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FLOW CONTROL AND WATER QUALITY TREATMENT PERFORMANCE OF A RESIDENTIAL LOW IMPACT DEVELOPMENT PILOT PROJECT IN WESTERN WASHINGTON

by:

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ABSTRACT AND BENEFITS

Abstract:

Washington State University and project partners implemented a flow monitoring project on a 3.35-hectare (8.27-acre) pilot project in western Washington (Meadow on the Hylebos) that incorporates low impact development (LID) stormwater management practices. LID practices used in the project design include bioretention swales, permeable concrete, compost amended soils, and surface flow dispersion. The primary goals of the monitoring effort are to evaluate the performance of individual LID practices and evaluate the effectiveness of integrating these practices into a stormwater management system. Continuous simulation modeling (Western Washington Hydrology Model) was used to assess peak flow and flow durations compared to stated flow control goals of the project. Flow rates for individual storms were assessed and water budgets developed that include surface and subsurface flow, infiltration and evapotranspiration in relation to precipitation inputs for bioretention swales and the project as a whole. Infiltration rates over time for the permeable concrete were also measured.

Benefits:

- Examines the storage and infiltration performance of individual LID practices (bioretention and permeable concrete) used at the site and the project as a whole.
- Assesses the potential for protecting aquatic systems using LID practices on sites that have soils with low infiltration rates.
- Provides data to refine the stormwater modeling programs for LID in the Puget Sound region.

Keywords: Low impact development, bioretention, permeable concrete, monitoring, flow control performance, stormwater, water quality treatment.

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LIST OF ACRONYMS

ASTM	American Society for Testing and Materials
BSM	Bioretention soil mix
LID	Low impact development
NOAA	National Oceanic and Atmospheric Administration
PIT	Pit infiltration test
POC	Point of compliance
WRCC	Western Regional Climate Center
WWHM	Western Washington Hydrology Model
DOE	Washington State Department of Ecology
ha	hectares
PERLANDS	Pervious land segments

EXECUTIVE SUMMARY

An extensive body of research conducted in the Pacific Northwest indicates that conventional land development and stormwater management practices are inadequate to protect streams, wetlands, and other aquatic resources in the region (Booth, Hartley and Jackson, 2002). A broad category of new stormwater management practices that come under the heading of low impact development (LID) show promise to improve flow control and water quality treatment.

While the decentralized LID approach shows promise and guidelines are in the initial stages of development, research investigating the stormwater management characteristics of bioretention, permeable paving, compost amended soils, and other LID practices that are integrated into a stormwater management system is limited in the Puget Sound region. Additionally, and perhaps most important, data is needed to evaluate the performance of LID practices in prolonged wet conditions and soils with low infiltration rates typical in the area.

To improve the design and application of LID practices, Washington State University and project partners implemented a flow monitoring project on a 3.35-hectare (8.27-acre), residential project in southern Puget Sound (Meadow on the Hylebos) that incorporates LID stormwater management practices. The primary goals of the monitoring effort are:

- Evaluate the performance of individual LID practices.
- Evaluate the effectiveness of integrating LID practices into a stormwater management system.

To accurately evaluate project performance, the monitoring effort continuously tracked the discharge from individual bioretention swales, point of compliance (POC) and the ultimate outfall of the project (Dispersion Slope). Monitoring wells recorded water table levels to assess the influence of groundwater on the drainage system. Surface and subsurface flow and onsite weather monitoring were used to create water budgets and assess flow rates associated with individual storms for the bioretention swales and the project as a whole.

Findings

The first year of monitoring was conducted October 2006 through May 2007; however, project construction was not complete until the spring of 2007. Accordingly, evaluation for sections of the project that were complete by the 2006-07 wet season are presented, as well as overall project performance for comparison to October 2007 through May 2008 flow statistics. Specifically, the following performance evaluations are included for 2006 through 2007:

- Summary statistics for overall project performance.
- Surface and subsurface flow characteristics of specific bioretention swales.
- Permeable concrete infiltration rates over time.

Overall, the project performed poorly for the 2006-07 wet season and significantly exceeded flow control targets. Total precipitation volume retained on site was approximately 62 percent. Initial flow control was, on the other hand, impressive. The site received approximately 104 mm (4.09 in.) of precipitation before any flow discharged from the site essentially eliminating the seasonal first flush of pollutants. Several factors may be contributing to the overall poor performance during the 2006-07 wet season. First, the largest bioretention area with the highest infiltration capacity was lined with an impervious membrane and effectively eliminated for flow control due to concerns of infiltration to sewer lines. The loss of this central infiltration feature likely degraded project performance significantly. Second, surface and subsurface flow monitoring of individual bioretention swales indicate that storm flow infiltrates rapidly through the bioretention soil mix and to the under-drains. As a result, detention time is not adequate for storm flows to infiltrate into the underlying native soil. Finally, measurements for the overall project were taken at the POC not accounting for the final flow control and water quality treatment practice (Dispersion Slope). The Dispersion Slope and associated monitoring station was completed and monitored for the 2007-08 wet season.

Construction of the project was complete for the second year of monitoring conducted October 2007 through May 2008. The following performance evaluations are included for 2007 through 2008:

- Summary statistics for the overall project performance.
- Surface and subsurface flow characteristics of specific bioretention swales.
- Overall project performance and performance of a sub-basin within the project (recorded peak flows, frequency and duration) compared to modeled western Washington flow control requirements (match 50 percent of the two-year and up to the full fifty-year peak flows and durations for pre-developed forested and pasture condition) for the same property. The pre-developed forest condition flow control guideline, proposed by Washington State Department of Ecology (DOE), is in the process of being adopted in western Washington (DOE standard). Flow durations are defined as the percent time flow rates exceed target rates over the 50 year precipitation record for western Washington.
- Individual storm analysis for peak flow and initiation of surface flow.
- Basic water quality assessment of the project at the POC.

The project performed well and actually exceeded flow control objectives for 2007-2008. At the final outfall of the project (Dispersion Slope), peak flow and durations met the DOE standard for forested pre-development condition. At the POC, peak flow and durations did not meet flow control goals for pasture pre-development condition. The flow control goal for the project was to match 50 percent of the two-year and up to the full fifty-year peak flows and durations for pre-developed pasture condition. However, the POC met the DOE standard for pre-development forested condition when the infiltration capacity of the largest bioretention area that was lined with an impermeable membrane was factored back into the system in the modeling analysis.

Surface and sub-surface flows were monitored for a sub-basin including seven homes and four bioretention areas 0.32 hectares (0.8 acres). During the wet season of 2006-2007 stormwater flows infiltrated rapidly through the soil mix and to the under-drains. The under-drains were plugged for the wet season 2007-2008. Once plugged, essentially all storm flows were infiltrated in the bioretention areas and the sub-basin met the DOE standard for pre-development forested condition.

Total precipitation volume retained on site for the 2007-2008 wet season was approximately 69 percent at the POC with the lined bioretention area (no infiltration) and 99 percent when the bioretention area was included without the liner in the modeled drainage system. Total precipitation volume retained at the final outfall (Dispersion Slope) was 96 percent and for the sub-basin monitored at Station 6 the volume retained was 99 percent.

CHAPTER 1.0

INTRODUCTION

1.1 Background

The transition from a forested landscape to a built environment increases impervious surfaces from roads, parking areas, sidewalks, rooftops, and compacted soils. Native vegetation and the upper soil layers that evaporate, transpire, store or infiltrate stormwater are typically removed. Water quality is impaired as stormwater flowing from impervious surfaces collect and convey oil, metals, pesticides and other pollutants to receiving waters. Additionally, the change in the quantity and timing of stormwater runoff can significantly erode and alter stream channel form, and change wetland hydroperiods (Booth, 1991; May, Horner, Karr, Mar, and Welch, 1997; Azous and Horner, 2001). An extensive body of research conducted in the Pacific Northwest indicates that conventional land development and stormwater management practices are inadequate to protect streams, wetlands, and other aquatic resources in the region (Booth, Hartley and Jackson, 2002).

The Puget Sound Partnership (lead agency for Puget Sound environmental policy) has established that improving stormwater management is one of the priority issues for protecting aquatic resources in the Puget Sound region. Additionally, The Partnership recommends using low impact development (LID) to reduce degradation of streams, wetlands, lakes and Puget Sound from stormwater inputs.

While the decentralized LID approach shows promise and guidelines are in the initial stages of development, research investigating the stormwater management characteristics of bioretention, compost amended soils, permeable paving, and other LID practices that are integrated into a stormwater management system is limited for the Puget Sound region. Additionally, more data is needed to evaluate the performance of bioretention systems, compost amended soils, permeable paving, and other LID practices in the difficult glacially compacted till soil and prolonged wet conditions typical in the area. Accordingly, pilot projects, and monitoring of those projects, are necessary to further develop design guidelines and effectively apply LID practices to protect aquatic systems.

Design for the Meadow on the Hylebos LID pilot project (the project) began early 2002 and construction was completed spring 2007. The project is one of the first residential LID pilot projects in the region and design, construction, and monitoring was implemented through a public private partnership that includes county government, the consulting engineering firm, the developer and property owner, and Washington State University (WSU). WSU is the lead entity for the pre- and post-construction monitoring.

1.2 Project Description

The 3.34-hectare (8.27-acre) site is located in southern Puget Sound and is bordered by a salmon bearing stream with associated wetlands. Previously, the site was approximately 80 percent pasture and 20 percents forest with a small farm house. The overall relief on-site is approximately 27 m (90 ft) with a low of about 3.05 m (10 ft) above sea level at the creek to about 30.50 m (100 feet) at the northwest end of the property. The site prior to construction sloped generally to the southeast with gradients ranging from 5-20 percent.

Figure 1-1: Pre-construction Site Conditions.

Figure 1-2: Site Plan View.

The site was cut and filled so that most lots are relatively flat. A rock wall, 1.2-1.8 m (4-6 ft) high retains the fill along the eastern portion of the site and a rock wall ranging from 3-6 m (10-20 ft) retains the cut along the western side of the property. The completed project is a medium density residential development with a total of 35 houses located on 1.75 hectares (4.33 acres) (20 units/hectare net density). The remaining 1.6 hectares (3.94 acres) is common open space and landscape area, stormwater facilities, recreation areas, and wetland and associated buffers. Average lot size is 373 m^2 (4,143 ft^2).

The central goals of the project are to protect adjacent stream values by designing an LID (decentralized) system that more closely mimics native hydrologic patterns, as well as construct an affordable and livable neighborhood.

The LID features in the project include:

- Cluster design to reduce the overall development envelop and disturbance to soil and vegetation.
- Bioretention swales along both sides of the access road.
- Permeable concrete shoulder along a portion of the access road.
- Native vegetation protection, compost incorporated into disturbed soils surrounding the homes, and a compost amended slope to disperse stormwater off the property and to the stream buffer.

The initial designs by the project engineer attempted to meet the new Washington Department of Ecology duration standard which is: match half of the two-year and up to the full fifty-year peak flows and durations for the pre-developed forest condition. However, given the limited set of LID practices accepted for the project, pre-development forested condition was not attainable on paper and pasture was used as the pre-development condition. The water quality standard is to treat 91 percent of the total project volume. Given that bioretention provides water quality treatment as well as flow control, sizing the bioretention swales for the above flow control standard meets water quality treatment requirements. To meet the above flow control and water quality treatment objectives, the drainage plan uses the following general approach (see Figure 1-3):

- Bioretention swales with a 46 cm (18 inch) bioretention soil mix depth and 15 cm (6 inch) ponding depth are located on both sides of the private access road within the road right-of-way
- Stormwater discharged from rooftops (downspouts are dispersed across compost amended landscape), driveways, and landscaping from the west side of the road enters the bioretention swales.
- On the east side of the road, bioretention swales collect stormwater from rooftops (dispersed across compost amended landscape), driveways, landscaping, sidewalks, and the access road which super-elevated to the swales.
- The bioretention swales are connected by under-drains and slotted corrugated metal drain pipe across the driveways.
- Surface and under-drain flow from both sides of the road are collected at a single catch-basin which discharges to a small detention pond (approximately 531 m^2 (5,900 ft^2)).
- The pond discharges to the point-of-compliance at the southeast of the property.

- From the point-of-compliance stormwater is directed to a 55 m (180 ft) long gravel level spreader and is dispersed down a compost-amended slope.
- Diffuse flow exits the property at the bottom of the slope to Hylebos Creek.

The largest bioretention swale with the highest infiltration rate (see Figure 2-1 for infiltration tests) located in the access road loop was lined with an impervious membrane due to concerns of infiltration to sewer lines. The impact of eliminating the largest infiltration area is significant for the flow control performance of the project and is evaluated in the modeling analysis.

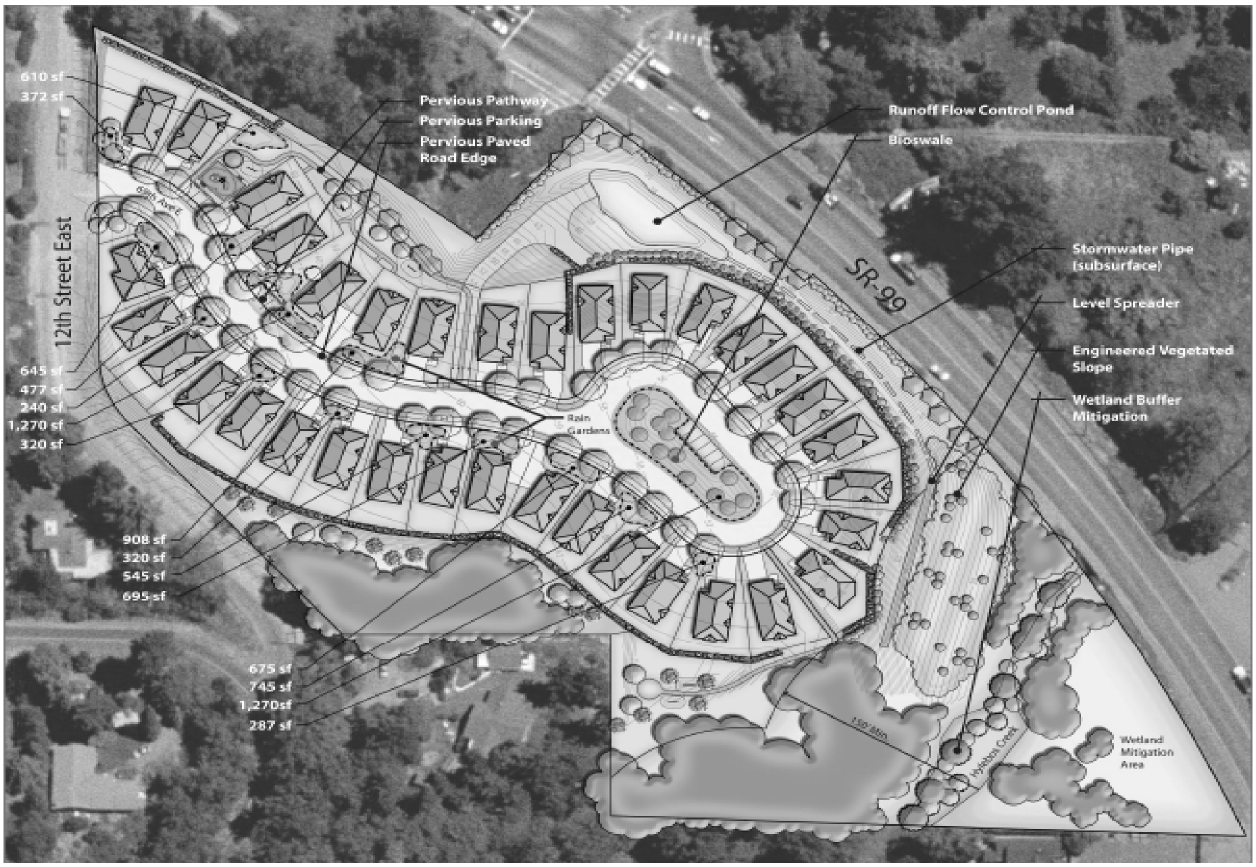

Figure 1-3: Site Plan View with Bioretention Areas and Other LID Features.

1.3 Monitoring Approach

Monitoring decentralized, low impact development stormwater systems presents significant challenges. LID practices are designed to receive and infiltrate storm flows from small contributing areas throughout the project site. As a result, understanding the hydrologic pathways in an LID project is more complex than a conventional stormwater system, and involves surface and sub-surface flow monitoring at multiple locations. If the data are to assist managers apply LID practices regionally, the monitoring effort should carefully assess site soil conditions and quantify subsurface and surface flow outputs in relation to precipitation inputs.

To accurately evaluate project performance, the monitoring effort tracked the discharge from individual bioretention swales, the POC and the ultimate outfall of the project. Monitoring wells recorded water table levels to assess the influence of groundwater on the drainage system. Surface and subsurface flow and onsite weather monitoring were used to create water budgets and assess flow rates for individual storms for the bioretention swales and the project as a whole. These data were used, along with existing, long-term precipitation data, to evaluate performance with continuous simulation modeling (see Figure 1-4 for monitoring station locations).

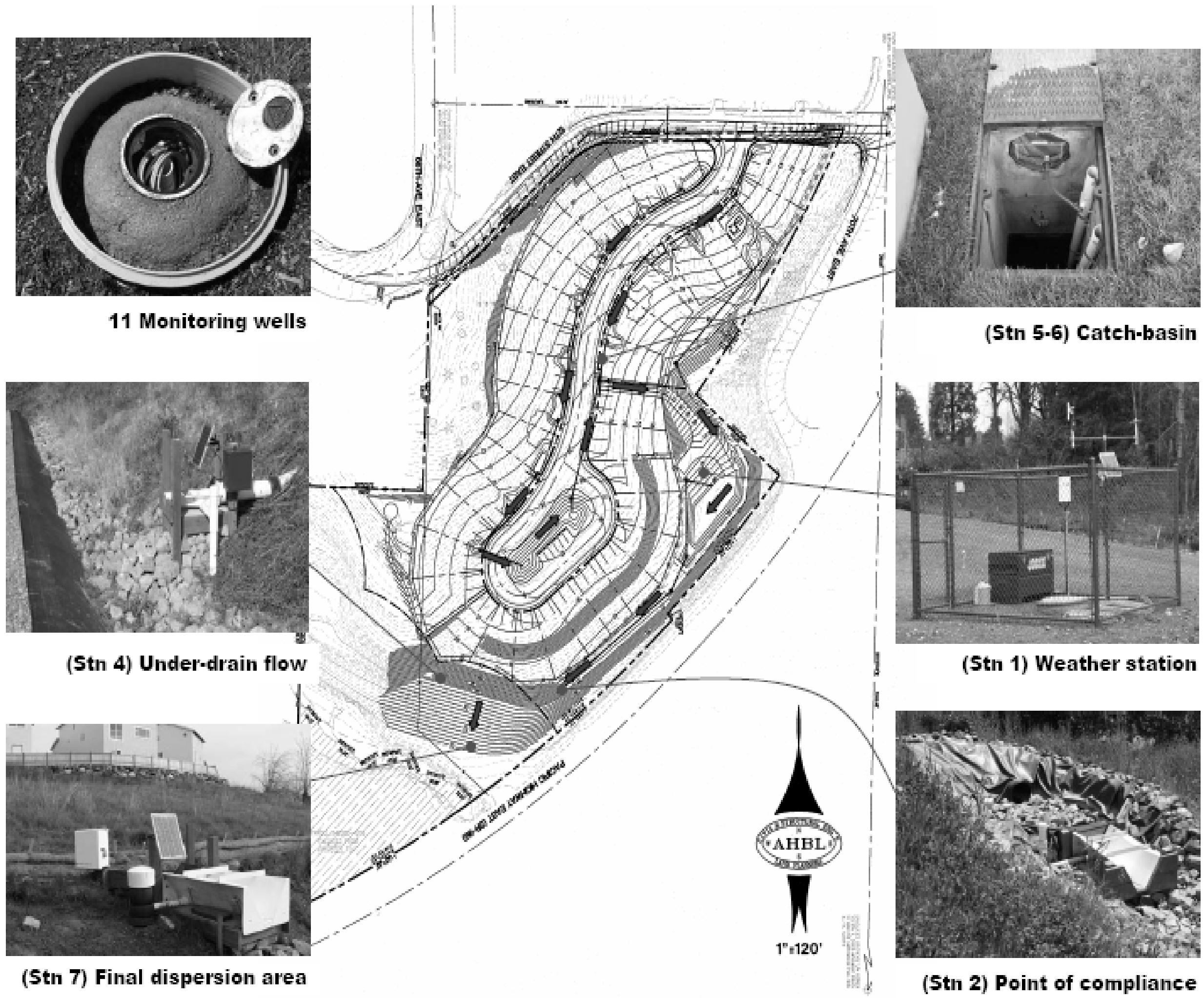

Figure 1-4: Monitoring Station Locations.

The flow monitoring stations employ highly accurate sensors, carefully matched to appropriate primary devices. Through careful selection and placement of instruments, total non-random error for individual flow monitoring stations is approximately 6 percent or less. Although the primary focus of the monitoring project is water quantity, water quality samples were collected at the point-of-compliance. For more information on monitoring instruments, water quality collection procedures, and accuracy, see Appendix A: Quality Assurance Project Plan.

CHAPTER 2.0

FINDINGS

2.1 Soils

Prior to construction, extensive soil analysis was completed to better understand existing soil water characteristics and infiltration capability. Eleven excavated soil pits revealed that the large majority of the site has a silt loam, glacial lake bed sediment cap. Most of the silt loams are underlain by a relatively thin layer of coarse-textured glacial meltwater deposits, some of which are well drained and some not. Underlying everything at depths ranging from as shallow as 0.9 m (3 ft) to greater than 3 m (10 ft) is a cemented till. The silt loam portions of the soil profiles show current evidence of poor drainage and seasonal perched water tables within a foot or two of the soil surface across the most of the site. Groundwater movement is mostly lateral, either draining sideways through the somewhat structured upper portions of the silt loam layers, or draining laterally across the surface of the till in the deeper portions of the soil profile. For more detail see Appendix C: Soils Investigation for the Meadow on the Hylebos.

After completion of the soil analysis, full scale pit infiltration tests (PIT) were conducted to examine infiltration capability in greater detail (see Figure 2-1 for PIT locations and results).

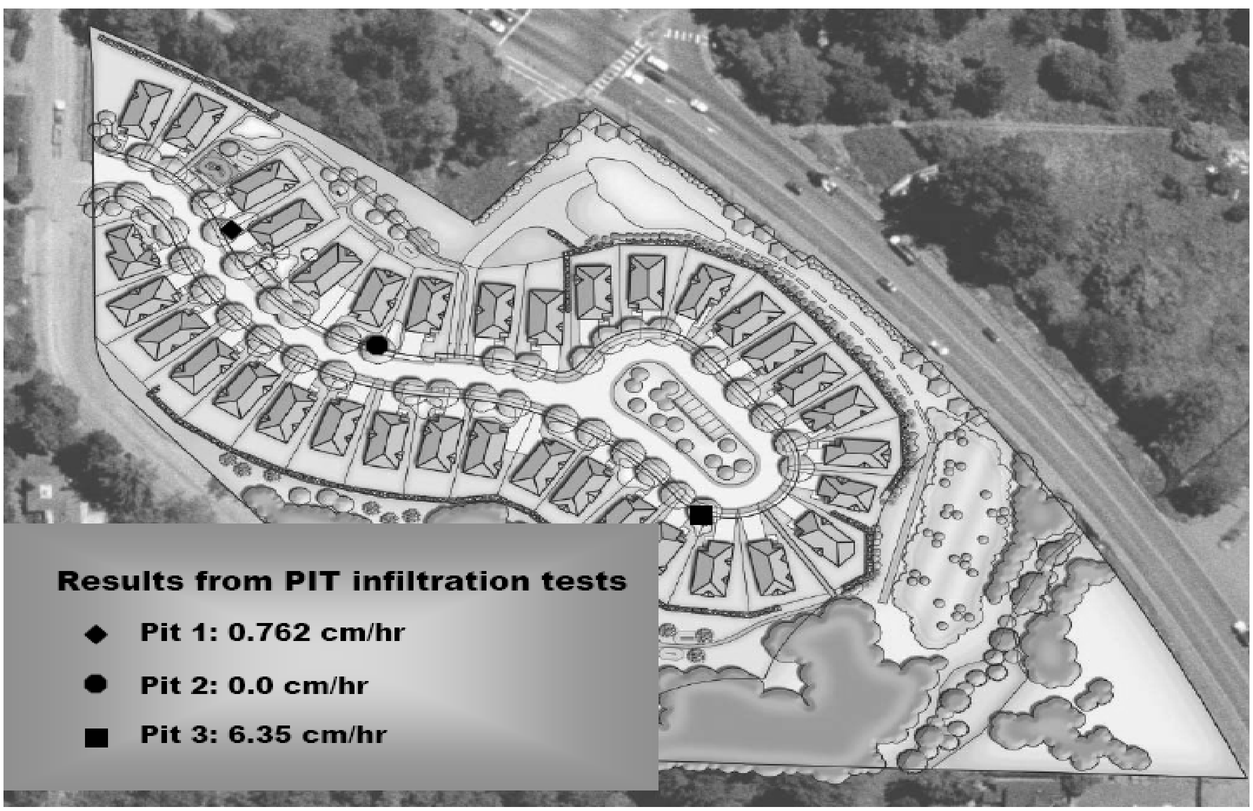

Figure 2-1: Pit Infiltration Test Locations.

The tests were performed using the following method. Three locations were selected for representative soil conditions and over bioretention swales near the entrance to the property, approximately midway on the access road, and at the end of the access road. Pits were excavated two feet deeper than the bottom of the infiltration facility. The bioretetion swales on site are approximately 1-1.5 m (3-5 ft) deep and tests pits approximately 1.5-2.0 m (5-7 ft) deep. A staff gauge is placed in the infiltration pit and the pit is filled with 15.0-25.0 cm (6-10 in.) of water. The pits are filled from a fire hydrant using a fire hose with an in-line low meter and an energy diffuser attached to the end of the hose. The flow is adjusted so that inflow matches infiltration (level remains steady on staff gauge) and the test continues for approximately 5 hours recording infiltration rates in 15-minute intervals. Finally, the inflow is discontinued and the time recorded to infiltrate all water in the pit.

2.2 Overall Hydrologic Characteristics and Monitoring Results

Total mean rainfall for October 1, 2007 through May 31, 2008 was 611.13 mm (24.06 in.). The mean precipitation for Tacoma from 1971-2000 is 989.33 mm (38.95 in.) (Western Regional Climate Center). The largest precipitation event was 101.35 mm (3.99 in.) on December 7th with a peak rate of 7.37 mm/hr (0.29 in./hr) and a duration of 86 hours. The mean total precipitation, 1-hr peak precipitation intensity and storm duration was 8.15 mm (0.32 in.), 2.03 mm (0.08 in.) and 15.48 hours respectively. Table 2-1 provides the precipitation totals by month measured on-site with mean totals from the Western Regional Climate Center (WRCC) for comparison. See Appendix One: Quality Assurance Project Plan for details on precipitation measurement and accuracy.

Table 2-1: Mean Monthly Precipitation Totals for October 1, 2007 through May 31, 2008.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Onsite Mean Precipitation (mm)	68.84	67.05	175.77	100.08	56.13	82.55	38.10	22.60
WRCC Mean 2007-08* Precipitation (mm)	92.46	67.31	212.34	117.60	72.14	105.66	44.70	25.65
WRCC Mean 1971-2000** Precipitation (mm)	86.11	154.94	149.61	136.65	112.78	106.17	72.90	51.05

*(http://nowdata.rcc-acis.org/SEW/pubACIS_results) (SeaTac International Airport)
**(http://www.wrcc.dri.edu/cgi-bin/climain.pl?wa8278)

The overall project is evaluated using summary water budgets from monitoring and continuous simulation modeling. Table 2-3 provides water budgets for the POC (Station 2) and Table 2-4 for the Dispersion Slope (Station 7) or the final outfall of the project. The POC is not the final outfall for the project, but was used as the point for confirming flow control performance during the design phase. The area used to calculate total precipitation volume is 2.50 hectares (6.18 acres) or 0.84 hectares (2.09 acres) less than the total site. The 0.80 hectares represents the area that is not controlled by the drainage system and from which stormwater (if any) exits the site as diffuse surface or subsurface flow (see Figure 2-2 for delineation). Total precipitation volume, precipitation volume leaving the site, and precipitation volume retained are calculated from mean values. Evapotranspiration is calculated within the data logging program using the Penman-Monteith equation from relative humidity, solar radiation, and wind speed recorded at the on-site weather station.

Figure 2-2: Area Located Outside Drainage System.

Figure 2-3: Stations 2 and 7 Locations.

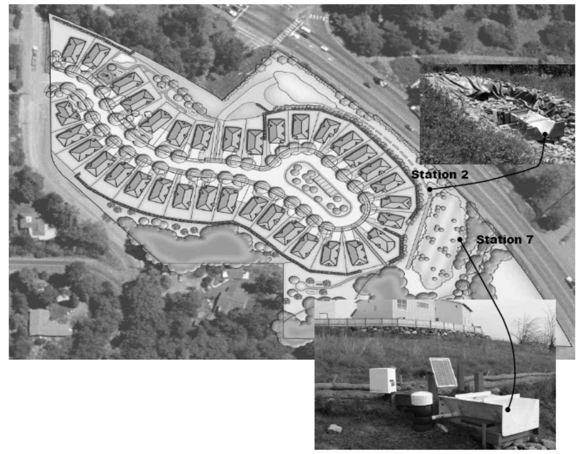

Table 2-2: Mean POC and Dispersion Slope Summary Water Budget for October 1, 2007 through May 31, 2008.

	Total Precipitation Volume (m^3)*	Evapotranspiration (mm) and (% of total precipitation volume)	Total Precipitation Volume Measured at point of compliance (m^3)	Total Precipitation Volume Retained on Site (m^3) and (% total volume)
2006-07 POC	19,697.97	254.39 (23%)	7,377.99	12,319.98 (62%)
2007-08 POC	10,884.21	140.56 (23%)	3,252.92	7,631.29 (70%)
2007-08 Slope	11,637.12	140.56 (23%)	431.08	11,206.04 (96%)

*Total precipitation volume is the product of the contributing area and total precipitation (minus ET).

2.3 Hydrologic Model Description and Site Characterization for Overall Project

The Western Washington Hydrology Model Version 3 Professional (WWHM3 Pro) was used for long-term hydrologic modeling of the site. WWHM is a continuous simulation model using the HSPF computational engine calibrated to precipitation, evapotranspiration, surface flow, interflow, and groundwater flow characteristics of western Washington. WWHM3 Pro is an approved model by the Washington State Department of Ecology for use in designing flow control and water quality treatment facilities to meet the 2005 *Stormwater Management Manual for Western Washington* (Ecology, 2005) flow control and water quality treatment requirements. WWHM3 Pro transforms long-term continuous time series of rainfall and evaporation into simulated long-term continuous time series of stormwater runoff. The simulated runoff time series is analyzed statistically within the model to calculate peak flow and flow duration statistics, which are needed to demonstrate compliance with the flow duration-based LID goals for this project.

Because a long-term continuous simulation record is needed to evaluate flow duration performance for this study, precipitation data from a long-term rain gauge installation (McMillan) for the period 1948 to 1996 (48 years) were used in the model with a precipitation scaling factor of 1.0, based on project location. The onsite recorded precipitation data for the period 2006 to 2008 have an insufficient period of record for flow duration analysis. Recommendations are provided below for using both the onsite precipitation and evaporation data for calibrating a model to simulate bioretention with underdrains and compost amended soil pervious land segments (PERLNDs).

A WWHM3 Pro model was constructed for the portion of the site that contributes stormwater runoff and seepage flows to the toe of the bioengineered dispersion slope (see Figure 1-3). This modeled area covers approximately 2.50 hectares (6.18 acres). The remainder of the site (0.84 hectares (2.09 acres)) is not within the drainage system and was, therefore, not included in the model.

Two pre-developed conditions were evaluated, including pre-developed forest and pre-developed pasture. For the developed site condition, two scenarios were evaluated: 1) no infiltration at bioretention area 1 (BA 1); and 2) infiltration at BA 1 using the measured infiltration rate of 6.35 cm/hour (2.5 in/hr) (Associated Earth Sciences, 2008).

Table 2-3: Summary of Sub-Basin Areas and Land Use Distributions (hectares).

Sub basin	Road	Sidewalk	Permeable Pavement[a]	Roof	Driveway	Landscape	Bioretention Swale[b]	Other[c,d]	Total Area
1	0.111	0.018	0.018	0.035	0.038	0.060	0.028	0.000	0.308
2	0.000	0.000	0.005	0.194	0.010	0.464	0.067	0.000	0.740
3	0.186	0.033	0.001	0.022	0.060	0.052	0.041	0.000	0.397
4	0.000	0.000	0.000	0.177	0.082	0.284	0.041	0.000	0.584
5c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.284	0.284
6d	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.160	0.160
Total	0.297	0.052	0.024	0.429	0.191	0.860	0.177	0.444	2.473

Notes:
a. Includes permeable pavement sidewalk, parking, and pathway.
b. Value in table represents bottom surface area of bioretention swales.
c. Undeveloped site area, consisting of approximately 50 percent forest and 50 percent pasture land cover.
d. Includes the gravel level spreader and bioengineered dispersion slope.

2.3.1 Sub-basin Delineation and Land Use Distribution

The modeled area was divided into six sub-basins. This sub-basin delineation and the evaluation of land use distribution within each sub-basin were based on review of the permit set drawings, including grading and drainage plans (AHBL 2005), aerial photography, and observations made during a site reconnaissance performed by WSU and Herrera staff on October 30, 2008. Figure 2-4 shows the resulting sub-basin delineation. Table 2-3 summarizes the sub-basin areas and land use distributions. A physical description of each sub-basin is provided below.

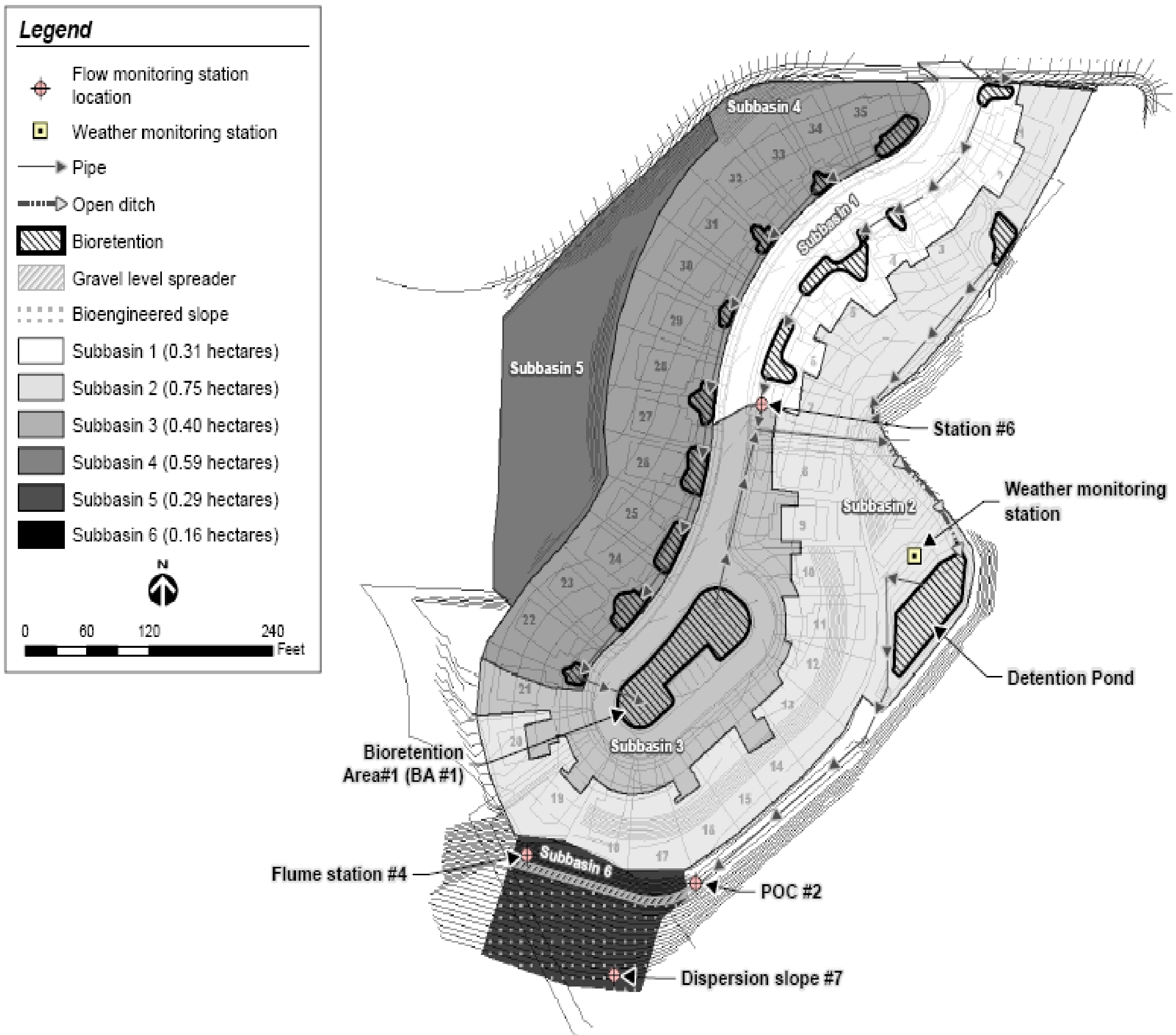

Figure 2-4: Sub-Basin Delineation for Modeling.

Sub-basin 1: isolates the drainage area to Station 6, which allows for modeling and evaluation of the flow duration performance of the bioretention swales along the east side of the road. The drainage area tributary to these bioretention swales includes roadway, sidewalk, and the front portions of lots 1 through 6. In addition to the drainage area tributary to the bioretention swales, sub-basin 1 also includes a small amount of roadway, sidewalk, and driveway area (lot 7) that contribute flow directly to Station 6, without first flowing to the bioretention swales.

Sub-basin 2: covers the back portion of lots 1 through 20, drained via yard drains that discharge to the small detention pond. A small rain garden manages stormwater runoff from the roofs and back yards of lots 2 and 3. Permeable pavement sidewalks also manage the stormwater runoff generated from their own footprint area. Other than these relatively small facilities, stormwater runoff from this sub-basin discharges primarily to the detention pond.

Sub-basin 3: includes the roadway, sidewalks, and front portions of lots 7 through 21 that sheet flow to BA 1.

Sub-basin 4: covers lots 21 through 35 (entire lots), which drain via sheet flow to the bioretention swales along the west side of the roadway. Stormwater that does not exfiltrate to native soil is conveyed via under-drain or overflow conveyance pipes to BA 1.

Sub-basin 5: is an undeveloped area at the western edge of the site with land use split approximately half and half between forest and pasture. This area is drained by an underdrain pipe in the retaining wall behind lots 23 through 35, which discharges through monitoring station 4 and to the gravel level spreader.

Sub-basin 6: includes the gravel level spreader and bioengineered dispersion slope at the southern end of the site. The level spreader receives direct discharge from the under-drain pipe from sub-basin 5, as well as excess stormwater runoff (i.e., runoff that did not exfiltrate to native soils) from sub-basins 1 through 4.

2.4 Hydrologic Model Assumptions and Methodologies for Overall Project

This section discusses the assumptions made and the methodologies used to model the site in WWHM3 Pro. Figure 2-5 illustrates the model schematic.

2.4.1 Dispersion of Roof Runoff to Landscape

Runoff from most of the roof area on the site sheet flows over landscaping before entering downstream facilities, such as bioretention swales, BA 1, or the detention pond. This sheet flow is beneficial for delaying and reducing the peak inflow rates to these facilities, thereby improving their flow control performance.

Within WWHM3 Pro, the lateral dispersion function was used to model sheet flow dispersion of roof runoff to adjacent lawns. The lateral dispersion function applies the roof runoff as additional rainfall to the receiving lawn areas. As such, the dispersed roof runoff is added to the rainfall in the model and is subject to the same partitioning over the surface area of the lawn, including surface ponding, evaporation, infiltration, and runoff.

In order to properly account for the flow control benefits of roof runoff dispersion, the ratio of contributing roof area to the receiving landscape area must be accurately estimated in the field and accounted for in the model. Lower ratios generally yield greater flow control benefits because hydraulic loading of the landscape surface is lower, allowing for better utilization of the available storage in the surface and subsurface layers. Table 2-4 summarizes the ratios that were used in the model based on observations made for each lot during the October 2008 field reconnaissance.

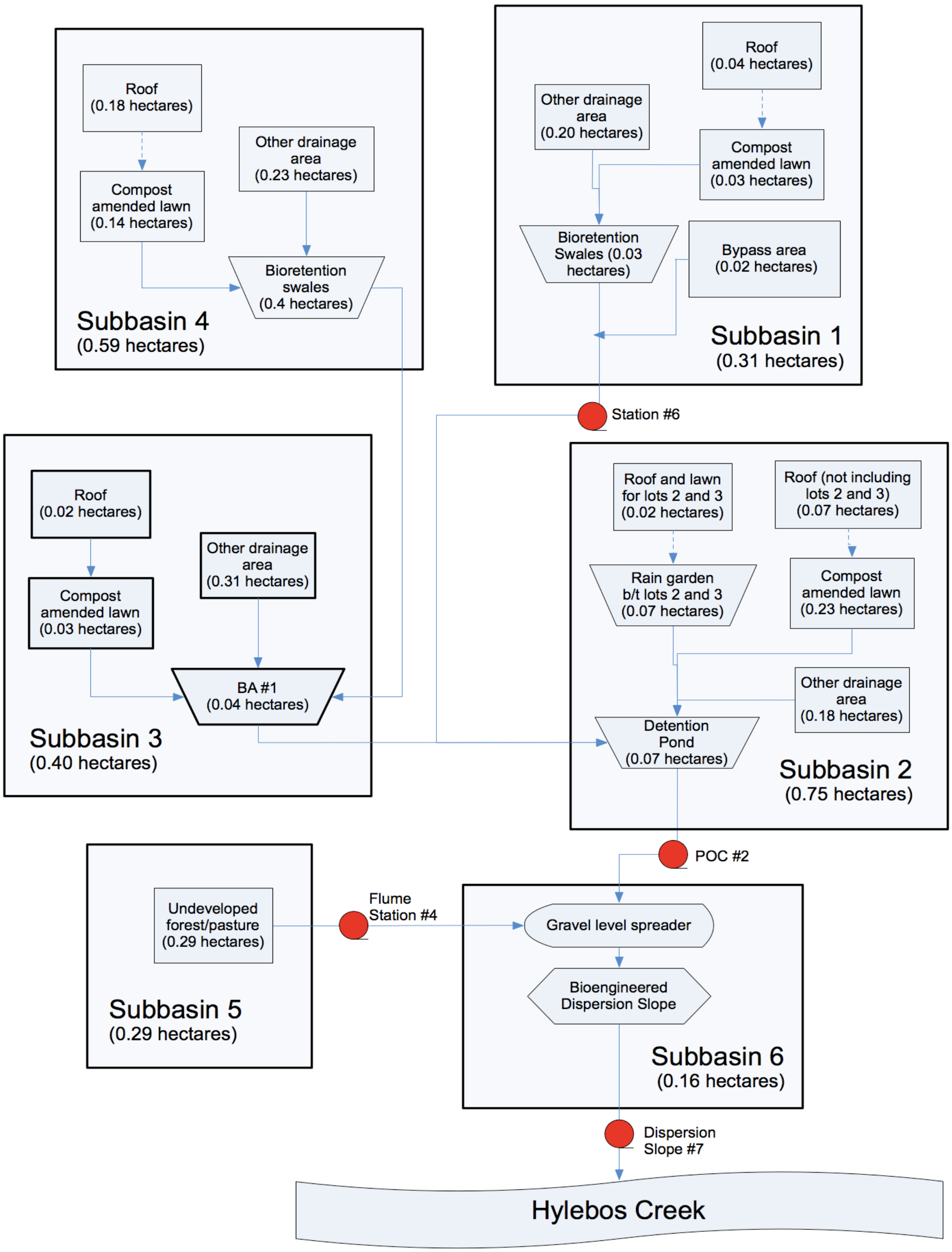

Figure 2-5: WWHM3 Model Schematic.

Table 2-4: Summary of Modeled Ratios of Roof Area Dispersed to Adjacent Lawn Area.

Sub-basin	Roof Area Dispersed to Landscape (hectares)	Lanscape Area Receiving Roof Runoff (hectares)	Ratio of Contributing Roof Area to Receiving Landscape Area (%)
1	0.035	0.030	116%
2	0.179	0.234	76%
3	0.023	0.026	86%
4	0.179	0.143	125%
5	0	0	0%
6	0	0	0%
Total	*0.415* [a]	*0.434* [a]	*96%* [b]

Notes:
[a] Total represents a summation.
[b] Total represents an average.

2.4.2 Permeable Pavement

Permeable pavement was modeled using the gravel infiltration trench module in WWHM3 Pro. With this method, the surface area of a permeable pavement facility is modeled as impervious area with runoff directed to a gravel infiltration trench. The gravel infiltration trench retains runoff in the voids of the aggregate base course (sub-base) to promote exfiltration to native soil. Rainfall in excess of the storage and exfiltration capacity overflows across the surface of the permeable pavement as sheet flow.

The permeable pavement was modeled as a 1.60 cm (4 inch) thick permeable concrete surface with a 2.40 cm (6 inch) thick aggregate base course with 45 percent void volume. The native soil exfiltration rate used was 0.76 cm/hr (0.3 in/hr) based on pit infiltration testing (Associated Earth Sciences, 2008). The initial model runs indicated that the permeable pavement infiltrates 100 percent of the runoff generated over its own footprint. The permeable pavement area was therefore subtracted from the final model in order to allow for faster run times without compromising accuracy.

2.4.3 Bioretention Swales

Bioretention swales and rain gardens were modeled in WWHM3 Pro using the bioretention swale module. Inputs to the bioretention swale module include bottom surface dimensions, side slopes, ponding depth, bioengineered soil depth and porosity, native soil exfiltration rate, and overflow design information.

The bioretention swales along the east and west side of the roadway were constructed with under-drains; however, those under-drains were plugged in 2008 for purposes of monitoring and providing feedback for future designs. The under-drains were, therefore, not included in the model for this study. Table 2-5 summarizes the key model parameters used in this study for the bioretention swales east and west of the roadway, the rain garden between lots 2 and 3, and BA 1.

Table 2-5: Summary of Bioretention Swale and Rain Garden Model Parameters.

Facility	Bottom Surface Area (m^2)	Side Slope (H:V)	BSM Depth (cm)	BSM Porosity (%)	BSM Infiltration Rate (cm/hr)	Native Soil Exfiltration Rate (cm/hr)	Outlet Structure
Bioretention swales east of roadway	272.25	3:1/ 4:1 [a]	45.70	35%	10.16	1.78	**Low flow:** None **Overflow:** 90-degree v-notch weir with invert 15.24 cm above swale bottom.
Bioretention swales west of roadway	402.84	3:1	45.70	35%	10.16	0.76	**Low flow:** None **Overflow:** 90-degree v-notch weir with invert 15.24 cm above swale bottom.
Rain garden between lots 2 and 3	56.25	3:1	45.70	35%	10.16	0.76	**Low flow:** None **Overflow:** None
BA #1	403.65	3:1	45.70	35%	10.16	0/6.35 [b]	**Low flow:** 1.27-cm orifice, 1.27 cm above swale bottom. **Overflow:** 30.48-cm riser 60.96 cm above swale bottom.

Notes:
H:V Horizontal:Vertical
BSM Bioretention soil mix
[a] Left side slopes 3:1, right side slopes 4:1.
[b] BA 1 was modeled with both a 0 in/hr and 6.35 cm/hr (2.5 in/hr) infiltration rate. The 0 in/hr infiltration rate represents actual conditions of the site as constructed, since an impermeable liner was installed beneath the facility. The 6.35 cm/hr infiltration rate represents potential performance based on the measured infiltration rate for that part of the site, assuming (hypothetically) that the liner was not installed.

2.4.4 Detention Pond

The small detention pond is the only conventional stormwater management practice at the Meadow on the Hylebos site. This facility was modeled using the detention pond module in WWHM3 Pro. Table 2-6 summarizes the key input parameters for this facility.

2.4.5 Dispersion Slope

The bioengineered dispersion slope at the downstream end of the site was modeled using the lateral dispersion function, as described above for dispersion of roof runoff to lawns. Outflow from the detention pond and runoff from sub-basin 5 is applied as additional rainfall on the bioengineered dispersion slope (see Figure 2-4 for pond and sub-basin locations).

Table 2-6: Summary of Detention Pond Model Parameters.

Facility	Bottom Surface Area (m^2)	Side Slope (H:V)	Effective Depth [a] (cm)	Native Soil Exfiltration Rate (cm/hr)	Outlet Structure
Detention Pond	260.46	3:1	45.72	0.0	**Low flow:** 7.14-cm orifice, 0.0 cm above swale bottom. **Overflow:** 30.48-cm riser 76.20 cm above pond bottom.

Notes:
H:V Horizontal:Vertical
[a] Live storage depth.

2.5 Hydrologic Modeling Results for Overall Project

As mentioned in the project description, the largest bioretention area (BA 1) with the highest infiltration rate located in the access road loop was lined with an impervious membrane due to concerns of infiltration to sewer lines. The impact of eliminating the largest infiltration area significantly degraded the flow control performance of the project.

With no infiltration in BA 1, flow duration requirements were not met for pre-developed forested or pasture conditions at the POC (Station 2). On average over the 48-year simulation period, storm event peak flows are reduced by approximately 45 percent and total precipitation flow volumes are reduced by approximately 49 percent. Figure 2-6 shows a comparison of long-term peak inflows and peak outflows with peak daily rainfall (McMillan rain gauge) shown on the secondary x-axis.

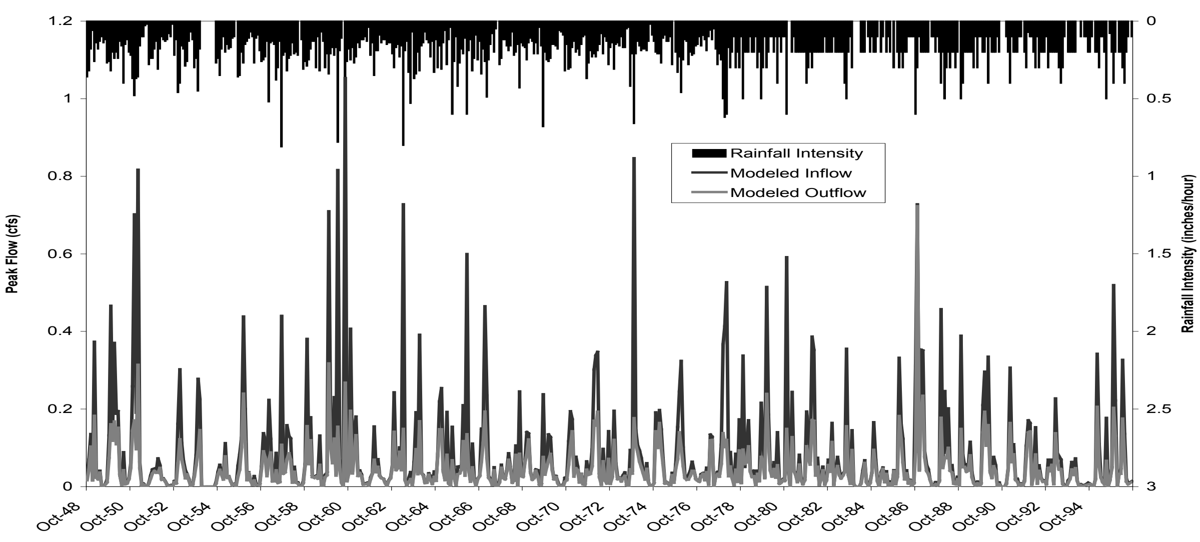

Figure 2-6: Comparison of Peak Inflows and Peak Outflows at POC 2 (1948-1994).

As part of the modeling process, BA 1 was added back into the drainage system. Assuming a 6.35 cm/hr (2.5 in/hr) infiltration rate (as measured in PIT 3), flow volumes are reduced by approximately 72 percent and the flow duration standards are met for both pre-developed pasture and forest conditions at the POC with BA 1 included. The 72 percent represents a volume reduction for the impervious surface within the POC contributing area. Figure 2-7 shows a comparison of the flow duration statistics for the forested, pasture, and developed site conditions, with and without infiltration at BA 1.

Regardless of whether infiltration is modeled with BA 1 included, the flow duration standards are met for both pre-developed pasture and forest conditions at the Dispersion Slope (Station 7) where stormwater actually discharges offsite. Figure 2-8 shows a comparison of the flow duration statistics for the forested, pasture, and developed site conditions (with no infiltration at BA 1). Figure 2-9 shows hydrographs of modeled peak daily flows for the same model scenarios. As shown in both figures 2-7 and 2-8, the developed site flow durations and release rates to Hylebos Creek from the POC and the dispersion slope are comparable to a forested condition and are much smaller than a pasture condition.

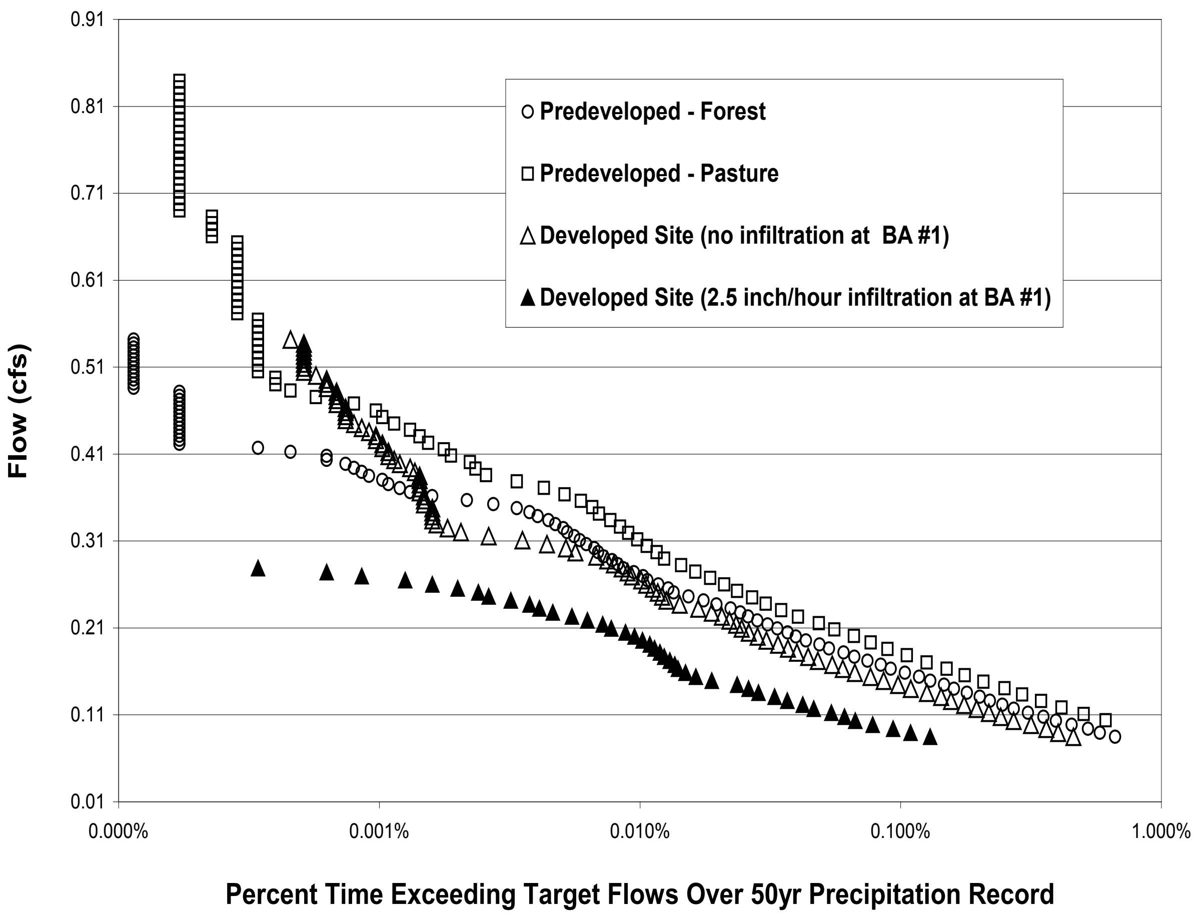

Figure 2-7: Flow Duration Evaluation for the POC (Station 2).

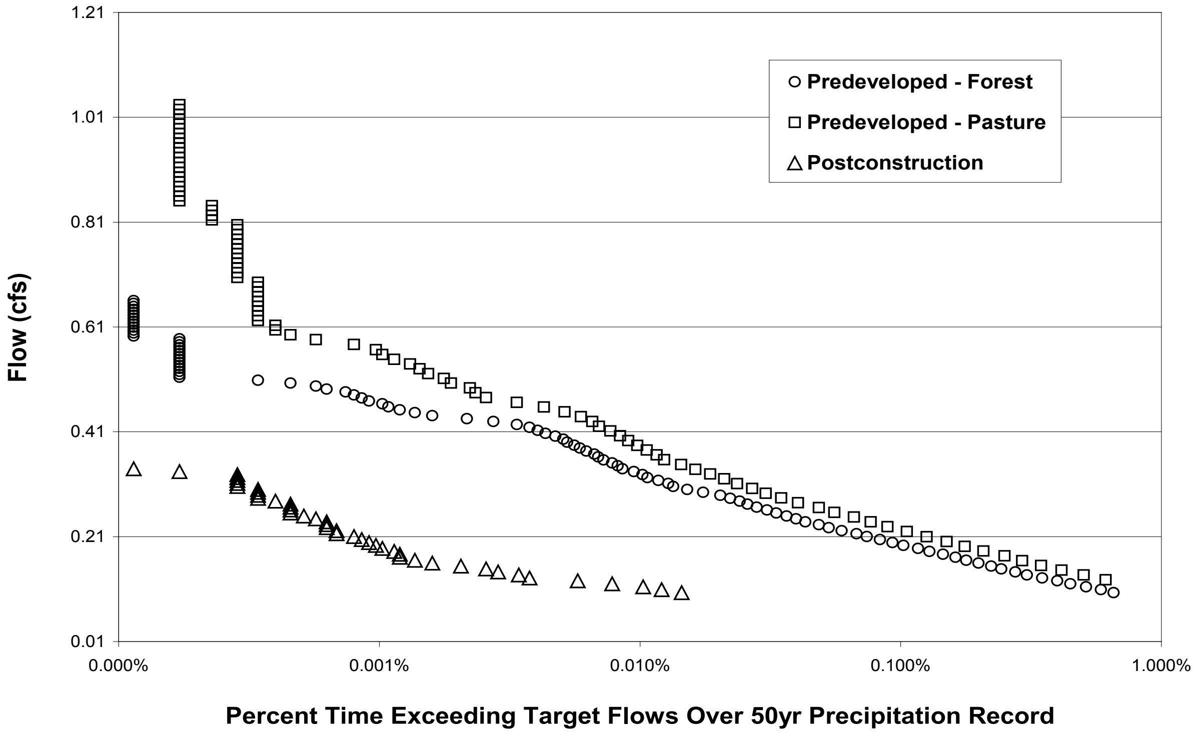

Figure 2-8: Flow Duration Evaluation for the Dispersion Slope (Station 7).

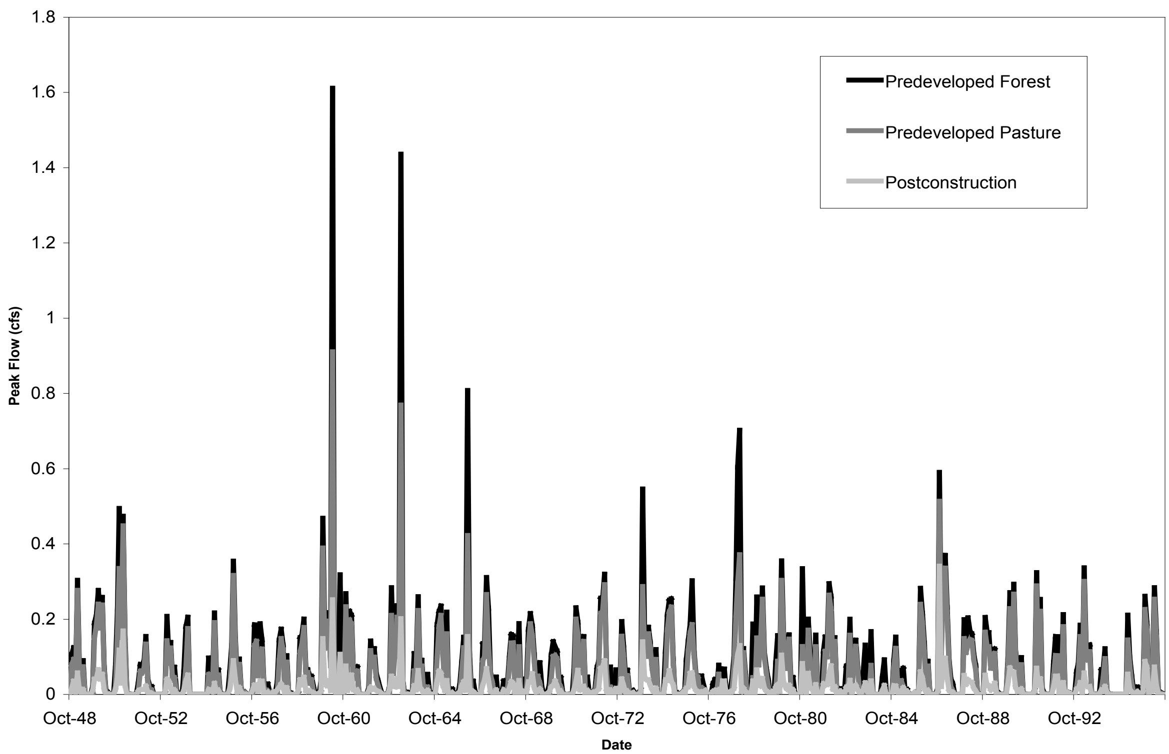

Figure 2-9: Hydrograph for the Dispersion Slope (Station 7).

2.6 Bioretention Swales

A 0.31 hectare (0.76 acre) sub-basin with a series of four bioretention swales that receive stormwater from the access road and seven lots was monitored for overall volume reduction and surface and sub-surface flow rates. A 10.20-cm (4-in.) under-drain and slotted corrugated metal drain pipes across the driveways at each lot, connect the four bioretention swales. Surface flow, through a 30.50-cm (12-in.) pipe and subsurface flow through the 10.20-cm under-drain, enter a catch basin with monitoring equipment. One 30.50-cm Thelmar weir is in the surface pipe entrance and one in the 30.50-cm discharge pipe from the catch-basin (see Figure 2-9 for location). Pressure sensors continuously record water depth behind the weirs (see Appendix One: Quality Assurance Project Plan for instrument and accuracy details).

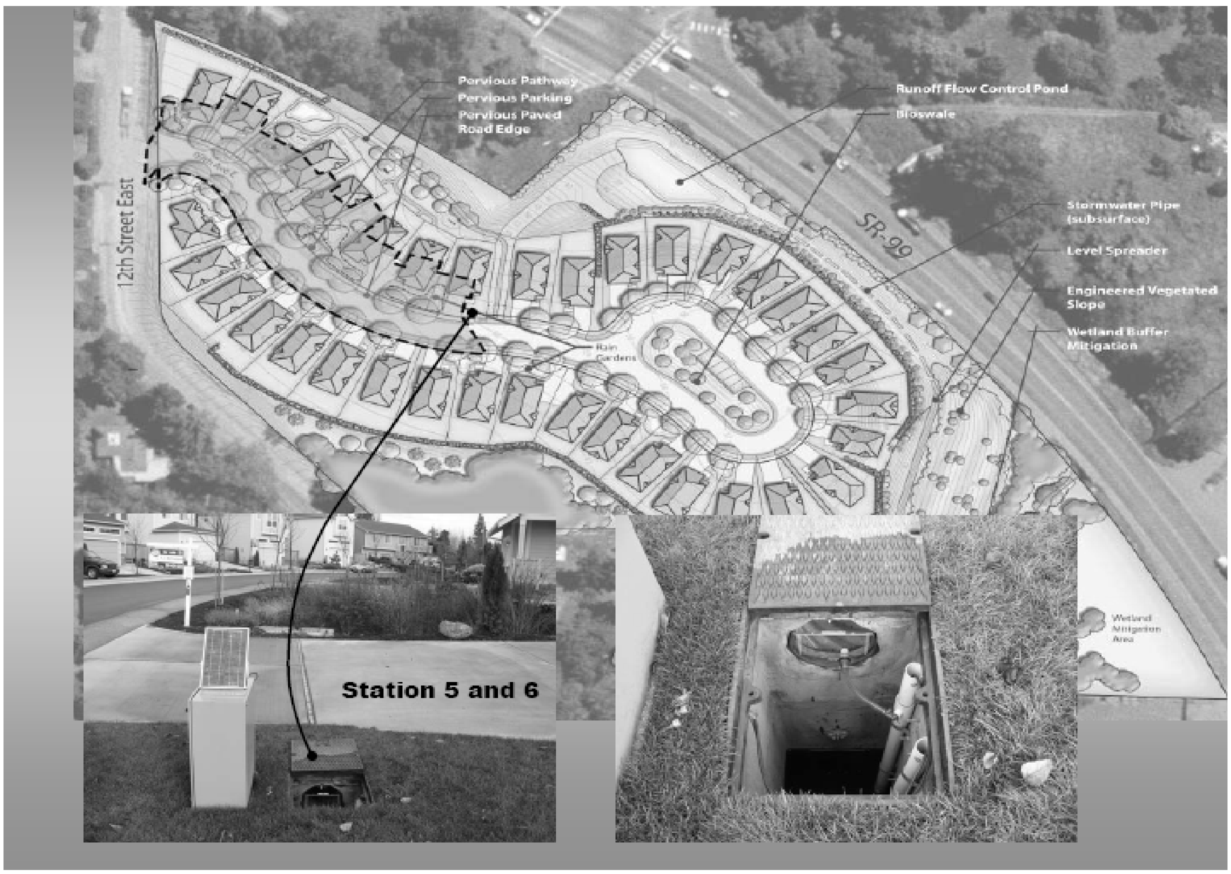

Figure 2-10: Sub-Basin Delineation and Monitoring Station Location.

2.7 Bioretention Swales Monitoring Results

Surface flow is measured directly and under-drain flow is measured by subtracting surface flow entering from the discharge flow exiting the catch-basin. The area contributing to the bioretention swales equals 0.280 hectares (0.692 acres) and includes 0.018 hectares (0.044 acres) of sidewalk, 0.149 hectares (0.368 acres) of road and driveway, 0.060 hectares (0.149 acres) of landscape, 0.018 hectares (0.046 acres) of permeable paving, and 0.035 hectares (0.086 acres) of roofs. Total area of the bioretention swales is 0.028 hectares (0.07 acres). The bioretention area is approximately 10 percent of contributing area. The road and driveway (93.74 m^2 (1,012.39 ft^2)), adjacent to the catch-basin monitoring station, discharge directly to the catch-basin through a slotted corrugated metal drain pipe rather than to a swale. The adjacent road and driveway are not included in totals so that only water movement through the swales and not uncontrolled impervious area is accounted for. This section of the project was complete for the 2006-07 wet season and the under-drain open to evaluate surface and sub-surface flow characteristics. Table 2-6 below provides a basic water budget for the contributing area and swales.

Table 2-7: Mean Bioretention Water Budget for October 1, 2006 through May 31, 2007.

Total precipitation volume * (m^3)	A: Surface Discharge (m^3)	B: Under-drain Discharge (m^3)	Total Discharge (A+B) (m^3)	Under-drain Discharge (%)	Volume Retained (%)
2,543.16	97.59	1,131.70	1,229.29	92	52

*Total volume is the product of the contributing area and total precipitation (minus ET). ET loss is approximately 23 percent of total precipitation.

No surface ponding or flow was observed in the bioretention swales during the 2006-07 wet season, which included the wettest month on record (406 mm (15.98 in.) for the month of November). Much of the flow in the bioretention swales was moving rapidly to the under-drain without adequate detention time for infiltration to the surrounding native soils. Accordingly, the under-drain was plugged for the 2007-08 wet season. The road and driveway (93.74 m^2 (1,012.39 ft^2)) adjacent to the catch-basin monitoring station discharge directly to the catch-basin through a slotted corrugated metal drain pipe rather than to a swale. The adjacent road and driveway are not included in totals so that only water movement through the swales and not uncontrolled impervious area is accounted for. Table 2-8 provides the basic water budget for 2007-08 with the under-drain plugged.

Table 2-8: Mean Bioretention Water Budget for October 1, 2007 through May 31, 2008.

Total Precipitation volume* (m^3)	Evapotranspiration (mm)	Total Discharge (m^3)	Volume Retained (m^3,%)
1,449.05	140.56 (23%)	5.45	1,443.60 (99.62%)

*Total volume is the product of the contributing area and total precipitation (minus ET). ET loss is approximately 23 percent of total precipitation.

2.8 Bioretention Swales Modeling Results

Bioretention swales and rain gardens were modeled in WWHM3 Pro using the bioretention swale module. Inputs to the bioretention swale module include bottom surface dimensions, side slopes, ponding depth, bioengineered soil depth and porosity, native soil exfiltration rate, and overflow design information.

The modeling results at this location show that the bioretention swales east of the roadway infiltrate approximately100 percent of the influent stormwater runoff. Consequently, the flow duration standards are met at this location for both pre-developed pasture and forested conditions. Figure 2-11 shows a comparison of the flow duration statistics for the forested, pasture, and developed site conditions.

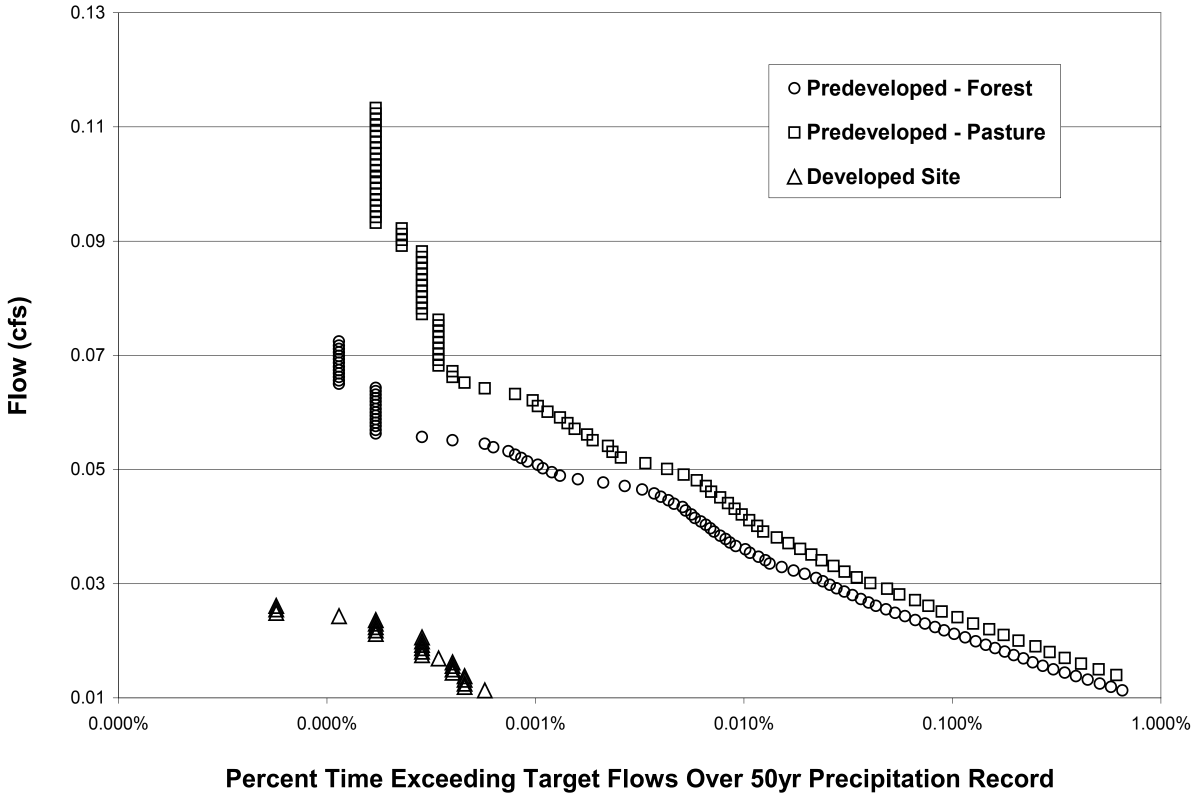

Figure 2-11: Flow Duration Evaluation for the Bioretention Swales (Station 6).

2.9 Precipitation Depth and Storm Flow Initiation

The cumulative precipitation depth to initiate surface stormwater flow was assessed at the POC (Station 2). For the wet season 2006-07 sub-surface or inter-flow was first observed from a rockery drain day-lighting at the POC on November 2. Surface flow was first observed and measured on November 4. No evidence of surface flow was observed reaching the dispersion slope (final control before discharge from the project) until November 6 (see Figure 2-11). On that date the site had received approximately 104 mm (4.09 in.) of precipitation. November 2006 was the wettest month on record for the Pacific Northwest.

For the wet season 2007-08 sub-surface or inter-flow was first observed from a rockery drain day-lighting at the POC on October 21. Surface flow was first observed and measured on December 4. No evidence of surface flow was observed reaching the dispersion slope (final control before discharge from the project) until December 3 (see Figure 2-12). On that date the site had received approximately 162.56 mm (6.4 in.) of precipitation.

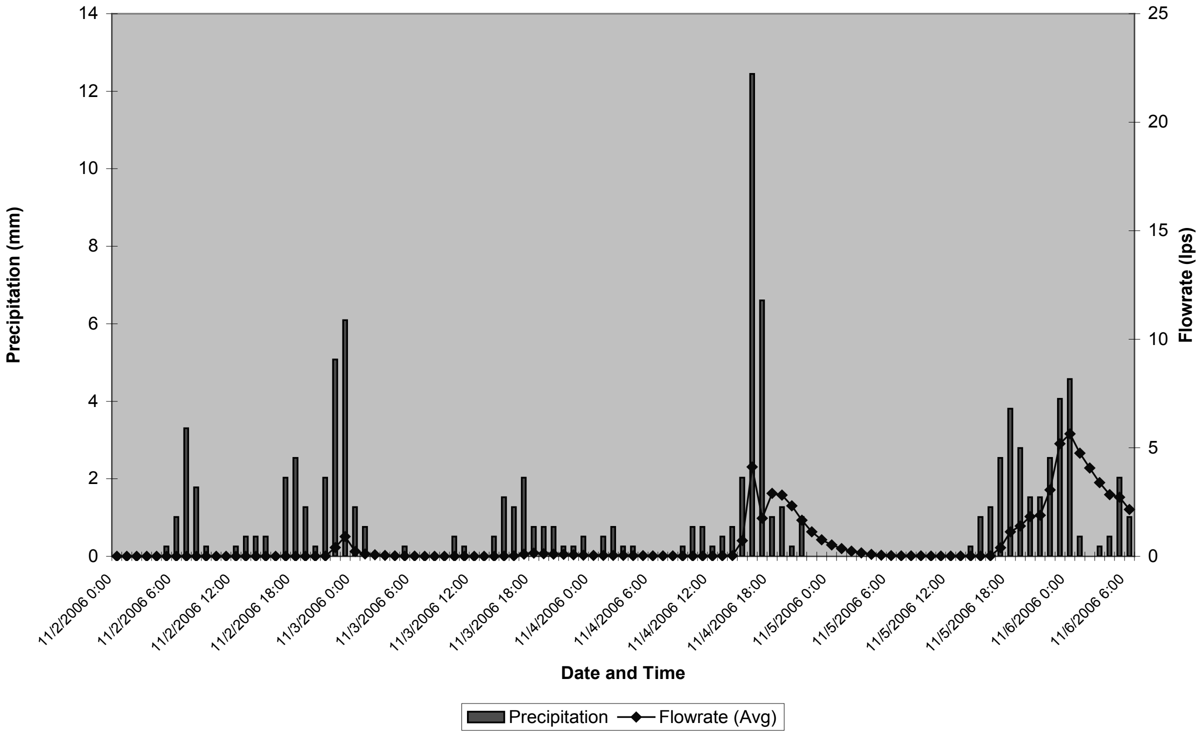

Figure 2-12: Mean Precipitation and Flow Response at the POC (Nov 2006)

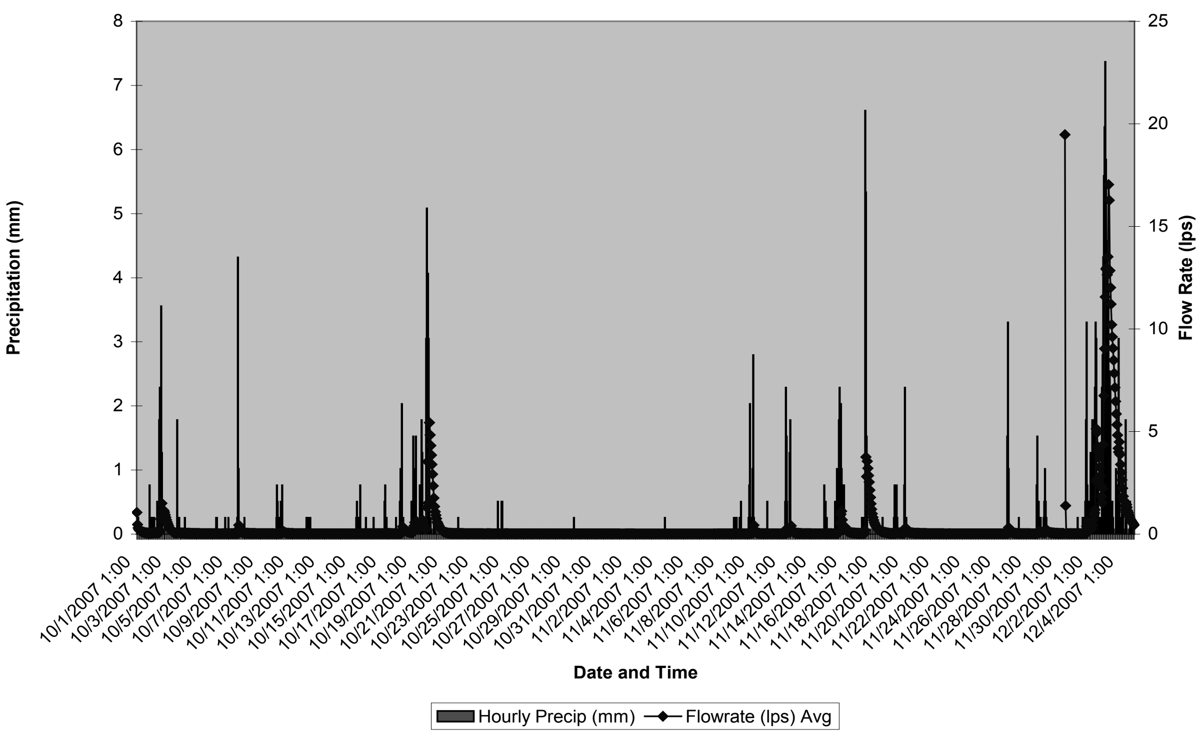

Figure 2-13: Mean Precipitation and Flow Response at the POC (Oct–Nov 2008)

2.10 Dispersion Slope Monitoring Results

To meet the flow control objective using a conventional stormwater approach a large pond would have been located at the southern end of the property. The LID design reduced the detention requirement for the project to approximately 531 m^2 (5,900 ft^2) (see Detention Pond, Figure 2-4). Eliminating the large detention requirement provided an area to incorporate an experimental dispersion slope for the final flow control and treatment practice that releases diffuse storm flows to a riparian buffer and Hylebos Creek.

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The compost-amended slope is approximately 55 m (180 ft) by 30 m (100 ft), has a 20 percent gradient and is planted with a conventional grass seed mix, as well as native shrubs and grass hedge rows. The compost amendment improves plant establishment and storm flow detention and retention. The densely-planted hedge rows were placed at three-foot intervals and designed to slow and better detain flows moving down slope. Unfortunately, the necessary irrigation was not provided for the establishment period and most of the plants in the hedge rows did not survive. The grass seed mix did establish and flourished to provide slope stabilization and improved flow control.

Surface and sub-surface flows to the dispersion slope were measured at the POC (Station 2) and Station 4 where an under-drain from the large rock wall on the western side of the property day lights to the dispersion slope (see Figure 1-4). Surface and shallow subsurface flows exiting the dispersion slope were monitored at Station 7. A shallow trench was cut at the bottom of the slope to direct flows through a flume. The trench was lined with an impermeable membrane that extended upslope approximately 25.40 cm (12 in.) at a depth of approximately 10.20 cm (4 in.) to collect shallow subsurface and surface flow.

Figure 2-14: Dispersion Slope, Collection Trench and Monitoring Station 7.

The dispersion slope significantly improved flow control for the project. The slope retained approximately 90 percent of the storm volumes falling on the slope plus discharges from the POC and Station 4 (see Table 2-12 and see section 2.2 and Figure 2-2 for overall flow control of the project measured at the Dispersion Slope).

Table 2-9: Mean Dispersion Slope Water Budget for October 1, 2007 through May 31, 2008.

Total Precipitation volume* (m^3)	Evapotranspiration (mm)	Total Discharge (m^3)	Volume Retained (m^3,%)
4,296.88	140.56 (23%)	431.08	3,865.80 (90%)

*Total volume is the product of the contributing area and total precipitation (minus ET) plus flow from Station 4 (Under-drain) and Station 2 (POC). ET loss is approximately 23 percent of total precipitation.

Important to note is that collecting disperse flow on a slope presents significant challenges. During much of the winter, the collection trench appeared to collect all surface flow and shallow subsurface flow from the top few inches of soil above the impermeable liner. However, during the largest storm of the year (December 2-3, 2007) surface flows were observed just down slope of the collection trench indicating that some flow likely bypassed the collection trench during this event.

2.11 Evaluation of Individual Storms and Monitoring Results

The WWHM3 modeling described above used a long-term continuous record of rainfall in order to evaluate flow duration statistics and determine whether flow control standards for the site are achieved. This section presents an evaluation of the 2007 and 2008 onsite rainfall and flow monitoring data for a more detailed understanding of the hydrologic performance of the bioretention swales and bioengineered dispersion slope for individual storms on record.

WWHM3 models, as described above, were used to estimate the inflows at Station 6 (Sub-basin 1), Station 2 (POC), and Station7 (Dispersion Slope). The modeled inflows were compared to the 2007–2008 wet season's monitored outflows at these same locations. The analysis then examined discrete precipitation events and corresponding inflows and outflows. WWHM3 models used in this exercise were similar to those described in the hydrologic modeling section above, except all bioretention and detention facilities were removed. This was done so that the model would simulate flows from the site in the absence of flow control facilities. For the remainder of this section, the term "modeled inflows" refers to the flows obtained using the models with no bioretention or detention facilities.

2.11.1 Defining Storms in Continuous Precipitation and Flow Records

Comparison of modeled flows and gauged flows was done on an event basis. The criterion used to start storm events was a 12-hour precipitation total of 1.02 mm (0.04 in.) or greater, and storm ends were defined when the 12-hour precipitation total declined to 0.76 mm

(0.03 in.) or less. No minimum storm depth or intensity was used to exclude storms for this analysis in order to examine hydrologic performance during storms of all sizes.

After the start and end times of discrete storms in the precipitation and flow records were defined, flow and precipitation durations, totals, averages, and peaks were calculated for each storm. The effects of storm characteristics on hydrologic performance of bioretention and detention facilities on the site were explored by examining modeled inflows and gauged outflows as functions of storm total precipitation and storm peak precipitation intensity. Scatter plots were used for a qualitative look at the ratio of inflow volume to outflow volume and to see whether this relation is a function of influent volume.

2.11.2 Results of the Monitoring Data Evaluation

Based on the storm criteria outlined above, 81 discrete storm events were identified from August 23, 2007 to May 30, 2008. The largest precipitation event was 101.35 mm (3.99 in.) on December 7th with a peak rate or 7.37 mm/hr (0.29 in/hr) and a duration of 86 hours. The median total precipitation, 1-hr peak precipitation intensity and storm duration was 5.08 mm (0.2 in.), 1.78 mm/hr (0.07 in/hr) and 15.48 hours respectively. Figures 2-15 through 2-17 plot storm flow as a function of peak storm precipitation intensity for Station 2 (POC), Station 7 (Dispersion Slope) and Station 6 (Sub-basin 1). In each of these figures, modeled inflows increase at a relatively constant and steep rate from storms with peak precipitation intensities of 0.254 mm/hr to 3.05 mm/hr (0.01 in/hr to 0.12 in/hr). For precipitation intensities less than 3.05 mm/hr, no outflows are recorded at Stations 7 and 6 indicating that these contributing areas are not producing surface flow for these precipitation intensities.

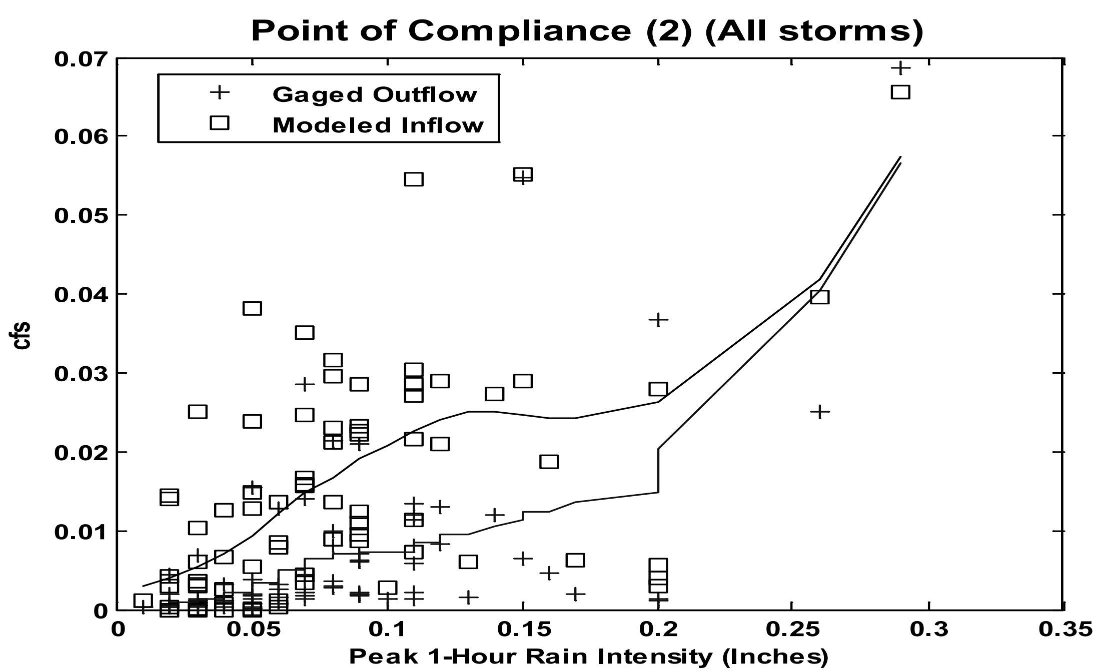

Figure 2-15: Storm Precipitation Peak Intensity vs. Mean Discharge at the POC.

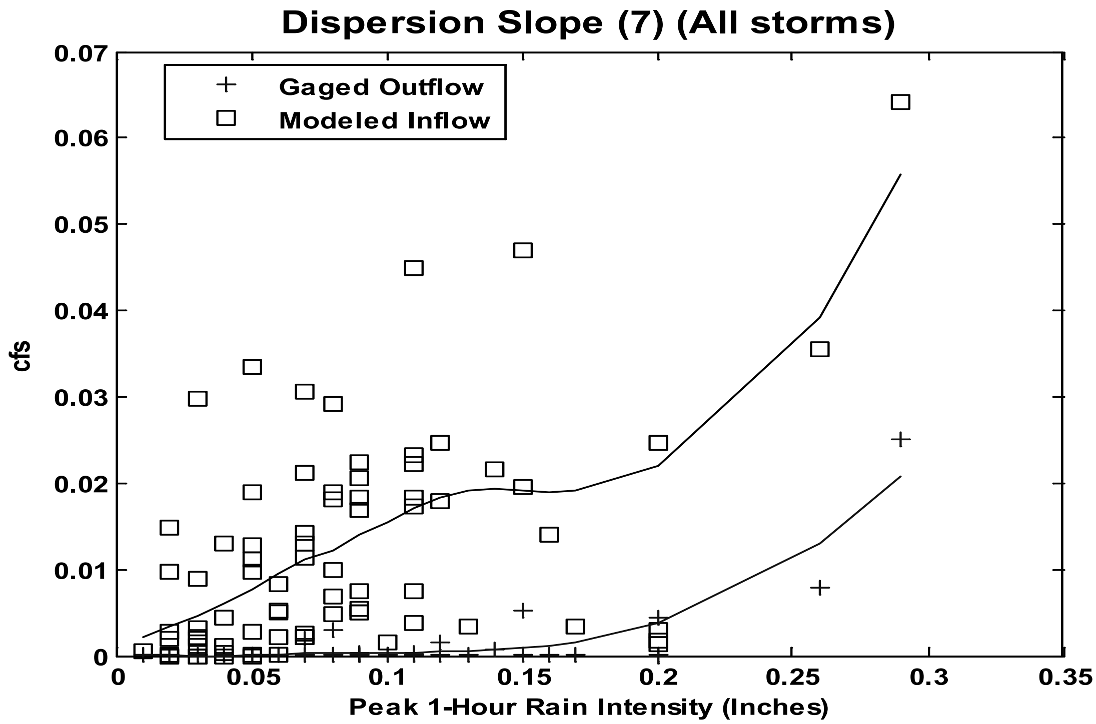

Figure 2-16: Storm Precipitation Peak Intensity vs. Mean Discharge at the Dispersion Slope.

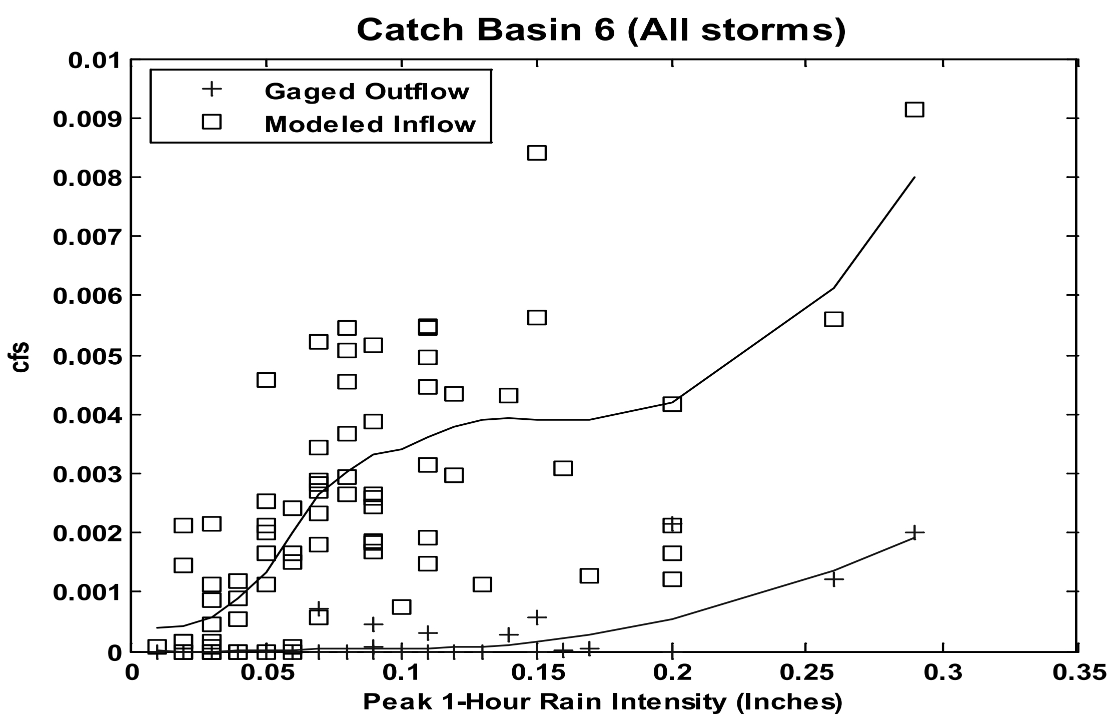

Figure 2-17: Storm Precipitation Peak Intensity vs. Mean Discharge at Sub-Basin 1.

Flow volume reduction performance of bioretention areas on site is best shown in Figures 2-18 through 2-20. These plot average modeled inflow and gauged outflow during the storm as functions of storm precipitation totals. For small storms (totals less than 5.08 mm (0.2 in.)), the modeled inflow volumes are a steeply increasing function of storm total precipitation, while gauged effluent flows increase slowly or not at all over this range. For Station 6, average storm flow is effectively zero for storms with total precipitation less than 10.16 mm (0.4 in.). Above 10.16 mm, Station 6 is recording direct flows from the adjacent road and driveway not controlled by the bioretention swales.

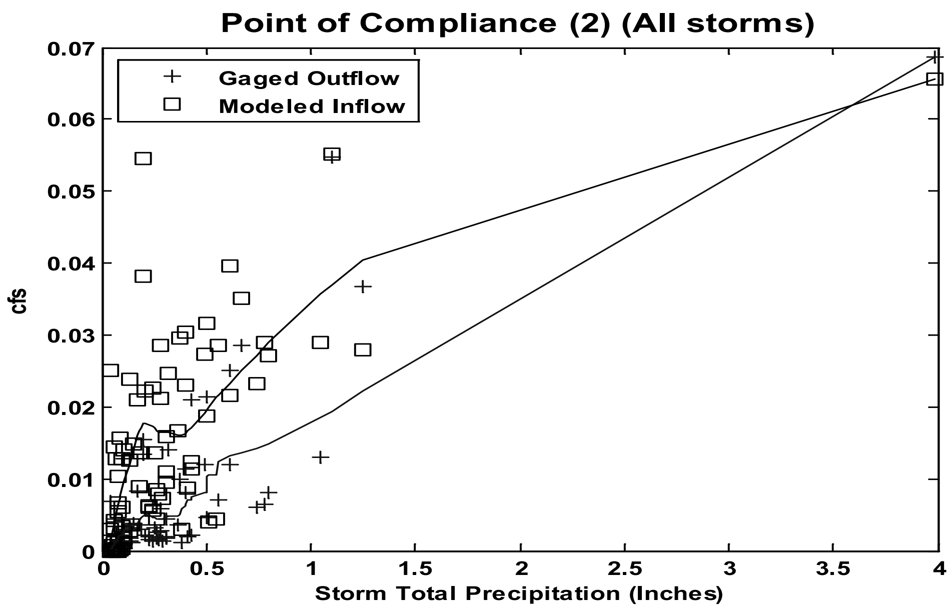

Figure 2-18: Storm Precipitation Total vs. Mean Discharge at POC.

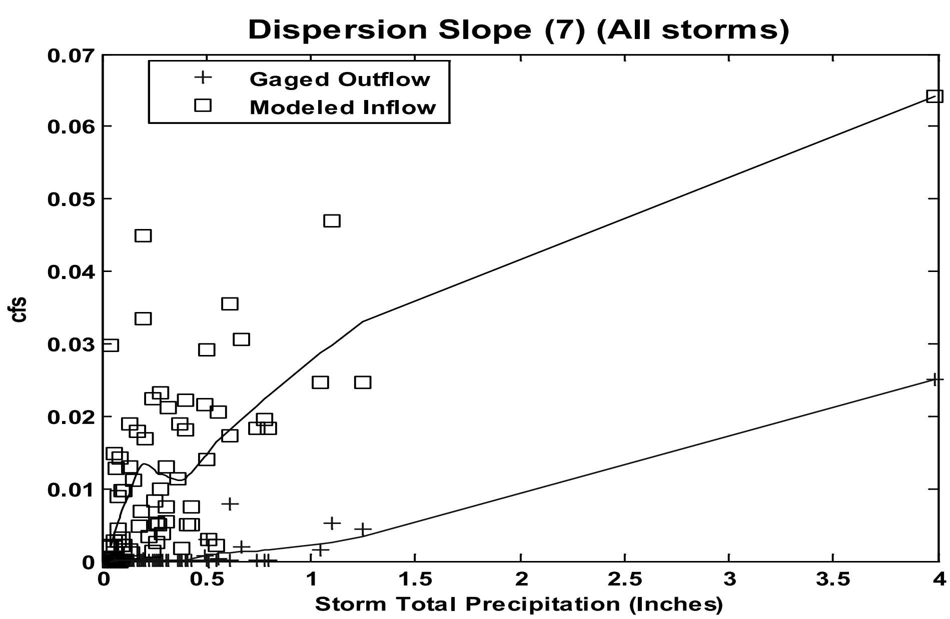

Figure 2-19: Storm Precipitation Total vs. Mean Discharge at the Dispersion Slope.

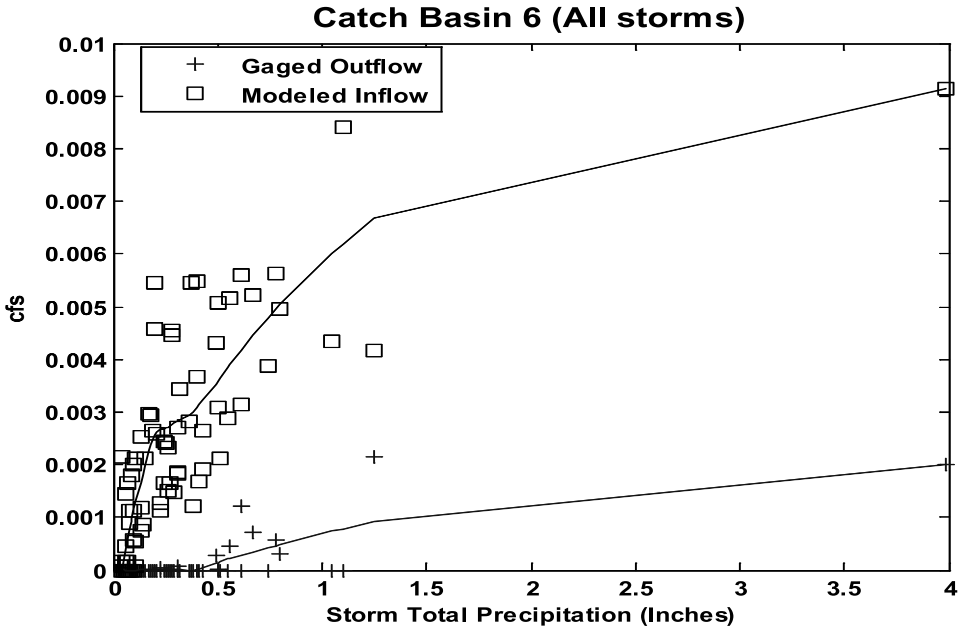

Figure 2-20: Storm Precipitation Total vs. Mean Discharge at Sub-Basin 1.

2.12 Permeable Concrete Infiltration Performance

The residential access road is super elevated from west to east rather than crowned. At the edge of the lower elevation, and along most of the access road, is a 1.2 m (4 ft) wide permeable concrete shoulder. Stormwater flows across the road, onto and through the permeable concrete, and into bioretention swales. Permeable concrete was also used for walkways located in open space areas and parking areas (see Figure 2-2).

Figure 2-21: Permeable Concrete Road Shoulder and Parking.

Three locations were selected to measure infiltration rates in the permeable concrete over time:

- ♦ Location 1: Pedestrian walkway under trees (control).
- ♦ Location 2: Parking pad near the subdivision entrance.
- ♦ Location 3: Road shoulder approximately halfway in the subdivision.

Falling head tests were conducted using a 9.50 cm (24 inch) cylinder glued to the concrete with plumber's putty. Fifteen liters of water was poured into the cylinder and the time recorded for all water to infiltrate. The test was performed three times and the three values averaged.

Throughout the home construction process no or inadequate erosion and sediment protection practices were implemented and the concrete received extreme sediment inputs. Material washed into or deposited directly on the concrete included construction dirt form the access road, landscaping soils, and concrete cement from foundation forms. As a result, the permeable concrete infiltration capability was severely degraded. Table 2-5 provides the initial (pre-home construction) and subsequent infiltration test results. Note that the location 2 marker was accidentally removed by construction activity and the site not used after the initial test.

Table 2-10: Permeable Concrete Infiltration Tests.

Date	Location 1	Location 2	Location 3
3/29/06 (newly installed)	1517.53 cm/hr	412.14 cm/hr	1096.49 cm/hr
2/1/07	Not measured	Not measured	3.32 cm/hr
11/30/07	933.74 cm/hr	Not measured	105.56

Figure 2-22: Weekly Street Cleaning and Construction Sediment Deposition in Permeable Concrete.

The February 1, 2007 test was conducted near the completion of the construction process and the concrete appeared completely clogged, but was still infiltrating. By the November 30, 2007 test, the concrete had been cleaned by the homebuilder using hand-held pressure wash followed by a vacuum truck.

To assess the structural characteristics of the permeable concrete, five 5-cm (2 in.) cores were extracted from representative locations and evaluated for percent voids and compression strength. Locations included the parking pads, walkways and road shoulders poured at the beginning, middle and end of the concrete installation process.

The recommendation for percent voids in permeable concrete is 15 to 21 according to ASTM C 138 (PSAT, 2005). For this evaluation Seattle Public Utilities Material Laboratory used ASTM C 642. The test results were fairly consistent among cores and all cores tested at the lower end of the recommended percent voids with three cores slightly lower than the recommended range. The mean values for each core are: 13.47, 15.57, 15.09, 14.89 and 14.60 percent.

To measure load carrying capacity and structural stability, the laboratory measured compressive strength. The test results varied widely from a low of 1091 psi to a high of 2748 psi. Mean values for each core are: 1567, 2293, 2380, 1735 and 2103 psi. Conventional compression tests have proven inconsistent and are not recommended for permeable concrete; however, tests were performed to compare this installation to other local test results.

2.13 Water Quality Sampling Results

The primary focus of the monitoring project was water quantity and flow analysis; however, water quality samples were collected to screen for any pollutant levels of concern. Flow weighted samples were collected with an ISCO 6700 at the POC. Individual 1-liter glass containers were collected in accordance with the Quality Assurance Project Plan and combined into one composite sample at the lab (see Appendix A: Quality Assurance Project Plan).

Many of the storms during the monitoring period produced small, sub-surface flow delivered to the POC through an under-drain pipe from a 76 m (250 ft) the rock wall rather than surface flow. As a result, only two storms were sampled. The first sample was collected on December 2, 2007 from the first surface flow reaching the POC. The second storm was collected on February 6, 2008 and was sub-surface flow from the rockery under-drain (see Tables 2-11 through 2-13). Both samples are reported if concentrations between events are different, one number reported indicates that the concentrations for both events were the same.

Polycyclic aromatic hydrocarbons (PAHs) were analyzed (EPA Method 525) on December 2, 2007 and February 12, 2008. All PAH compounds were below detection levels for both sample events. Herbicides were analyzed (EPA Method 515.1) on December 2. All compounds were below detection levels.

Table 2-11: Sample Results for Nutrients with Comparative Studies.

	Ammonia-N (mg/L)	Total Kjeldahl-N (mg/L)	NO2+NO3 (mg/L)	P-total (mg/L)	Ortho-phosphate (mg/L)
Project Sample	<1.0	<1.0	1.15	0.49/0.23	0.32/0.22
NURP* (median)	not reported	1.9	0.74	0.38	not reported
NSQD** (median)	0.32	1.4	0.6	0.3	not reported

*National Urban Runoff Program (residential land use)
**National Stormwater Quality Database (residential land use)
Project sample: one number reported if both sampling events the same,12/02/07 sample/2/6/08 sample reported if different.

Table 2-12: Sample Results for Solids and Hydrocarbons with Comparative Studies.

	TSS[a] (mg/L)	TDS[b] (mg/L)	TVS[c] (mg/L)	Turbidity (NTU)	Diesel (mg/L) (NWTPH-DX)	Heavy oil (mg/L) (NWTPH-DX)
Project Sample	13/7	162/147	73/54	23.6/21	<0.25	<0.25/<0.50
NURP* (median)	101	not reported	not reported	not reported	not reported	not reported
NSQD** (median)	48	not reported	not reported	not reported	not reported	not reported

*National Urban Runoff Program (residential land use)
**National Stormwater Quality Database (residential land use)
[a] Total Suspended Solids
[b] Total Dissolved Solids
[c] Total Volatile Solids
Project sample: one number reported if both sampling events the same,12/02/07 sample/2/6/08 sample reported if different.

Table 2-13: Sample Results for Metals with Comparative Studies.

	Pb total (µg/L)	Cu total (µg/L)	Zn total (µg/L)	Pb dissolved (µg/L)	Cu dissolved (µg/L)	Zn dissolved (µg/L)
Project Sample	0.002/0.003	0.02/<0.02	<0.05	<0.002	<0.02	<0.05
NURP* (median)	144	33	135	not reported	not reported	not reported
NSQD** (median)	12	12	73	3.0	7.0	31.5

*National Urban Runoff Program (residential land use)
**National Stormwater Quality Database (residential land use)
Hardness: 110/74 (mg/L as calcium carbonate) for project samples
Project sample: one number reported if both sampling events the same,12/02/07 sample/2/6/08 sample reported if different.

CHAPTER 3.0

DISCUSSION

3.1 Soils, Hydrology and Site Design

The physical setting, timing and housing density at the Meadow on the Hylebos present a significant test for an LID design. The large majority of the site has a silt loam, glacial lake bed sediment cap. Much of the silt loam is underlain by a relatively thin layer of coarse-textured glacial meltwater deposits, some of which are well drained and some not. Underlying everything at depths ranging from as shallow as 0.9 m (3 ft) to greater than 3 m (10 ft) is a cemented till. Infiltration tests indicate that much of the site is poor draining 0.0 to 0.76 cm/hr (0 to 0.3 in/hr); however, one PIT location produced and infiltration rate of 6.35 cm/hr (2.5 in/hr).

3.2 Project Implementation

Constructing an LID project in a dense residential development (average lot size approximately 4,100 square feet) presents challenges for minimizing soil compaction and implementing effective erosion and sediment control to prevent degradation of the bioretention and permable paving systems. Specific and well coordinated construction sequencing and jurisdictional over site are essential for optimal implementation. Few if any construction guidelines were provided for the developer and homebuilder and specifications for the LID practices applied at the project were minimal. As a result, inadequate temporary erosion and sediment control resulted in large sediment inputs to some of the bioretention areas. The sediment deposits were not removed from the bioretention cells, but rather incorporated into the bioretention soil mix, planted and mulched. Construction sediment, cement and landscaping materials were washed into the permeable concrete. Finally, the largest bioretention area (BA 1) located in the road loop with the highest infiltration rate was lined with an impermeable membrane due to speculation of infiltration to sewer infrastructure.

3.3 Hydrologic Performance

Despite the implementation problems, the project has exceeded design objectives. The flow control goal for the project was to match 50 percent of the two-year and up to the full fifty-year peak flows and durations for pre-developed pasture condition. Below are the results and discussion for the project hydrologic performance in relation to the flow control objectives.

3.3.1 Overall Hydrologic Performance

At the final outfall of the project (Dispersion Slope) measured surface and shallow subsurface flow volume reduction was 96 percent of total precipitation input. Hydrologic modeling results exceed initial flow control objectives and match 50 percent of the two-year and up to the full fifty-year peak flows and durations for pre-developed forest condition.

The flow volumes (approximately 62 percent during 2006-07 and 70 percent during 2007-08) and durations at the POC exceeded the initial flow control objectives with the largest bioretention area (BA 1) excluded. However, when BA 1 was factored back into the system in the modeling analysis, the POC met the DOE standard for pre-development forested condition.

3.3.2 Sub-Basin 1 Hydrologic Performance

Sub-basin 1 is a 0.31 hectare (0.76 acre) contributing area with seven homes and four bioretention areas. Surface and sub-surface flows were monitored for Sub-basin 1 during the 2006-2007 monitoring period. Ninety-two percent of the flow through the swales was conveyed by the under-drain suggesting that precipitation infiltrated through the bioretention soil mix and to the under-drains where flows were rapidly conveyed through the drainage system. Without adequate detention time, much of the storm flow did not move laterally or vertically to the underlying native soil.

The under-drains were plugged for the wet season 2007-2008. Once plugged, Sub-basin 1 exceeded flow control objectives and essentially infiltrated 100 percent of contributing area storm flow. The bioretention swales are approximately 10 percent of the contributing area in the sub-basin. Ten percent is a relatively large sizing factor compared to many other regions of the US where systems are often designed primarily for water quality treatment and modest flow control. However, the design at the Meadow on the Hylebos demonstrates that bioretention can provide and aesthetic design within the road right-of-way for dense residential development on poor draining soils and achieve the highest flow control standard. Managing all storm flow volumes within the bioretention systems also provides 100 percent removal of all pollutants from receiving waters and enhanced treatment of the storm flows before exfiltration into surrounding native soils.

3.3.3 Factors Influencing Hydrologic Performance

Two factors likely influence the greater than expected performance for the project as a whole and Sub-basin 1. First, current modeling approaches including HSPF driven WWHM may not be adequately calibrated yet to accurately account for performance of LID systems. Lateral infiltration and conventional pond sizing algorithms used in bioretention sizing may be two areas needing additional calibration (see Section 3.5 for additional modeling discussion). Second, LID systems are dispersed across the project site. Soil infiltration rates can vary significantly over small distances particularly in Puget Sound where complex soil patterns are present as a result of advancing and receding phases of glacial activity. Accordingly, dispersed LID systems may increase the probability of engaging distributed pockets of soils with higher infiltration rates and, therefore, improve anticipated performance.

The LID approach focuses on distributed infiltration. Soils analysis for the project suggests that storm flows may move laterally above the till layer located 0.9 m (3 ft) to greater than 3 m (10 ft) below the upper dense silt loam cap. Sides and toes of slopes were observed regularly during the monitoring project. During the largest storm of the 2007-08 monitoring period surface flows were observed at the bottom of the Dispersion Slope indicating that sub-surface flow was surfacing below the collection trench for Station 7. No other flow was observed surfacing on other slopes during the monitoring period; however, quantifying sub-surface lateral flows at this scale was not feasible and the quantity and form of all flows moving offsite can not be verified.

3.4 Individual Storm Analysis

Storm-event based analysis of the flow monitoring data confirms that storm outflows were not strongly affected or produced little to no surface flow from storm peak precipitation intensities in the 0 to 3.05 mm/hr (0 to 0.12 in/hr) range. A similar but more variable pattern was observed between storm outflow volume and storm total precipitation, with gauged outflow much less than modeled inflow for storms with precipitation totals less than 5.08 mm (0.2 in.). For Sub-basin 1 no surface flow was produced for all storm intensities and total precipitation. Discharge shown on figures 2-17 and 2-20 is a result of direct input from adjacent, uncontrolled impervious surface (road and driveway) into the monitoring station catch-basin.

Little data exists measuring the flow reduction capability of LID facilities for various storm intensities and total precipitation. Current speculation suggests that LID facilities will perform well for small storms. For the 2007-08 monitoring period, the largest peak intensity was 7.37 mm/hr (0.29 in/hr) and the median total precipitation and 1-hr peak precipitation intensity was 5.08 mm (0.2 in) and 1.78 mm/hr (0.07 in/hr) respectively. The LID facilities for the monitoring period were able to eliminate flows for peak intensities significantly exceeding median peak intensities and up to median total precipitation.

3.5 Modeling

The application of LID is relatively new in the Puget Sound region. Accurate and efficient sizing and design require calibration of recommended continuous simulation models. This section compares the results from long-term continuous modeling in WWHM3 and evaluation of the raw flow monitoring data. Table 3-1 provides a summary comparison of the methods used and the resulting estimates in flow volume reductions at Station 6, POC (Station 2), and Dispersion Slope (Station 7) based on both methods of analysis. Note that median values are presented in this comparison and mean values in the monitoring findings in Chapter 2.0.

Table 3-1: Comparison of Modeled and Monitored Flow Volume Reductions (Percent Reduction[a])

	Modeling	Monitoring Data Evaluation
Period of analysis	1948 to 1998	2007 and 2008
Time step	1 hour	1 hour
Summary of methods	WWHM3 modeling of inflows and outflows at each location using 50-year rainfall record for McMillan	Median storm event volume reduction (with bootstrapped 95% confidence interval for the median)
Results		
Sub-basin 1 (Station 6)	100%	100% (100% to 100%)
POC (Station 2)	49%	73.6% (61.4% to 76.4%)
Dispersion Slope (Station 7)	84%	99.9% (99.8% to 99.9%)

Notes:
[a] Percent reduction = (inflow – outflow)/inflow * 100%.

The event-based monitoring data evaluation results agree with the long-term continuous modeling results for Station 6. Both methods show approximately 100 percent flow volume reduction. For POC (Station 2) and Dispersion Slope (Station 7), the monitoring data evaluation and continuous modeling results are not in agreement. Several reasons related to methodology could explain the differences:

- The monitoring data evaluation looks at performance event-wise, while the continuous modeling looks at performance on long-term annual averages. Since the model is uncalibrated, it does not adequately separate quick runoff, interflow, and baseflow. With this error in flow timing, volume estimates on an event basis are less accurate than long-term average volume estimates. For example, if the model partitions too much precipitation into quick runoff, the modeled inflows could be rather high compared to gauged outflow, thereby increasing apparent removal efficiency on an event basis but not affecting removal efficiency on an annual basis.
- The monitoring data evaluation looked at a specific short time period (wet season 2007–2008), while the continuous modeling used a long (50-year) time series. This means that the continuous modeling looked at inflow to outflow relations under a more complete distribution of precipitation durations and intensities than the monitoring data evaluation.

3.6 Water Quality Sampling

Two flow-weighted water quality samples were collected to screen for any pollutant levels of concern. Turbidity samples were 23.6 and 21 NTU’s. State of Washington background levels in receiving waters from which percent increase is allowed is 50 NTU’s (Ecology, 2006). Total Suspended Solids were quite low compared to national levels.

Total and dissolved metals, were very low (2-3 orders of magnitude) compared to levels indicated in national studies. Dissolved copper was <0.02 µg/L and dissolved zinc <0.05 µg/L. U.S. EPA and recommendations are 6.5 to 21 µg/L criteria continuous concentration (CCC) and 9.2 to 34 µg/L criteria maximum concentration (CMC) for dissolved copper and 59 to 190 µg/L

(CCC) and 65 to 210 µg/L (CMC) for dissolved zinc. The two numbers are for hardnesses of 50 and 200 mg/L respectively (U.S. EPA, 1994).

Herbicides and PAH's were below detection limits. Laboratory studies for TSS, metals, organics, hydrocarbons and PAH's management in bioretention indicated excellent removal capability (Davis et al., 2003; Hong, Seagren and Davis, 2002; DiBlasi et al.). Influent concentrations are not known for the project; however, the low concentration levels compared to other national studies for residential areas and laboratory findings suggest that the bioretention systems are providing excellent capture for pollutants that are present.

Nutrient levels were similar to national studies. Bioretention soil mixes contain compost and nitrogen and phosphorus removal in these systems can be variable (Davis et al., 2001; Hunt 2006). The source for nutrients present in samples from the project is likely the bioretention systems, especially considering the soil, plant system is new and soil structure and biota are just establishing.

Temperature fluctuated from a mean low in December, 2007 of 4.5ºC to a high in August of 17.5ºC. State of Washington Aquatic Life Criteria (7-day average of the daily maximum temperature) range from 9ºC for Char spawning to 17.5ºC for salmonid spawning, rearing and migration (Ecology, 2006).

Note that flow weighted samples were collected for the project. Time weighted sampling is considered to provide a more representative sampling regime for comparison to water quality criteria and aquatic biota exposure. Nevertheless, flow weighted and water quality criteria are compared above for context of project performance and currently accepted receiving water pollutant concentrations.

3.7 Permeable Concrete

The permeable concrete road shoulder was subject to extreme sediment loading during the home construction phase of the project. Throughout the construction process no or inadequate erosion and sediment protection guidelines were implemented. Material washed into or deposited directly on the concrete included construction dirt form the access road, landscaping soils, and concrete cement from foundation forms. As a result, the permeable concrete infiltration capability was severely degraded.

The infiltration rate at Location 3 was reduced from approximately 1096.49 cm/hr to 3.32 cm/hr (431.69 to 1.31 in/hr). While this is a dramatic reduction, 3.32cm/hr is adequate to infiltrate large storms in western Washington. Cleaning the concrete subsequent to construction provided impressive results considering the extreme sediment loading and increased the infiltration rate to 105.56 cm/hr (41.56 in/hr), which is more than adequate to infiltrate the largest storms recorded or anticipated in the region.

APPENDIX A

STORMWATER MONITORING PLAN FOR THE MEADOW ON THE HYLEBOS LOW IMPACT DEVELOPMENT (LID) PILOT STUDY

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PREFACE

The following monitoring plan presents the goals and objectives of the stormwater monitoring program and the procedures to attain the goals for the Meadow on the Hylebos Low Impact Development (LID) Pilot Project. The monitoring plan details the type and quality of data to be collected through the project and describes the methods for collecting and assessing those data. This monitoring plan focuses on the surface water hydrology components of the project and does not include all elements of a standard quality assurance project plan (QAPP). The plan generally follows guidelines for QAPPs, including the Washington State Department of Ecology's (Ecology) Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (Ecology 2001), the Environmental Protection Agency's (EPA) EPA Requirements for Quality Assurance Project Plans (QA/R-5) (U.S. EPA, 1999), and Ecology's Guidance for Evaluation the Performance of Stormwater Pollutant Removal Technologies (Ecology 2004). Appendix A contains a table illustrating how this document relates to the Ecology and EPA QAPP guidance documents.

The monitoring plan is intended to be a dynamic document and can be amended during the project as monitoring conditions warrant method modification. Specifically, additional sections can be added to describe the data collection objectives and procedures for other elements of the project, such as groundwater monitoring, weather monitoring, and LID construction/implementation.

CHAPTER 1.0

INTRODUCTION

1.1 Background

The Meadow on the Hylebos Pilot Project monitoring (the project) will collect stormwater quantity and quality runoff data to quantify the performance of selected low impact development (LID) integrated management practices (IMPs). The development, located in northwest Pierce County, Washington incorporates cluster design, bioretention swales, permeable paving, compost amended soils, and other small-scale, dispersed stormwater controls. The central goals for constructing the project are to protect adjacent stream values by incorporating LID IMPs that more closely mimic native hydrologic patterns, as well as construct an affordable and livable neighborhood. The project is a pilot study to better understand design, permitting, construction and hydrologic performance of LID IMPs. The LID techniques used for this project are a limited set of new IMP practices from the Low Impact Development Technical Guidance Manual for Puget Sound (PSAT 2005). The LID techniques are also included in the Washington State Department of Ecology's 2005 update to the Stormwater Management Manual for Western Washington (Ecology 2005).

1.2 Monitoring Goals

The goals of the monitoring program are:

1. Monitor the stormwater runoff quantities at several locations to deterimine a water budget for stormwater inputs to and outputs from individual LID techniques.
2. Monitor stormwater runoff quantity at the project point-of-compliance (POC) to evaluate overall performance in relation to stormwater management design criteria for project.
3. Monitor stormwater runoff quality at the POC to assess the water quality output of the project as a whole.

1.3 Monitoring Objectives

The objectives for meeting the monitoring goals described above are:

1. Collect water level data at selected locations (see Figure App1.1) to monitor stormwater volumes and flow rates. These locations and measurements include:

- ♦ Weather Station (Station 1) for precipitation inputs and evapotranspiration.
- ♦ Point of Compliance (Station 2) to measure overall project flow volume and rates.
- ♦ Soil water content along transects at various depths in the western bioretention swale at the project entrance (Station 3).
- ♦ Under-drain (Station 4) for subsurface flows from the western hill slopes.

♦ Surface and subsurface flows in catch-basin 4 (Station 5 and 6) to measure outflow from the northeast bioretention swales.
♦ Final surface and shallow interflow output of the project at the bottom of the dispersion slope (Station 7) at the southern end of the property.

2. Collect water samples at the POC to assess downstream (post-treatment) water quality. Water samples will be collected during storm events as flow-weighted composites to determine event mean concentrations. Water samples will be analyzed for a suite of parameters (see Table App 1.1).

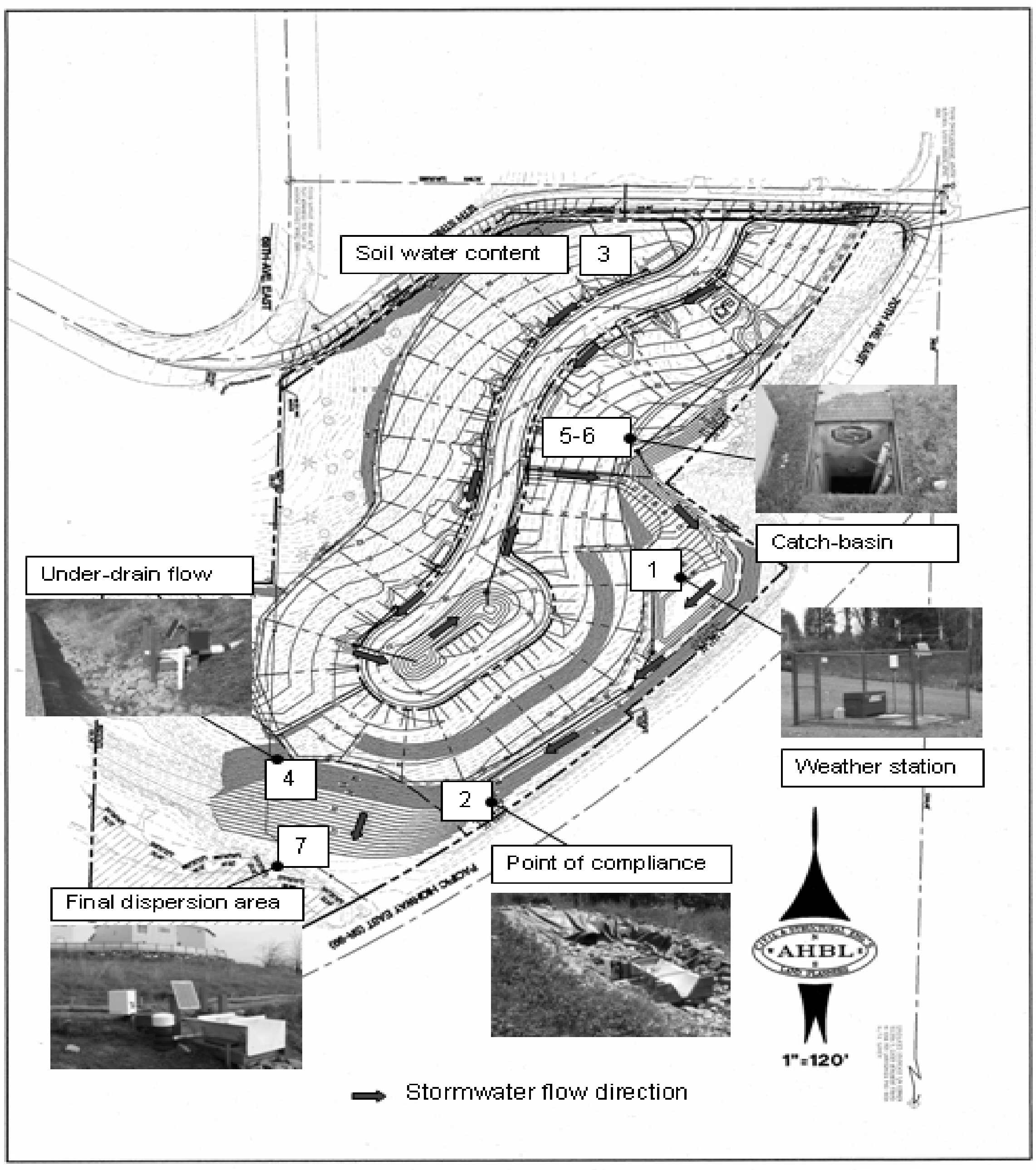

Figure App A 1.1: Monitoring Station Locations.

Table App 1.1: Water Quality Parameters for Storm Event Sample Collection.

Parameter	Sample Type
Fecal coliform bacteria (fecals)	Grab, autosampler
Total petroleum hydrocarbons (TPH)	Grab, autosampler
Ammonia nitrogen (Ammonia N)	Composite, autosampler
Nitrate+Nitrite N (NO2-NO3)	Composite, autosampler
Kjeldahl nitrogen (TKN)	Composite, autosampler
Hardness	Composite, autosampler
Metals, dissolved (Cu, Pb, Zn, Cd, Cr)	Composite, autosampler
Metals, total recoverable (Cu, Pb, Zn, Cd, Cr)	Composite, autosampler
Chlorinated herbicides (Chl H) *§	Composite, autosampler
Organophosphorus pesticides (Org P) *§	Composite, autosampler
Polynuclear aromatic hydrocarbons (PAH) §	Composite, autosampler
Total dissolved solids (TDS)	Composite, autosampler
Total phosphorus (TP)	Composite, autosampler
Orthophosphate	Composite, autosampler
Total suspended solids (TSS)	Composite, autosampler
Total volatile solids (TVS)	Composite, autosampler
Turbidity	Composite, autosampler

* Pesticides will be measured on samples from one to three storm events during Spring and/or Summer.
§ Specific compounds to be analyzed for Chl H, Org P, and PAH will be selected later in the project.

Data collection objectives in this plan address some but not all of the monitoring effort. Additional locations not described in this plan will be monitored for water level and/or flow to fill in additional pieces of the water budget.

CHAPTER 2.0

DATA COLLECTION

The following section describes the data collection objectives and methods. These include: 1) the data quality objectives which describe the accuracy and precision goals for the data collection; 2) the experimental design to describe the specific methods for collecting the data; 3) the field procedures to describe the protocols during a water sampling event; 4) the laboratory methods to describe the analytical methods for water sample analysis; and 5) the quality control procedures to describe steps to determine data accuracy.

2.1 Data Quality Objectives

The quality of data collected for field-based projects is determined by project objectives, project budget, and methods of quality assurance and quality control. In order to meet the overall monitoring objectives, the data will be assessed for precision, bias, representativeness, completeness, and comparability. In addition, the specific quality control objectives for the laboratory analytical data (see section 2.5) will be used to assess if water quality data meet the data quality objectives.

2.1.1 Precision

Precision is a measure of the scatter in data due to random error. For field-based studies, random error can occur from sampling and analytical procedures as well as instrument drift from calibration values. For laboratory analysis, precision will be assessed using laboratory duplicates. To assess precision of field-based water sampling, autosampler duplicates will be collected for at least 10 percent of the samples submitted to the laboratory for analysis. Autosampler duplicates will be submitted to the laboratory as blind duplicates, and relative percent difference (RPD) will be calculated for duplicate results. To assess precision of field instrumentation, specifically the pressure transducers, a log will be kept to record drift from calibration values.

2.1.2 Bias

Bias is the difference between the mean of the results of an infinite number of replicate measurements and the true value due to systematic error. Defining and following standardized sampling methods such as those set forth in this monitoring plan minimizes error due to bias. Bias affecting laboratory measurement procedures will be assessed by the use of matrix spike recovery, method blanks, and check samples in accordance with methods used by Water Management Laboratories, Inc. a Washington Department of Ecology certified laboratory. Bias in water sample collection will be measured by collecting field blanks at a rate of 10 percent of the samples submitted for analysis. Bias will also be reduced by regularly calibrating instruments and consistently following set field procedures.

2.1.3 Representativeness

Representativeness is defined as the degree to which the data obtained describes the site conditions that the project seeks to evaluate. Representativeness is improved by selection of appropriate sampling locations, times, and methods, and the consistent application of those methods. To ensure representativeness of the water sample data, water samples will be collected to best represent water quality conditions at the sampling point. Water samples will be collected as flow-weighted composites to represent conditions over all or a portion of the storm hydrograph. Consistent and standard sampling and analytical procedures as set forth in this monitoring plan will be followed. Water level measurement locations will be selected to best represent water flow conditions at the site given the constraints of obtaining accurate measurement.

2.1.4 Completeness

Completeness is defined as the percentage of valid data obtained from a measurement system compared to the percentage of data that would result from ideal conditions. For ideal conditions, 100 percent complete data record can be expected. For field environmental data collection, which often includes non-ideal conditions, the goal for completeness is to obtain data necessary to meet the project objectives, which may be accomplished with a portion (less than 100 percent) of a data record. The completeness goal for the water quantity data collection portion of this project is a flow record that can be used to construct a water budget for the period of data collection. For water quality, the completeness goal is to collect sets of water samples during storm events that can be used to determine event mean composite results. Data completeness goals will be pursued by following standard field procedures and testing equipment prior to use. Data completeness will be evaluated throughout the data collection period and if the data record appears too incomplete, the project manager will consider corrective actions to adjust data collection procedures.

2.1.5 Comparability

Data comparability will be ensured through the application of standard analytical procedures, analytical methods, units of measurement, and detection limits. To ensure data comparability with other monitoring results in western Washington, procedures for sample collection, sample analysis, and data analysis will be consistent with Ecology's monitoring guidelines (Ecology 2004) to the extent possible. By following these guidelines, data will be comparable to other similar studies that focus on pollutant removal by stormwater IMPs, especially LID techniques.

2.2 Water Quantity: Experimental Design Measurement Accuracy

Due to the need for accurate water quantity measurement for the project, the accuracy of field instrumentation used for water measurement is outlined here. Accuracy is determined by summing the published potential non-random errors associated with the different components of the water measurement instrumentation.

2.2.1 Weather Station (Station 1)

A weather station, located onsite, will record precipitation inputs, wind, temperature, solar radiation, humidity, and soil temperature. Evapotranspiration will be determined using the Penman equation. Precipitation will be measured by two tipping bucket rain gauges one buried with the rim at ground level and one installed with the rim at five feet. All instruments will be tested and calibrated by WSU and MeasureTek, Inc. previous to installation and at least once per year in subsequent years. A security fence was installed to limit access to data collection personnel. The station is located 50 feet ft from the tallest proximate embankment and house which is 40 feet tall and southwest of the center of the station. The data collection intervals are 1 day and 1 hour.

Instrument	**Individual Instrument Error**
CS 770-L (rain gauge #1)	±2% @ 3.9 in/hr
Novalynx 26-2500 (rain gauge #2)	±1%@1-3in/hr and ±3%@0-6in/hr
CS 107 Temperature Probe	±0.4C (-24-48C) ±9C (-38-53C)
SP-LITE Silicon Pyranometer	±5%
HMP45C Temperature and Relative Humidity Probe	±2% (0-90% RH) ±3% (90-100% RH)
05103 R.M. Young Wind Monitor	unknown
CR 10X data logger	±0.05% FSR (zero to 40 °C)

2.2.2 Point of Compliance (Station 2)

Surface flow volume and rate will be measured at the Point of Compliance (POC) to determine if the project is meeting the stated flow control objectives. While the POC is the regulatory release from the property, one more surface flow monitoring station is located at the bottom of the dispersion slope (Station 7) where water actually leaves the property. Water quality samples will also be collected at the POC (see water quality section).

Water quantity at the project POC will be determined by measuring water level in the trapezoidal flume. Flow rate will be determined by using the rating curve provided from the flume manufacturer. All instruments will be tested and calibrated by WSU and MeasureTek, Inc. previous to installation and at least once per year in subsequent years. The data collection intervals are 1 day, 1 hour and 15 minute.

Instrument	Individual Instrument Error
Plasti-Fab Extra Large 60º Trapezoidal Flume	±5%
Druck PDCR 1830 1 psig Pressure Transducer (individually calibrated by NIST)	±0.06% FS BSL*, temperature effects ±0.6%FS
CR 10X data logger	±0.05% FSR (zero to 40 °C)
Total non-random error	±5.71% FSR

* combined non-linearity, hysteresis and repeatability.

2.2.3 Bioretention Swale (Station 3)

Soil water content sensors are placed in and adjacent to a bioretention swale at the entrance to the property attempting to measure the movement of subsurface flows out of the swale. The sensors (CS 616) are installed in three transects: 1 in the middle of the swale and one on each side approximately 2 feet outside the swale. Sensors are placed at 18, 36, 54, and 72 inch depths, and will be installed to manufacture's specifications (sensor rods remain parallel when inserted in soil pit side walls or otherwise buried, soil disturbance minimized, no air pockets around sensor rods). Sensors placed in bioretention swales or cells will be in soils with high organic matter. Sensors are not factory calibrated for this type of soil and will need to be recalibrated using a tray calibration method (Bilski, 2004). Soil samples will be collected at sensor locations to assess grain size distribution and visual inspections will be conducted for soil stratigraphy, color/mottling, etc. The data collection interval is 1 hour.

Instrument	Individual Instrument Error
CS 616 Water Content Reflectometer	±2.5% volumetric water content
CR 10X data logger	±0.05% FSR (zero to 40°C)
Total non-random error	±2.55% FSR

2.2.4 Under-Drain (Station 4)

To determine a more accurate water budget for the project, subsurface flows are collected from an under-drain located at the base of a large rock wall that collects water from the western 1/3 of the property.

Water quantity at the under-drain will be determined by measuring water level in the trapezoidal flume. Flow rate will be determined by using the rating curve provided from the flume manufacturer. All instruments will be tested and calibrated by WSU and MeasureTek, Inc. previous to installation and at least once per year in subsequent years. The data collection intervals are 1 day, 1 hour and 15 minute.

Instrument	Individual Instrument Error
Plasti-Fab Small 60º Trapezoidal Flume	±5%
Druck PDCR 1830 1 psig Pressure Transducer (individually calibrated by NIST)	±0.06% FS BSL*, temperature effects ±0.6%FS
CR 510 data logger	±0.05% FSR (zero to 40°C)
Total non-random error	±5.71% FSR

* combined non-linearity, hysteresis and repeatability.

2.2.5 Catch-Basin (Station 5 and 6)

To better understand how under-drains influence the detention and retention of bioretention systems, surface and subsurface flows are measured in a set of bioretention swales along the northeast section of the subdivision road.

A Catch-basin (CB) at the end of the swales will be used to measure surface and sub-surface (under-drain) flow from the bioretention swales. A Thel-mar weir will be placed in the surface flow inlet to the CB to measure surface flow. A second Thel-mar weir will be placed in the CB outlet. Inflow will be subtracted from outflow to measure under-drain flow.

Instrument	Individual Instrument Error
(2) Thel-mar Weirs (12”)	±5%
(2) Druck PDCR 1830 1 psig Pressure Transducers (individually calibrated by NIST)	±0.06% FS BSL*, temperature effects ±0.6%FS
(2) CR 510 data loggers	±0.05% FSR (zero to 40°C)
Total non-random error	±5.71% FSR

* combined non-linearity, hysteresis and repeatability.

2.2.6 Dispersion Slope (Station 7)

A compost amended dispersion slope is the last IMP before stormwater leaves the property. Water entering the slope is measured at the POC (Station 2) and an under-drain (Station 4). Effectiveness of the dispersion slope will be assessed by determining flow inputs and outputs. Grab samples for turbidity will also be collected (see water quality section)

Water quantity at the bottom of the dispersion slope will be determined by measuring water level in the trapezoidal flume. Flow rate will be determined by using the rating curve provided from the flume manufacturer. All instruments will be tested and calibrated by WSU and MeasureTek, Inc. previous to installation and at least once per year in subsequent years. The data collection intervals are 1 day, 1 hour and 15 minute.

Instrument	Individual Instrument Error
Plasti-Fab Extra Large 60º Trapezoidal Flume	±5%
Druck PDCR 1830 1 psig Pressure Transducer (individually calibrated by NIST)	±0.06% FS BSL*, temperature effects ±0.6%FS
CR 10X data logger	±0.05% FSR (zero to 40 °C)
Total non-random error	±5.71% FSR

* combined non-linearity, hysteresis and repeatability.

2.2.7 Monitoring Wells

Wells will be located adjacent to the bioretention swale with water content sensors (Station 3) and at three locations (top, middle and bottom) on the dispersion slope. At each location wells will be in pairs with one shallow and one deep well. The shallow wells are located in the upper soil strata and the deep wells in lower soil strata to measure shallower and deeper groundwater. In general, upper soil strata were A, B, C horizons (generally ranging to six feet), and to a depth that exhibited structure that may convey water from above or horizontally relatively rapidly (i.e. days or weeks). Deeper strata were generally dense parent material that may be restricting layers or convey deeper groundwater slowly (deeper wells are approximately 25 feet).

Eleven monitoring wells measure groundwater levels in and adjacent to LID IMPs. Instrumentation Northwest (INW) self-logging pressure transducers are located in each well and are factory calibrated annually. Calibration will be checked once annually during the wet season using a Solonist capacitance water level meter. The data recording interval is 6 hours

Instrument	**Individual Instrument Error**
INW PT2X Pressure Sensor	±0.1 FSO (BFSL at 25 C), temperature error ±0.5% FSO max
Total non-random error	±6.00% FSR

Additional sources of error may be present that could diminish the overall accuracy for water level measurement. These errors include operator error and instrument error. An example of operator error would be if the field technician inadvertently programmed the equipment incorrectly. An example of instrument error would be if water flow conditions do not meet the manufacturer recommendations for the instrument (such as if sediment-laden water clogs the atmospheric ventilation tube on a pressure transducer). These sources or error are not systematic or predictable and therefore cannot be quantified before they occur.

2.2.8 Data Collection Procedures

All water quantity monitoring data will be collected weekly by WSU using a palm pilot. During site visits field personnel will record the following information in a field notebook:

- Name of site visit personnel, and date and time of site visit.
- Weather and flow conditions.
- Stations downloaded and field measurements (flume staff gauge readings).
- Log of any photographs taken.
- Comments on condition of monitoring equipment.
- Unusual conditions (e.g. debris in flume entrances) and any corrective measures.

Field notes will be copied and reviewed by the principal investigator. Any equipment repairs or adjustments will be addressed immediately. Staff gauge and pressure transducers readings will be compared weekly for error and trends in error. Data will be downloaded to Excel and reviewed weekly.

2.3 Water Quality: Experimental Design Measurement Accuracy

Water quality will be measured at one location, the project POC. Water samples will be collected during storm events using an Isco 3700 autosampler connected to a CSI CR10X data logger. Samples will be collected using the following criteria as a guideline for targeting storm events:

- ♦ Total storm precipitation of at least 0.2 inches.
- ♦ Precipitation intensity of at least 0.02 inches per hour for storm event duration.
- ♦ Minimum storm event duration of ten hours.
- ♦ Antecedent dry period of 12 hours with 0.04 inches or less of rain.
- ♦ End of storm conditions – at most 24 hours from the last aliquot of the first composite sample (due to sample holding time prior to analysis).

The above storm criteria guidelines were adapted from Ecology's guidance manual (Ecology 2004) for evaluating proprietary stormwater treatment technologies. The precipitation criteria for this project are higher (requires more precipitation) than Ecology's because of the widespread use of LID stormwater treatment at the project site. Infiltration is a key component of stormwater treatment by LID technologies therefore it is assumed that a greater amount and duration of rainfall are needed to produce distinct storm hydrographs than for single location non-infiltration based technologies, for which the Ecology guidelines were primarily written.

Water samples will be collected using a two-part sampler program that includes grab samples at the onset of the storm event (bottles one through four) and subsequent multiple flow-weighted composites (bottles five through 24) during the remainder of the storm event. This approach was chosen to allow analysis of selected organic compounds in the first flush of a storm event and then analysis of a suite of parameters for the remaining storm event (see Table 1). The composites will be combined into a single sample to provide an event mean concentration (EMC) for each water quality parameter per storm.

The autosampler will be set up with 24 350-ml glass bottles. The grab sample (first part of the sampling program) at the onset of a storm event will be collected in bottles one through four as three aliquots per bottle of approximately 110 ml each every two minutes. The grab sample will be analyzed for fecal coliform bacteria (fecals) and total petroleum hydrocarbons (TPH). The second part of the sampler program will begin after the first part is completed and will comprise filling bottles five through 24 sequentially for the remainder of the storm event. Each of the bottles will be filled with three aliquots each of approximately 110 ml providing up to 20 flow-weighted composite samples for each storm event. Sample water from the individual composite sample bottles will be combined at the laboratory into a single flow-weighted composite sample for analysis of all of the parameters listed in Table 1.

The data logger will control the autosampler by initiating the sampling program and pacing the sample collection. The autosampler will be programmed to collect an aliquot after receiving a pulse from the data logger.

Criteria for qualifying samples will follow Ecology's (2003) recommendation of at least 10 aliquots covering at least 75 percent of the storm hydrograph. If the storm event or qualifying sample criteria are not exactly met during storm events, professional judgment will be used after reviewing the storm hydrograph to determine whether or not samples are acceptable. For example, if the sample criteria were met but the storm event delivered only 0.18 inches of rain or if the antecedent period was only 10 hours, the samples may still provide useful information.

2.4 Procedures for Water Sample Collection

This section describes procedures to be followed for collecting water samples during storm events. Field procedures are emphasized here and are divided into three sections that correspond with three basic activities for water sample collection: pre-storm, mid-storm, and post-storm.

2.4.1 Pre-storm

Field activities for water sample collection prior to the onset of a storm event are referred to as pre-storm. Most of the pre-storm activities are to be done after a storm event has been identified from weather forecasts as likely to meet the storm event criteria (see Section 2.3). A few activities can be done further in advance.

The pre-storm setup comprises two major activities: 1) reading and interpreting weather forecasts; and 2) setup and programming of equipment. Weather forecasts themselves are usually a meteorologist's interpretation of weather data. For the purpose of deciding if a weather system(s) will produce the rainfall needed for a qualifying storm event, it is not necessary to refer to raw weather data. Rather, understanding a few basic meteorological concepts and the terms forecasters use can be helpful in interpreting the forecaster's certainty in predicting the behavior of a weather system and the duration, depth, and area of precipitation. brief description of which forecasts to use for this project and how to interpret them.

Once a storm event has been targeted for sample collection, the onsite water sampling equipment will be setup and programmed. Setup includes getting bottles cleaned, labeling bottles, placing bottles and a clean suction line in the autosampler, and running the autosampler through a series of functional and diagnostic checks. These setup steps can be done any time prior to beginning sample collection. Programming the equipment for sample collection is best done after a storm event has been identified for sample collection and includes programming the autosampler and datalogger with the specific conditions for beginning sample collection and pacing sample collection throughout the storm event.

For sample tracking and data storage purposes, individual sample bottles will be labeled and identified as follows: [sample type]–[bottle number]–[date of collection]. For this project, two sample types will be collected during storm events, a first flush grab and multiple storm event composites. An example label for a grab sample from January 1st, 2006 would be "Grab–1–010106" and an example label for composite sample bottle five would be "Comp–5–010106." The grab sample will always be bottles one through four and the composite samples will always be bottles five through 24.

Ideally, sample collection should begin when runoff begins flowing to the project POC where the autosampling station is located. For this project, the datalogger will control the autosampler, thus the conditions for beginning and pacing sample collection will be programmed into the datalogger. The starting condition for sample collection will be a rise in water level of a nominal amount over the baseflow level present just prior to the onset of a storm event. This “enable” level is typically represented by an increase in water level of 0.05 feet or more above baseflow. To fine-tune the enable level for this project, previous flow record will be examined to determine the variability in baseflow and how quickly water level at the POC responds to rainfall.

For pacing sample collection, a rainfall-to-runoff relationship needs to be established for the sampling location. A best-guess can be used the first time and as more data are collected, the relationship can be calculated and refined. The procedure for determining pacing rate is to divide the total number of aliquots by the expected runoff volume to provide a value of runoff volume per aliquot. Runoff volume should be expressed in liters, which are the units that flow is recorded in the data logger. For this project, a maximum of 63 aliquots are possible (21 composite bottles with three aliquots each). The rainfall-to-runoff relationship could vary substantially between storms and seasonally depending on the residual runoff stored in the ponds and in the soil at the onset of the targeted storm event.

2.4.2 Mid-storm

Field activities for water sample collection during a storm event are referred to as mid-storm. There are three main purposes of the mid-storm field activities: 1) check weather forecasts to see if forecasted conditions have changed significantly since the pre-storm forecast; 2) retrieve the grab sample bottle and bring it to the lab for analysis; and 3) check the sampling equipment for proper operation. Because the fecals have a 24-hour holding time, it is necessary to bring them to the lab for analysis within 24 hours of the sample collection time. The sample collection time for the grab sample will be the time the last aliquot was pumped into the grab sample bottle.

During the mid-storm field check, the sampling equipment will be checked for proper operation. This includes downloading and checking the water level (and flow) record to confirm sampling began at the proper enable level and that sample collection has proceeded correctly based on the programmed pacing rate. Also, the sample bottles will be visually checked for the proper sample volume and the water level reading will be checked for the correct reading. In addition, rainfall from the on-site rain gauge will be downloaded to see if the storm event rainfall has met the qualifying criteria. Other mid-storm activities are noted on the Mid-Storm Field Sheet in Appendix B.

2.4.3 Post-storm

Field activities for water sample collection after a storm event are referred to as post-storm. These activities include downloading and reviewing the flow record to check for the proper aliquot timing, checking the sample volumes, checking the equipment for proper operation, assessing if the samples and storm event rainfall meet the qualifying criteria, collection of the composite sample bottles, and delivering the composite samples to the lab.

2.5 Laboratory Analytical Methods

Storm event samples will be taken to Water Management Laboratories, Inc. in Tacoma, Washington for chemical analysis. Sixteen parameters or groups of parameters will be assessed in the chemical analysis of the storm water samples for the project. Table App A 2.1 shows the parameters that will be measured, the method to be used, sample volume needed for each parameter or group of parameters, and the recommended holding time between sample collection and analysis.

Glass bottles will be used for the collection of all water samples. Samples will be put into a cooler and on ice for transportation to the lab. The laboratory will composite samples rather than in the field. If required, additional preservation of samples will be done by laboratory personnel after sample drop-off. All samples will be accompanied by a chain-of-custody (COC) form for sample tracking purposes.

Table App A 2.1: Analytical Methods for Stormwater Parameters.

Sample Type	Parameter	Method	Reporting Limit	Vol (ml)	Holding Time
Grab	Total Petroleum Hydrocarbons	Ecology 97-602 (NWTPH-Dx)	0.25 mg/l	1000	14 days
Grab	Fecal Coliform bacteria	SM 9222 D	2.0 cfu/100 ml	250	24 hours
Composite	Ammonia Nitrogen	SM 4500 NH3F	0.04 mg/l	250	7 days
Composite	Chlorinated herbicides	EPA 515.1	0.1 µg/l	1000	24 hours
Composite	Hardness	SM 2340	1.0 mg/l	100	6 months
Composite	Kjeldahl Nitrogen	SM 4500 N Org	1.0 mg/l	250	28 days*
Composite	Metals, dissolved (Cd, Cr, Cu, Pb, Zn)	EPA 200.8	1.0 to 5.0 µg/l	100	6 months*
Composite	Metals, total (Cd, Cr, Cu, Pb, Zn)	EPA 200.8	1.0 to 5.0 µg/l	100	6 months*
Composite	Nitrate-Nitrite N (NO2+NO3)	EPA 300.0	0.2 mg/l	n/a 2	28 days*
Composite	Organophosphorus pesticides	EPA 525.2	0.1 to 1.0 µg/l	1000	24 hours
Composite	Polynuclear Aromatic Hydrocarbons	EPA 525.2	0.1 to 1.0 µg/l	1000	24 hours
Composite	Total Dissolved Solids	SM 2540	1.0 mg/l	n/a 1	2 days
Composite	Total Phosphorus	SM 4500 PD	0.05 mg/l	100	7 days
Composite	Total Suspended Solids	SM 2540	1.0 mg/l	250	2 days
Composite	Total Volatile Solids	SM 2540	1.0 mg/l	n/a 1	2 days
Composite	Turbidity	SM 2130	0.1 NTU	50	2 days

NOTES
* with filtration within 24 hours
1 Add-on to TSS analysis – no extra sample volume needed.
2 Volume taken from other nutrient samples.

2.6 Quality Control

Quality control (QC) for field water sampling and laboratory analyses of water samples will be achieved through several types of quality control samples (Table 4). Field quality control will be measured through the collection of autosampler duplicates and equipment rinsate blanks for approximately 10 percent of the total number of samples collected. Autosampler duplicates will be collected to test for consistency of the autosampler in aliquot collection. Autosampler duplicates will be collected by reprogramming the Isco sampler to pump two aliquots back-to-back into two bottles so that after an aliquot is pumped into one bottle another aliquot is immediately pumped into the next bottle. This will effectively provide two sets of bottles with nearly identical sample water. A change-out of bottles will need to occur during the mid-storm field check to extend the duplicate sampling to the same period a non-duplicate storm event would have lasted.

Equipment rinsate blanks will be collected to test for equipment contamination. Blanks will be collected by pumping deionized (DI) water through the suction line and autosampler into a clean glass bottle. This will be done at the end of a storm event during the post-storm field visit after the autosampler program has finished.

Several types of laboratory QC samples will be analyzed, including method blanks, method reporting limit (MRL) checks, laboratory duplicates, check samples, and matrix spikes. The purpose of each type of QC sample is described in Table 4. Lab QC samples will be analyzed at varying frequencies based on the laboratory's standard procedures.

Quality control results will be reviewed by the laboratory and field project managers. Corrective action will be taken if needed based on the sample quality control acceptance guidelines are outlined Table App A 2.2.

Table App A 2.2: Quality Control Samples.

Type of Control Sample	Description	Frequency	Criteria	Initial Corrective Action
Method blank	Reagent grade sample matrix analyzed to provide an indication of laboratory contamination	Every 10 samples	Less than half the MDL for each analytical method or less than 10 percent of the lowest sample reported.	Laboratory QA/QC manager will review laboratory procedures and determine if samples should be rerun
Method reporting limit check	Verify MRL by running calibration standard through analysis	Once per batch	Within 20 percent of calibration standard value	Laboratory QA/QC manager will review laboratory procedures and determine if samples should be rerun

Table App A 2.2 (continued): Quality Control Samples.

Type of Control Sample	Description	Frequency	Criteria	Initial Corrective Action
Matrix spike	An aliquot of sample to which known quantities of analytes are added, processed in exactly the same manner (to determine bias)	One per analytical batch, up to 10% of samples	Within 15 percent of true value	Laboratory QA/QC manager will review laboratory procedures and determine if samples should be rerun
Autosampler duplicate	Duplicate samples collected in the field with the autosampler	Ten percent of the total number of samples collected	Less than 20 percent difference for samples greater than five times the MDL	Project manager will review sample collection procedures.
Equipment rinsate blank	Reagent grade water that has been processed as a field sample, used as an indicator of sampling process contamination	Ten percent of the total number of samples collected	Less than two times the detection limit or less than 10 percent of the lowest result reported.	Project manager will review sample collection procedures.
Laboratory replicates (duplicates)	A second aliquot of sample processed in exactly the same manner (to determine precision)	Every 10 samples	RPD less than 20 percent for samples greater than five times the MDL. No RPD if results below detection limit	Laboratory QA/QC manager will review laboratory procedures and determine if samples should be rerun
Check samples (a.k.a. calibration blank)	Prepared independently from analytical standards and used to provide an indication of the accuracy of the analytical determination	Minimum of 10 percent of samples	Within 10 percent of expected value	Laboratory QA/QC manager will review laboratory procedures and determine if samples should be rerun

Abbreviations: MDL-method detection limit; RPD-relative percent difference; MRL-method reporting limit.

CHAPTER 3.0

DATA MANAGEMENT AND REVIEW

This section describes the management, review, and analysis of the stormwater data that will be collected from the project site. The data verification and validation procedures will evaluate if the project data quality objectives are met, and the data analysis procedures will be used to guide creation of a water budget.

3.1 Data Verification and Validation

Two types of surface water data will be measured during this project - water level and concentrations of water quality parameters. Data verification involves examination of the data for errors or omissions and for meeting the quality control acceptance criteria. Data validation involves the examination of the complete data package to determine whether the procedures in the monitoring plan were followed.

For verifying the data, periodic reviews will be done to check for errors. Water level data will be verified in the field by reviewing field notes for accuracy and completeness at the end of each field visit. Water level data that is downloaded from the data loggers will be verified at least monthly by reviewing water level hydrographs in relation to rainfall and other monitoring gauges at the project site.

Water quality data will be verified in the field by noting the completeness of sample collection for each water sampling event. Water quality data from the analytical laboratory will be verified after each transmittal of results from the laboratory. Results will be checked against the quality control objectives (see Table 4) and will include determining RPDs for duplicates and comparing blanks to the method detection limits.

For validating the data, water level and water quality data will be reviewed together after each water sample collection event. The overall level of the specific areas of data quality objectives will be surmised, including the precision, bias, representativeness, completeness, and comparability of the data. Typically in environmental data collection, not every data quality objective is met 100 percent, therefore professional judgment will be used to validate data as being acceptable or not.

3.2 Data Analysis

After the data have been verified and validated to meet the data quality objectives, it can be used for data analysis. For this project, the intended use of the water quantity data is to support the creation of a water budget to track water entering and leaving the project site, and the intended use of the water quality data is to determine the quality and quantity of the stormwater leaving the project site. This document presents the objectives and methods for only a select portion of the data required to construct a complete water budget. Therefore, the complete data analysis procedures for creating a water budget are not presented here. Rather some general guidelines are explained for how to prepare data that will eventually be used in the creation of a water budget.

All water level data collected for this project will be converted to volumetric flow. Because a water budget tracks the inputs and outputs of water to a bounded area, the flow data should be presented in the same units for all inputs and outputs. For this project, units that could be used are cubic feet, millions of gallons, or acre-feet.

Water quality data collected for the project will be reported as concentrations. Concentrations will represent either discrete samples (corresponding to bottles one through four) or event mean concentrations (EMCs, corresponding to bottles five through 24). These data will be compared to similar studies of stormwater treatment as well as to the Washington State water quality standards (where possible). EMCs will be expressed following treatment efficiency calculations recommended by Ecology (2004).

In addition, water quality results and storm event characteristics will be entered into an electronic database after each sampled storm event. Storm event data will be summarized and will include calculation of average storm event rainfall and comparison to climatological normal rainfall values. Water quality data will also be summarized and will include descriptive statistics, including mean, minimum, median, and maximum for each parameter, assuming a minimum of three storm events are sampled.

No further data analysis products are planned at the time of preparation of this document. However, additional data analysis products could include calculation of loading values to describe the mass of the parameter that was measured (for TSS, nutrients, and metals). Mass of water quality parameters are calculated as the product of concentration and flow volume. Loading values are expressed for storm events or whatever time period is of interest for which water quality data is collected.

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APPENDIX B

INSTRUMENT ACCURACY CHECKS FOR FLOW MONITORING

1.0 Calibration and Accuracy Checks

Calibration checks for all flow monitoring equipment were performed at the beginning of each wet season (October 1 to May 31). Accuracy checks, comparing staff gauge and data logger readings were recorded during each data download. The following provides the record of the calibration and periodic accuracy checks. No flow was observed in the Catch-basin (Stations 5 and 6) during data downloads; accordingly, no data logger, staff gauge accuracy checks were recorded.

Table App B 1-1: Point of Compliance Calibration Check.

Accuracy Check and Calibration: Station 2 POC
Equipment: extra large Plasti-Fab 60 degree flume and Druck PDCR 1830 1 psig pressure transducer (Serial Number: 2269244 see calibration certificate)
Date: 9-26-07
Personnel: Rob Hibbs, Curtis Hinman
Weather: sunny

Multiplier: incorrect multiplier recorded in program. Old multiplier = 0.924. New multiplier = 1.0235
Error: 0.1% FS BSL max. = 0.001 x 2.31 ft/psi = 0.00231 ft
Procedure: Plug both ends of flume with wood dams. Zero the transducer with stilling pipe filled just to the bottom of the flume.
Fill flume with water at 0.01 ft intervals up to 0.3 ft and then 0.5 ft to 0.8 ft. Record flume and data logger readings.
Level: width-yes, length-yes

Flume Depth	Data Logger Reading (ft)	Error (ft)	Error (%)
0	0	0	0
0.01	0.00034	0.010	0.966
0.02	0.00573	0.014	0.714
0.03	0.01347	0.017	0.551
0.04	0.02326	0.017	0.419
0.05	0.0374	0.013	0.252
0.06	0.04431	0.016	0.262
0.07	0.05729	0.013	0.182
0.08	0.0667	0.013	0.166
0.09	0.08488	0.005	0.057
0.1	0.09163	0.008	0.084
0.11	0.09903	0.011	0.100
0.12	0.10815	0.012	0.099
0.13	0.11891	0.011	0.085
0.14	0.1283	0.012	0.084
0.15	0.13875	0.011	0.075
0.16	0.15036	0.010	0.060
0.17	0.16096	0.009	0.053
0.18	0.17275	0.007	0.040
0.19	0.18115	0.009	0.047
0.2	0.19496	0.005	0.025
0.21	0.2017	0.008	0.040
0.22	0.2155	0.005	0.020
0.23	0.22661	0.003	0.015
0.24	0.23266	0.007	0.031
0.25	0.24379	0.006	0.025
0.26	0.25523	0.005	0.018
0.27	0.26634	0.004	0.014
0.28	0.27879	0.001	0.004
0.29	0.28384	0.006	0.021
0.3	0.29597	0.004	0.013
0.35	0.34549	0.005	0.013
0.4	0.39904	0.001	0.002
0.45	0.45228	-0.002	-0.005
0.5	0.50112	-0.001	-0.002
0.55	0.55266	-0.003	-0.005
0.6	0.6042	-0.004	-0.007
0.65	0.65708	-0.007	-0.011
0.7	0.70829	-0.008	-0.012
0.75	0.75679	-0.007	-0.009
0.8	0.81204	-0.012	-0.015

Table App B 1-2: Point of Compliance Accuracy Checks.

Date	Datalogger (ft)	Staff Gauge (ft)	Error (ft)
10/15/2007	0.047	0.050	0.003
11/2/2007	0.031	0.035	0.004
11/13/2007	0.056	0.058	0.002
11/20/2007	0.084	0.085	0.001
11/26/2007	0.041	0.041	0.000
11/30/2007	0.062	0.060	-0.002
12/2/2007	0.408	0.400	-0.008
12/3/2007	0.605	0.595	-0.010
12/4/2007	0.230	0.230	0.000
12/17/2007	0.051	0.055	0.004
12/28/2007	0.121	0.130	0.009
1/13/2008	0.053	0.070	0.017
1/23/2008	0.040	0.036	-0.004
2/1/2008	0.083	0.085	0.002
2/13/2008	0.052	0.055	0.003
2/28/2008	0.034	0.035	0.001
3/19/2008	0.064	0.065	0.001
4/2/2008	0.043	0.045	0.002
4/17/2008	0.034	0.035	0.001
5/9/2008	0.014	0.025	0.011
5/30/2008	0.051	0.065	0.014
7/7/2008	0.071	0.075	0.005

1psig Druck 1830 pressure tranducer (1 psig = 2.31 ft)
Error: 0.1% FS BSL max. = 0.001 x 2.31 ft/psi = 0.00231 ft

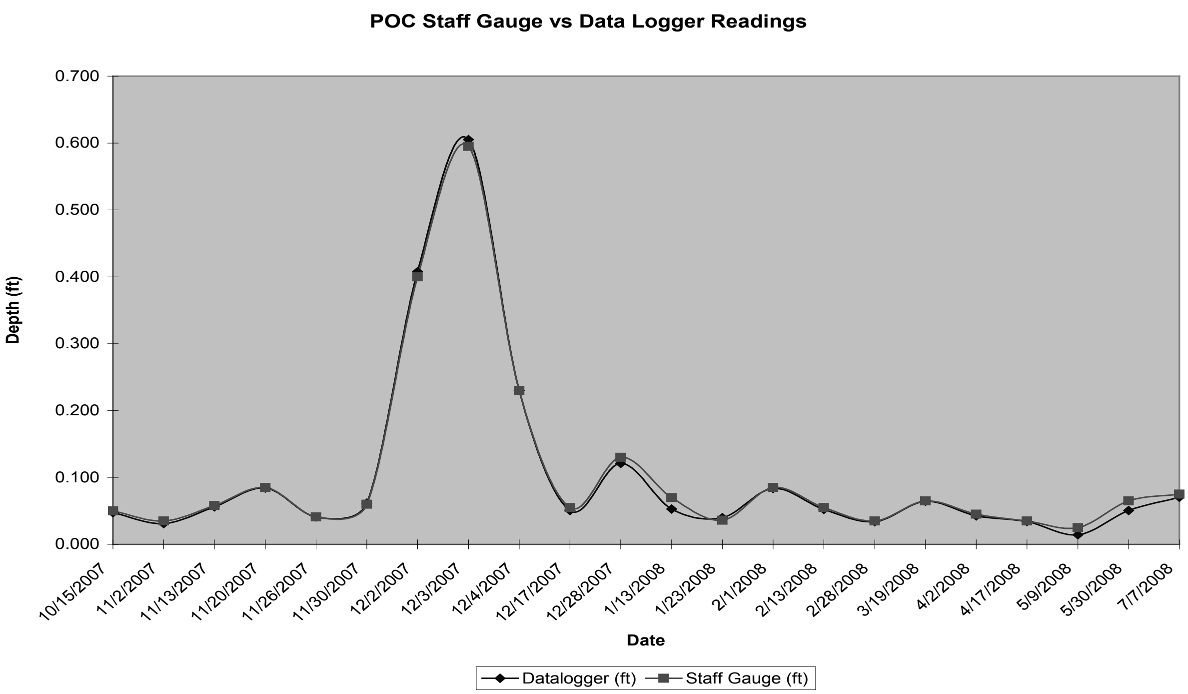

Figure App B 1-1: Point of Compliance Accuracy Checks Chart.

Table App B 1-3: Catch-Basin Calibration Check.

Equipment: 12 inch Thelmar weir and Druck PDCR 1830 1 psig pressure transducer (Serial Number: 2251963 see calibration certificate)
Date: 10-25-06
Personnel: Rob Hibbs, Curtis Hinman
Weather: sunny

Multiplier: unknown
Sensor error: 0.1% FS BSL max. = 0.001 x 2.31 ft/psi = 0.00231 ft
Procedure: Run garden hose in corrugated culvert and record weir and data logger levels as water rises.
Level: yes

Weir Plate (ft)	Datalogger Reading (ft)	Error (ft)	Error (%)
0	0.002	-0.0020	-0.0009
0.016	0.01246	0.0035	0.0015
0.023	0.02112	0.0019	0.0008
0.03	0.02531	0.0047	0.0020
0.036	0.03626	-0.0003	-0.0001
0.043	0.03895	0.0041	0.0018
0.049	0.047	0.0020	0.0009
0.056	0.05436	0.0016	0.0007
0.062	0.06211	-0.0001	0.0000

No flow was observed in the Catch-basin (Stations 5 and 6); accordingly, no data logger, staff gauge accuracy checks were recorded.

Table App B 4-1: Dispersion Slope Calibration Check.

Equipment: extra large Plasti-Fab 60 degree flume and Druck PDCR 1830 1 psig pressure transducer (no calibration certificate)
Date: 9-26-07
Personnel: Rob Hibbs, Curtis Hinman
Weather: sunny

Multiplier: unknown
Error: 0.1% FS BSL max. = 0.001 x 2.31 ft/psi = 0.00231 ft
Procedure: Plug both ends of flume with wood dams. Zero the transducer with stilling pipe filled just to the bottom of the flume.
Fill flume with water at 0.01 ft intervals up to 0.3 ft and then 0.5 ft to 0.8 ft. Record flume and data logger readings.
Level: width-yes, length-no

Flume Depth	Data Logger Reading	Error (ft)	Error (%)
0	0	0.000	0.000
0.01	0.0036	0.006	0.640
0.02	0.0074	0.013	0.630
0.03	0.0172	0.013	0.427
0.04	0.02883	0.011	0.279
0.05	0.03557	0.014	0.289
0.06	0.04935	0.011	0.178
0.07	0.05671	0.013	0.190
0.08	0.06311	0.017	0.211
0.09	0.07352	0.016	0.183
0.1	0.07965	0.020	0.204
0.11	0.0934	0.017	0.151
0.12	0.10319	0.017	0.140
0.13	0.10901	0.021	0.161
0.14	0.11942	0.021	0.147
0.15	0.13133	0.019	0.124
0.16	0.14143	0.019	0.116
0.17	0.15062	0.019	0.114
0.18	0.1601	0.020	0.111
0.19	0.16867	0.021	0.112
0.2	0.17663	0.023	0.117
0.21	0.18606	0.024	0.114
0.22	0.19984	0.020	0.092
0.23	0.20443	0.026	0.111
0.24	0.21424	0.026	0.107
0.25	0.22404	0.026	0.104
0.26	0.22925	0.031	0.118
0.27	0.24261	0.027	0.101
0.28	0.24934	0.031	0.110
0.29	0.25653	0.033	0.115
0.3	0.27013	0.030	0.100
0.35	0.31391	0.036	0.103
0.4	0.36101	0.039	0.097
0.45	0.40448	0.046	0.101
0.5	0.45381	0.046	0.092
0.55	0.49575	0.054	0.099
0.6	0.54328	0.057	0.095
0.65	0.59135	0.059	0.090
0.7	0.63353	0.066	0.095
0.75	0.6816	0.068	0.091
0.8	0.73136	0.069	0.086

Table App B 4-2: Dispersion Slope Accuracy Checks.

Date	Datalogger (ft)	Staff Gauge (ft)	Error (ft)
10/15/2007	0.007	0.000	-0.007
11/2/2007	0.009	0.000	-0.009
11/13/2007	0.005	0.000	-0.005
12/2/2007	0.207	0.225	0.018
12/4/2007	0.101	0.110	0.009
12/17/2007	0.006	0.000	-0.006
12/28/2007	0.024	0.030	0.006
1/13/2008	0.001	0.000	-0.001
1/23/2008	0.000	0.000	0.000
2/1/2008	0.004	0.000	-0.004
2/13/2008	0.000	0.000	0.000
2/28/2008	0.002	0.000	-0.002
3/19/2008	0.002	0.000	-0.002
4/2/2008	0.000	0.000	0.000
4/17/2008	0.000	0.000	0.000
5/9/2008	0.000	0.000	0.000
5/30/2008	0.000	0.000	0.000
7/7/2008	0.000	0.000	0.000

1psig Druck 1830 pressure tranducer (1 psig = 2.31 ft)
Error: 0.1% FS BSL max. = 0.001 x 2.31 ft/psi = 0.00231 ft

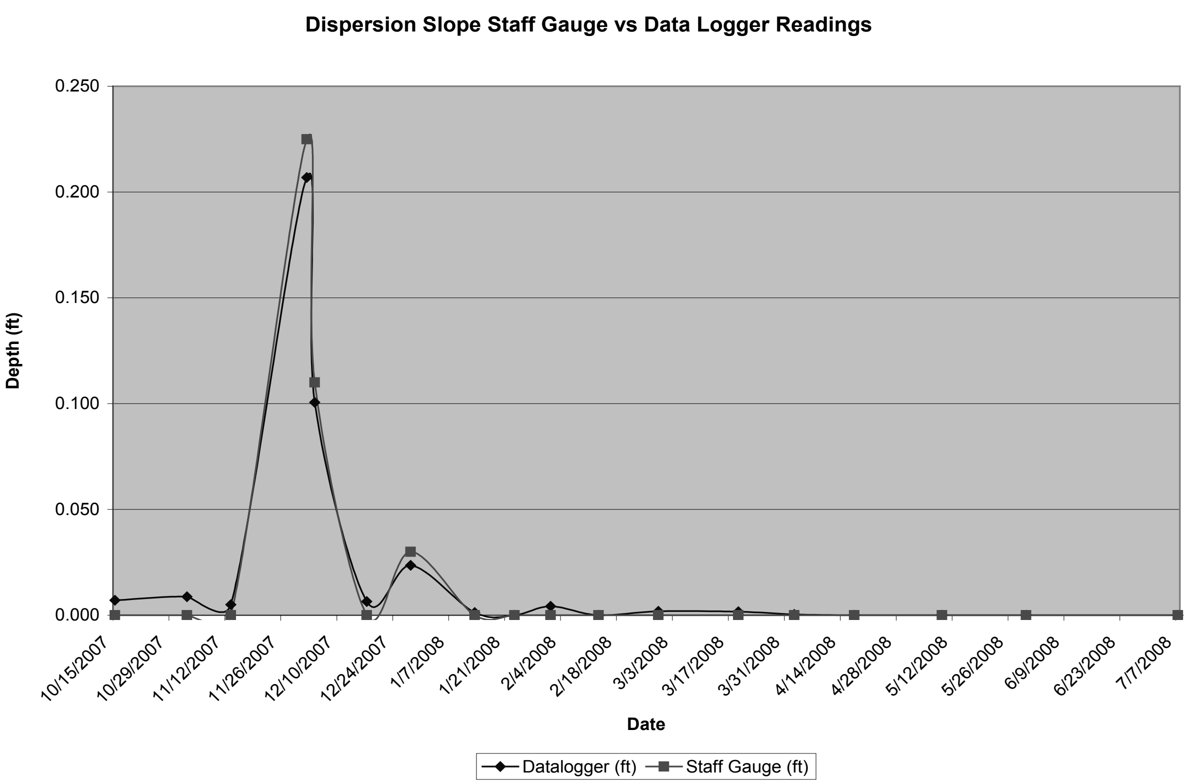

Figure App B 4-3: Dispersion Slope Accuracy Check Chart.

APPENDIX C

SOILS INVESTIGATION FOR THE MEADOW ON THE HYLEBOS

1.0 Introduction

An onsite soils investigation was performed on January 15, 2003, by Charles Herrmann (soil scientist) and Lisa Palazzi (ARCPACS certified soil scientist). The intent of the work was to identify and characterize on-site soil conditions and how they would affect onsite hydrology and stormwater facility design. The purpose of this document is to report the results of those investigations.

2.0 Methods and Materials

2.1 Office and Field Research

The Pierce County Soil Survey was consulted to determine how local soils are mapped. A soils report prepared by GeoEngineers was also reviewed. On January 15th, 11 soil pits were excavated with a backhoe to as much as 11 feet depth (see site map, Appendix IV). Soil profiles were evaluated in each pit with special emphasis on soil texture and structure in each horizon. Soil pits were also evaluated for any sign of a long-term or seasonal water table. Information obtained from the soil profile description was also used to predict potential soil percolation or infiltration rates.

3.0 Results and Discussion

3.1 Site Description

The study site (8.27 acres) is located at 6825 Pacific Hwy. East (Old Highway 99) in Pierce County, Washington (See vicinity map, Appendix IV). The central and southern majority of the site is open pasture, but there is an existing single-family house and three outbuildings in the south-central portion of the site. The northwestern and northeastern portions of the site are forested with a mixed-age stand of deciduous and coniferous trees with a thick Himalayan blackberry understory. Hylebos Creek – a locally important salmon-bearing stream – runs across the southern end of the site.

It is proposed to develop the site using Low Impact Design technologies for 35 single family home site lots. The preliminary site layout map provided by the client indicates the eastern and southern portions of the site as potential locations for stormwater facilities.

According to the topography provided by the client (provided in Appendix IV), overall site relief is about 90 feet. On-site elevation ranges from a low of about 10 feet along Hylebos Creek (in the far southern portion of the site to a high of slightly greater than 100 feet in the northwestern property corner. Most of the area proposed for home sites lies between about 34 and 88 feet elevation. The site lies near the southern end of a large regional north to south trending ridgeline that forms the eastern edge of broad floodplain flats to the west. Hylebos Creek drains along the ridgeline toe slope, so is assumed to recharge at least partially from collection of side slope drainage. The bulge of the end of ridgeline slope almost bisects the site, just west of center. Surface drainage runs west, south and east off its sides. The southern and western slopes of the ridge drain to Hylebos Creek; the eastern slopes drain into and through a small wetland depression in the northeast portion of the site, then down a steep side slope toward Old Highway 99 near the eastern site corner. We understand that additional, offsite drainage is collected from a subdivision to the north then diverted onto the site from 12th Street East on its northern end; this surface flow also contributes to drainage volumes through the depressional wetland system and down the slope toward Old Highway 99. We assume that the drainage from the wetland area also eventually drains to Hylebos Creek.

3.2 Mapped Soils Description

According to the Pierce County Soil Survey, the following soil series are mapped on or near the site:

1) The Alderwood gravelly sandy loam, 2-8%, 8-15% and 15-30% slopes (classified as a loamy-skeletal, mixed, mesic Dystric Entic Durochrept[1]): The Alderwood soils are formed in ablation till overlying basal till. A weakly to strongly cemented hardpan is usually found at 20 to 40 inches depth, and will cause seasonally perched water tables to develop above that surface. These soils are mapped along the top of the large north to south trending ridgeline, which ends at the study site and parallels the Hylebos Creek system.

2) The Kitsap silt loam, 8-15% slopes (classified as Aquic Xerochrepts[2]): The Kitsap silt loams are formed in fine textured layers of silt and clay glacial lake sediments on remnant terraces along the Puget Sound. They are expected to develop a seasonal perched water table at 18-30 inches depth during winter months. The Kitsap soils are mapped across the entire site.

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[1] Loamy-skeletal, mixed, mesic Dystric Entic Durochrept, generally meaning the soil has minimal horizon development (ept and entic), has a pale-colored, low base saturation surface horizon (ochr), has an silicate-cemented subsurface layer (dur), has a low sub-surface base saturation, generally indicative of poor nutrient status (dystric), has a mesic temperature regime (mean annual temperature ranges from 8-15^{o}C (47-59^{o}F), has no specific mineralogic source (mixed), texture of the fine fraction is loam and coarse fragment content is greater than 35% (loamy-skeletal).

[2] Aquic Xerochrepts, generally meaning the soil has minimal horizon development (ept), has a pale-colored, low base saturation surface horizon (ochr), has developed under climatic conditions of wet winters and dry summers (xer), and has a seasonal high water table within 100 cm. of the soil surface (aquic), has a mesic temperature regime (mean annual temperature ranges from 8-15^{o}C (47-59^{o}F)

3) Dystric Xerochrepts 60-90% slopes[3]: This is a generalized map unit used to indicate very steep slopes on terrace or marine bluffs. Generally, there are 26 to 60 inches of very gravelly sandy loams underlain by compact glacial till. They are mapped along the western sideslope of the large regional ridgeline terrace described above.

Standard characteristics of the mapped soil series are described in Section 6.0. Please note that the SCS soil series maps and descriptions characterize expected characteristics in only the top 60 inches of soil. Furthermore, the map units can have extensive inclusions of other soil types, and in some rare cases, can be entirely in error. Please refer to the individual pit descriptions in Appendix I and to the discussion in the text below for specifics on observed site soil conditions.

3.3 Onsite Soil Descriptions

Eleven soil pits were excavated onsite. Pits 10, 9, 1 and 2 were located from southwest to the northeast along a transect crossing the lower elevation areas onsite with approximate surface elevations of 38, 40, 41 and 48 feet, respectively. Pits 8, 6, 4 and 5 were located along a second more or less parallel transect crossing at about mid-site with approximate surface elevations of 68, 68, 58, and 62 feet, respectively. Pit 7 was located in the in the northwestern portion of the property in the highest elevation area with ~ surface elevation of 90 feet. Pit 3 was located on a small isolated ridge top in the northeastern corner at about 62 feet elevation. Pit 11 was the only pit located on the west side of the western-midsite ridge at about 64 feet elevation. The intent of this layout was to characterize the site soils overall, but also to assess affect of landscape position and slope on drainage potential and related characteristics.

In relation to previous soil pit investigations carried out by GeoEngineers (GE), PRSW Pit 10 was about 30 feet upslope of the GE Pit 1 (which was located on the small terrace beside Hylebos Creek at the lowest elevation point onsite) and about the same distance downslope of GE Pit 3 (which was located directly southwest of the onsite house on the sideslope above the creek). PRSW Pit 1 was in the same vicinity as the GE Pit 2 – the small bench in the southeast portion of the site targeted for a stormwater detention facility. PRSW Pit 5 was about 15 feet upslope from GE Pit 4 in the far northern corner near where offsite water enters the site to drain to the small depressional wetland. And PRSW Pit 3 was sited on the same ridge as GE Pit 5 – a small remnant ridge top that occurs in the northeastern corner of the site, east of the depressional wetland. We will discuss the cumulative results of GE and PRSW investigations in the discussion below.

A preliminary site layout map provided by the client indicates a small bench in the southeast portion of the site as a potential location for a stormwater detention pond. That area will collect the majority of onsite surface drainage that accumulates after running through

[3] Dystric Xerochrept, generally meaning the soil has limited horizon development (ept), has a pale-colored, low base saturation surface horizon (ochr), has developed under climate conditions of wet winters and droughty summers (xer), and has a low base saturation subsurface soil, generally indicating a poor nutrient status (dystric), has a mesic temperature regime (mean annual temperature ranges from 8-15°C (47-59°F).

various rain gardens and other small, disperse stormwater management facilities designed to encourage infiltration. Once it reaches the retention pond, the overflow is sent down a swale that runs to the southwest across the top of the slope paralleling Old Highway 99 to what we assume is some sort of dispersion trench or device that meters the flow into the Hylebos Creek buffer area.

Of the areas that were investigated by both GE and PRSW, soil descriptions are reasonably similar, but with some important differences. GE describes Vashon glacial till for the entire soil profile in GE Pit 1 and Pit 3. PRSW found glacial till at about 70 inches depth in the base of PRSW Pit 10. But the soils above the till were non-gravelly silt loam (glacial lake sediment) from the surface to about 3.5 feet overlying layers of loamy coarse sand to 70 inches. These sediments appeared to be post glacial flood deposits. This suggests that glacial lake sediments were laid down on the surface after the glacier began to recede. The silty portion of the profile was distinctly mottled directly over the loamy sands – indicating that water perches at that interface as a result of textural differences. Water was seeping from above the till surface, verifying the assumption that seasonal groundwater will collect and flow downslope across the till surface. Typically, soils that form over glacial till are not weathered till to the surface unless the surface was removed at some time in the past – either by geologic forces or by humans. Usually the glacial till has a cap of either post-glacial flood deposits, or of melted deposits of gravel, sands and silts that were previously suspended within the ice above the till.

GE describes weathered glacial till for the entire profile of GE Pit 5. PRSW observed a very gravelly sandy loam surface in PRSW Pit 3 that more resembled a meltwater deposit to about 28 inches depth. Directly below that, there was a transitional horizon that was more or less a mixture of weathered till and meltwater deposit. That layer was weakly cemented, distinctly mottled and effectively impermeable to vertical water movement. However, layers would allow some horizontal flow, and indeed, the soils were seeping at 67 inches on the day of the field visit. We would expect some water to perch seasonally as shallow as 28 inches depth. From 72 inches down, the substrate was strongly cemented, impermeable glacial till.

GE describes a Vashon recessional outwash sand deposit in GE Pit 4. PRSW sited their Pit 5 just upslope from the GE pit and found a non gravelly silt loam to 72 inches. It non-gravelly condition suggests a still-water deposit – i.e., a lake environment. That agrees with the surface conditions observed at PRSW Pit 10. The surface silt loam deposit is underlain by a very gravelly (40% coarse fragments) sandy loam to the pit base at 93 inches. This deposit is more like an outwash deposit, although is not well-sorted. The deeper sandy deposit observed in the PRSW pit may be what was observed at the surface in the slightly downslope GE Pit 4. The silt loams above were distinctly and prominently mottled from 26 inches down. No seeping was observed at any depth in the PRSW pit, but the wetlands no more than 30 feet away (slightly downslope) are saturated to the surface.

GE Pit 2 was described as having fill from the surface to 3 feet depth. The underlying native soil layers were described as being weathered till and glacial till to 10 feet depth. The PRSW Pit 1 had three different episodes of surface fill; the top layer is a sandy loam cap about 6 inches thick. Directly below to about 4 feet depth, the fill was a mixture of organic and metal garbage with what appeared to be parts of car doors. The bottom fill layer was similar “garbage” mixed with what was probably native silt loam – severely mottled and wet to about 83 inches.

Below that, the native subsoils were layers of sand and silt loams to 112 inches. These deposits appeared to be post-glacial meltwater flood deposits, and are effectively impermeable to vertical flow. However, seasonal horizontal flow along the more coarse-textured layers is expected. No seeping was observed during the investigation, but the soils were quite wet. Any extra water will result in some flow. The potential for deeper soil contamination from seeping through the garbage is high.

The rest of the PRSW pits were sited in areas without any GE pits. Pits 2, 4, 5, 6, 7 and 8 were all located in the midsite area above the existing house where the predominance of the homesite lots are proposed. They were all quite similar in terms of soil texture and expected function. All were at least partially fine-textured glacial lakebed sediments; some were underlain by post-glacial meltwater deposits that we assume overlies till at some depth. Details are provided below.

PRSW Pit 2 was located on the bench above the area proposed for a stormwater detention facility, within a few feet of a small swale that drains the upslope depressional wetland. There was no water flow in the swale on the day of the site visit. But the grasses in the swale were laying down in a manner that indicated recent, significant surface flow volumes. **This indicates that there is already a significant amount of onsite surface "through-flow" that must be accounted for when modeling site hydrology for stormwater facility storage volume design.** The upper portion of the soil profile was non-gravelly, but moderately well-structured silt loam from the surface to about 42 inches depth. However, the silt loams were faintly to distinctly mottled from 10 inches down, indicating that groundwater may fluctuate significantly in this area during periods of extended rainfall. The silt loam layer from 42-60 inches was massive, severely mottled, and effectively impermeable to vertical water movement. From 60 to 120 inches, the substrate was a very gravelly sandy loam with no mottles, so may possibly be well-drained in the winter. The soil profile was seeping at 10 inches and at 42 inches.

PRSW Pit 4 was located about 8-10 feet upslope from pit 2, on the same side of the wetland drainage swale, and only few feet upslope from the depressional wetland area. The entire profile was non-gravelly silt loam. The surface 27 inches of soil had some structure, but was distinctly mottled and gleyed below 12 inches. The silt loam lakebed substrate below 27 inches was massive, impermeable and increasingly clayey with depth. No seeping was observed, but the soils were quite wet and sticky. *The backhoe bucket was almost impossible to clear between samples, as occurred across the entire sideslope.*

PRSW Pit 6 was located about 150 feet southwest of Pit 5 – slightly upslope but still about midslope overall. PRSW Pit 7 was located west-northwest and upslope from Pit 6, in the highest elevation portion of the site. These two pits were almost identical. The entire profile was non-gravelly silt loam – glacial lakebed sediment. These soils were distinctly mottled and gleyed below about 2 feet, indicating seasonal saturation from a perched water table at that depth. The silt loams below about three feet were massive and impermeable to vertical water movement. The soils were very sticky and difficult to work.

PRSW Pit 8 was located almost directly south of Pit 6, but along the same midslope elevation setting. Similar to other pits, most of the upper profile was glacial lakebed sediments – non-gravelly mottled silt loams to 55 inches. The substrates from 55 to 100 inches were gravelly loamy fine sand meltwater deposits. The entire profile was mottled and gleyed below 22 inches depth – indicating seasonal saturation, probably from perched water tables that are expected to develop by mid to late winter in most years.

Pits 9 and 10 were located in what is now a llama pasture area east and south of the house. Pit 10 was described earlier in the section comparing results of PRSW and GE soils investigations. The basic pattern observed in Pit 10 follows in Pit 9. Pit 9 was sited east southeast of the house at the bottom of the slope near an installed groundwater piezometer in order to assess soil conditions in relation to piezometer results. Similar to patterns observed in other pits, the upper 39 inches of the soil profile was silt loam. From 39 to 51 inches depth, the subsoils were very gravelly loamy coarse sand– a post-glacial meltwater deposit. Below 51 inches, the substrate was cemented glacial till. The soils were seeping below 51 inches on the day of the field visit. But soil colors in the upper silt loam portions of the profile indicate that a seasonal water table develops below 23 inches, possibly as a result of perching over the coarse-textured sub-soils.

Pit 11 was the only pit sited on the western sideslope due to that geographic setting being a relatively small portion of the whole site. The surface soils in that area were relatively permeable, non-gravelly sandy loams to about 58 inches overlying interbedded massive layers of sandy loam and silt loam to 114 inches depth. These soils were only faintly mottled from 10 inches down, but the layered soils below 58 inches are expected to be effectively impermeable to vertical water movement, so will perch seasonal groundwater.

4.0 Conclusion

In summary, the great majority of the site does have a silt loam glacial lake bed sediment cap, as indicated originally by the Pierce County soil survey that described the onsite soils as Kitsap silt loams. Furthermore, most of the silt loams are underlain by a relatively thin layer of coarse-textured glacial meltwater deposits – some of which are well drained and some not. Underlying everything at depths ranging from as shallow as 3 feet to greater than 10 feet is a cemented glacial till, as indicated by the Pierce County Soil survey mapping of Alderwood soils on the ridgeline and sideslopes to the north of the site.

The silt loam portions of the soil profiles have minimal potential for effective infiltration. Even in an undisturbed condition, they show current evidence of poor drainage and seasonal perched water tables within a foot or two of the soil surface across the most of the site. Once they are disturbed, whatever fragile structure they have now will be destroyed by mixing, surface traffic and compaction. In most of the upper midslope areas, the lakebed sediments are quite deep – more than 10 feet – making potential for effective post-construction infiltration minimal. In several pits, seeping from the pit sidewalls was observed, both in the silts and in the more gravelly layers below. By late winter in most years, we expect most of the onsite surface soils to be relatively saturated to within a couple of feet of the soil surface. The deeper soil drainage conditions will be a result of groundwater movement from upslope, offsite since almost no water is expected to drain from the upper silt loam soils into the gravelly soils below.

It should be noted that the silt loam soils were almost impossible to work with the backhoe on the day of our field visit. They were wet enough to be very sticky. The filled bucket was almost impossible to clear. We had to dig it out with a shovel, and even then were unable to clear more than about half the volume. Working these soils when wet will be very costly and a waste of heavy equipment time.

Aside from Hylebos Creek, onsite surface water movement is only apparent through the depressional wetland and its upslope and downslope drains. But that flow is significant during storms. It was our impression that most of the water source for the depressional wetland was surface drainage from offsite sources. However, the eastern majority of the site has potential to contribute hydrology either from surface flow or from subsurface groundwater flow.

Groundwater movement is mostly lateral, either draining sideways through the somewhat structured upper portions of the silt loam layers, or draining laterally across the surface of the glacial tills in the deeper portions of the soil profile. In general, perched water tables that develop within 2 feet of the surface in the silt loam layers are expected to follow surface topography drainage patterns and direction. But the deeper groundwater movement is controlled by topography and slope direction of the deeper sediment deposits and the glacial till surface.

The depth to till varies greatly with depths as shallow as about 3 feet to depths greater than 10 feet. This suggests that the till surface was reworked and severely bisected prior to development of the glacial lake environment that created the current silt loam surface sediments. Therefore, deeper groundwater flow directions could be quite variable, resulting in significantly concentrated flow in some areas and almost none in others. But we do expect till at some depth below the soils across the entire site, so still should assume lateral groundwater flow rather than vertical.

Seeps on the steep sideslopes along Old Highway 99 to the southeast are expected wherever the till surface is exposed by the roadcut. The same will occur by any onsite grading which results in deep cuts into the layered, gravelly sandy post-glacial meltwater deposits that were observed overlying the glacial till in several pits. For those reasons, we recommend minimization of deep cuts. If deep cuts are unavoidable, plans should be included to capture and divert any seasonal groundwater seeps that may develop and collect at the cutwall base during winter months.

The area currently proposed as a stormwater detention area in the southeast portion of the site is an old dump. Several feet of garbage and fill must be removed before the area can be used. If the downslope sidewall is compromised during the removal process, great care must be taken to reinforce it to avoid failure and downslope impacts. The native surface soils in that area are so disturbed that we are unable to provide much information. But if the pattern follows what was observed on the majority of the site upslope, the surface soils will be silt loams, and may need special engineering solutions even under the best of conditions. In any case, if infiltration is desired in this area, it is recommended to first test the soils in the infiltration facility base to ensure that there are no residual undesirable contaminants that might move with infiltrating stormwater.

We assume that due to having mostly fine textured soils with high seasonal groundwater tables across the site will force design toward a stormwater system that is predominantly surface storage, surface treatment and surface release. If any of the native soil's infiltration capabilities are to be utilized, soils disturbance and surface traffic in the areas intended for surface infiltration must be **entirely avoided**. Even so, both infiltration and lateral transmission rates will be slow. In most areas, only the top 2-2.5 feet of the silt loam soils had any structure at all. But the structure in these relatively young and undeveloped silt loam soil profiles is not strong and will collapse with any significant surface weight – particularly when wet. If careful management of the soil surface in those areas is not possible, then they should be assumed to be relatively impermeable for purposes of modeling.

I hope this report provides enough information to proceed with project planning. Please call if you have any questions or require additional detail or clarification on any of these issues.

Thank You,

Pacific Rim Soil & Water, Inc.

Lisa Palazzi	Charles Herrmann
ARCPACS certified soil scientist	soil scientist
Certification #3313	

5.0 Pit Log

5.1 Pit 1

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
Fill 1	0-6	2.5Y5/3	5	SL	WMG	0.06-0.2	–	–	FF	3	<10
Fill 2	6-48	car and organic waste									
Fill 3	48-83	2.5Y5/3	0	SiL	Massive	0.06-0.2	–	CMD	–	–	–
C	83-112	2.5Y4/2	0	LMS/SiL	SG/Mass	0.06-0.2	–	CMD	–	<3	10

Fill or disturbed to 83 inches. Fill 1 is a surface cap, and Fill 3 is a mixed layer of native soils and garbage. Soils below 83 inches appear to be what would have originally be a C horizon, suggesting that this was first an excavated hole that was then filled with garbage. Distinct mottling below 48 inches in both fill and native soils could be either a result of seasonal water, or effects of seepage through garbage – so is not conclusive evidence of hydrology conditions.

5.2 Pit 2

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-10	10YR2/1	<15	SiL	MFG	0.6-2	–	–	MF	5	15
B1	10-20	10YR5/2	<15	SiL	MMSAB	0.2-0.6	–	CMF	CF	4	15
B2	20-42	2.5Y5/2	<15	SiL	MFSAB	0.06-0.2	–	MMD	FF	<3	15
C1	42-60	2.5Y5/2	40	VGrSiL	Massive	0.06-0.2	–	MMD	–	<3	15
C2	60-120	2.5Y5/2	40	VGrSL	SG	0.6-2	–	–	–	<3	15

Kitsap variant. Has the silt loam lakebed surface sediments, but underlain by gravelly flood deposits. Evidence of seasonal saturation to 20 inches. Seeping in the B1 and in the C1. C2 is a mix of layers of sandy loam, loamy medium sand and silt loam – sandy loam average.

5.3 Pit 3

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-7	10YR2/2	50	VGrSL	WMG	0.6-2	–	–	MF,CM	5	12
B	7-28	2.5Y4/4	50	VGrSL	MMSAB	2-6	–	CMF	CF,FC,FM	4	15
C1cw	28-67	2.5Y4/4	50	VGrSL	Massive	0.6-2	–	CCD	FF,FM	<3	15
C2	67-72	2.5Y4/4	50	VGrSL	Massive	0.2-0.6	–	CCD	–	<3	15
C3cs	72-96	2.5Y4/4	50	VGrSL	Massive	0.06-0.2	–	–	–	<3	15

Alderwood series. Very gravelly sandy loam surface overlying glacial till at 72 inches. Seeping in C2 above till. Evidence of seasonal perched water table in the weakly cemented C1 (at 28 inches).

5.4 Pit 4

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-12	10YR2/1	0	SiL	WMG	0.6-2	–	–	CF	5	15
B	12-27	10YR5/2	0	SiL	MMSAB	0.2-0.6	–	CFD	FF	4	15
C1	27-64	2.5Y5/3	5	SiL	Mass	0.06-0.2	–	CFD	–	<3	20
C2	64-96	2.5Y5/3	5	SiL	Mass	0.06-0.2	–	CFD	–	<3	25

Kitsap variant. The Kitsap is expected to have a seasonal water table at between 18 and 30 inches, but this pit indicates a seasonal water table at 12 inches. The entire profile is glacial lakebed sediments.

5.5 Pit 5

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-11	10YR3/3	5	SiL	MMG	2-6	–	–	CF	5	15
B1	11-26	10YR5/3	0	SiL	MMSAB	0.6-2	–	FMF	FF	<3	15
B2	26-34	2.5Y6/2	0	SiL	MMSAB	0.06-0.2	–	CMD	FF	<3	15
C1	34-72	2.5Y6/2	0	SiL	Massive	0.06-0.2	–	MCD	–	<3	15
C2	72-93	2.5Y5/2	40	VGrSL	SG	2-6	–	–	–	<3	<10

Kitsap variant. Moderately structured silt loam to 34 inches. Massive silt loam to 72 inches. Coarse textured melt water deposits below to 93 inches. Evidence of seasonal saturation to 26 inches.

5.6 Pit 6 and 7

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-10	10YR3/3	5	SiL	MMG	2-6	–	–	CF	5	15
B1	10-26	2.5Y5/3	0	SiL	MMSAB	0.06-0.2	–	FMF	FF	<3	15
B2	26-32	2.5Y6/2	0	SiL	MMSAB	0.06-0.2	–	CMD	FF	<3	15
C	36-132	2.5Y6/2	0	SiL	Massive	0.06-0.2	–	MCD	–	<3	15

Kitsap series. Pits almost identical. Entire profile to 11 feet is glacial lakebed silt loam sediments. Evidence of seasonal perched water at about 2 feet depth. Soils below are effectively impermeable.

5.8 Pit 8

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-10	10YR3/3	5	SiL	MMG	2-6	–	–	CF	5	15
B1	10-22	10YR5/3	0	SiL	MMSAB	0.6-2	–	FMF	FF	<3	15
C1	22-55	2.5Y6/2	0	SiL	Massive	0.06-0.2	–	CMD	FF	<3	15
C2	55-70	2.5Y5/2	40	LFS	Massive	0.2-0.6	–	CMD	–	<3	<10

Kitsap variant. Similar to Pit 5. Expect seasonal perched water at 22 inches by end of winter.

5.9 Pit 9

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-9	10YR3/3	0	SiL	MMG	0.6-2	–	–	CF	5	15
B	9-23	10YR5/3	0	SiL	MMSAB	0.6-2	–	–	FF	<3	15
C1	23-39	2.5Y6/2	0	SiL	Mass	0.06-0.2	–	CMD	–	<3	<10
C2	39-104	2.5Y5/2	0	LCS/till	SG/Mass	0.06-0.2	–	–	–	<3	<10
C3	104+	2.5Y5/2	0	till	Mass	<0.06 –	–	–	-	<3	<10

Kitsap variant. Glacial lakebed surface to 39 inches overlying coarse textured meltwater deposits to 104 inches. Below that substrate is glacial till. Seeping below 51 inches. Expect seasonal perched water table at 23 inches.

5.10 Pit 10

No detailed pit description. Kitsap variant. Very similar to Pit 9. Seeping from 70-93 inches depth.

5.11 Pit 11

Horiz	Dpth	Col	CF	Txt	Struc	Perc	Type	Mott	Roots	OM	%C
A	0-10	10YR2/2	0	SL	WMG	2-6	–	–	FF,FM	5	<10
B	10-58	2.5Y4/3	0	SL	WMSAB	2-6	–	FMF	FF	<3	<10
C	58-114	2.5Y4/3	0	SL,SiL	Massive	0.2-0.6	–	FMF	-	<3	15

Kitsap variant. Non-gravelly sandy loam surface is not silt loam as occurs across the rest of the site.

6.0 Soil Series Description

6.1 Alderwood Series

The Alderwood gravelly sandy loams are moderately deep, moderately well-drained soils formed in ablation till overlying basal till. Generally, the upper soils are gravelly or very gravelly sandy loams. A weakly cemented hardpan is usually found at around 30 inches depth, and a strongly cemented duripan is found underlying the hardpan at 20 to 40 inches depth.

Average soil percolation rates in the upper horizons are expected to be moderately rapid (2-6 inches per hour) above the pan and very slow (less than 0.06 inches per hour) in the pan – effectively impermeable.

The Alderwood soils are generally suitable for woodland and homesites with the main limitation being seasonal wetness (a perched water table) at 18 to 36 inches depth.

The main limitations for onsite septic and stormwater treatment are related to both the minimal depth to the hardpan and seasonal wetness. Soil water percolating through these soils will move laterally in the soil rather than down. The seasonal high water table and/or the shallow till layer limits the amount of soil available to effectively treat stormwater or septic effluent.

6.2 Dystric Xerochrepts

The Dystric Xerochrepts (60-90% slopes) are moderately deep to very deep, well-drained soils on escarpments formed in glacial till and colluvium. No single profile is typical of these soils, but generally, there are 26 to 60 inches of very gravelly sandy loams underlain by compact glacial till.

Average soil percolation rates are expected to be moderate (0.6-2 inches per hour) through the upper soils and very slow (less than 0.06 inches per hour) through the till. Runoff is rapid and hazard from water erosion is severe.

These areas are suitable for woodland with limitations related to steep slopes, and seasonal limitations on trafficability. They can have significant silt content and therefore be highly erodible and unstable. Mass failure can occur at any time, but is exacerbated by activities that disturb vegetation or toeslopes. Trees can be prone to windthrow due to shallow root systems. For that reason, slope stabilization with plants should focus on establishment of shrubby and herbaceous rather than tree-form vegetation.

6.3 Kitsap Series

The Kitsap silt loams are deep, moderately well-drained soils formed in glacial lake sediments on remnant terraces along the Puget sound and on hillsides south of Puyallup. Generally, the surface 17 inches are silt loams or silty clay loams; subsoils have similar textures (silt loams and silty clay loams, but are also mottled – indicating that the soils at those depth are periodically saturated.

Soil permeability is very slow (0-0.06 inches per hour), and water holding capacity is very high. As a result, a perched, seasonal high water table is expected at a depth of 18-30 inches from December to May.

Kitsap soils are used for hayland, pasture, woodland or homesites. The main limitations this soil presents for homesites is related to the very slow permeability and the seasonal high water table. These soils are easily compacted, and on steep slopes, due to slow infiltration rates, can have excessive runoff during periods of extended rainfall. Due to the seasonal perched water table, onsite sewage systems often fail or malfunction during periods of extended rainfall. Drainage problems around the homesite caused by the seasonal high water table must be properly designed for to avoid flooding of crawlspaces.

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