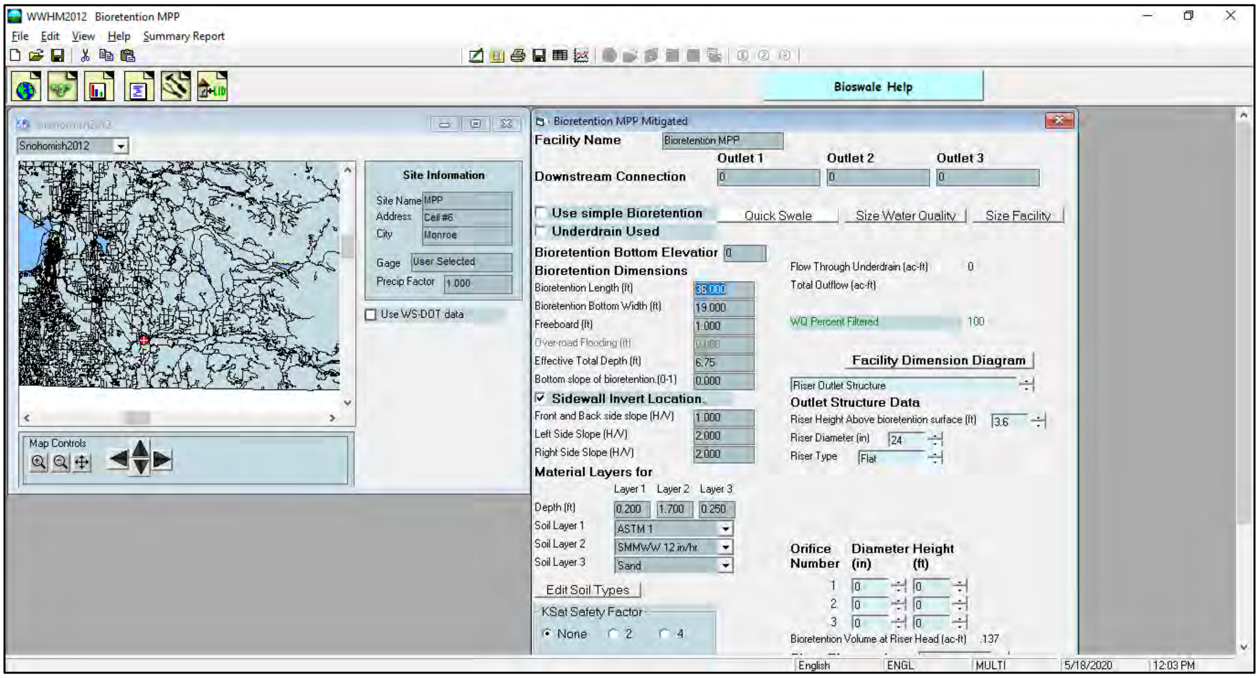


Figure M3Q-3. M3Q Hourly Soil Layer Well Point Elevations

Figure M3Q-3 shows the simulated (red) and recorded (blue) hourly maximum 15-minute soil layer well point elevations (stage) values and, along the top of the figure, the M3Q site monitored hourly maximum 15-minute rainfall data. The simulated values show more fluctuation than the recorded well point data. Similar results were seen at the nearby M1C bioretention site. The difference in simulated and recorded well point results may be due to faster drainage through the native soil than was modeled.

The long-term modeling results based on the Snohomish County Everett rain gage record show that M3Q passes both MR #5 and MR #6. Ability to pass these two minimum requirements is due to infiltration of almost 100% of the total runoff volume. This was also true for the nearby M1C site.

MPP: Monroe, Snohomish County



The MPP bioretention site is located in Monroe, Snohomish County, Washington. The drainage area to MPP consists of 0.19 acres of C soil, lawn vegetation, flat slope (0-5%) and 0.29 of road on a flat slope (0-5%).

The MPP surface area footprint is 1320 square feet at top of overflow. This equals 6.3% of the 0.48-acre tributary drainage area to MPP.

MPP has no surface outlet control structure but overtops the site at 3.6 feet above the surface bottom. All of the inflow to MPP is infiltrated into the native soil beneath the bioretention soil layers.

A native soil infiltration rate of 3 inches per hour together with a bioretention top soil layer of mulch or similar organic material (represented by ASTM1 soil), a second soil layer of Ecology SWWMM soil mix (12-inch per hour infiltration rate), and a third soil layer of sand best reproduced the monitored soil moisture and surface ponding conditions. The top organic layer appears to restrict infiltration of the inflow into the bioretention soil and was added to the model to reproduce monitored surface ponding depths.

Figure MPP-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the MPP site monitored daily rainfall data. The simulated daily inflow volumes are relatively consistent with the recorded inflow volumes.

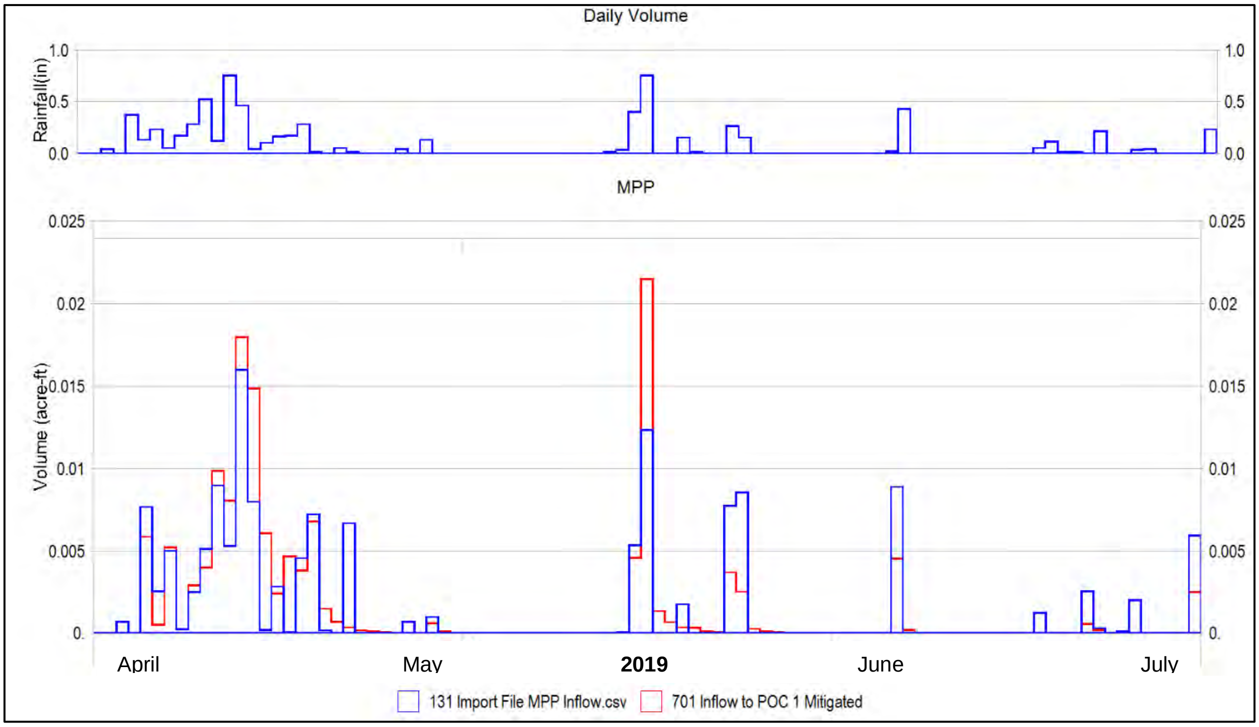


Figure MPP-1. MPP Daily Inflow Volumes

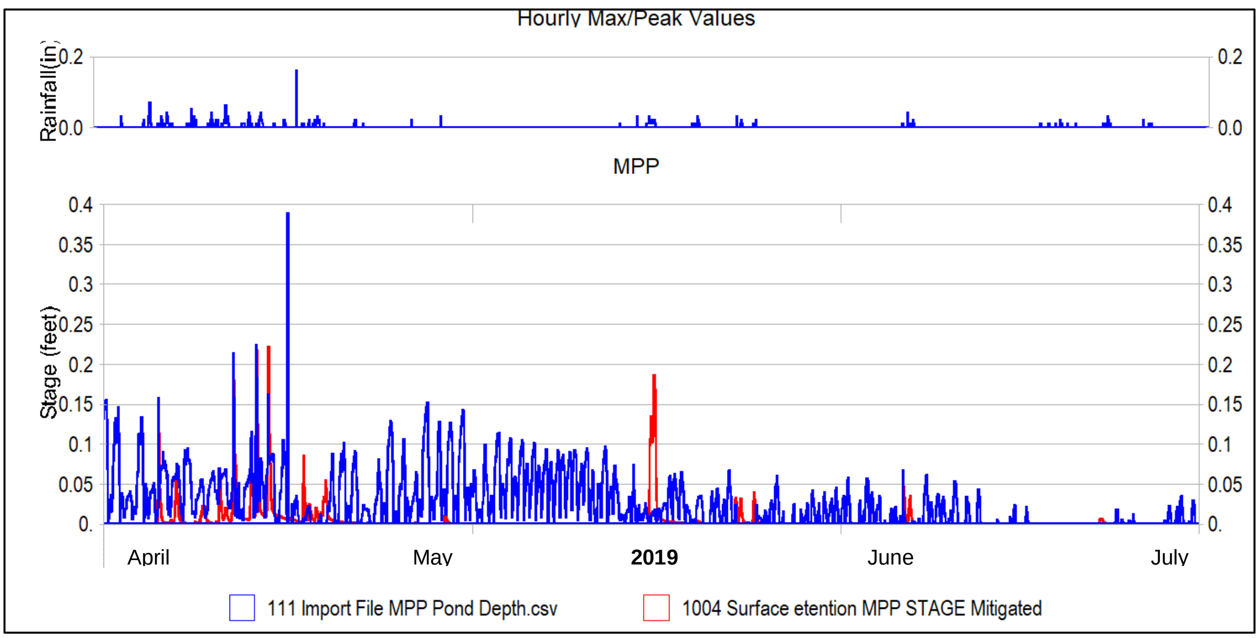


Figure MPP-2. MPP Hourly Surface Ponding Depths

Figure MPP-2 shows the simulated (red) and recorded (blue) hourly maximum 5-minute surface ponding (stage) values and, along the top of the figure, the MPP site monitored hourly maximum 5-minute rainfall data. The simulated and recorded ponding values show mixed results. As observed at some of the other sites, monitored ponding depth values fluctuate due to diurnal temperature changes.

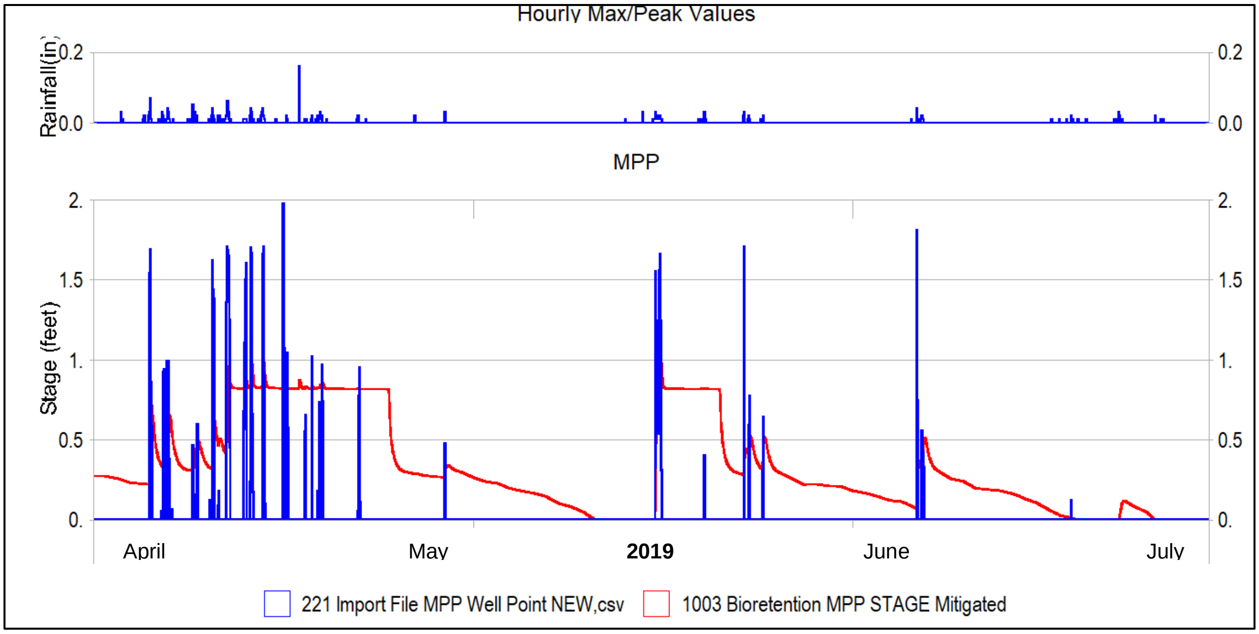
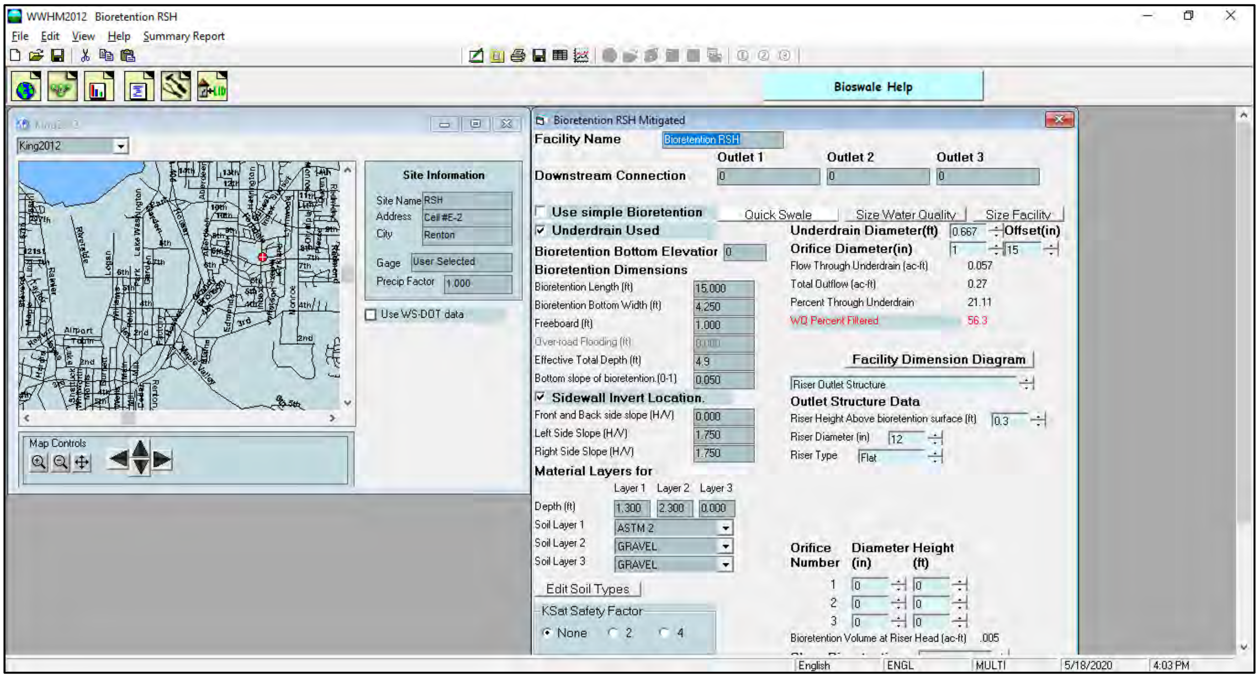


Figure MPP-3. MPP Hourly Soil Layer Well Point Elevations

Figure MPP-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the MPP site monitored hourly maximum 5-minute rainfall data. The simulated values show less fluctuation than the recorded well point data. The reason for the very rapid discharge from the well points into the underlaying native soil is not clear based on the field-measured infiltration rate.

The long-term modeling results based on the Snohomish County Everett rain gage record show that MPP passes both MR #5 and MR #6. Ability to pass these two minimum requirements is due to infiltration of almost 100% of the total runoff volume.

RSH: Renton, King County



The RSH bioretention site is located in Renton, King County, Washington. The drainage area to RSH consists of 0.0283 acres of A/B soil, lawn vegetation, on a moderate slope (5-15%), and 0.1417 acres of roads on a moderate slope (5-15%).

The RSH surface area footprint is 68 square feet at top of overflow. This equals 0.9% of the 0.17-acre tributary drainage area to RSH.

RSH has a surface outlet at 0.3 feet above the surface bottom. RSH also has an underdrain. The underdrain is set at 15 inches above the bottom of the lowest bioretention soil layer. Approximately one-half of the inflow to RSH is infiltrated into the native soil beneath the bioretention soil layers. The underdrain is connected to an outlet pipe that connects to the municipal stormwater system.

AESI measured infiltration rate for the top bioretention soil layer to be only 2 inches per hour. For this reason the ASTM2 soil was used to represent this top layer. Below the bioretention soil layer is a gravel layer. Under the gravel layer is a native soil with a low infiltration rate. For modeling purposes, a native soil infiltration rate of 0.5 inches per hour was used.

Figure RSH-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the RSH site monitored daily rainfall data. The simulated daily inflow volumes generally match well with the recorded data for most of the April-June period.

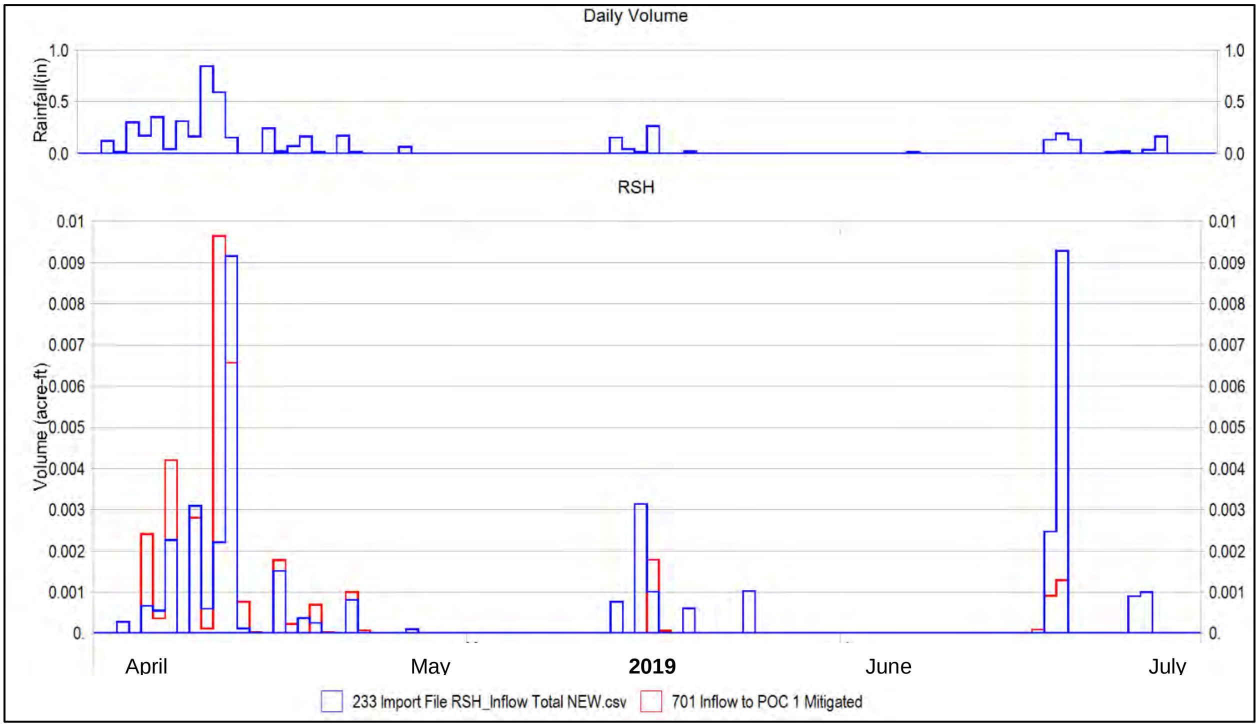


Figure RSH-1. RSH Daily Inflow Volumes

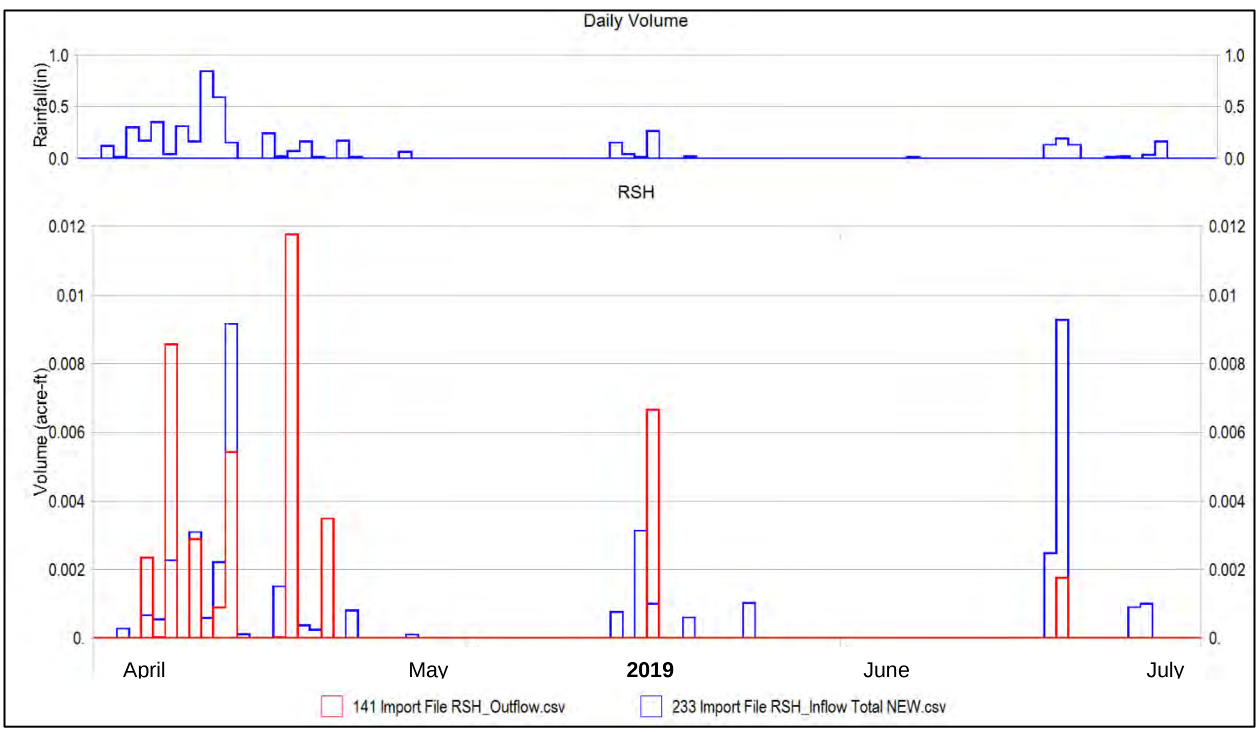


Figure RSH-2. Comparison of RSH Daily Inflow and Outflow Measured Volumes

In Figure RSH-2 the collection of measured outflow at the site made it possible to compare the RSH recorded inflow (blue) and the recorded outflow (red). It is expected that the inflow (blue) would be higher than the outflow (red) for each rainfall event. As shown in the figure, that expectation is often true, but there are some obvious exceptions in April and May 2019. These periods where the outflow volume is greater than the inflow volume are probably due to the errors inherent with the difficulty of measuring very small inflow and outflow rates from this small bioretention facility.

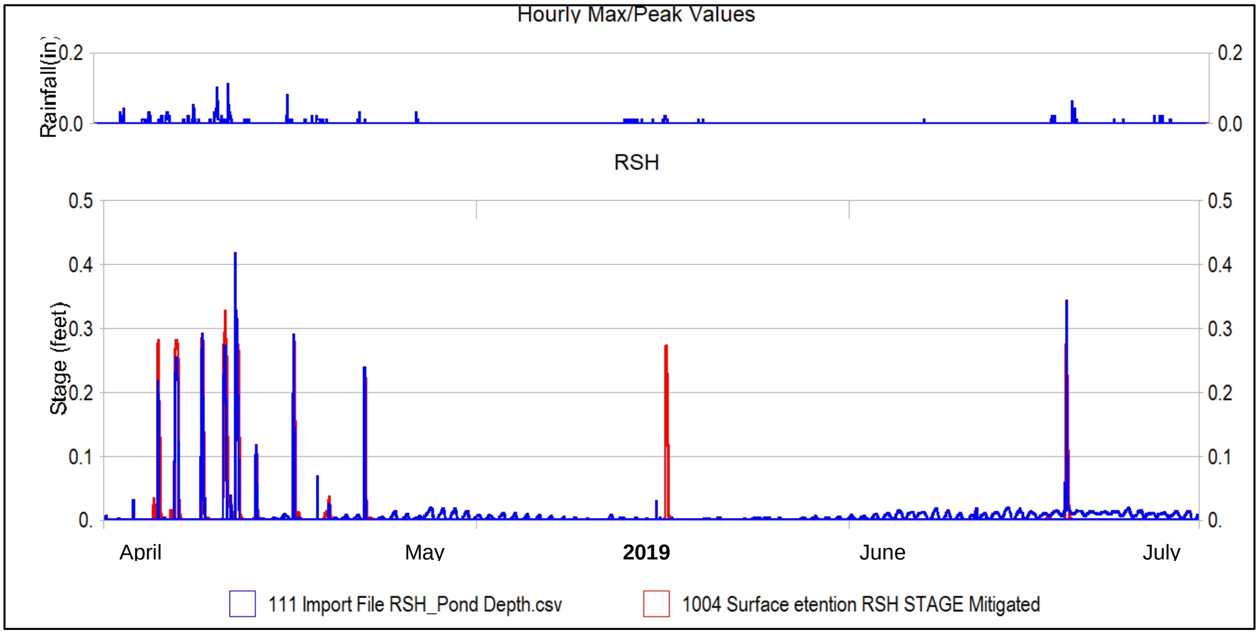


Figure RSH-3. RSH Hourly Surface Ponding Depths

Figure RSH-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute surface ponding (stage) values and, along the top of the figure, the RSH site monitored hourly maximum 5-minute rainfall data. The simulated and recorded ponding values show that the simulated ponding depths compare well to the recorded depths. Because of RSH's small size and limited ponding storage before overflow occurs the bioretention facility regularly fills to a depth of 0.3 feet and then overflows. That situation is observed in multiple storm events in the months of April, May, and June.

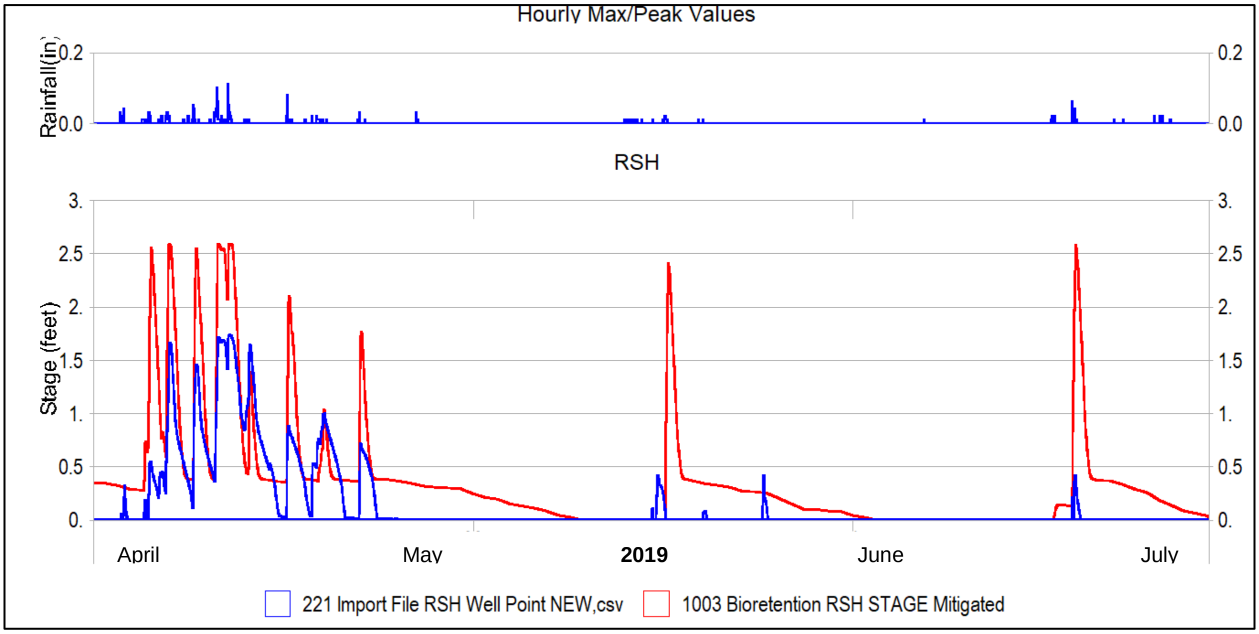


Figure RSH-4. RSH Hourly Soil Layer Well Point Elevations

Figure RSH-4 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the RSH site monitored hourly maximum 5-minute rainfall data. The simulated values are larger than the recorded well point data, but in general both show a similar response to rainfall events.

RSH has an underdrain, but due to its location and how it was connected to the downstream outlet pipe to the municipal stormwater system it was impossible to measure the flow exiting the underdrain. Bryan Berkompas, the monitoring lead, described the situation as follows:

> "The underdrain at RSH was plumbed into a small plastic pipe with a sump and an outlet that discharged into the outlet/overflow catch basin. The outlet pipe was a couple of inches higher than the inlet within the plastic riser. We measured levels relative to the outlet invert figuring that the underdrain would not discharge until the level exceeded that invert so we declared that to be zero for our measurements.
>
> As for the flow, I had originally hoped that the orifice on the downstream end of the underdrain outlet was at an elevation that would allow us to measure flow out of the underdrain using the level in the sump. Unfortunately that pipe was steep enough that the water level acting on the orifice could not be related to the water level in the sump. Given that the water level in the discharge pipe could be either inlet or outlet controlled at any given moment I did not pursue further."

As a result of this situation, no underdrain outflow measurements are available.

The RSH simulated combined outflow was compared with the measured/recorded outflow to better understand the relative magnitude of the surface discharge and the underdrain outflow.

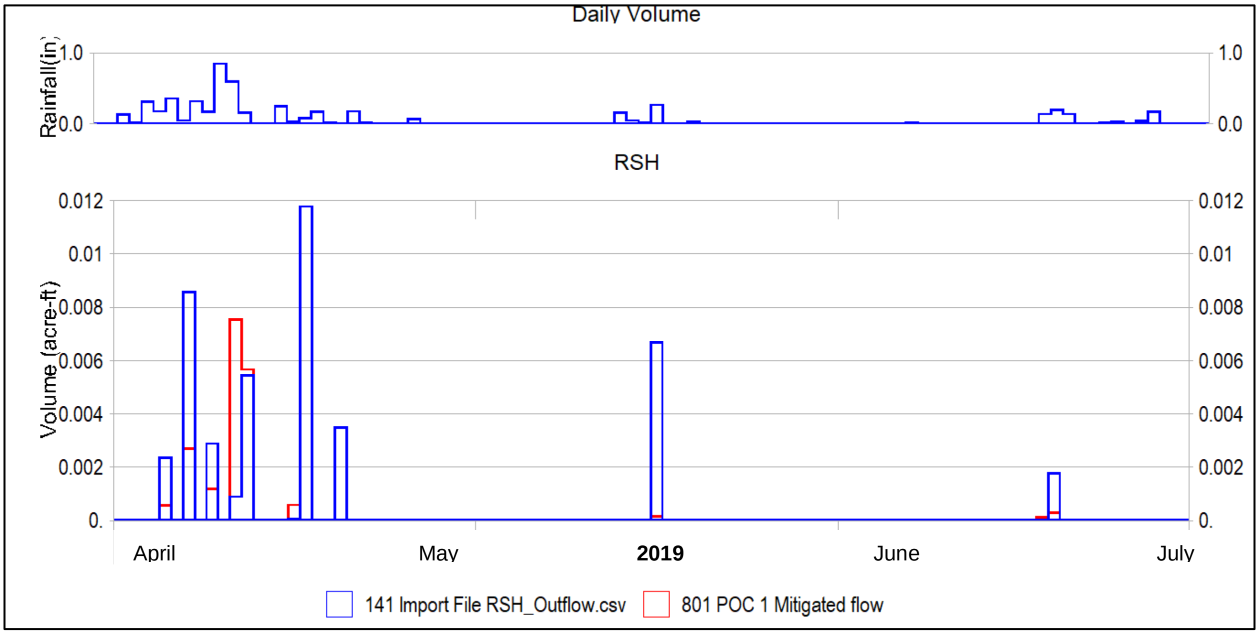
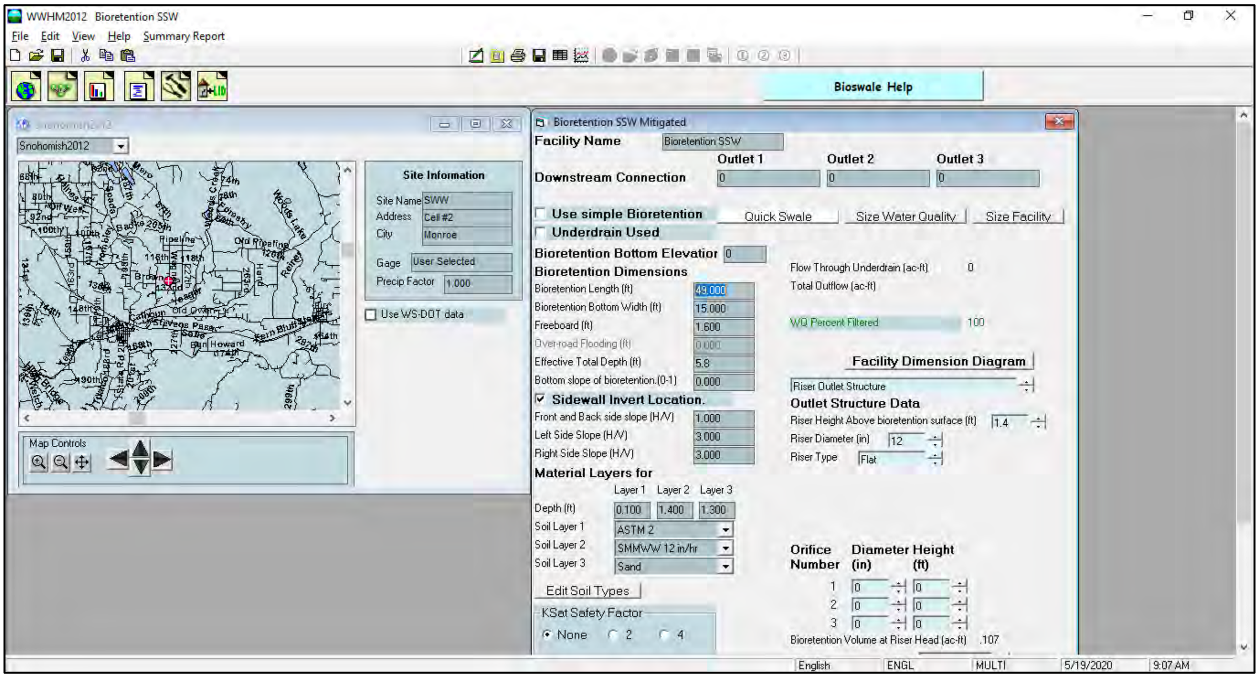


Figure RSH-5. RSH Daily Outflow Volumes

In Figure RSH-5 the RSH recorded outflow (blue) and the simulated outflow (red) daily volumes are shown. The simulated outflow is the sum of the surface discharge and the outflow from the underdrain. For most events the recorded outflow (blue) greatly exceeds the simulated outflow. As noted in the discussion above about recorded inflow and outflow, events when the outflow volume is unexpectedly large are probably due to the errors inherent with the difficulty of measuring very small outflow rates from this small bioretention facility.

The long-term modeling results based on the King County Sea-Tac Airport rain gage record show that RSH fails both MR #5 and MR #6. RSH's bottom area is only 0.9% of the drainage area to RSH. This site is too small to meet these minimum requirements and is overwhelmed by large runoff events.

SSW: Monroe, Snohomish County



The SSW bioretention site is located at Salem Woods Elementary School, just north of Monroe, Snohomish County, Washington. The drainage area to SSW consists of 0.4 acres of road on a moderate slope (5-15%). The original design assumed a drainage area of 0.22 acres of lawn vegetation, 0.03 acres of roof and 0.46 acres of road. However, site investigation work conducted by AESI and Aspect concluded that the roof and lawn area drainages were not connected to the bioretention site, as originally designed. A review of the drainage design also led to a small reduction in the roadway area draining to the site.

The SSW surface area footprint is 1022 square feet at the top of overflow. This equals 5.9% of the 0.40-acre tributary drainage area to SSW.

SSW has a surface outlet at 1.4 feet above the surface bottom. SSW has no underdrain. Overflow from the bioretention facility is discharged to an adjacent infiltration trench.

A native soil infiltration rate of 16 inches per hour together with a bioretention top soil layer of wood chips (represented by ASTM2 soil), a second soil layer of Ecology SWWMM soil mix (12-inch per hour infiltration rate), and a third soil layer of sand best reproduced the monitored soil moisture and surface ponding conditions. The wood chip layer was described in the geotechnical findings and added to reproduce monitored surface ponding depths.

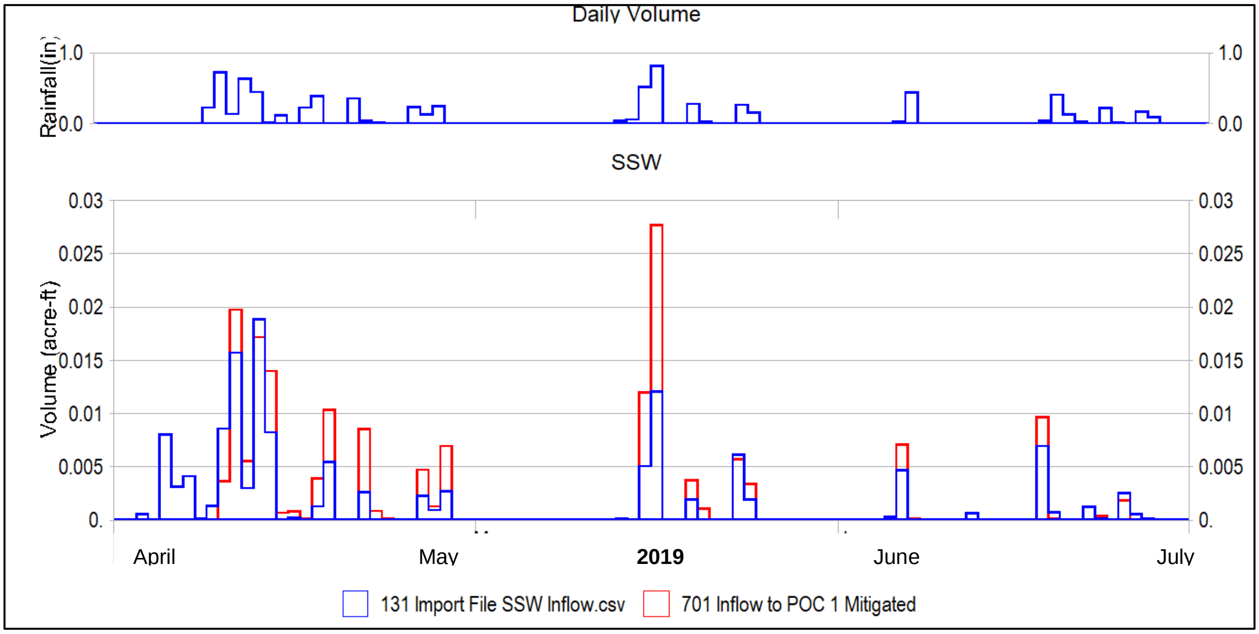


Figure SSW-1. SSW Daily Inflow Volumes

Figure SSW-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the SSW site monitored daily rainfall data. The simulated daily inflow volumes are larger than the recorded volumes. This difference may be caused by an over-estimation of the drainage area (even with the reduction noted above) or problems with measuring the actual inflow to the bioretention facility. The latter explanation is the most likely as the simulated and recorded ponding depths match well (Figure SSW-2).

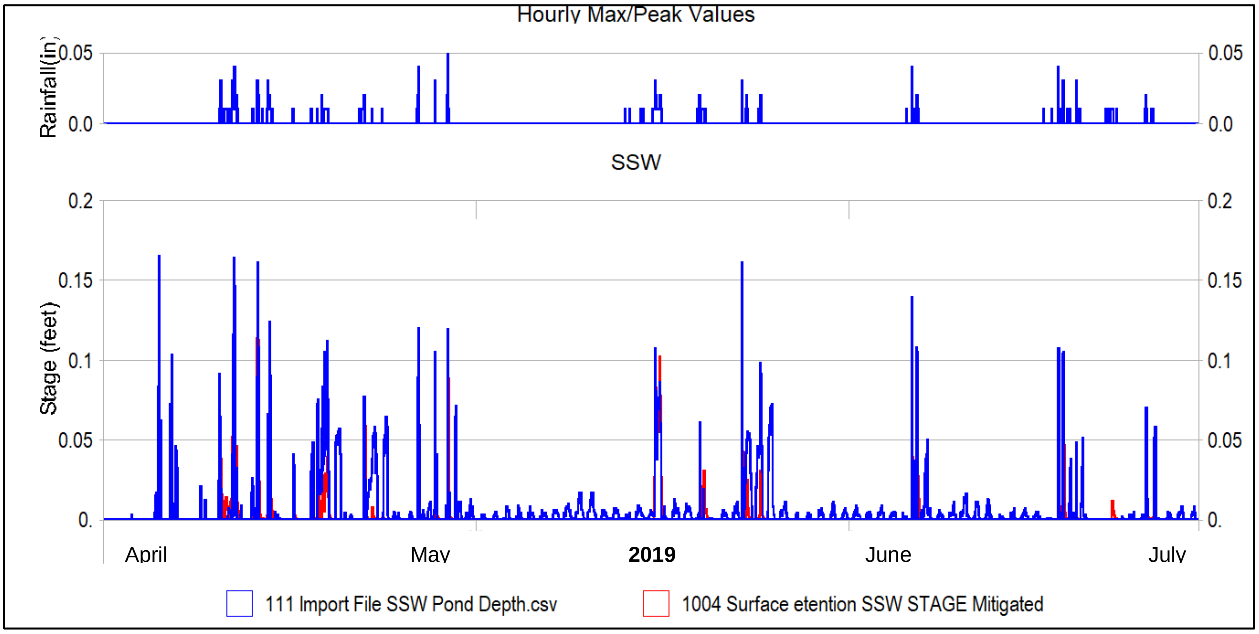


Figure SSW-2. SSW Hourly Surface Ponding Depths

Figure SSW-2 shows the simulated (red) and recorded (blue) hourly maximum 5-minute surface ponding (stage) values and, along the top of the figure, the SSW site monitored hourly maximum 5-minute rainfall data. The simulated and recorded ponding values match well (note that some of the simulated red lines are hidden by the recorded blue lines). As observed at some of the other sites, monitored ponding depth values fluctuate during dry periods due to diurnal temperature changes that affect the ponding depth sensor.

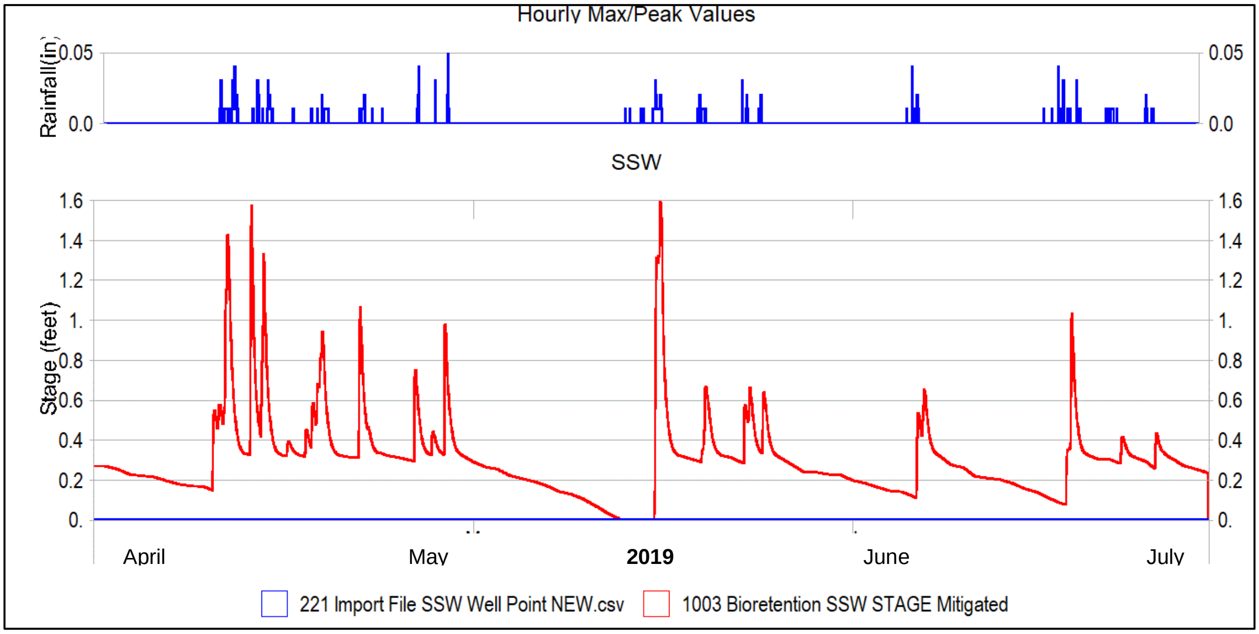
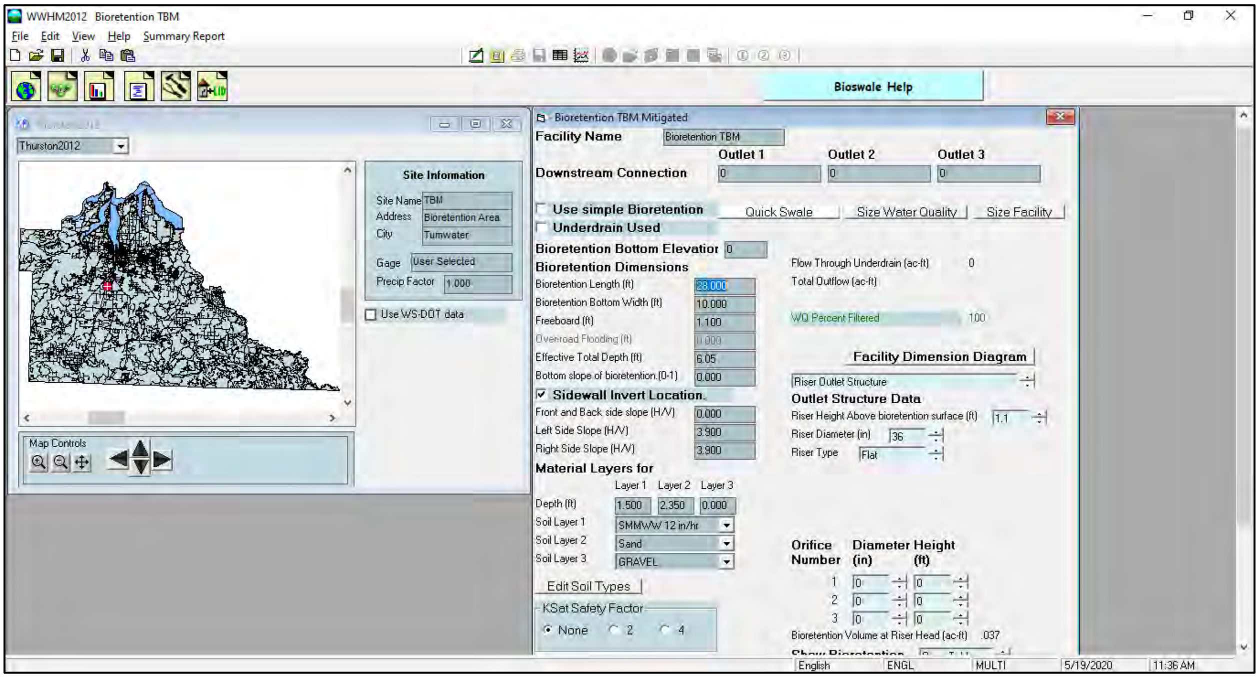


Figure SSW-3. SSW Hourly Soil Layer Well Point Elevations

Figure SSW-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the SSW site monitored hourly maximum 5-minute rainfall data. The simulated values show higher water levels in the soil layer than the recorded well point data. The geotechnical report states that the underlying soil has a high infiltration. With the bottom of the monitoring well placed only 3 feet below the soil surface and the soil draining rapidly, it appears that the soil water levels never rose to the bottom of the monitoring well. Aspect reviewed the monitored data to doublecheck that there wasn't an error in the monitoring record,. No identifiable problems were found.

The long-term modeling results based on the Snohomish County Everett rain gage record show that SSW passes both MR #5 and MR #6. Ability to pass these two minimum requirements is due to infiltration of 100% of the total runoff volume (overflow from the bioretention facility was directed to an adjacent infiltration trench to ensure 100% infiltration was achieved).

TBM: Tumwater, Thurston County



The TBM bioretention site is located in Tumwater, Thurston County, Washington. The design drainage area to TBM consisted of 0.05 acres of A/B soil, lawn vegetation, flat slope (0-5%) and 0.13 acres of road on a flat slope (0-5%). Model inflows to the bioretention facility when compared to the monitored inflows were only approximately one-half of the monitored inflow volume. Monitored results led us to conclude that there must be additional drainage area contributing to TBM. Doubling the road drainage area from 0.13 acres to 0.26 acres produced more realistic model inflows, pond depths, and well point data.

The TBM surface bottom footprint is 366 square feet. This equals 2.7% of the tributary drainage area to TBM based on a total drainage area of 0.31 acres.

TBM has no surface outlet control structure but overtops the site at 1.1 feet above the surface bottom. All of the inflow to TBM is infiltrated into the native soil beneath the bioretention soil layers.

A native soil infiltration rate of 8 inches per hour together with a bioretention top soil layer of Ecology SWWMM soil mix (12-inch per hour infiltration rate), and a second soil layer of sand was observed on the site.

Figure TBM-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the TBM site monitored daily rainfall data. The simulated daily inflow volumes are low compared to the recorded inflow volumes. The water entering the bioretention facility apparently does not drain through the Ecology soil mix as quickly as calculated by the model.

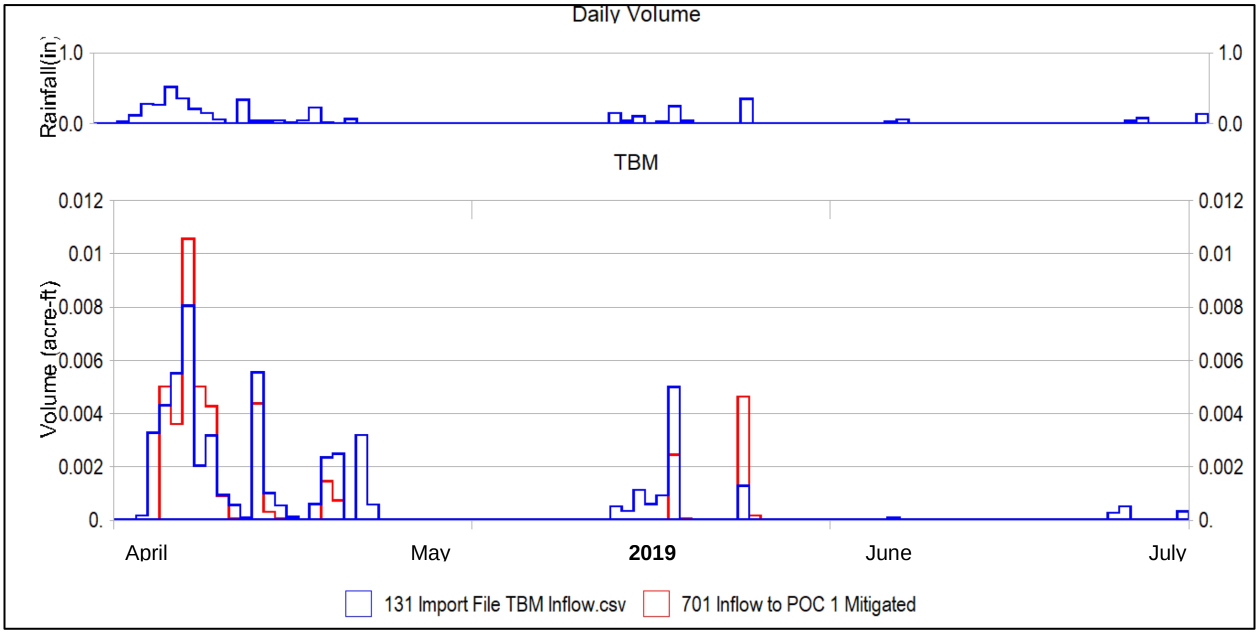


Figure TBM-1. TBM Daily Inflow Volumes

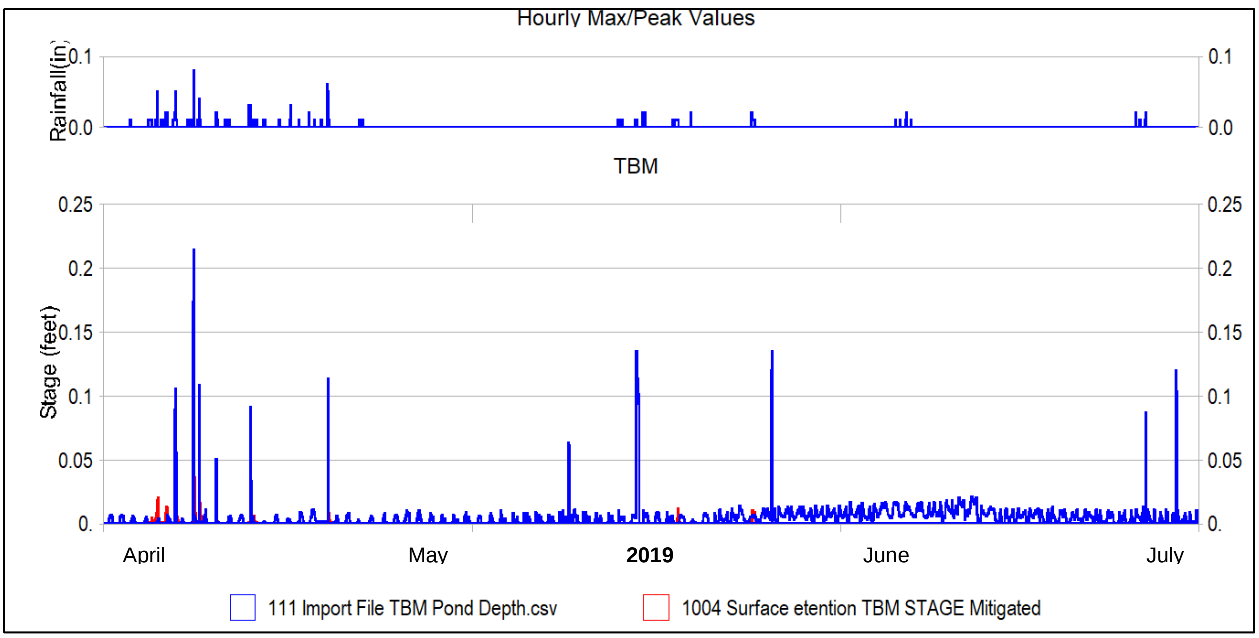


Figure TBM-2. TBM Hourly Surface Ponding Depths

Figure TBM-2 shows the simulated (red) and recorded (blue) hourly maximum 5-minute surface ponding (stage) values and, along the top of the figure, the TBM site monitored hourly maximum 5-minute rainfall data. The simulated ponding depths are consistently lower than the recorded ponding depths. As observed at some of the other sites, monitored ponding depth values fluctuate during dry periods due to diurnal temperature changes.

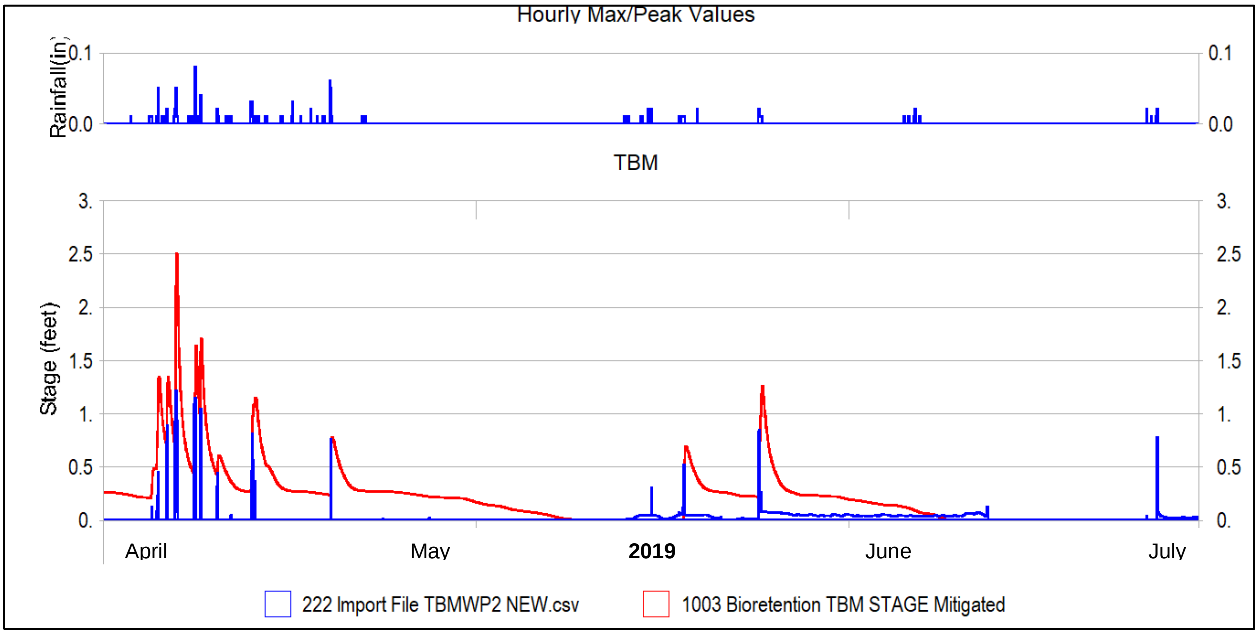
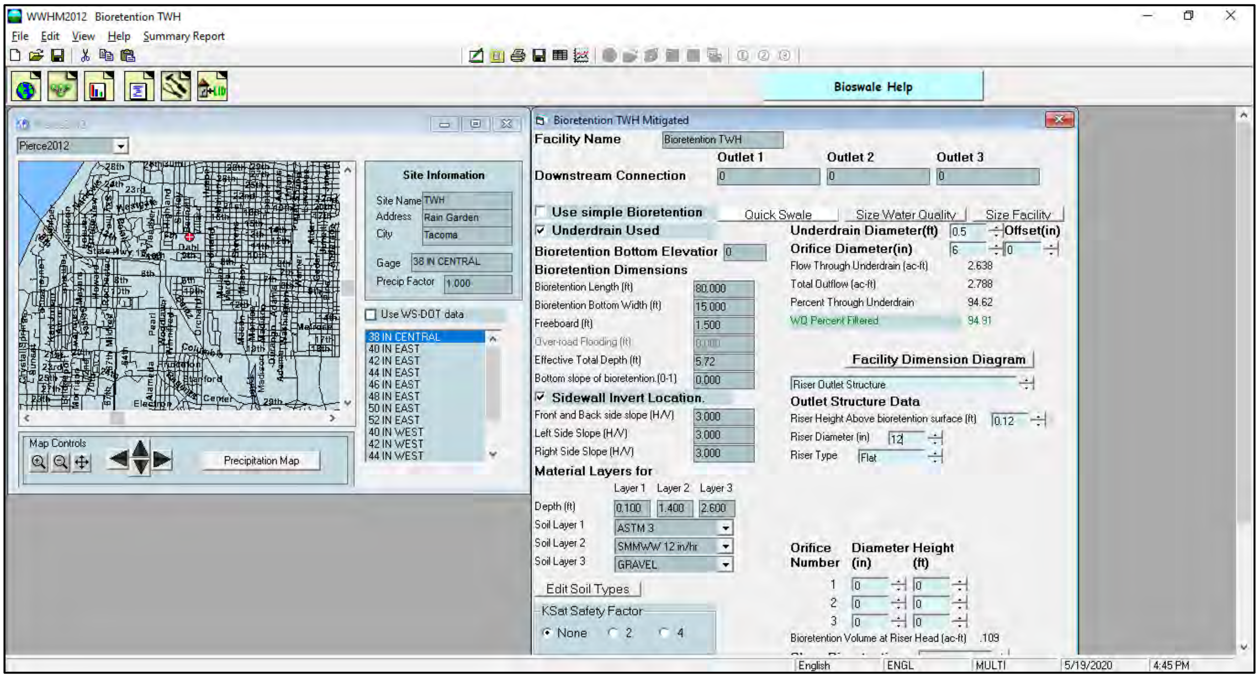


Figure TBM-3. TBM Hourly Soil Layer Well Point Elevations

Figure TBM-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the TBM site monitored hourly maximum 5-minute rainfall data. The simulated values show longer drain times through the soil layers than the recorded well point data.

The long-term modeling results based on the Thurston County Olympia Airport rain gage record show that TBM passes MR #6 (water quality) but fails MR #5 (LID flow duration). TBM fails MR #5 because the surface overflow exceeds the flow duration standard for MR #5 (8% of Q2 to 50% of Q2) when ponding depths exceed 1.1 feet.

TWH: Tacoma, Pierce County



The TWH bioretention site is located in Tacoma, Pierce County, Washington. The drainage area to TWH consists of 0.19 acres of C soil, lawn vegetation, on a flat slope (0-5%) and 1.43 acres of road on a flat slope (0-5%).

The TWH surface area footprint is 1269 square feet at the top of overflow. This equals 1.8% of the 1.62-acre tributary drainage area to TWH.

TWH has a surface outlet control structure that is only 0.12 feet above the surface bottom. Most of the inflow to TWH is infiltrated into the bioretention soil mix beneath the top vegetative layer and then exits through an underdrain.

A native soil infiltration rate of 0.05 inches per hour together with a bioretention top soil layer of ASTM3 soil, a second soil layer of bioretention soil mix SMMWW (12 in/hr), and a third soil layer of gravel best reproduced the monitored soil moisture and surface ponding conditions. The top ASTM3 layer of 0.1 feet represents vegetative litter. This was added to reproduce monitored surface ponding depths.

Figure TWH-1 shows the simulated (red) and recorded (blue) daily inflow volumes and, along the top of the figure, the TWH site monitored daily rainfall data. The simulated daily inflow volumes are higher than the recorded volumes for some the rainfall events although overall the recorded peak inflows are larger than the simulated hourly inflow peaks (see Table 4).

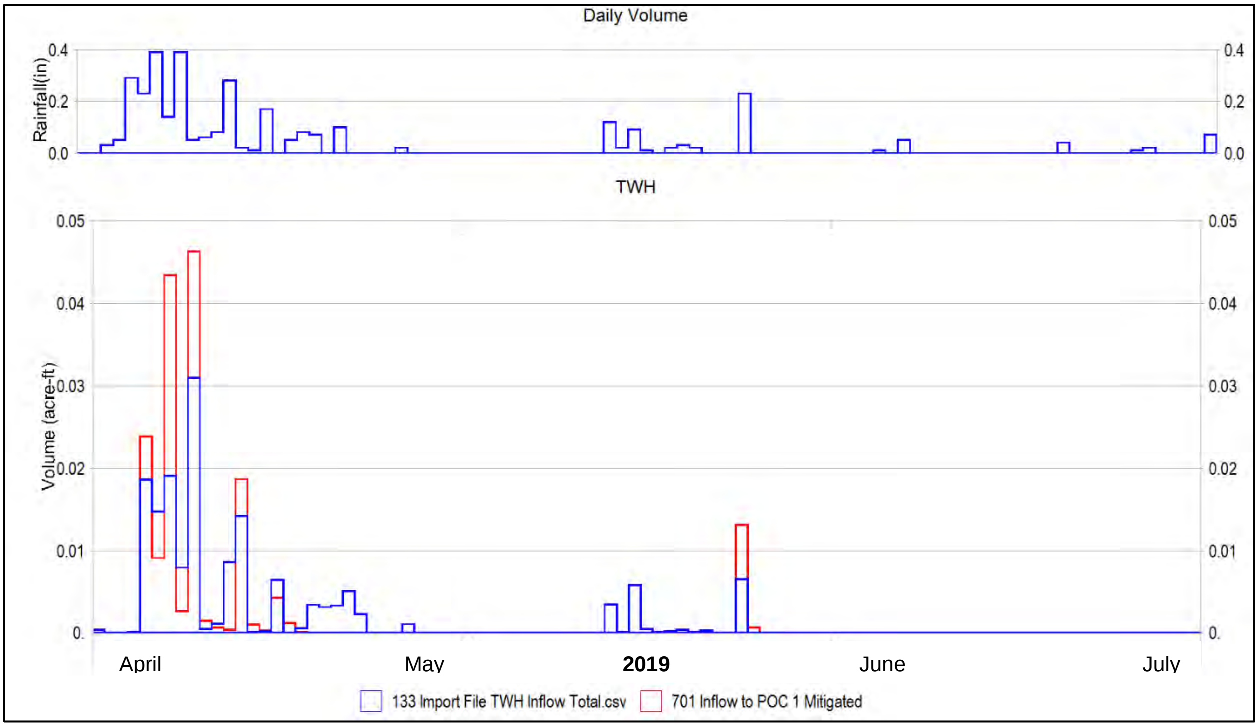


Figure TWH-1. TWH Daily Inflow Volumes

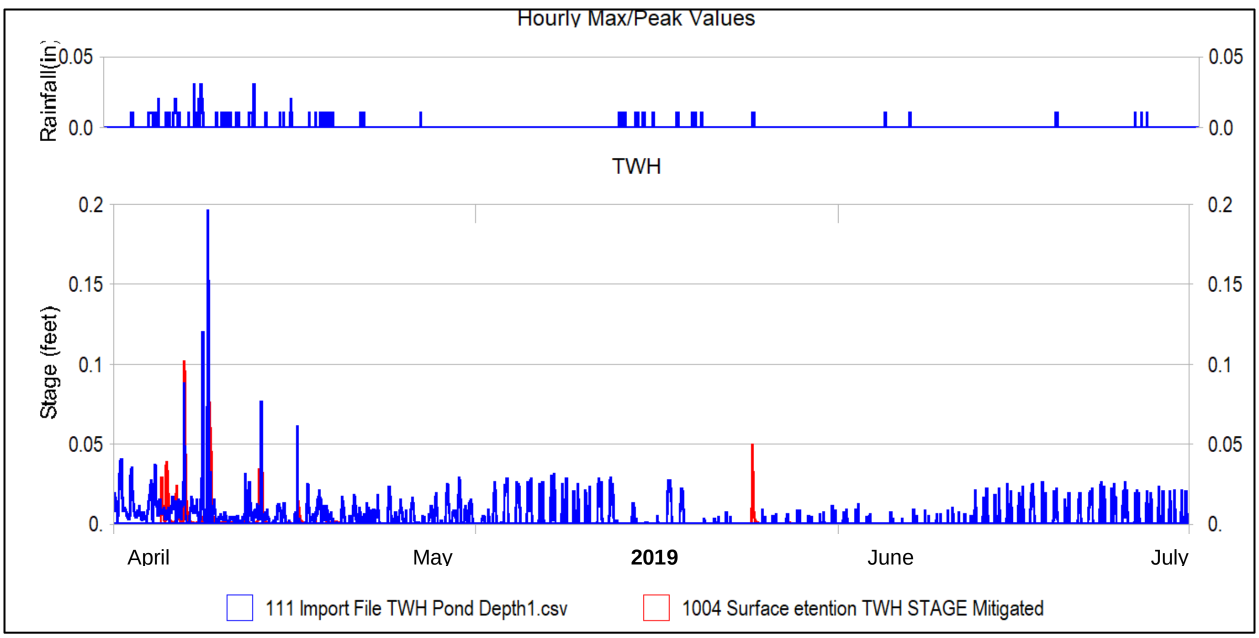


Figure TWH2. TWH Hourly Surface Ponding Depths

For TWH ponding depths were measured at two locations in the bottom of the bioretention facility. Figure TWH-2 shows the simulated (red) hourly maximum 5-minute surface ponding (stage) values; the recorded hourly maximum values for monitoring site 1 are shown in blue (monitoring site 2 values are less representative of the bioretention ponding depths than site 1). Along the top of the figure is the TWH site monitored hourly maximum 5-minute rainfall data. The simulated ponding values generally lower than the recorded values. As observed at some of the other sites, monitored ponding depth values fluctuate during dry periods due to diurnal temperature changes that affect the ponding depth sensor. These temperature changes are the source of the small daily recorded pond depths when there is no measured rainfall.

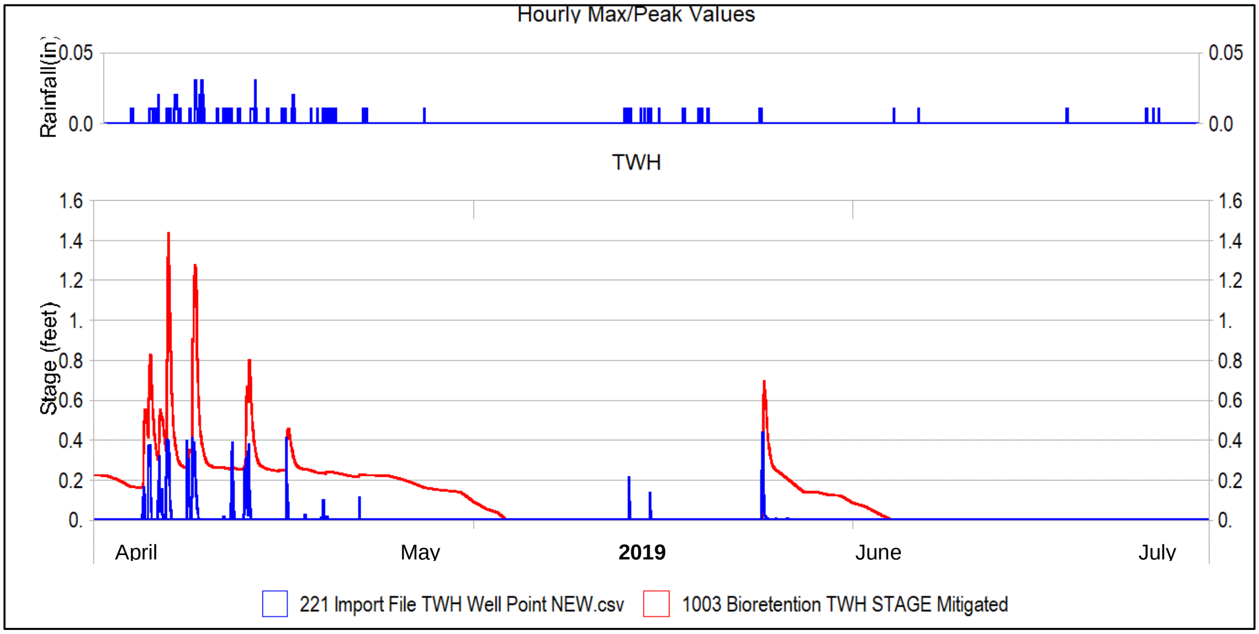


Figure TWH-3. TWH Hourly Soil Layer Well Point Elevations

Figure TWH-3 shows the simulated (red) and recorded (blue) hourly maximum 5-minute soil layer well point elevations (stage) values and, along the top of the figure, the TWH site monitored hourly maximum 5-minute rainfall data. The simulated values show longer drain times through the soil layers than the recorded well point data.

TWH has an underdrain, but there was no access to install monitoring equipment to measure the flow exiting the underdrain. As a result of this situation, no underdrain outflow measurements are available.

The TWH simulated combined outflow was compared with the measured/recorded outflow.

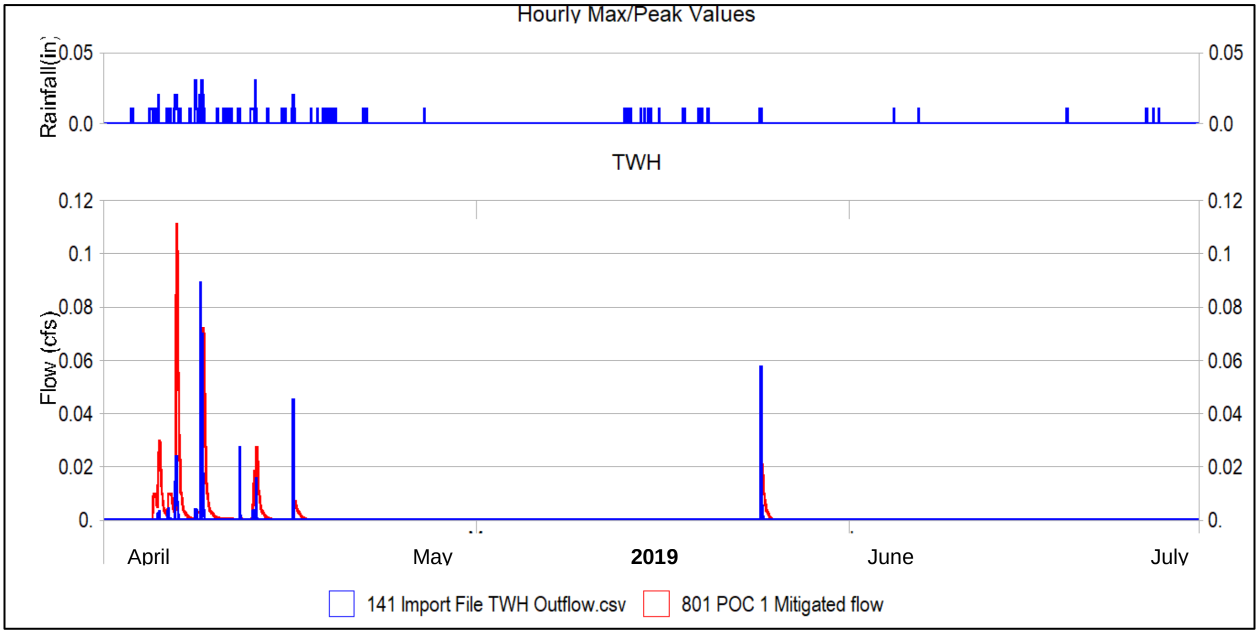


Figure TWH-4. Comparison of TWH Hourly Outflow Simulated and Measured Peak Flows

In Figure TWH-4 the TWH recorded outflow (blue and the combined simulated surface discharge and the underdrain outflow (red) hourly peak flows are shown. The recorded outflow (blue) and simulated outflow (red) results are similar. The surface discharge is very small compared to the underdrain outflow and is insignificant. For all practical purposes the underdrain produces all of the outflow. This same observation was made by AESI during the infiltration testing.

The long-term modeling results based on the Pierce County WSDOT 38-inch Central rainfall record show that TWH fails both MR #5 and MR #6. TWH's bottom area is only 1.7% of the drainage area to TWH. The relatively small size of TWH combined with its low riser height (0.12 feet) produces too much surface discharge to meet these minimum requirements and as a result TWH is overwhelmed by large runoff events.

Summary

In general the hydrologic performance of the ten bioretention facilities was well represented by WWHM2012. The range in performance in terms of ponding depths and well point elevations met or exceeded the expected WWHM2012 model graphical results comparison with the monitored data for many of the sites, although there was a frustrating lack of consistency from one site to another.

In general, the WWHM2012 models of the ten bioretention sites reproduced the monitored bioretention hydrologic performance data with accurate results when viewing the long-term graphical trends. Accurate results are defined as periods where the simulated results match closely with the recorded (monitored) data and other periods where the simulated results are sometimes high and sometimes low. Overall there is no obvious bias high or low.

As noted in our earlier study, it appears that there are two major model inputs that may be influencing the results. The vegetative litter cover can, at some sites, reduce the infiltration rate of the ponded water into the bioretention soil mix. At sites MPP, RSH, SSW, and TWM this vegetative litter cover was modeled using a limiting soil type (ASTM 1, ASTM 2, or ASTM 3). At the other six sites no vegetative litter cover was modeled.

The other major model input that may be influencing the results is the evapotranspiration (ET) from the bioretention soil mix. It is set in WWHM2012 to equal 0.5*PET (Potential ET). There is evidence from the well point data that the 0.5 multiplier factor should be higher. That will help to remove water faster from the bioretention soil mix layer.

As discussed above, Table 10 represents modeling for long term, and does not necessarily to match current hydrologic conditions of the sites at this current time. The long-term model results show the issues and problems that bioretention facilities are faced with in the real world. Some sites are undersized and do not meet MR#5 and MR#6, as a result. This may be due to retrofitting a site for stormwater control by adding a bioretention cell where space is limited. If the site is too small then the bioretention may not function as expected. As noted above, MR#5 failures are the result of either too much surface discharge (overtopping) or too fast underdrain discharge (due to the large diameter of the underdrain pipe and the absence of an underdrain orifice to restrict the underdrain discharge).

As a side note, sites with underdrains provide unique challenges. As was found by our field monitoring staff, underdrains are difficult and sometimes impossible to monitor. Without the ability to observe underdrain flows it is difficult to know where the underdrain water is going and at what rate.

MR#6 non-compliance is solely due to too much surface discharge. The limiting factors in meeting MR#6 are the surface area of the bioretention facility and the overflow height. The four sites that fail MR#6 (BCK, BUW, RSH, and TWH) all have small surface areas and low overflow heights. While some small sites met MR#6, no site with a surface area ratio percent less than 5% met both MR#5 and MR#6 standards.

The performance of the bioretention cells monitored in this study will be discussed as part of the final report.

At this time, based on the bioretention modeling completed for this study, we do not recommend any changes in the Ecology bioretention sizing criteria.

The complete set of WWHM2012 models for the ten sites has been provided to the Department of Ecology.

APPENDIX 17

Bioretention Hydrologic Performance (BHP) Study II Summary of Final Conclusions and Recommendations Deliverable 5.4. Taylor Aquatic Science. 10/27/2020

Taylor Aquatic Science and Policy

Technical Memo

To:	Eric Christensen, City of Olympia Brandi Lubliner, SAM Coordinator, Ecology
From:	William J. Taylor, Taylor Aquatic Science and Policy Douglas Beyerlein, Clear Creek Solutions, Inc. Jenny Saltonstall, Associated Earth Sciences, Inc. Bryan Berkompas, Aspect Consulting Anne Cline, Raedeke Associates, Inc. Chris Wright, Raedeke Associates, Inc.

Date:	October 27, 2020
Re:	Bioretention Hydrologic Performance (BHP) Study II Summary of Final Conclusions and Recommendations Deliverable 5.4

Introduction

Even as the use of bioretention as stormwater treatment increases in new and redevelopment in the Puget Sound region, surprisingly little assessment has been conducted of the hydrologic performance of constructed facilities. As population grows and developable space in the Puget Sound region is increasingly scarce, natural stream channel ecosystems remain vulnerable to stormwater runoff. Evidence is needed that stormwater control measures are efficiently using space available to achieve protection of local waters.

This memo provides a summary of findings and recommendations from the Bioretention Hydrologic Performance Study Phase II site data, and performance of the design model to represent 10 bioretention facilities located in western Washington State.

As with the previous Phase I project, this Phase II project involved an initial review of many candidate sites, discussions with local jurisdiction owners, design engineers and maintenance staff; and site-specific documentation of dimensions and elevations, bioretention soil media (BSM) structure, infiltration rates, vegetation conditions, and measured hydrologic response of the facility. The measured site conditions and hydrology were then used to evaluate the sites and the performance of the Western Washington Hydrology Model (WWHM) 2012 to represent constructed facilities.

This Phase II project selected ten facilities that were designed using the updated WWHM 2012, while Phase I selected and studied ten facilities that used the previous version of the WWHM and other models as well. This enabled evaluation of the performance of the WWHM 2012 model itself against facilities designed using the model, in addition to performance of the facilities themselves.

The distinction between the two models is that the 2012 model version uses updated infiltration algorithms within a dedicated bioretention design module, where previously the WWHM used a more simplified representation. The results are intended to be more accurate in predicting the continuous hydrologic performance of designed facilities, and therefore better achieve the Minimum Requirement goals of the SWMMWW (2012/14) for bioretention facilities.

The use of the WWHM 2012 also meant the ten facilities selected in Phase II have more recently been constructed (the 2012 version of the model was available in 2012 but not more broadly used until year 2015 and later). As a result, these facilities were not "aged" by years of infiltration, maintenance, and plant growth, and more represent initial conditions as represented by the designer's model.

This memo is Deliverable 5.4 and is intended to be discussed at the next Stormwater Work Group meeting.

As a result of the comprehensive nature of the assessment, it should be noted that many of the insights and conclusions come not just from the physical measurements, vegetation composition, hydrologic performance data, and modeling, but also from the more anecdotal observations gained from owners, engineers and operators of the facilities, as well as our own site-specific observations.

In addition to conclusions learned from these steps, some new questions emerged that could further address the performance of bioretention facilities but were not evaluated as the analyses require unavailable or uncollected data, or are beyond the scope of the project (for example sensitivity analysis of the effect of variability of infiltration rates, contributing area, and site specific rainfall).

The main goals of the project were to:

1. Provide a hydrologic assessment of how ten constructed bioretention facilities designed using WWHM 2012 and located throughout Puget Sound are performing.

2. Identify major influences of the site designs and performance constraints affecting the performance (e.g. BSM, infiltration rates, percent of drainage area, vegetation composition), to help inform the design and modeling process for more efficient and predictably performing facilities.

3. Provide recommendations for engineers and jurisdiction reviewers to better model, design and review future bioretention facility designs.

Results

<u>Representativeness of Sites Assessed</u>
As with the previous Phase I project, over seventy individual bioretention cells were evaluated through site visits in the field and review of design documents. After affirming a site was designed using WWHM 2012 as a bioretention facility (and not a conveyance swale or pond for example) the decisive selection criterion was the feasibility of monitoring flow at the site inflow and outflow locations. As a result of the wide range of geographic locations and site conditions, the selected projects represent a wide cross section of meteorological and geomorphic and hydrogeologic conditions, as well as drainage area ratios.

<u>Design Conditions</u>
Design dimensions and other information for each of the ten sites was collected from the original design drawings and, when available, from hydraulic and geotechnical reports supporting the design. The modeling approaches were evaluated to assess the original modeling approach (model version, approach to modeling, etc.) to help ascertain whether design features and performance were related to the modeling approach taken.

<u>Constructed Dimension</u>
Constructed cell dimensions were measured in the field and found to be generally as per project design dimensions. Inflow volumes were also assessed through the WWHM model developed for each site by matching apparent inflow volumes with measured ponding or well depths. Field documentation of contributing areas was not conducted.

Following are a summary of findings for the various disciplines evaluated at each of the sites.

Issues with Existing Designs or Construction Practices

<u>Site Design Review</u>

- All the selected study facilities were designed using WWHM 2012.
- Approach to modeling was often not set up properly, even with the available new WWHM 2012 bioretention module. Some engineers using WWHM 2012 fail to use the bioretention element to represent bioretention facilities in their models. Others use the bioretention element but do not input the correct values that represent the actual design conditions.
- Where any site facility surface area to drainage area ratio was smaller than recommended (5%) the site did not meet performance standards.
- In-field hydrologic performance of the facilities was most often due to oversizing or undersizing of facilities beyond current safety factors, and/or not following BSM criteria.
- Using long term county precipitation records and using the SWMMWW-prescribed lower infiltration rates equally across the entire lifespan (rather than what was actually measured at the site), six of the facilities did not meet Minimum Requirement (MR) #5 and four of the facilities did not meet MR #6; in reality much of each facility life span will reflect the higher initial infiltration rate thus actually meeting these MRs for some period.

Hydrologic Monitoring Data and Findings

- 8 months of continuous wet season monitoring (November 2018 – June 2019) – however this data was highly confounded by frequent freezing, snow accumulation, and owner maintenance practices during the winter. Full records were collected and delivered.
- Only 3 months of data, April 2019 – June 2019 was usable for comparison to modeling results.
- Volumetric runoff at each site is variable even for apparently near 100% impervious contributing areas. Measured continuous runoff records were overall considered less dependable than the simulated, so simulated volumes were used in the model evaluation. However, a regression of measured runoff volumes for a range of storm events still often had good R2 values.
- Ponding and well point responses for infiltrating sites (not underdrained) showed good reflection of the BSM infiltration rates and subgrade conditions. Underdrained sites showed rapid runoff of infiltrated waters, resulting in well point elevations reflecting underdrain elevations.
- Evidence of water movement not captured in the modeling occurred through possible subsurface leakage into subsurface utility trenches.
- At one site near a tidal shoreline, well point data had a clear tidal signal but groundwater did not affect infiltration rates.

Geotechnical and Hydrogeologic Findings

- Sites covered a wide range of geomorphic and hydrogeologic conditions.
- Bioretention soil texture was generally coarser than current guidelines, resulting in greater infiltration rates than would be expected under the current media guidelines.
- Wide range of measured infiltration rates, with measured rates in the field for both the media and subsurface soils much greater than site design values used in all but one case.
- Compaction of the bioretention soil was documented in three facilities and is interpreted to have reduced the bioretention soil infiltration rate in two underdrained facilities.
- Bark mulch floated and was re-distributed during controlled infiltration testing and can be a source of clogging if conveyed to a small-diameter orifice-controlled outlet.
- Bioretention without underdrains on outwash sites provides recharge to shallow aquifer settings. Shallow aquifer levels remained below the facility base, and groundwater mounding did not affect infiltration rates.
- Bioretention on low-permeability sites resulted in mounding on hydraulic restrictive layers. The mounded water was collected by the underdrain.

Vegetation Findings

- Phase II facilities studied were only very recently planted (within 2 years) so still showing original plantings.
- Plantings generally followed the specified planting plans.

- Bioretention soils and native soils drain rapidly in most cases and hydrophytic plants appeared not to survive well at one example site - even within 2 years since installation.
- Shrubs have higher survival rates than herbaceous vegetation and appear to reduce the maintenance of cells.

Modeling Findings

- Viewing long-term graphical trends, the WWHM 2012 models reproduced the monitored bioretention hydrologic performance data with accurate results.
- An additional bioretention "limiting" surface leaf layer was utilized to best represent four of the facilities. This suggested some surface infiltration was limiting in these facilities, while not visually obvious.

Major Influences and Recommendations for Improved Bioretention Designs and Performance

Given the above findings, major influences and recommendations intended for engineers, geotechnical specialists, and landscape architects, as well as development reviewers at local jurisdictions for each of the design elements include:

Design Features

- Contributing drainage areas, inflows, and minimum facility sizes are a major influence on projects.
  Recommendations:
  - Conduct as-built surveys of inlets, overflows and bioretention surface.
  - Conduct a field inflow test to confirm positive drainage into the cell.
  - Provide better review of design plans and models before accepting for construction. This review should include contributing area calculations and reviewing the design model to determine the appropriate minimum facility size as a percentage of drainage area.

Geotechnical and Hydrogeologic Conditions

- Outwash sites are good settings for bioretention systems. More precisely known subsurface conditions are a major influence on project performance.
  Recommendations:
  - Collect site-specific data to understand shallow soil, geologic and groundwater conditions affecting subsurface infiltration rates.
  - Consider potential for lateral flow, and the ultimate path of the infiltrated water, for sites with low or spatially variable infiltration rates.
  - Consider potential for utility corridor capture of infiltrated waters, particular in retrofit applications.
- Soil media composition is a major influence on the infiltration rate, especially at the smaller particle range, resulting in rapid infiltration in most cases.
  Recommendations:
  - Provide testing of soil media for consistency with the specifications provided in the Ecology Manual, especially the less than sieve 40, 100, and 200 fractions.

    - Conduct a study of “aging” of facility infiltration rates over time, whether decreasing, increasing, or staying the same.

- Plan reviews by permitting jurisdictions seemed to miss some important geotechnical design elements.
  Recommendation:
    - Conduct geotechnical plan review of permit plans and during construction so that plans adequately incorporate geotechnical recommendations (e.g. are bioretention cells located near infiltration test locations or at different elevations; does the grading plan (improperly) remove the permeable horizon?).

- Actual conditions observed during construction can be important to appropriately modify the design.
  Recommendations:
    - Conduct observations during construction to observe whether the subsurface geologic and groundwater conditions are consistent with the basis of design (i.e. if site design is based on outwash soils being present, and subsurface conditions are consolidated glacial till, a design change is required).
    - Soil compaction can occur during bioretention soil placement, irrigation installation, placement of inlet protection or energy dispersion elevation or from planting; compacted soil should be remediated prior to acceptance.
    - We speculate based on limited observations that soil compaction impacts are more common for narrow facilities. Evidence for surface compaction was exhibited in five of the ten facilities.

<u>Vegetation Plant Composition and Survival</u>

As discussed in the previous study, bioretention units with underdrains tend to drain very quickly. Units with underdrains, especially large cells with underdrains, need to be planted with extremely adaptable plants that err on the side of having a wetland indicator status of facultative upland or upland plants (not wetland plants). Plant schedules should include the wetland indicator status of plants used in the design.
Recommendations:

- Cells that were planted with only herbaceous species, or where the woody plants had been heavily browsed by deer, tended to be growing a greater density of noxious weeds. Shrubs tend to compete better with noxious weeds and therefore should be used more frequently in units to reduce maintenance.
- Herbaceous species tend to have poor survival rates in bioretention cells compared to shrubs. Units should be planted with a variety of shrubs and herbs. Native shrubs tend to be large and might be inappropriate for some units due to limited sight lines. Consider using smaller shrubs such as (*Cornus sericea ‘Kelseyi;*) and shiny-leaf spirea (*Spiraea betufolia var. lucidaf).*
- Specify water tolerant plants in bottom areas near the inflow, and fan out to more facultative, facultative upland plants farther away from the inflow.

- Cells tend to be planted with plants that commonly occur in wetlands, however wetland soils are anaerobic, waterlogged, and poorly draining. Bioretention soil is very-well draining. Wetland species that require constant water-logged soil will not grow well in bioretention cells and should be avoided (except for *Carex obnupta*).
- Maintenance plans and contingency plans should be developed along with the planting designs to allow adaptive changes. Designers should follow-up on the effectiveness of the design a year or two after installation.

<u>Modeling Influences and Recommendations</u>

- Some input surface BSM default infiltration rates did not provide results consistent with an accurate model of measured conditions.
  Recommendation:
  - Use of a limiting “leaf litter layer” surface modeling layer in the model may improve model results where non-wood mulch will be applied.

- Using the default evapotranspiration rate appeared to have a substantial effect on results.
  Recommendation:
  - Use a higher evapotranspiration rate than the default 0.5, especially for solar exposed sites.

- Rapid infiltration to underdrains resulted in rapid drainage of subsurface water after infiltrating.
  Recommendation:
  - Jurisdictions that encourage infiltration even in soils that have low infiltration rates should include a capped underdrain as a back-up discharge management option.

- WWHM is a 1-dimensional model, meaning uneven (laterally or longitudinally differential) infiltration observed at various sites both in Phase II and Phase I infiltration testing or other field observations is not represented in the model.
  Recommendation:
  - The effects of uneven infiltration should be further evaluated and incorporated in the design approach (see same issue regarding planting plans above).

- It is recognized that new and retrofit facilities have different minimum requirement criteria. As a result designers and reviewers recognize the degree of performance will differ between them.
  Recommendations:
  - Ecology conduct a sensitivity analysis of the magnitude of effect of the variability of safety factor infiltration rates, contributing drainage area, and use of regional rainfall records on new facility performance on long-range ability to meet MR #5 and MR #6.
  - Reviewers should run the WWHM 2012 model for the site and analyze results for compliance with MR #5 and MR #6 before approving new development site design.

Discussion

This Bioretention Hydrologic Performance Phase II study included study of facilities distinctly different from those in Phase I: these facilities were all modeled using the updated WWHM 2012 hydrologic model which includes a specifically designed bioretention modeling module. The use of this more current model would presumably result in more consistent outcomes in accuracy and precision of the performance. In addition, these facilities were all more recently designed and constructed, suggesting they may provide insight to current practices in bioretention.

As with Phase I, most Phase II facilities showed rapid infiltration due to high measured infiltration rates of their bioretention soil media; the exceptions were RSH and BCK where compacted soils were observed in combination with a low overflow elevation. Notably combined with these high infiltration rates were several undersized retrofit facilities (as a percent of their drainage area), many cells using underdrains, one cell had a very low and uncontrolled overflow elevation of the outlet structure, and some cells had apparent lateral flow (possibly through utility trenches). These conditions occurred either alone or in combination. As a result of these conditions long term modeling of many of the facilities did not meet MR #5 and MR #6 (meeting the pre-developed flow duration curve at 8% of the two year to 50% of the 50 year, and infiltrating 91% of the total runoff volume, respectively).

This combination of the number of undersized facilities and the much higher rates of infiltration than designed, together with deficient structural features (e.g. allowing rapid outflow to underdrains and overflows, and lateral flow), was the greatest influence on the apparent success or lack of success of these facilities overall.

Interestingly, a second, co-occurring property of many facilities' performance was identified in both this and the previous Phase I project study: spacially uneven infiltration of the inflowing water. This observation simply recognizes the reasonable expectation that inflows to the facility will tend to infiltrate first near the inflow point and will tend to do so until near surface infiltration is saturated before surface flows progress across the facility. This adds a complex second dimension to the conceptual model and design plans regarding how bioretention facilities hydrologically perform. For example, planting plans should anticipate differential moisture conditions to improve planting plan performance. How to model this effect and to what extent it may affect the hydrologic performance of any one facility is difficult to predict.

Other than the higher number of undersized facilities seen in this set of study sites, many of the findings and observed (or inferred) performance was in many way similar to Phase I: highly infiltrating conditions, influence of underdrains, highly variable shallow native soil infiltration rates, and the use of plants with a wetland indicator status of obligate or facultative not surviving long-term.

The project sites evaluated were in most cases either over-sized or under-sized relative to their drainage areas. High infiltration rates occurred at half the sites compared to the site design rates. The lower site design infiltration rates may have resulted from either jurisdictionally mandated limits on assumed infiltration rates through bioretention soil or from correction factors applied to the native subgrade infiltration rate based on the type of infiltration testing. Alternatively, the area available at the site may simply have allowed the facility to be oversized (relative to the infiltration design rate) to serve as a landscape amenity and not just a stormwater facility. The undersized facilities appeared to underperform simply based on their small size, even with high actual infiltration rates.

Retrofit and new development sites where space is limited and where more efficient sizing is desired would likely benefit from greater subsurface hydrogeological investigation for greater accuracy of the potential infiltration capacity. Anecdotally, some engineers' apparent level of discomfort with the complexity of bioretention facilities' design and the uncertainty of subsurface infiltration rates may be contributing to discounting of the feasibility of bioretention at some sites. Similarly, vegetation composition and maintenance appear to become an afterthought in design of the facilities relative to the institutions' needs or commitment to maintenance and may contribute to owner's disinclination to include bioretention in site designs.

Nonetheless, these findings should not distract from the benefit of these bioretention facilities that they still perform: reducing flows from conventional curb and gutter runoff and discharge to receiving waters. These facilities, even with the above recommended design improvements, still served the function to reduce runoff delivery rates and volumes and provided water quality treatment for protection of receiving waters.

Recognizing the facilities in this study were only recently constructed, they appear to be serving an adequate function without large shortcomings that could result in under capacity or local flooding.