QUALITY ASSURANCE PROJECT PLAN

Low Impact Development Research Program: Mesocosm Performance Monitoring

Prepared for

Washington State University
Puyallup Research and Extension Center

September 2010

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QUALITY ASSURANCE PROJECT PLAN

Low Impact Development Research Program: Mesocosm Performance Monitoring

Prepared for

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QUALITY ASSURANCE PROJECT PLAN
Low Impact Development Research Program: Mesocosm Stormwater Treatment Performance Monitoring

September 2010

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Introduction

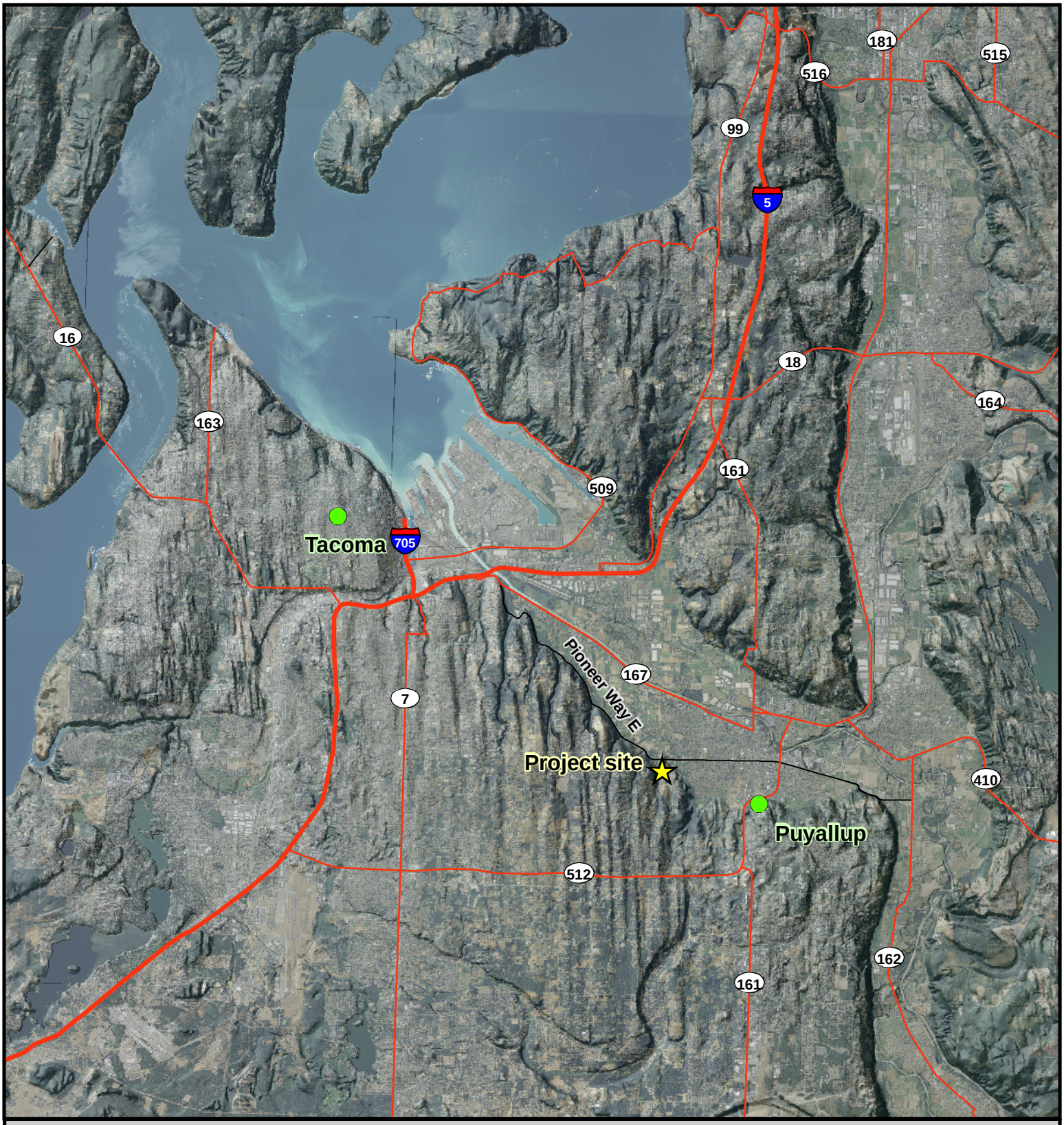
Washington State University (WSU) is collaborating with the City of Puyallup, Washington and other partners to implement the Low Impact Development (LID) Research Program on the campus of the WSU Research and Extension Center in Puyallup (Figure 1). The LID Research Program is funded by a Washington State Department of Ecology (Ecology) grant with the primary objective of improving stormwater management on the 110-year-old campus using LID practices. Performance monitoring is also required under the grant program; however, WSU is providing significant in-kind resources to design, install, and implement a LID research program within a functional stormwater management system.

Initially, the LID Research Program will focus on two practices: permeable pavement and bioretention. To facilitate performance evaluations of these practices, the largest parking area on campus (impervious asphalt) was removed and replaced with pervious asphalt and concrete. In addition, a 0.24 hectare (0.6 acre) gravel area adjacent to the parking lot was also removed and replaced with 39 bioretention cells. Sixteen of the bioretention cells are conventional rain garden installations in the ground, and twenty of the bioretention cells are deep tanks or "mesocosms" for performing more controlled testing on different bioretention soil mixes.

This installation has two unique characteristics. First, the permeable paving and bioretention research plots are full-scale and replicated. This provides a unique opportunity for bioretention research because flow control and water quality treatment performance are largely driven by plant soil interactions and the ecology that develops within these system. The full-scale systems will also operate long-term and thus allow for a more complex ecology to develop compared to laboratory scale research. Second, the permeable pavement and bioretention systems can receive stormwater from natural storms delivered by gravity flow; alternatively, synthetic stormwater can be blended and applied from cisterns at specific flow rates, volumes, and pollutant concentrations.

This document is the Quality Assurance Project Plan (QAPP) for the bioretention performance monitoring to be performed on the mesocosms described above. Separate QAPPs will be prepared for permeable pavement and rain garden performance monitoring. This QAPP was jointly prepared by WSU and Herrera Environmental Consultants (Herrera). It specifically describes the data collection, processing, and analysis procedures that will be used to meet monitoring requirements that are specified in the grant for the LID Research Program.

Monitoring to be performed on a subset of the mesocosms will also be used to meet requirements specified in Section S.8.F of the City of Seattle's Phase I Municipal Stormwater Permit. In accordance with a Memorandum of Agreement (MOA) between the City of Seattle and WSU, monitoring activities for this subset of mesocosms will conform to requirements identified in the permit and Ecology (2008) guidelines for monitoring emerging stormwater treatment technologies. Appendix A describes specific monitoring activities within this QAPP that will be performed pursuant to these requirements.



Legend

- Project site
- City
- Highway
- Road

Figure 1. Vicinity map of the Washington State University LID research center, Puyallup, WA.

N

0 1.25 2.5 5 Miles

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This QAPP was prepared in accordance with Ecology's *Guidelines for Quality Assurance Project Plans* (Ecology 2004), and includes the following:

- **Background** – An explanation of why the project is needed.
- **Project Description** – Project goals and objectives, and the information required to meet the objectives.
- **Organization and Schedule** – Project roles and responsibilities, and the schedule for completing the work.
- **Quality Objectives** – Performance (or acceptance) thresholds for collected data.
- **Sampling Process Design** – The sampling process design for the study, including sample types, monitoring locations, and sampling frequency.
- **Sampling Procedures** – A detailed description of sampling procedures and associated equipment requirements.
- **Measurement Procedures** – Laboratory procedures that will be performed on collected samples.
- **Quality Control** – Quality control (QC) requirements for both laboratory and field measurements.
- **Data Management Procedures** – How data will be managed from field or laboratory recording to final use and archiving.
- **Audits and Reports** – The process that will be followed to ensure this QAPP is being implemented correctly and the quality of the data is acceptable.
- **Data Verification and Validation** – The data evaluation process, including the steps required for verification, validation, and data quality assessment.
- **Data Quality (Usability) Assessment** – The procedures that will be used to determine if collected data are of the right type, quality, and quantity to meet project objectives.

Background

An extensive body of monitoring and research suggests that land use development and associated stormwater are primary causes of fresh and marine water degradation. Increased runoff volume, peak flows and flow durations accelerate sediment delivery, scour stream channels, reduce habitat complexity, and change hydroperiods in wetlands. A wide range of pollutants are associated with stormwater flows including heavy metals, oil and grease, pesticides, polycyclic aromatic hydrocarbons, sediment, and nutrients (nitrogen and phosphorus). In some land use settings, pollutant concentrations in stormwater runoff can exceed levels that are considered acutely toxic. Pollutant concentrations can also exceed chronic toxicity levels in urbanized streams. Little is known about the impacts of mixtures of pollutants on aquatic biota, but recent research indicates synergism or increased toxicity for mixtures of some pesticides. Suspended sediment and nutrients in stormwater also impact aquatic biota through various mechanisms.

The current structural approach to stormwater has limitations for fully mitigating the flow from and water quality impacts of urban development. Increasingly, stormwater engineers and designers are exploring and implementing distributed, low impact development (LID) strategies that seek to preserve the natural hydrologic regime of watershed by managing stormwater as close to its source as possible. In western Washington (northwestern US), LID will be required in all Phase I communities (cities and counties with populations greater than 100,000) by early 2012. Low impact development will likely be required in all Phase II communities (cities and counties with populations greater than 10,000) in the next 4 to 5 years.

Research focused on LID practices has increased dramatically over the past few years in the US. Four major university research programs exist in the eastern US. This year, WSU and project partners will complete the construction of the first university LID Research Program in the western US. The program will focus on permeable pavement and bioretention initially, and use full-scale replicated research plots to test the water quality treatment and flow control performance of these systems.

Project Description

The primary objective of the mesocosm research is to examine the hydrologic and water quality treatment performance of various bioretention soil mixes. Accordingly, the same plant palette will be used for all mesocosms (shrub and grass mix). The following five bioretention soil mixes will be tested in connection with this research:

- 60 percent mineral aggregate and 40 percent compost by volume (approximately 8 percent organic matter by weight).
- 80 percent mineral aggregate and 20 percent compost by volume (approximately 4 percent organic matter by weight).
- 60 percent mineral aggregate, 15 percent compost, 15 percent shredded cedar bark, and 10 percent water treatment residuals (alum sludge or new alum) by volume.
- 60 percent mineral aggregate, 30 percent compost, and 10 percent water treatment residuals (alum sludge or new alum) by volume.
- 60 percent mineral aggregate, 15 percent biosolids, 15 percent shredded cedar bark, and 10 percent water treatment residuals (alum sludge or new alum) by volume. This is a proposed mix and is subject to change based on preliminary testing.

More detailed information on the compost and mineral aggregate specifications for these bioretention soil mixes is presented in Appendix B.

The 60 percent aggregate and 40 percent compost is a typical bioretention soil mix for the region. (Note: monitoring of this specific bioretention soil mix is also being performed to meet requirements specified in the City of Seattle's Phase I Municipal Stormwater Permit [see Appendix A].)

Water treatment residuals are being added to two of the bioretention soil mixes in an effort to improve their treatment performance for phosphorus. Water treatment residuals are a by-product of municipal drinking water treatment plants and have been shown to adsorb substantial quantities of soluble phosphorus (Wagner et al. 2008; Agyin-Birikorang et al. 2009).

The exact specification of the fifth bioretention soil mix in the list above will depend on initial column tests to determine suitability of biosolids or other material for use in bioretention applications. These specifications and the start date for the associated monitoring will be presented in an addendum to this QAPP when this information becomes available.

During the initial phase of the LID Research Program, stormwater will be delivered to each mesocosm by gravity in connection with "natural storms"; in a later phase of the program,

stormwater will be pumped to each mesocosms to create "synthetic storms" for characterizing treatment performance at specific flow volumes, rates, and pollutant concentrations. In either case, the following data will be collected in connection with each mesocosm:

- Soil physical and chemical properties at baseline (i.e., mesocosm construction) and over time
- Continuous monitoring of influent and effluent flow rates and volumes
- Influent and effluent pollutant concentrations during discrete storm events (both natural and synthetic)
- Continuous monitoring of soil water content at various depths within the bioretention soil mixes

Pollutants of interest include suspended sediment, heavy metals, hydrocarbons, and nutrients.

Potential logistical problems that might be encountered during the monitoring program include:

- The treatment performance for a particular parameter cannot be evaluated during natural storms because influent concentrations are consistently at levels that are considered irreducible. Should this occur, it may be possible to evaluate the treatment performance for these parameters using synthetic storms.
- Uneven delivery of flows and/or water pollutants to each mesocosm during testing. In conjunction with quality assurance procedures described herein, routine testing will be performed to evaluate this potential. If this testing determines there are discrepancies, it may be possible to make corrective adjustments to the flow and/or water quality data. Alternatively, modifications to the stormwater distribution system may be explored to eliminate this problem entirely.

Organization and Schedule

WSU is collaborating with the City of Puyallup and other project partners to implement the LID Research Program. Funding for the program was obtained through a grant from Ecology's Stormwater Management Implementation Grant Program. WSU is also providing significant in-kind resources to fund major elements of the program. A more detailed breakdown of the funding from these sources is provided in Appendix C. Finally, additional funding for the program was obtained from the City of Seattle for monitoring elements that are related to requirements in the city's Phase I Municipal Stormwater Permit.

Key personnel members for the mesocosm research component of the program are shown in Table 1 with their roles and responsibilities.

Key milestones for the mesocosm component of the LID Research Program are summarized in Table 2.

It is anticipated that an addendum to this QAPP will be prepared to present the specifications for a fifth bioretention soil mix to be monitored in connection with the LID Research Program. A separate addendum will also be prepared to describe the procedures that will be used during Phase 2 monitoring. However, because the start dates for these elements of the monitoring are not known, these addendums have not been incorporated into schedule of key milestones that is presented in Table 2.

Table 1. Key personnel for the mesocosm research component of the Low Impact Development Research Program.

Name	Organization	Role	Responsibilities	Phone
Curtis Hinman	Washington State University	Program Director	Responsible for ensuring tasks and other requirements of this QAPP are executed on time. Responsible for verifying the QAPP is followed and the study is producing data of known and acceptable quality. Ensures adequate training and supervision of all monitoring and data collection activities. Supervises all assigned study personnel. Tracks project schedule and budgets.	Office: (253) 445-4590
Craig Cogger	Washington State University	Soil Science Technical Lead	Responsible for coordinating project technical issue related soil chemistry and analysis.	Office: (253) 445-4512
Andy Barry	Washington State University	Compost Science Technical Lead	Responsible for coordinating project technical issue related compost chemistry and analysis.	Office: (253) 445-4500
Rita Hummel	Washington State University	Plant Science Technical Lead	Responsible for coordinating project technical issues related to plant growth and development	Office:(253) 445-4524
Eric Miltner	Washington State University	Plant Science Technical Lead	Responsible for coordinating project technical issues related to plant growth and development	Office:(253) 445-4594
Mark Harris	Analytical Resources Incorporated	Laboratory Manager for Water Analyses	Responsible for supervision of laboratory personnel involved in generating water quality analytical data for this study. Responsible for ensuring that laboratory personnel involved in generating analytical data have adequate training and a thorough knowledge of the QAPP and all SOPs specific to the analyses or task performed and/or supervised. Responsible for oversight of all operations, ensuring that all QA/QC requirements are met, and documentation related to the analysis is completely and accurately reported. Enforces corrective action, as required. Develops and facilitates monitoring systems audits.	Office: (206) 695-6200
Brent Thyssen	Soiltest Farm Consultants	Laboratory Manager for Soil Analyses	Responsible for supervision of laboratory personnel involved in generating soil analytical data for this study. Responsible for ensuring that laboratory personnel involved in generating analytical data have adequate training and a thorough knowledge of the QAPP and all SOPs specific to the analyses or task performed and/or supervised. Responsible for oversight of all operations, ensuring that all QA/QC requirements are met, and documentation related to the analysis is completely and accurately reported. Enforces corrective action, as required. Develops and facilitates monitoring systems audits.	Office: (509) 765-1622

Table 1 (continued). Key personnel for the mesocosm research component of the Low Impact Development Research Program.

Name	Organization	Role	Responsibilities	Phone
John Lenth	Herrera Environmental Consultants	Contractor Project Manager for QAPP Development	In coordination with WSU staff, responsible for overseeing preparation of the QAPP. Ensures monitoring procedures specified in the QAPP meet requirements that are specified in the grant for the LID Research Program and Section S.8.F of the City of Seattle's Phase I Municipal Stormwater Permit.	Office: (206) 441-9080 x144 Mobile: (206) 245-7539
Deborah Cornett	Washington State Department of Ecology	Grant Manager	Acts as the grant manager for the Ecology. Ensures the grant requirements for the project are met. Approves QAPP for grant.	Office: (360) 407-7269
Rachel McCrea	Washington State Department of Ecology	Municipal Stormwater Permit Compliance Oversight	Acts as the Municipal Stormwater Permit manager for the Ecology. Ensures the City of Seattle permit requirements for monitoring are met through this the project. Approves QAPP for permit.	Office: (425) 649-7223
Kevin Buckley	Seattle Public Utilities	Municipal Stormwater Permit Compliance Oversight	Acts as the Municipal Stormwater Permit manager for the City of Seattle. Ensures the permit requirements for monitoring are met through this the project.	Office: (206) 733-9195
Curtis Hinman (interim)	Washington State University	Quality Assurance Coordinator	Oversees review of all water quality and hydrologic data to verify they meet quality objectives specified in this QAPP.	Office: (253) 445-4500

LID: low impact development
QA/QC: quality assurance/quality control
QAPP: quality assurance project plan
SOP: standard operating procedures
WSU: Washington State University

Table 2. Schedule of key milestones for the mesocosm research component of the Low Impact Development Research Program.

Project Milestone	Date
Draft QAPP Submitted	May 2010
Final QAPP	September 2010
Mesocosm Construction and Baseline Monitoring	Spring-Summer 2010
Phase 1 Monitoring Initiation	October 2010
Phase 2 Monitoring Initiation	No earlier than October 2011

QAPP: quality assurance project plan

Quality Objectives

A primary purpose of this QAPP is to ensure that the data collected for this study are scientifically accurate, useful for the intended analysis, and legally defensible. Therefore, the collected data will be evaluated using the following indicators of quality assurance:

- **Bias**: The systematic or persistent distortion of a measurement process that causes errors in one direction (i.e., the measured mean is different from the true value).
- **Precision**: A measure of the variability in the results of replicate measurements due to random error.
- **Representativeness**: The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency and duration, and sampling methods.
- **Completeness**: The amount of data obtained from the measurement system.
- **Comparability**: The ability to compare data from the current study to data from other similar studies, regulatory requirements, and historical data.

Measurement quality objectives (MQOs) are performance or acceptance criteria that are established for each of these quality assurance indicators. The specific MQOs to be used for this study are described below in separate subsections for hydrologic and laboratory data, respectively.

Measurement Quality Objectives for Hydrologic Data

Hydrologic monitoring will involve direct measurement of discharge and precipitation depth. MQOs for these measurements are expressed in terms of bias, precision, representativeness, completeness, and comparability. The associated MQOs for hydrologic monitoring are defined below.

Bias

Bias in discharge data collected through this study will be assessed based on periodic comparisons of actual readings from tipping bucket flow meters (see description below in *Sampling Process Design* section) to their theoretical accuracy, as specified from the manufacturer. The actual readings will be determined by adding water incrementally to each tipping bucket flow meter and measuring the volume of water required to initiate one tip of the

associated bucket mechanism. The actual readings will then be compared to the manufacturer's specified volume for initiating one tip of the bucket mechanism to evaluate potential bias in the discharge data. The MQO for discharge data will be a difference of no more than 15 percent between the actual reading and the manufacturer's specified volume.

Similarly, bias in precipitation data will be assessed using periodic comparisons of actual readings from the rain gauge (see description below in *Sampling Process Design* section) to its theoretical accuracy, as specified from the manufacturer. Again, actual readings will be determined by adding incremental drops of water to the rain gauge and measuring the volume of water required to initiate one tip of the associated bucket mechanism. The actual readings will then be compared to the manufacturer's specified volume for initiating one tip of the bucket mechanism to evaluate potential bias in the precipitation data. The MQO for precipitation data will be a difference of no more than 5 percent between the actual reading and the manufacturer's specified volume.

Precision

Precision will be assessed by taking replicate measurements during constant hydrologic conditions. For the tipping bucket flow and rain gauges, the volume of water required to tip the mechanism (see description in previous subsection) will be recorded during each of ten replicate measurement pairs. The relative percent difference (RPD) for each measurement pair will subsequently be calculated using the following equation.

$$RPD = \left(\frac{\left| V_1 - V_2 \right|}{V_1 + V_2} \right) \times 200\%$$

Where: RPD = Relative percent difference

V_1 and V_2 = Tip volumes

The RPD for each possible replicate pair will be calculated and subsequently averaged. The precision MQO for both the tipping bucket flow and rain gauges is for the RPD not to exceed 15 percent.

Representativeness

The representativeness of the flow monitoring data will be ensured by the proper installation of tipping bucket flow gauges. Additionally, monitoring will be conducted in a mesocosm configuration with quadruplicate replication. The replication will help ensure that the final hydrologic results are representative of true mean flow conditions though each representative bioretention soil mix.

Representativeness of the precipitation data will be ensured by placing the rain gauge in a location which is unobstructed by adjacent structures but still sheltered from strong winds. The rain gauge will also be placed in close proximity to the mesocosm drainage area, so it can be assumed that the precipitation measured at the device is representative of the precipitation that falls on the drainage basin.

Completeness

Completeness will be assessed on the basis of gaps in the data record for all hydrologic monitoring equipment. Less than 10 percent missing and rejected data will be considered acceptable for this study. Completeness will be ensured through routine maintenance of all monitoring equipment and the immediate implementation of corrective actions if problems arise.

Comparability

There is no numeric MQO for this data quality indicator; however, standard monitoring procedures, units of measurement, and reporting conventions will be applied in this study to meet the goal of data comparability.

Measurement Quality Objectives for Water Quality and Soil Data

MQOs for laboratory data are expressed in terms of bias, precision, representativeness, completeness, and comparability. The specific MQOs that have been identified for this project are described below and summarized in Tables 3 and 4. Note that the term "reporting limit" in this document refers to the practical quantification limit established by the laboratory, not the method detection limit.

Bias

Bias will be assessed based on analyses of method blanks, equipment rinsate blanks, matrix spikes, and laboratory control samples (LCS). The values for method blanks will not exceed the reporting limit, and values for equipment rinsate blanks will not exceed 2 times the reporting limit. Bias in matrix spikes will be evaluated based on their percent recovery, as calculated using the following equation:

$$\%R = \frac{(S - U)}{C_{sa}} \times 100\%$$

Where: %R = Percent recovery

S = Measured concentration in spike sample

U = Measured concentration in unspiked sample

C_{sa} = Actual concentration of spike added

Table 3. Measurement quality objectives for water quality data.

Parameter	Laboratory Method Blank	Rinsate Blank	Control Standard Recovery	Surrogate Recovery	Matrix Spike Recovery [a]	Laboratory Duplicate *RPD* [b]	Field Duplicate *RSDp* [c]
pH	NA	NA	NA	NA	NA	≤20%	≤35%
Total suspended solids	≤RL	NA	80-120%	NA	NA	≤20% or ±2 × RL	≤35%
Suspended sediment concentration	≤RL	NA	NA	NA	NA	≤20% or ±2 x RL	≤35%
Particle size distribution	NA	NA	NA	NA	NA	≤20%	≤35%
Hardness	≤RL	NA	80-120%	NA	75-125%	≤20% or ±2 × RL	≤35%
Biological oxygen demand	≤RL	NA	80-120%	NA	75-125%	≤20% or ±2 × RL	≤35%
Chemical oxygen demand	≤RL	NA	80-120%	NA	75-125%	≤20% or ±2 × RL	≤35%
Total phosphorus	≤RL	≤ 2 x RL	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Total dissolved phosphorus	≤RL	≤ 2 x RL	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Orthophosphorus	≤RL	≤ 2 x RL	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Total Kjeldahl nitrogen	≤RL	NA	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Nitrate + nitrite nitrogen	≤RL	NA	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Dissolved cadmium, copper, and zinc	≤RL	≤ 2 x RL	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Total cadmium, copper, and zinc	≤RL	≤ 2 x RL	80-120%	NA	75–125%	≤20% or ±2 × RL	≤35%
Polycyclic aromatic hydrocarbons	≤RL	≤ 2 x RL	30-115%	23-120%	30-115%	≤30% or ±2 × RL	≤45%
Total petroleum hydrocarbons (diesel)	≤RL	≤ 2 x RL	56-103%	35-131%	56-103%	≤30% or ±2 × RL	≤45%
Total petroleum hydrocarbons (motor oil)	≤RL	≤ 2 x RL	30-160%	NA	30-160%	≤30% or ±2 × RL	≤45%

[a] For inorganics, the Contract Laboratory Program Functional Guidelines state that the spike recovery limits do not apply when the sample concentration exceeds the spike concentration by a factor of four or more (Ecology 2005).
[b] The relative percent difference must be less than or equal to the indicated percentage for values that are greater than 5 times the reporting limit. RPD must be ±2 times the reporting limit for values that are less than or equal to 5 times the reporting limit.
[c] The pooled relative standard deviation will only be calculated for values that exceed 5 times the RL.
NA = not applicable.
RL = reporting limit.
RPD = relative percent difference.
RSDp = pooled relative standard deviation.

Table 4. Measurement quality objectives for soil data.

Parameter	Laboratory Method Blank	Reference Sample Recovery	ISV Recovery	Control Standard Recovery	Matrix Spike Recovery	Laboratory Duplicate *RPD*	Field Duplicate *RSDp*
pH	≤MDL	NA	NA	NA	NA	≤20%	≤35%
Total carbon by loss on ignition	≤ MDL	a	NA	NA	NA	≤20%	≤35%
Percent total solids	NA	NA	NA	NA	NA	≤20%	≤35%
Particle size distribution	≤MDL	NA	NA	NA	NA	≤20%	≤35%
Bulk density	NA	NA	NA	NA	NA	NA	≤35%
Compost stability	NA	NA	NA	NA	NA	NA	≤35%
Cation exchange capacity	≤MDL	NA	80-120%	80-120%	NA	≤20%	≤35%
Total carbon	≤MDL	a	80-120%	80-120%	NA	≤20%	≤35%
Total nitrogen	≤MDL	a	NA	NA	NA	≤20%	≤35%
Ammonia	≤MDL	a	80-120%	80-120%	50-150%	≤20%	≤35%
Nitrate	≤MDL	a	80-120%	80-120%	50-150%	≤20%	≤35%
Total phosphorus	≤MDL	b	NA	80-120%	50-150%	≤20%	≤35%
Bray phosphorus	≤MDL	a	80-120%	80-120%	50-150%	≤20%	≤35%
Water soluble phosphorus	≤MDL	75-125%	80-120%	80-120%	50-150%	≤20%	≤35%
Oxalate phosphorus	≤MDL	TBD	80-120%	80-120%	NA	≤20%	≤35%
Oxalate iron and aluminum	≤MDL	TBD	80-120%	80-120%	NA	≤20%	≤35%
Total cadmium, copper, zinc, and lead	≤MDL	b	80-120%	80-120%	50-150%	≤20%	≤35%
DTPA-extractable cadmium, copper, and zinc	≤MDL	a	80-120%	80-120%	50-150%	≤20%	≤35%
Calcium, magnesium, and potassium	≤MDL	a	80-120%	80-120%	50-150%	≤20%	≤35%

[a] Reference sample recovery will be based on North American Proficiency Testing Program sample statistics.
[b] Reference sample recovery will be based on Environmental Resource Associates QC sample statistics.
DTPA = Diethylenetriamine penta-acetic acid.
ISV: internal standard verification.
RPD = relative percent difference.
RSDp = pooled relative standard deviation.
TBD = to be determined.

If the analyte is not detected in the unspiked sample, then a value of zero will be used in the equation.

The specific MQOs for the percent recovery in matrix spikes are defined in Tables 3 and 4 for water quality and soil parameters, respectively. Bias in LCS will also be evaluated based on their percent recovery. In this case, percent recovery will be calculated using the following equation:

$$\%R = \frac{M}{T} \times 100\%$$

Where: %R = Percent recovery
M = Measured value
T = True value

The specific MQOs for the percent recovery in LCS are defined in Tables 3 and 4 for water quality and soil parameters, respectively.

Precision

In this study, overall project data quality will be based on total precision and analytical precision. Total precision is the measure of the variability in the results of replicate measurements due to random error that is introduced during sample collection and processing in the field *and* the laboratory analytical procedure. Total precision will be estimated based on the pooled relative standard deviation (RSD_p) of the field duplicates from all sampling events. The RSD_p of these samples will be calculated using the following formula:

$$S_p = \sqrt{\frac{\sum (Ci_1 - Cj_2)^2}{2m}} \quad \text{and } RSD_p = \frac{S_p}{\bar{x}} \times 100\%$$

Where: S_p = Pooled standard deviation
RSD_p = Pooled relative standard deviation
Ci_1 and Cj_2 = Concentration values
m = Number of pairs
$\bar{x}$ = Mean of all concentration values

When one or both values are less than or equal to 5 times the reporting limit, they will not be included in the RSD_p calculation. The specific MQOs for total precision are defined in Tables 3 and 4 for water quality and soil parameters, respectively.

Analytical precision is the measure of the variability in the results of replicate measurements due to random error that is introduced from just the laboratory analytical procedure. Analytical

precision will be assessed based on the relative percent difference (*RPD*) of laboratory duplicates that are run with each batch of samples. The *RPD* of these samples will be calculated using the following formula:

$$RPD = \left(\frac{\left| C_1 - C_2 \right|}{C_1 + C_2} \right) \times 200\%$$

Where: RPD = Relative percent difference
C_1 and C_2 = Concentration values

The specific MQO's for analytical precision are defined in Tables 3 and 4 for water quality and soil parameters, respectively. For all parameters, the *RPD* must be ±2 times the reporting limit if the duplicate concentrations are both within 5 times the reporting limit. If either of the duplicate concentrations is at or below the reporting limit, the *RPD* cannot be calculated.

Representativeness

Sample representativeness will be ensured by collecting an adequate number of samples for characterizing the variability in stormwater treatment performance across a wide range of storm event conditions with respect to rainfall volume, rainfall intensity, and antecedent dry period. To meet this goal, the following criteria for defining the acceptability of specific storm events for sampling were adopted from Ecology (2008) guidelines for monitoring emerging stormwater treatment technologies:

- Target storm depth: A **minimum of 0.15 inches** of precipitation over a 24 hour period.
- Antecedent conditions: A period of **at least 6 hours** preceding the event **with less than 0.04 inches** of precipitation.
- Minimum duration: Target storms must have **a duration of at least 1 hour**.
- End of storm: A continuous **6-hour period with less than 0.04 inches of precipitation**.

During each event, the goal will be to collect flow-weighted composite samples that provide representative event-mean concentrations (EMCs) for each targeted parameter. To meet this goal, the following sampling criteria were also adopted from Ecology (2008) guidelines for monitoring emerging stormwater treatment technologies:

- Samples shall be collected for at least **75 percent of the storm event hydrograph** as measured by volume.

- The maximum time period over which samples are to be collected is **36 hours**.
- A minimum of **10 sample aliquots** is collected for compositing during each storm event.

Finally, the representativeness of both water quality and soil samples collected through this study will be ensured by employing consistent and standard sampling procedures, as identified in this QAPP.

Completeness

Completeness will be calculated by dividing the number of valid values by the total number of values. Valid sample data consists of unflagged data and estimated data. A qualitative assessment will be made as to which estimated data may need to be excluded from this calculation prior to annual reporting. If less than 95 percent of the samples submitted to the laboratory are judged to be valid, then additional samples will be collected until at least 95 percent are judged to be valid.

Comparability

Standard sampling procedures, analytical methods, units of measurement, and reporting limits will be applied in this study to meet the goal of data comparability.

Sampling Process Design

The primary objective of the mesocosm research is to examine the hydrologic and water quality treatment performance of four bioretention soil mixes identified in the *Project Description* section above.

This section describes the sampling process design that will be used to meet this goal, including a general description of the monitoring site, detailed information about mesocosm components, and descriptions of monitoring activities performed during each phase of the monitoring program.

Mesocosm Design

The mesocosm performance monitoring program will be implemented on the WSU campus in Puyallup, Washington (see vicinity map in Figure 1). Figure 2 shows a general site plan for the campus, and Figure 3 provides a detail of the campus area devoted to the mesocosm performance monitoring program. Twenty mesocosms will be constructed on the campus. The sampling process design will rely on four replicate~~s~~ mesocosms for each of the four bioretention soil mixes described above; hence, 16 mesocosms will be actively monitored in this program, and the remaining four mesocosms will be used to test other soil mixes that, in the future, show promise for improved water quality treatment.

There are three basic physical components to the mesocosm sampling process design:

- Cistern and flow distribution system
- Media tank and underdrain system
- Outlet flow control structure

These components are shown in Figures 3 through 6 and described in more detail in the following subsections.

Cistern and Flow Distribution System

To facilitate monitoring of the mesocosms, stormwater will be collected from a 72,084 square foot impervious drainage area on the WSU campus. Runoff from approximately 25 percent of this area (18,021 ft^2) will be routed to a 11,370 liter (L) (3,000 gallon) cistern for storage and delivery to the mesocosms. The cistern's location on the campus and associated drainage area are shown in Figure 3. Elevations of stormwater conveyance structures in the drainage area to the cistern are provided in Appendix D. Stormwater from the cistern can be routed via gravity flow to the mesocosms to assess treatment performance during natural storms; alternatively, water can be pumped from the cistern at specific flow rates, volumes, and pollutant concentrations to produce synthetic storms for testing mesocosm performance. In either case, weir boxes

constructed at the water surface elevation inside the cistern will distribute flows evenly to each mesocosm, with one distribution line bypassing the mesocosms and terminating at a separate Influent Monitoring Station (Figure 3). Influent flows and chemistry for all the mesocosms will be generalized based on representative data that are collected at this station. Figure 4 provides a more detailed cross-section view of the cistern, associated weir boxes, pump system, and distribution lines.

It should be noted that the cistern will be kept full during ongoing mesocosm performance monitoring using natural storms; therefore, any stormwater that enters the cistern from the associated drainage basin will flow directly to the mesocosms and Influent Monitoring Station without attenuation. Furthermore, eductors installed inside the cistern will be activated during sampled storm events to keep particulate bound pollutants from settling out in the cistern prior to reaching the mesocosms. This will minimize any pretreatment that might occur in the cistern that would bias the results from the mesocosm monitoring.

Media Tank and Underdrain System

Each mesocosm will be constructed with a 152.4 centimeter (cm) (60 inches) diameter by 132 cm (52 inches) deep media tank to hold the bioretention soil mix during testing. The bottom of each media tank will be filled with coarse sand to a depth of 30.5 cm (12 inches) thick; 61 cm (24 inches) of the soil mix will then be placed over the aggregate layer within the tank and hand packed before water is introduced to the system. A slotted underdrain pipe within the aggregate layer will serve as the drain for the media tank. Flow will enter the tanks through a manifold constructed of plastic piping perforated with drilled holes that distributes water across the surface of the tank. Figures 5 and 6 show cross-section and plan views of a typical media tank with related components.

Outlet Flow Control Structure

The underdrain pipe described in the previous subsection connects to a vertically oriented outlet flow control structure with upper and lower outlets (see Figures 5 and 6). Discharge from the lower outlet is regulated by an orifice that can be set at different heights within the outlet flow control structure. This outlet can be used to control the saturated zone level and hydraulic residence time within the media tank; thereby affecting denitrification processes (conversion of nitrate to nitrogen gas) that are mediated by anaerobic bacteria. The upper outlet serves as a bypass weir that can also be set at different heights within the outlet flow control structure. Adjustment of this weir can be used to control hydraulic residence time and ponding depth within the media tank.

Note that the outlet flow control structures will not be utilized in the first one to two years of monitoring; rather, the mesocosms will be operated with bypass valves (see Figures 5 and 6) for the outlet flow control structures set to remain open. With these bypass valves open, the flow of water through the bioretention soil mixes will not be subject to any artificial controls and will essentially mimic the natural drainage condition. Once the performance of the bioretention soil

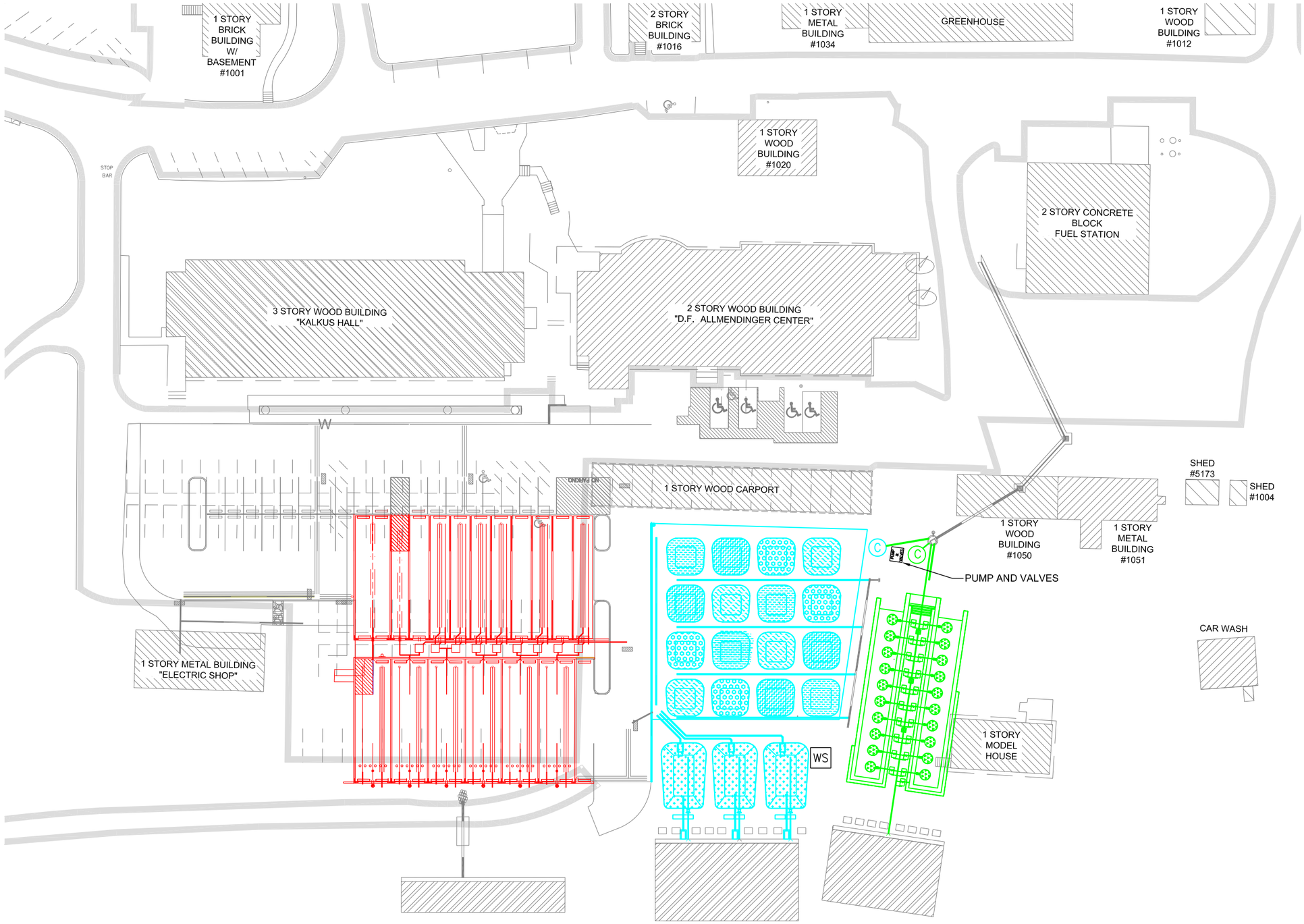

Figure 2.
Plan view of Washington State University low impact development research facility.

Legend

- CISTERN
- WEATHER STATION
- PERVIOUS PAVEMENT TEST FACILITY
- RAIN GARDEN TEST FACILITY
- MESOCOSM TEST FACILITY
- INFILTRATION SLOPES

N

0 25 50 100

scale in feet

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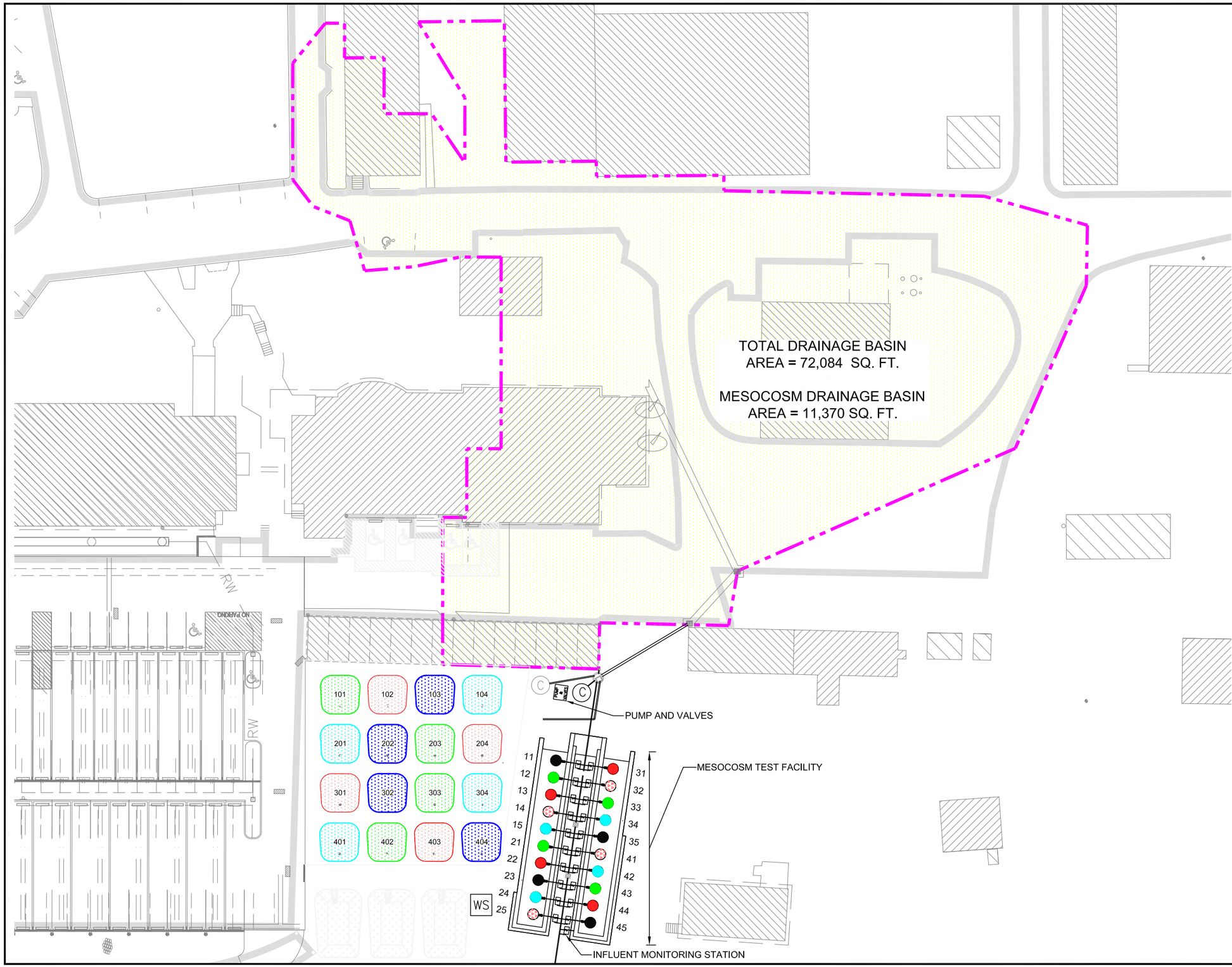

Figure 3.
Plan view of mesocosm test facility.

Legend

- (C) MESOCOSM CISTERN
- WS WEATHER STATION
- 60% AGGREGATE, 40% COMPOST
- 80% AGGREGATE, 20% COMPOST
- 75% AGGREGATE, 15% COMPOST, 10% WATER TREATMENT RESIDUALS
- TO BE DETERMINED
- 55% AGGREGATE, 35% COMPOST, 10% WATER TREATMENT RESIDUALS
- DRAINAGE BASIN

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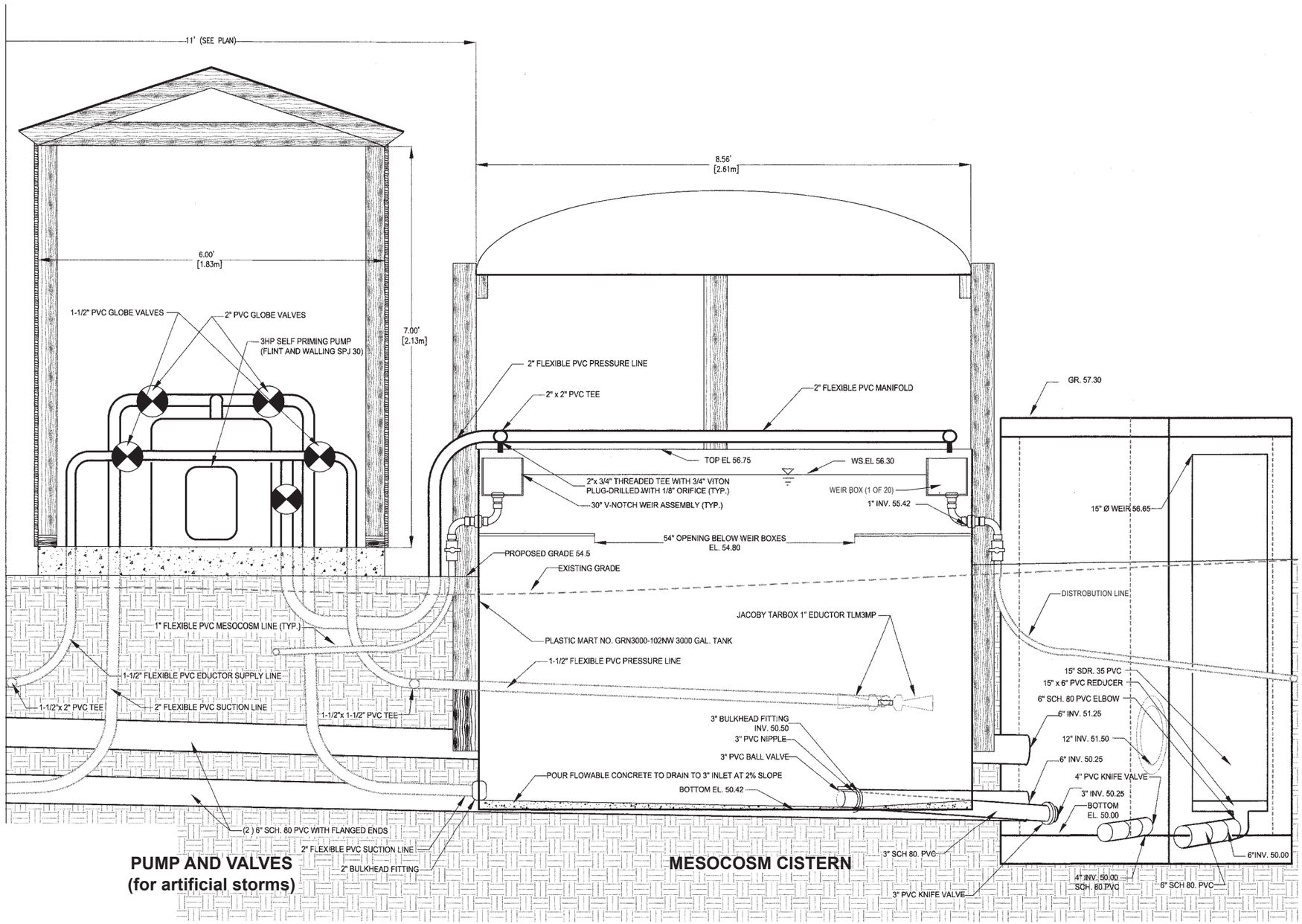
Figure 4.
Cross-section view of mesocosm cistern and pump system.



Legend

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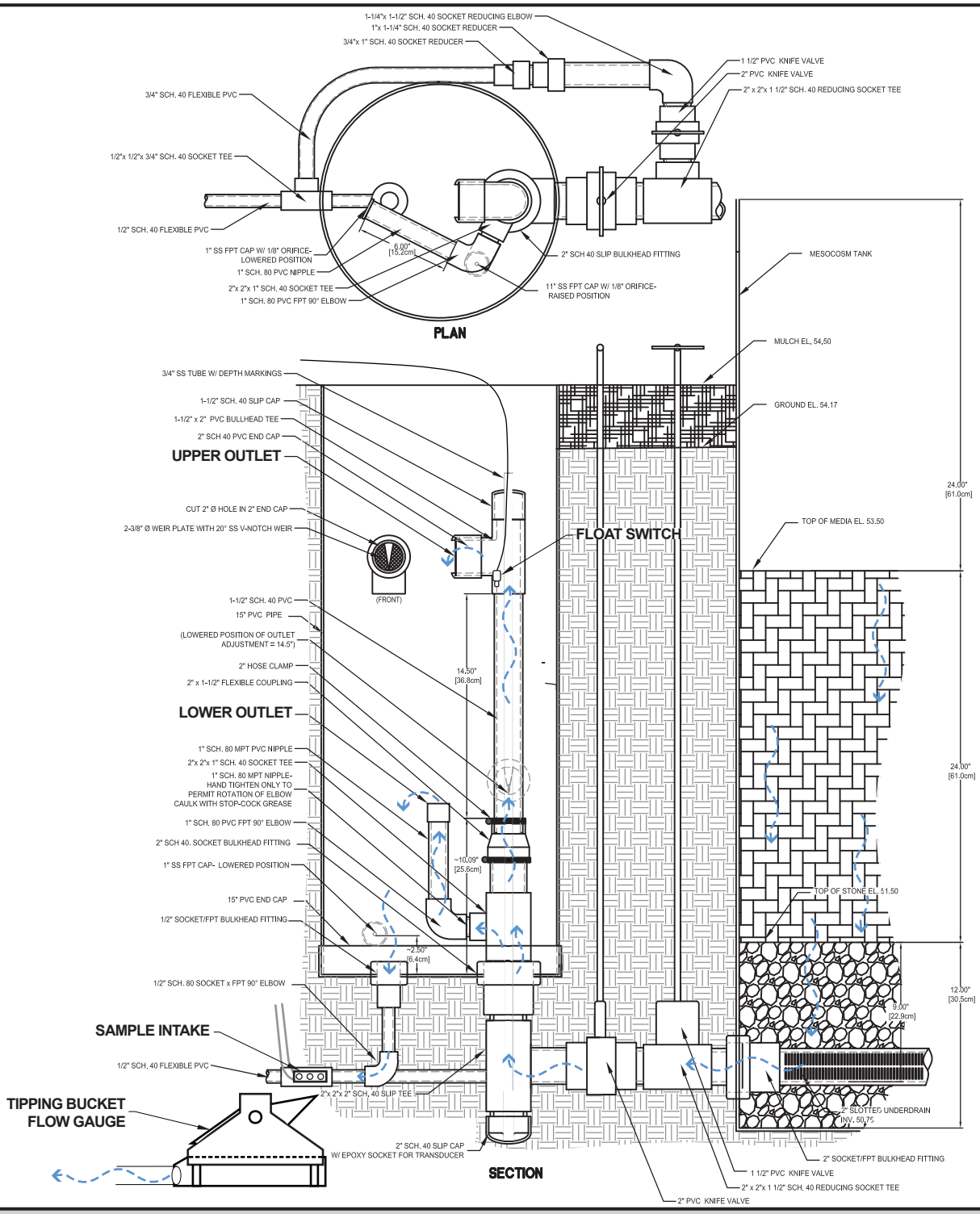

Figure 5.
Cross section and plan view of typical mesocosm with associated underdrain and outlet flow control structure.

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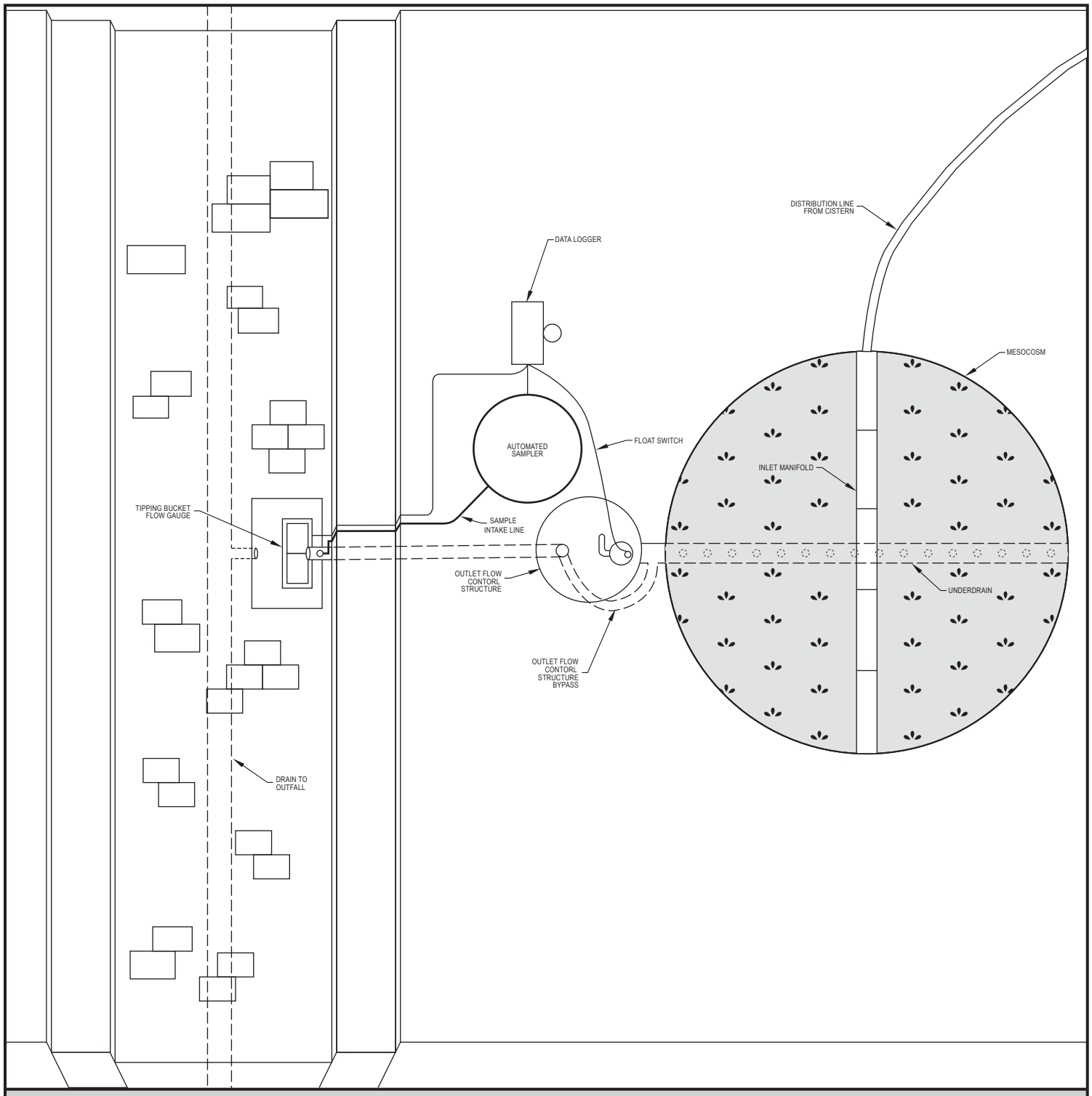

Figure 6.
Plan view of an individual mesocosm with associated monitoring equipment.

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mixes has been evaluated under this "baseline" condition, the outlet flow control structures will then be brought on-line to evaluate performance under other hydraulic scenarios of interest.

Monitoring Design

Monitoring activities will occur in three phases that are herein referred to as Baseline monitoring, Phase 1 monitoring, and Phase 2 monitoring. Baseline monitoring will characterize the physical and chemical properties of the various bioretention soil mixes prior to the onset of monitoring activities that are performed to quantify their treatment performance. Phase 1 monitoring will involve quantifying the treatment performance of the mesocosms using stormwater that is generated during natural storms and routed by gravity to the individual mesocosms via the cistern (see description above and Figures 3 and 4). Phase 2 will involve quantifying treatment performance of the mesocosms using stormwater that is stored in the cistern and pumped to mesocosms at specific flow rates, volumes, and pollutant concentrations to generate synthetic storms.

Baseline monitoring will be performed in the spring and summer of 2010 during construction of the mesocosms. Phase 1 monitoring will then initiate at the start of water year 2011 and be ongoing thereafter. Phase 2 monitoring will be implemented to provide supplemental performance data from different influent flow and chemistry scenarios that cannot be achieved during natural storms in the Phase 1 monitoring. Given this consideration, it is anticipated that Phase 2 monitoring will not initiate any earlier than water year 2012.

The specific activities that will be performed during these monitoring phases are described in the following subsections.

Baseline Monitoring

The goal of the Baseline monitoring is to characterize the physical and chemical properties of the various bioretention soil mixes before they are affected by stormwater that is introduced to the mesocosms during Phase 1 and Phase 2 monitoring. To meet this goal, samples of each bioretention soil mix will be collected from stockpiles that will be used to construct the individual mesocosms. Specifically, nine individual samples will be collected from different locations within each stockpile and composited into a single sample for each mesocosm. The collected bioretention soil mix samples will then be submitted to an accredited laboratory where they will be analyzed for the following parameters:

- pH
- Cation exchange capacity
- Total carbon
- Total nitrogen

- Ammonia
- Nitrate
- Total phosphorus
- Bray phosphorus
- Water soluble phosphorus
- Oxalate phosphorus
- Oxalate iron and aluminum
- Total cadmium, copper, lead, and zinc
- Diethylenetriamine penta-acetic acid (DTPA)-extractable cadmium copper, and zinc
- Calcium, magnesium, and potassium
- Total petroleum hydrocarbons

In addition to the above parameters, WSU will perform the following soil analyses at a non-accredited laboratory located on the WSU Puyallup campus:

- Total carbon by loss on ignition
- Particle size distribution
- Bulk density
- Compost stability

Phase 1 Monitoring

The goal of Phase 1 monitoring will be to quantify the treatment performance of the mesocosms using stormwater that is generated during natural storms. To meet this goal, Phase 1 monitoring will include the following design elements: precipitation and evapotranspiration monitoring, flow monitoring, infiltration testing, water quality monitoring, soil chemistry monitoring, and soil moisture content monitoring. Each of these design elements is described in more detail in the following subsections.

Precipitation and Evapotranspiration Monitoring

To facilitate mesocosm monitoring, a weather station with two tipping bucket rain gauges will be used to continuously monitor precipitation totals at the monitoring site (Figure 3). These data will be used to delineate qualifying events for sampling and to assess mesocosm hydrologic performance relative to precipitation depth, duration, peak intensity, and average intensity. The weather station will also monitor wind speed and direction, solar radiation and relative humidity. Evapotranspiration is calculated using these data and the Penman-Montieth equation.

Flow Monitoring

Stormwater inflows and outflows to each mesocosm during natural storms will be measured continuously in connection with the Phase 1 monitoring. These data will then be analyzed to compare the flow control treatment performance of each bioretention soil mix, including their effects on influent flow peaks, volume, and duration. In conjunction with the water quality monitoring described below, these data will also facilitate event-based pollutant loading analyses for characterizing water quality treatment performance.

Infiltration Testing

During Phase I monitoring, the infiltration rate in each mesocosm will be assessed on an annual basis. Infiltration testing will be conducting following a falling head procedure described in the *Sampling Procedures* section. Testing will occur immediately after planting and then on an annual basis from that date forward. The results from these tests will be used to assess how soil compaction, rhizosphere (root system) development, and sediment loading impact infiltration rates over time.

Water Quality Monitoring

The goal of water quality monitoring will be to quantify water quality treatment performance of the four different bioretention soil mixes. In connection with this monitoring, stormwater that is generated during natural storms from the drainage area to the cistern (i.e., parking lots and rooftops) will be routed by gravity to the individual mesocosms via the cistern and associated weir boxes (see description above and Figure 4). Using automated samplers, flow weighted composite effluent samples will be collected from each mesocosm and used to characterize effluent chemistry. Similarly, one flow weighted composite sample will be collected from the Influent Monitoring Station (Figure 3) and used to represent influent chemistry across all the mesocosms. The goal will be to collect flow weighted composite samples from each sampling location during at least five storm events each year.

The collected flow weighted composite samples will be submitted to an accredited laboratory where they will be analyzed for the following parameters:

- pH*
- Particle size distribution*
- Total suspended solids
- Suspended sediment concentration
- Hardness
- Total phosphorus
- Orthophosphorus
- Total Kjehldahl nitrogen
- Nitrate+nitrite nitrogen
- Total and dissolved cadmium copper and zinc
- Polycyclic aromatic hydrocarbons

- Biological oxygen demand
- Chemical oxygen demand

*****Particle size distribution and pH will only be measured in influent and effluent samples that are collected from mesocosms that are constructed with 60 percent aggregate and 40 percent compost by volume. These samples are required pursuant to monitoring requirements specified in City of Seattle's Phase 1 Municipal Stormwater Permit (see Appendix A).

In addition to the flow weighted composite samples, grab samples will also be collected from the Influent Monitoring Station and the outlet of each mesocosm during monitored storm events. These samples will be submitted to an accredited laboratory for analysis of total petroleum hydrocarbons.

Soil Chemistry Monitoring

The goal of soil chemistry monitoring will be to track changes in soil chemistry in several soil horizons over time as stormwater pollutants are treated. For example, metals attenuation as a function of depth will be compared through time and among the different BSM treatments. The horizons that will be sampled include: 0 to 7.6 cm (0 to 3 in), 7.6 to 15.2 cm (3 to 6 inches), and 15.2 to 30.5 cm (6 to 12 inches). These samples will be collected once yearly and submitted to an accredited laboratory where they will be analyzed for the following parameters:

- Total carbon
- Total nitrogen
- Total phosphorus
- Bray phosphorus
- Water soluble phosphorus
- Oxalate phosphorus
- Oxalate iron and aluminum
- Ammonium and nitrate
- Total cadmium, copper, lead, and zinc
- DTPA-extractable copper, zinc, and cadmium
- Cation exchange capacity

In addition to the above parameters, WSU will perform the following soil analyses on samples from all four bioretention soil mixes at a non-accredited laboratory located on the WSU Puyallup campus:

- Total carbon by loss on ignition
- Bulk density

Finally, the soil surface elevation in each mesocosm will be documented annually at the same time the soil samples are collected.

Soil Water Content

The goal of soil water content monitoring will be to collect continuous (five-minute) soil moisture data at three horizons in four mesocosms. Four mesocosms, representing the four different bioretention soil mixes, will be instrumented with time domain reflectometry (TDR) probes installed at depths of 15.2, 30.5, and 45.7 cm (6, 12, and 18 in). This will allow analysis of moisture content through the soil horizon as a function of various storm event characteristics (e.g., precipitation antecedent dry period, depth, duration, and intensity).

Phase 2 Monitoring

Phase 2 monitoring will be implemented to provide supplemental performance data for different influent flow and chemistry scenarios that cannot be achieved during natural storms in the Phase 1 monitoring. Phase 2 monitoring will specifically involve capturing stormwater runoff in the cistern (see description above and Figures 3 and 4), adding a pollutant (or an appropriate surrogate) to the stormwater to achieve a desired concentration, continuously mixing the tank to achieve more uniform application of the synthetic stormwater, and then pumping the stormwater to the mesocosms to produce synthetic storms. This will allow treatment performance of the mesocosms to be evaluated across a wider range of influent pollutant concentrations relative to what is present in the stormwater runoff during natural storm events.

By varying the pumping rate of stormwater from the cistern, it will also be possible to test the effect of runoff rate (pumping rate in this case) on chemical and/or hydrological treatment performance. Finally, using pumped synthetic stormwater instead of natural stormwater will make it possible to quantify the effects of bioretention soil age on treatment performance. This could be achieved, for example, by adding the equivalent of 10 years of pollutant loading to each mesocosm using synthetic storm events to artificially “age” the bioretention soil mixes.

Phase 2 monitoring will not occur until a sufficient amount of data have been collected through the Phase 1 monitoring to identify supplemental data needs for the mesocosm research. Given this consideration, it is anticipated that Phase 2 monitoring will not begin before water year 2012. Prior to beginning the Phase 2 monitoring, an addendum to this QAPP will be prepared to describe the following elements of the design:

- Goals and objectives
- Target parameters
- Target influent concentrations
- Target influent flow rates
- Number of synthetic storms to be sampled per mesocosm

Sampling Procedures

This section describes in detail the sampling procedures that will be followed by field personnel during each phase of the monitoring. This section has been divided into subsections for Baseline monitoring, Phase 1 monitoring, and Phase 2 monitoring, respectively.

Baseline Monitoring

Prior to initial construction of each mesocosm, the four bioretention soil mixes described in the *Project Description* section will be stockpiled on the monitoring site. When the soil mixes are first placed within each mesocosm field personnel will collect samples of each bioretention soil mix using the following procedures:

1. A stainless steel scoop or spoon will be used to collect sample aliquots from nine different locations in each mesocosm.
2. All the sample aliquots will be combined in a clean stainless steel bowl and then homogenized using a stainless steel spoon.
3. The contents from the bowl will be used to fill soil bags for the required parameters that will be obtained from the analytical laboratory.
4. The soil bags will be labeled in the field and immediately placed in a drying oven until the samples are desiccated.
5. Once samples are desiccated they will be transported to the laboratory within the allowable limits for sample holding times and with the appropriate chain of custody documentation.

Once at the laboratory, the samples for each mesocosm will be analyzed for the suite of parameters that were identified in the *Sampling Process Design* section for Baseline monitoring.

Phase 1 Monitoring

Phase 1 monitoring will involve flow monitoring, water quality sampling, soil chemistry monitoring, and soil moisture content monitoring. The field procedures that will be used for each of these monitoring elements are presented in this section.

Precipitation Monitoring

To monitor precipitation, two Hydrological Services TB3 tipping bucket rain gauges (see detailed specifications in Appendix E) will be installed in an area adjacent to the mesocosms that

is unobstructed by buildings and/or trees (Figure 3). One gauge will be mounted on a 5-foot pole and one at ground level. Each will be leveled upon installation. Data from the gauge will be recorded on an alternating current (AC) powered Campbell Scientific CR1000 datalogger (see detailed specifications in Appendix E). The datalogger will be programmed to scan every 10 seconds and record totalized rainfall on a 5-minute interval. The stored data will be automatically downloaded on a daily basis via radio telemetry to a central server located in an adjacent campus building. On at least a monthly basis, field personnel will check the rain gauge to ensure it is still level. On an annual basis, the calibration of the gauge will be checked and adjusted if necessary (see *Quality Control* section below).

Flow Monitoring

As described in the *Sampling Process Design* section, water will be distributed to each mesocosm and the Influent Monitoring Station (Figure 3) via weir boxes placed at a uniform height within the cistern (Figure 4). Because influent flows into each weir will frequently be below the recommended minimum flow rate for v-notch weirs (4 gpm) (Walkowiak 2006), the weirs will not be used as primary flow measurement devices; instead, their sole purpose will be to ensure an even distribution of flow to each mesocosm and the Influent Monitoring Station. To this end, the height of the weir boxes will be checked on a monthly basis during the first year of monitoring using a laser level or the cistern water level to assure the weirs are at the same elevation (see *Quality Control* section below). In all subsequent years of monitoring, the height of the weir boxes will be checked at a minimum on a quarterly basis.

Influent flows to each mesocosm will be estimated by routing water through a Hydrological Services TB1-L tipping bucket flow gauge (see detailed specifications in Appendix E) that will be installed at the Influent Monitoring Station (Figure 3). The tipping bucket flow gauge will be connected to a Campbell Scientific CR1000 datalogger. The datalogger will measure each tip of the flow gauge bucket mechanism and convert the signal to a volume estimate. The volume estimates will be totalized over a 5-minute logging interval, converted to an estimate of discharge for that period, and stored along with the precipitation data within the datalogger. The stored data will be automatically downloaded on a daily basis via radio telemetry to a central server located in an adjacent campus building. The discharge data collected from the Influent Monitoring Station will be used to estimate influent discharge rates to all of the mesocosms. These discharge estimates will be valid so long as flow is uniformly distributed to each mesocosm via the weir boxes in the cistern. As noted above, the height of the weir boxes will be checked monthly during the first year of monitoring and at least quarterly thereafter to ensure an even distribution of flow to each mesocosm.

Effluent discharge rates will be measured at the point of discharge for each mesocosm's outlet flow control structure (Figures 5 and 6). Flow from each outlet flow control structure will be routed into a separate Hydrological Services TB1-L tipping bucket flow gauge for each mesocosm. These flow gauges will be connected to the same Campbell Scientific CR1000 datalogger described above, in connection with the Influent Monitoring Station. The discharge

measurements from these flow gauges will be stored and downloaded using procedures described above for the Influent Monitoring Station.

To quantify the amount of water that exits the outlet flow control structures for each mesocosm via the associated upper and lower outlets that will be used in Phase 2, a float switch will be mounted in the upper outlet for each mesocosm. Under normal conditions, water will exit each mesocosm via the lower outlet and be captured and recorded by the tipping bucket flow gauges described above. However, under high flow conditions, water will also begin to exit the outlet flow control structures via the upper outlet. At the point in time when water reaches the upper outlet, the float switch will send a signal to the Campbell Scientific CR1000 datalogger described above to record this occurrence. Any increase in flows measured by the tipping bucket flow gauge after this point in time will be attributed to the upper outlet. When the flow of water begins to subside and water ceases discharging through the upper outlet, the float switch will again send a signal to the datalogger to indicate this occurrence; flows at this point will only be attributed to the lower outlet.

Infiltration Testing

On an annual basis infiltration testing will be conducted in each mesocosm. The infiltration testing will consist of the following steps.

1. The 1.5 inch knife valve at the end of the underdrain will be closed.

2. Water will be released into the mesocosm until there is 6 inches of standing water.

3. To assure saturation the water will be allowed to stand for 1 hour. Water levels will be checked again after the hour and adjusted to 6 inches of standing water if necessary.

4. The knife valve will be opened and the time it takes for the 6 inches of water to infiltrate will be recorded.

Field personnel will record all the pertinent information on standardized field forms (see example in Appendix F) which will be scanned and stored in the project database.

Water Quality Sampling

Flow weighted composite samples will be collected during four to five storm events on an annual (water year) basis for characterizing influent and effluent pollutant concentrations for each mesocosm. Influent samples will be collected using an Isco Model 6700 series automated sampler (see detailed specification in Appendix E) that will be installed in association with the Influent Monitoring Station (Figure 3) and each mesocosm (Figures 5 and 6). The automated sampler intake for the Influent Monitoring Station will be suspended in a tray mounted just downstream of the point of discharge for water from the cistern (see description in *Sampling*

Process Design section), and just upstream of the station's tipping bucket flow gauge (see description in previous section). The automated sampler intake for each mesocosm will be installed immediately upstream of the tipping bucket flow gauges described in the previous subsection. In both cases, the sampler intakes will be positioned to ensure the homogeneity and representativeness of the collected samples. Specifically, sampler intakes will be installed to make sure adequate depth is available for sampling, and to avoid capture of litter, debris, gross solids, or floatables that might be present towards the bottom or top of flow stream.

During implementation of the Phase 1 monitoring, long-range precipitation forecasts from the Center for Ocean-Land-Atmosphere Studies (http://wxmaps.org/pix/meteograms.html) will be examined daily to determine if specific storms should be tracked for sampling based on the criteria identified in the Quality Objectives section for representative storms. Within 72 hours of an approaching storm, short-range precipitation forecasts will be examined for a more accurate assessment of the storm characteristics relative to these criteria. The short-range forecasts will be obtained primarily from Quantitative Precipitation Forecasts (QPF) that are generated by the National Oceanic and Atmospheric Administration (NOAA) and accessible via the following website (http://www.weather.gov/forecasts/xml/SOAP_server/ndfdXML.htm). The QPFs show forecasted rainfall totals for the next 72 hours in 6-hour increments. Monitoring personnel will review these data to determine the expected precipitation total, duration, and intensity of an approaching storm. In addition to the QPF data, Table 5 lists secondary sources for short-range precipitation forecasts that may also be reviewed by the weather monitoring lead to obtain this information.

Table 5. Sources for short-range precipitation forecasts.

Source	Website URL
National Weather Service Forecast Office, Seattle, Washington; Area Forecast Discussion	http://www.wrh.noaa.gov/sew/get.php?wfo=sew&pil=AFD&sid=SEW
Center for Ocean-Land-Atmosphere Studies, Global Forecast System; 180-hour meteogram	http://wxmaps.org/pix/seagfs.png
Center for Ocean-Land-Atmosphere Studies; Global Forecast System; 84-hour meteogram	http://wxmaps.org/pix/seanam.png
National Oceanic and Atmospheric Administration, National Weather Service; Graphical Forecasts – Washington	http://www.nws.noaa.gov/forecasts/graphical/sectors/washington.php
University of Washington, Department of Atmospheric Sciences, Weather Loops; MM5 Real-Time Forecasts	http://www.atmos.washington.edu/~ovens/loops/wxloop.cgi?mm5d1_pcp3+///3
Unisys 72-hour NGM Meteogram for Seattle, Washington	http://weather.unisys.com/mos/meteogram/mos_met_SEA.html

Based on information obtained from the short-range forecasts, the Program Director (Table 1) will make a "go" or a "no go" for sampling a particular storm event. If a decision is made to target a storm event for sampling, the laboratory will be notified, and the sampling teams will be mobilized to conduct a pre-event site visit in preparation for the event.

During the pre-event site visits, field personnel will perform routine maintenance activities on the monitoring equipment as described in the *Quality Control* section below. Once these activities are complete, field personnel will perform the following steps to prepare each automated sampler for sampling:

- Flush sample line for each automated sampler with dilute (1:100) Liquinox detergent solution and then deionized water.
- Attach sample line to automated sampler and position the associated intake in the respective sampling locations described above for the Influent Monitoring Station and mesocosms.
- Place a clean 20 L glass sample bottle into the automated sampler and pack ice around each sample bottle.
- Attach the automated sampler head to its base.
- Initiate the automated sampler's program.

During the storm event sampling, each automated sampler will be programmed to enable in response to a predefined increase in flow at the respective station. The automated samplers will then collect 400-milliliter (mL) sample aliquots at preset flow increments with the goal of collecting at least 10 sample aliquots, covering at least 75 percent of each storm's total runoff volume. Sample pacing for the automated samplers will be determined based on rainfall versus runoff relationships that are developed using linear regressions of data that were collected during previous storm events. These regressions will be continually updated throughout the year to reflect changing hydrologic conditions. The rainfall versus runoff regressions will be used to convert forecast rainfall totals into runoff volumes. The resultant runoff volume (cubic feet) will then be divided by 25 (the median number of 400 mL aliquots that a 20 L bottle will hold) to estimate the sample pacing (cubic feet) volume necessary to collect an adequate number (greater than 10) of aliquots across at least 75 percent of the storm.

During the actual storm event, the Campbell Scientific CR1000 datalogger described in the previous subsection will send an alarm when the flow rate at the Influent Monitoring Station reaches a user customizable threshold. This alarm will notify field personnel that an event is underway and that a grab sample needs to be collected. Field personnel will then collect grab samples for total petroleum hydrocarbons at the Influent Monitoring Station and each mesocosm outlet in pre-labeled 1 L amber glass bottles. As appropriate, additional grab samples may also be collected to verify the data from the Influent Monitoring Station are indeed representative of the influent to each of the mesocosms (see *Quality Control* section). Sample bottles will be immediately placed on ice and kept below 6°Celsius (C) until delivery to the laboratory. During the grab sample field visit, field personnel will also check the field equipment and perform any maintenance that is necessary without interfering with the functioning of the sampling equipment.

After each targeted storm event, field personnel will make visual and operational checks on each automated sampler, and determine the total number of aliquots composited. Pursuant to the sampling goals identified in the *Measurement Quality Objectives* section above, the minimum number of composites that constitutes an acceptable sample is 10. (A minimum volume of approximately 5.75 L must be collected to perform all the targeted analyzes in this study with the associated laboratory quality control requirements.) If the sample is acceptable, the sample bottle will be immediately capped, removed from the automated sampler, labeled (see labeling conventions in *Quality Control* section), and kept at 4°C until delivery to the laboratory. Once in the laboratory, water from the carboy will be used to fill pre-cleaned, preserved (where appropriate) sample bottles for the required analyses. All collected flow-weighted composite samples will then be analyzed for the parameters identified in the *Sampling Process Design* section. If insufficient sample volume is available to analyze of all the identified parameters, the following subset of parameters will be prioritized for subsequent analysis in descending order of importance:

1. Total suspended solids
2. Total phosphorus
3. Total and dissolved copper and zinc
4. Orthophosphorus
5. Particle size distribution
6. Hardness
7. pH
8. All other

During pre-event, mid-event, and post-event field visits, detailed notes will be kept in standardized field forms (see example in Appendix F) specifically developed for the project.

Soil Chemistry Monitoring

Samples will be obtained for each bioretention soil mix on an annual basis to assess pollutant attenuation within the soil column at the following horizons: 0 to 7.6 cm (0 to 3 in), 7.6 to 15.2 cm (3 to 6 inches), 15.2 to 30.5 cm (6 to 12 inches), and 30.5 to 61 cm (12 to 24 inches). Using this approach, 64 samples will be obtained annually across all the mesocosm and depth combinations (16 mesocosms × 4 depths = 64 samples).

A 2-inch diameter push probe will be used to collect the soil samples from each mesocosm. To obtain the required soil volume for analyses, four separate push probe samples will be collected at randomly selected locations within each mesocosm. Different push probe samplers will be used to collect the samples for each bioretention soil mix. Soil from each of the soil horizons identified above will then be removed from the four push probes and composited. For example, to obtain enough soil volume for the 0 to 7.6 cm soil horizon, soil corresponding to this depth will be removed from the four push probes and placed in a single container. This process would then be repeated for the remaining three soil horizons.

After sampling is complete, voids left in the mesocosms will be filled with stockpiled bioretention soil mix retained from the initial mesocosm installation. The new soil mix will be packed into the void left by the push probe so that water introduced during subsequent storm events will not bypass the bioretention soil mix and flow directly to the underdrain with minimal treatment. Finally, the sampling location will be marked so that subsequent samples are not collected in the same location. It is estimated that the four cores will occupy 0.4 percent of the surface area of the mesocosm, so annual coring will not constitute a significant removal of material from the mesocosms.

Samples from each horizon within each mesocosm will be labeled in the field (see labeling conventions in *Quality Control* section), placed in a cooler with ice, and transported to the laboratory within the allowable limits for sample holding times and with the appropriate chain of custody documentation. Once at the laboratory, the samples will be analyzed for the suite of parameters that were identified in the previous section for Phase 1 soil chemistry monitoring.

In addition to the soil sampling described above, the soil surface elevation in mesocosm will be measured annually in relation to the top of the mesocosms. These measurements will be made using a modified t-square or a level and leveling rod. Five separate measurements will be made in each mesocosm (center, north, south, east, and west sides) and then averaged to determine the overall soil surface elevation.

Soil Moisture Content Monitoring

Four mesocosms, representing the four different bioretention soil mixes (i.e., no replication), will be instrumented with TDR probes installed at depths of 15.2, 30.5, and 45.7 cm (6, 12, and 18 inches). The TDRs will be installed horizontally within the bioretention soil mix during the construction of the mesocosms. The bioretention soil mix will be packed around each TDR to assure maximum contact between the probe tines and the soil. Each TDR will be connected to a single Campbell scientific CR1000 datalogger and soil moisture content (0 through 100 percent) will be logged on a continuous 5 minute interval. Soil moisture data from each TDR will be downloaded, managed, and stored with the flow and precipitation data described in the subsections above.

Phase 2 Monitoring

As described *Sampling Process Design* section above, an addendum to this QAPP will be prepared to describe specific elements of the sampling process design for Phase 2 monitoring, once supplemental data needs have been identified through the Phase 1 monitoring. It is anticipated that field procedures related to flow monitoring, soil chemistry monitoring, and soil moisture content monitoring during Phase 2 monitoring will remain unchanged relative to those described above for Phase 1 monitoring. However, the field procedures related to water quality sampling will be altered because natural storms will no longer be tracked and sampled. Instead, synthetic storm events will be generated and storm volumes and flow rates controlled. Because

flow rates and storm volumes will be pre-determined, there will be no need for rainfall versus runoff relationships to estimate what the storm volume might be. Due to this consideration, collecting adequate sample volume across the duration of the "event" should be relatively straightforward.

Measurement Procedures

This section describes the laboratory methods that will be used for the analysis of samples collected for the mesocosm research. This information is presented in separate subsections below for water quality and soil samples, respectively.

Water Quality Measurement Procedures

Laboratory analytical procedures for water quality parameters will generally follow methods that are approved in the Federal Register by the U.S. Environmental Protection Agency (U.S. EPA 2007). These methods provide reporting limits that are low enough to assess state and federal regulatory criteria or guidelines. The preservation methods, analytical methods, reporting limits, and sample holding times for all water quality parameters to be evaluated in this study are presented in Table 6.

The Federal Register indicates that dissolved metals and orthophosphorus samples must be filtered, and pH must be measured, within 15 minutes of the end of a qualifying event. However, when collecting flow-weighted composite samples during storm events, this requirement generally cannot be met because the collection time of the last sample aliquot cannot be reliably predicted. Once the samples are retrieved and delivered to the laboratory, the laboratory staff will be required to split the composite sample and immediately filter the dissolved metals and orthophosphate samples and measure the pH. If sample retrieval occurs during the laboratory's non-business hours or the laboratory is not able to receive, filter or process the samples; sampling staff will split, filter, and preserve the samples as soon as possible after retrieval. The samples will then be stored in a secure refrigerator and maintained at the required holding temperature until they can be delivered to the laboratory the morning of the next business day.

The laboratory identified for this project (Analytical Resources Incorporated) is certified by Ecology and participates in audits and interlaboratory studies by Ecology and the U.S. Environmental Protection Agency. These performance and system audits have verified the adequacy of the laboratory's standard operating procedures, which include preventive maintenance, data reduction, and quality assurance/quality control (QA/QC) procedures.

The laboratory will provide the analytical results within 30 days of receipt of the samples in standardized reports that are suitable for evaluating the project data. Each report will be provided in both hardcopy format and as an Electronic Data Deliverable (EDD). These reports will specifically include the following information:

- All raw values including those below the reporting limit and between the method detection limit and the laboratory reporting limit
- The laboratory method detection limits and reporting limits for all parameters for each batch

- All laboratory quality assurance (QA) results, including matrix spike, lab-replicate split, laboratory blank, and laboratory control sample results

The reports will also include a case narrative summarizing any encountered problems in the analyses, corrective actions taken, and changes to the referenced method, and an explanation of data qualifiers.

Soil Measurement Procedures

Laboratory analytical procedures for soil parameters are identified in Table 7 with associated preservation methods, analytical methods, reporting limits, and sample holding times. The WSU-Puyallup campus is an agricultural research center that has non-accredited laboratory facilities capable of processing and analyzing soil samples. Consequently, the following parameters will be analyzed on campus:

- Total carbon by loss on ignition
- Particle size distribution
- Bulk density
- Compost stability

The remainder of the soil parameters will be analyzed at Soiltest Farm Consultants, Inc. This laboratory is certified by Ecology and participates in audits and interlaboratory studies by Ecology and the U.S. Environmental Protection Agency. These performance and system audits have verified the adequacy of the laboratory's standard operating procedures, which include preventive maintenance, data reduction, and QA/QC procedures.

The laboratory will report the analytical results within 30 days of receipt of the samples. These reports will provided in both a hardcopy and electronic format, and contain the same information as described above for water quality parameters.

Table 6. Methods and detection limits for water quality analyses.

Parameter	Analytical Method	Method Number [a]	Volume of Water Required for Analysis	Field Sample Container	Pre-Filtration Holding Time	Total Holding Time [b]	Field Preservation	Laboratory Preservation	Reporting Limit/ Resolution	Units
pH	Electrometric	SM 4500 - H^+	100 mL	20 L glass bottle	15 minutes [e]	15 minutes [e]	Maintain ≤ 6°C	NA		
Total suspended solids	Gravimetric [c]	SM 2540D	1 L		7 days	7 days		Maintain ≤ 4°C	1.0	mg/L
Suspended sediment concentration	Gravimetric [c]	ASTM D3977-97C	1 L						0.5	mg/L
Particle size distribution	Sieve and Coulter Counter	TAPE Appendix F	1 L						0.1	microns
Hardness	Titrimetric (EDTA)	SM2340-C	100 mL		NA	6 months		Maintain 4°C,HNO_3 to pH < 2	1	mg/L as $CaCO_3$
Biological Oxygen Demand (BOD)	Winkler 5-day	EPA 405.1	1 L		48 hours	48 hours		Maintain ≤ 6°C	2.0	ppm
Chemical Oxygen Demand (COD)	Closed reflux	EPA 410.4	250 mL		NA	28 days		H_2SO_4 to pH < 2	5.0	ppm
Total phosphorus	Strong Acid	EPA 365.3	200 mL		NA	28 days		Maintain ≤ 4°C, H_2SO_4 to pH < 2	0.016	mg/L
Total dissolved phosphorus										
Orthophosphorus	Heteropoly Blue	EPA 365.3			15 minutes [e]	48 hours [f]			0.004	mg P/L
Total Kjeldahl nitrogen	Digest, ISE	EPA 351.2			NA	28 days			0.6	mg/L
Nitrate + nitrite nitrogen	Cd-red, Auto-NED	EPA 353.2			48 hours	28 days			0.01	mg/L
Cadmium, dissolved	ICP-MS	EPA 200.8	200 mL		12 hours [e]	6 months		Maintain ≤4°C, HNO_3 to pH < 2 after filtration [f]	0.0002	mg/L
Cadmium, total					NA			Maintain ≤ 4°C, HNO_3 to pH < 2	0.0002	mg/L
Copper, dissolved					12 hours [e]			Maintain ≤4°C, HNO_3 to pH < 2 after filtration [f]	0.0005	mg/L
Copper, total					NA			Maintain ≤ 4°C, HNO_3 to pH < 2	0.0005	mg/L
Zinc, dissolved					12 hours [e]			Maintain ≤ 4°C, HNO_3 to pH < 2 after filtration [f]	0.004	mg/L
Zinc, total					NA			Maintain ≤ 4°C, HNO_3 to pH < 2	0.004	
Polycyclic aromatic hydrocarbons	GC/MS	EPA 8270D	2 x 500 mL		NA	7 days		Maintain ≤ 6°C	1.0	µg /L
Total petroleum hydrocarbons (diesel)	GC/FID	NWTPH-Dx [d]	2 x 500 mL	1 L glass bottle	7 days	7 days		Maintain ≤ 4°C, H_2SO_4 to pH < 2	0.25	mg/L
Total petroleum hydrocarbons (motor oil)			2 x 500 mL						0.5	mg/L

[a] ASTM method numbers are from ASTM (2003); EPA method numbers are from U.S. EPA (1983; 1984); TAPE methods are from the Washington State Department of Ecology (Ecology 2008); NWTPH-Dx method is from the Washington State Department of Ecology (Ecology 2007)
[b] Holding time specified in U.S. EPA guidance (U.S. EPA 1983, 1984).
[c] A G4 glass fiber filter will be used for the total suspended solids and suspended sediment concentration filtration.
[d] Washington State Department of Ecology methods (Ecology 2007) includes silica gel extract cleanup step.
[e] EPA requires filtering for dissolved metals, nutrients and pH measurement to be performed within 15 minutes of the collection of the last aliquot. Due to logistical consideration related to the collection of flow-weighted composite sampling, this goal may be difficult to meet..
[f] A 0.45 micron fiber nylon filter will be used for dissolved metals (copper and zinc) filtration.
C = Celsius.
ICP-MS = inductively coupled plasma/mass spectrometry.
GC/MS = gas chromatography/ mass spectrometry.
L = liter
mg/L = milligrams per liter.
µg/L = micrograms per liter.
NA = not applicable.

Table 7. Methods and detection limits for soil analyses.

Parameter	Analytical Method	Method Number [a]	Volume Required for Analysis	Field Sample Container	Pre-processing Holding Time	Total Holding Time	Field Preservation	Laboratory Preservation	Reporting Limit/ Resolution	Units
pH	Electrometric	S -2.20 [b]	0.5 g	Soil bags	48 hours [f]	NA	Maintain < 6°C	Room temperature	NA	Standard units
Total carbon by loss on ignition	Gravimetric	S -9.20 [b]	0.5 g		48 hours [f]	NA			0.01	%
Percent total solids	Gravimetric	P -1.10 [b]	50 g		NA	48 hours		Maintain < 6°C	0.10	%
Particle size distribution	Sieve/Hydrometer	ASTM D422	500 g		NA	6 months			0.10	%
Bulk density	Volumetric	TMECC 03.01-A [c]	200 g		NA	7 days			NA	lb/ft^3
Compost stability	Respiration	TMECC 02.05-B [c]	500 g		NA	48 hours			NA	mg CO_2-C/g OM/day
Cation exchange capacity	Na replacement	S -10.10 [b]	2 g		48 hours [f]	NA		Room temperature	0.1	meq/100g
Total carbon	Combustion	ASTM D5373	0.5 g		48 hours [f]	NA			0.02	%
Total nitrogen	Combustion	ASTM D5373	0.5 g		48 hours [f]	NA			0.01	%
Ammonium	1N KCL/Flo Injection	S –3.50 [b]	5 g		48 hours [f]	NA			0.8	mg/kg
Nitrate	1N KCL/Flo Injection	S -3.10 [b]	5 g		48 hours [f]	NA			0.7	mg/kg
Total phosphorus	ICP	EPA 3050A/6010B	0.5 g		48 hours [f]	NA			4.3	mg/kg
Bray phosphorus	Colorimetric	S -4.20 [b]	2.7 g		48 hours [f]	NA			0.9	mg/kg
Water soluble phosphorus	ICP	TEMECC 04-12 D [c]	5 g		48 hours [f]	NA			0.2	mg/kg
Oxalate phosphorus	ICP	SSSA Mono.9 6-2.3 [e]	0.125 g		48 hours [f]	NA			TBD	mg/kg
Oxalate iron and aluminum	ICP	SSSA Mono.9 6-2.3 [e]	0.125 g		48 hours [f]	NA			1.0/1.0	mg/kg
DTPA-extractable cadmium, copper, and zinc	DTPA/ICP	S -6.11 [b]	10 g		48 hours [f]	NA			Cd: TBD/Cu: 0.3/Zn: 0.3	mg/kg
Calcium, magnesium, and potassium	NH4OAC/ICP	S -5.10 [b]	2 g		48 hours [f]	NA			Ca 0.2/Mg 0.1/K 11	meq/100g; K mg/kg
Total cadmium, copper, lead, and zinc	ICP	EPA 6010B	0.5 g		6 months	2 years		Maintain < 6°C	Cd:0.5/Cu: 0.2/Pb: 0.6/Zn: 0.5	mg/kg

[a] ASTM method numbers are from ASTM (2003); EPA method numbers are from U.S. EPA (1983; 1984); NWTPH-Dx method is from the Washington State Department of Ecology (Ecology 2007).
[b] From Gavlak et al. 2003.
[c] From Test Methods for the Examination of Composting and Compost; A joint project of the United States Department of Agriculture and the US Composting Council.
[d] Washington State Department of Ecology methods (Ecology 2007) includes silica gel extract cleanup step.
[e] Test method from the Soil Science Society of America.
[f] Samples will be dried on-site at 40°C. Once samples are transferred to the laboratory they will be pulverized using a hammer mill apparatus, and sieved through a 2 millimeter mesh screen (from Brown [1998]; Recommended Chemical Soil Test Procedures for the North Central Region).
C = Celsius.
DTPA = Diethylenetriamine penta-acetic acid.
lb/ft^3 = pounds per cubic foot.
g = grams.
G OM/day = grams organic matter per day.
ICP = inductively coupled plasma.
Meg/100g = milli-equivalents per 100 grams.
mg/kg = milligrams per kilogram.
mg = milligrams.
NA = not applicable.
TBD = to be determined.

Table 8. Anticipated annual number of samples and associated quality assurance requirements for each water quality parameter.

Parameter	Samples per Station	Number of Stations	Total Number of Samples	Laboratory Method Blanks	Rinsate Blanks	Laboratory Control Standard	Matrix Spike	Lab Duplicates [a]	Field Duplicates [b]	Distribution Systems Checks	Total Annual Number of Samples [c]
Total suspended solids	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	NA	2/batch [a]	1/batch	5	77 - 95
Suspended sediment concentration	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	NA	2/batch [a]	1/batch	NA	72 - 90
Particle size distribution	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	NA	2/batch [a]	1/batch	NA	72 - 90
Total phosphorus	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Orthophosphorus	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	5	79 - 97
Total Kjeldahl nitrogen	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	72 - 90
Nitrate + nitrite nitrogen	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	72 - 90
Cadmium, dissolved	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Cadmium, total	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Copper, dissolved	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Copper, total	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Zinc, dissolved	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Zinc, total	4 -5	17	68 - 85	1/batch [a]	2	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	74 - 92
Polycyclic aromatic hydrocarbons	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	72 - 90
Total petroleum hydrocarbons (diesel)	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	72 - 90
Total petroleum hydrocarbons (motor oil)	4 -5	17	68 - 85	1/batch [a]	NA	1/batch [a]	1/batch [a]	2/batch [a]	1/batch	NA	72 - 90

[a] Laboratory quality assurance samples will be analyzed with each batch of samples submitted to the laboratory for analysis. A laboratory batch will consist of no more than 20 samples.
[b] Field duplicates will be collected and analyzed for at least 5 percent of the total number of submitted samples.
[c] Total annual number of samples includes project samples, rinsate blanks, field duplicates, and distribution system checks.
NA: not applicable.

Table 9. Anticipated annual number of samples and associated quality assurance requirements for each soil parameter.

Parameter	Samples per Mesocosm	Number of Mesocosms	Total Number of Samples	Laboratory Method Blanks	Laboratory Control Standard	Matrix Spike	Lab Duplicates	Field Duplicates	Total Annual Number of Samples [b]
pH	4	16	64	1/batch	NA	NA	1/batch	4	68
Total carbon by loss on ignition	4	16	64	1/batch	NA	NA	1/batch	4	68
Percent total solids	4	16	64	NA	NA	NA	1/batch	4	68
Particle size distribution	4	16	64	1/batch	NA	NA	1/batch	4	68
Bulk density	4	16	64	NA	NA	NA	NA	4	68
Compost stability	4	16	64	NA	NA	NA	NA	4	68
Cation exchange capacity	4	16	64	1/batch	1/batch	NA	1/batch	4	68
Total carbon	4	16	64	1/batch	1/batch	NA	1/batch	4	68
Total nitrogen	4	16	64	1/batch	NA	NA	1/batch	4	68
Ammonia	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
Nitrate	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
Total phosphorus	4	16	64	1/batch	1/batch	NA	1/batch	4	68
Bray phosphorus	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
Water soluble phosphorus	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
Oxalate phosphorus	4	16	64	1/batch	1/batch	NA	1/batch	4	68
Oxalate iron and aluminum	4	16	64	1/batch	1/batch	NA	1/batch	4	68
Total cadmium, copper, zinc, and lead	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
DTPA-extractable cadmium, copper, and zinc	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68
Calcium, magnesium, and potassium	4	16	64	1/batch	1/batch	1/batch	1/batch	4	68

[a] Field duplicates will be collected and analyzed for at least 5 percent of the total number of submitted samples.
[b] Total annual number of samples includes project samples and field duplicates.
BSM: bioretention soil mix.
NA: not applicable.

Quality Control

Quality control procedures are identified below for field and laboratory activities. The overall objectives of these procedures are to ensure that data collected for this project are of a known and acceptable quality, and that data quality objectives are met.

Field Quality Control Procedures

Quality control procedures that will be implemented for field activities are described below. The frequency and type of quality control samples to be collected in the field are also summarized in Tables 8 and 9 for water quality and soil parameters, respectively.

Instrument Maintenance and Calibration

On a monthly basis and before each targeted event, routine maintenance and operational inspections will be performed to ensure that the equipment is functioning properly. Maintenance activities and operational inspections will include:

- Inspection of power connections
- Inspection of desiccant in data loggers enclosures and automated samplers
- Inspection of the rain gauge, including level check and debris removal
- Inspection of tipping bucket flow gauges, including level check and debris removal.
- Inspection of automated sampler tubing, including check for kinks and debris removal
- Inspection of weirboxes (see Figure 4), including debris removal
- Inspection of outlet flow control structures (see Figure 5), including level of upper and upper outlets
- Inspection of float switches (see Figure 5), include checking level and float mechanism mobility

Instrument maintenance and calibration activities will be documented on standardized field forms (see example in Appendix F).

The rain gauge and tipping bucket flow gauges (see *Sampling Procedures* section) are robust instruments that will only require annual calibration. During each calibration event, water will be

metered into the gauges with a burette until the tipping bucket mechanism triggers. This process will be repeated and adjustments on the gauges will be made until an equivalent volume of water triggers the tipping mechanism in either direction. For the rain gauge, each bucket tip is calculated as equivalent to 0.01 inches of rain; consequently, the volume of water that should initiate a bucket tip equals 0.01 inches multiplied by the area (in square inches) of the top of the rain gauge. For the flow gauges, the tipping buckets will be calibrated such that each tip is equivalent to 1 L.

Because the tipping bucket flow gauges hold a larger mass of water and tip more frequently than the rain gauge, it will also be necessary to conduct dynamic calibration checks of these gauges. To conduct these checks, field personnel will run water though each tipping bucket flow gauge with a metered hose that is connected to the cistern described in the *Sampling Process Design* section (Figure 3 and 4). The flow from the cistern will be measured with a rotometer; flow from the rotometer will then be compared with the flow from the tipping bucket flow gauge to assess instrument accuracy. This procedure will be repeated twice at 1 L per minute and twice at 25 L per minute for each tipping bucket flow gauge. Tests at each flow rate will be performed for 10 minutes. The dynamic calibrations will be conducted on an annual basis or as needed.

The float switches in the upper outlet of each flow control structure (see *Sampling Procedures* section) are also robust devices that only require periodic calibration. To calibrate these devices, the knife valve separating the mesocosm from the outlet flow control structure will be closed (Figures 5 and 6). In addition, the outlet to the outlet flow control structure will be closed. Water will then be added to the outlet flow control structure with a hose until it reaches the elevation of the float switch. When water first flows through the upper outlet, the time will be noted and compared to the time of the float switch trigger on the data logger. The elevation of the float switch will then be iteratively adjusted until it triggers at the very moment that flow begins to move through the upper outlet. This calibration procedure will be conducted on an annual basis or as needed.

The TDR instruments will be factory calibrated and will be recalibrated by the manufacturer at the end of the study period when the BSM is removed from the mesocosms. Sensors for the weather station (i.e., wind speed and direction, solar radiation and relative humidity) will also be factory calibrated at the onset of monitoring and then recalibrated once every two years thereafter.

Field Notes

During each pre- and post-storm site visit to each monitoring station, the following information will be recorded on a waterproof, standardized field form (see example in Appendix F):

- Mesocosm media tank identification
- Date/time of visit and last sample collected (if sampled)
- Name(s) of field personnel present

- Weather and flow conditions
- Rain gauge condition
- Desiccant condition
- Sample volume (if sampled)
- Sampler pacing (if sampled)
- Lower and upper outlet elevation
- Sample duplicated? (if sampled)
- Presence of obstructions in system and remedial actions taken
- Unusual conditions (e.g., oily sheen, odor, color, turbidity, discharges or spills, and land disturbances)
- Modifications of sampling procedures

During each soil sampling field visit, the following information will be recorded on a waterproof standardized field form (see example in Appendix F):

- Mesocosm media tank identification
- Date/time of visit
- Name(s) of field personnel present
- Weather and flow conditions
- Number of samples collected/composited
- Sample depth
- Sample duplicated?
- Unusual conditions (e.g., oily sheen, odor, color, turbidity, discharges or spills, and land disturbances)
- Modifications of sampling procedures

Equipment Rinsate Blanks

Equipment rinsate blanks will be collected at the Influent Monitoring Station (Figure 3) to verify that the automated sampler tubing or bottle is not a source of contamination. At a minimum, two equipment rinsate blanks will be collected for this purpose; the first prior to sampling the first storm event in any given monitoring year, and the second midway through the monitoring year.

Samples will be collected using the following procedure:

1. The sample line will be rinsed with dilute (1:100) Liquinox detergent solution and then deionized water in accordance with pre-storm event set-up procedures described in the *Sampling Procedures* section.

2. A pre-cleaned 20 L glass bottle from the laboratory will be placed in the automated sampler.

3. The sample line will be detached at the point of sample collection and placed in a carboy of reagent grade water.

4. The sampler will be programmed to draw 20 L of reagent grade water through the sampler tubing and into the 20 L glass bottle.

5. The 20 L glass bottle will then be removed from the automated sampler, placed on ice, and submitted to laboratory as a separate (blind) sample.

Once in the laboratory, the water from the 20 L glass bottle will be analyzed for the following subset of parameters:

- Total phosphorus
- Orthophosphorus
- Cadmium, dissolved
- Cadmium, total
- Copper, dissolved
- Copper, total
- Zinc, dissolved
- Zinc, total

If any of these parameters are detected in a rinsate blank at concentrations greater than 2 times the reporting limit, the sampling lines for all automated samplers will be cleaned or replaced. Protocols for cleaning sampling lines will be reviewed and augmented if necessary to target contamination from the specific pollutant detected in the rinsate blank. Finally, the laboratory will be contacted to evaluate the adequacy of bottle cleaning procedures.

Distribution System Checks

As described in the *Sampling Process Design* section, stormwater from the cistern (Figures 3 and 4) will be routed via gravity flow or pumped to the Influent Monitoring Station (Figure 3) and individual mesocosms during testing related to the mesocosm research. In either case, weir boxes constructed at the water surface elevation inside the cistern will distribute flows evenly to each mesocosm, with one distribution line bypassing the mesocosms and terminating at the Influent Monitoring Station. Using this design, influent flows and chemistry for all the mesocosms will be generalized based on representative data that are collected at the Influent Monitoring Station.

To verify that flow and chemistry data collected at the Influent Monitoring Station are indeed representative of the influent entering each of the mesocosms, the following checks will be performed:

- Weir box elevation checks
- Influent Monitoring Station and mesocosm flow checks
- Influent Monitoring Station and mesocosm chemistry checks

Each of these checks is described in more detail in the following subsections.

Weir Box Elevation Checks

To ensure there is an even distribution of flow to each mesocosm and the Influent Monitoring Station, the height of the weir boxes will be checked on a monthly basis during the first year of monitoring using a laser level to assure they are at the same elevation. In all subsequent years of monitoring, the height of the weir boxes will be checked on a quarterly basis at a minimum. If the cistern must be entered to perform these checks, monitoring personnel will follow all required safety procedures for confined space entry.

Influent Monitoring Station and Mesocosm Flow Checks

To verify there is an even distribution of flow to each mesocosm and the Influent Monitoring Station, manual measurements of flow will be made at each mesocosm during storm events and compared to the flow measured at the Influent Monitoring Station. Flow measurements at each mesocosm will be made by recording the amount of time it takes to collect a known volume of water from the inlets to each mesocosm. These data will then be compared to the flow recorded by the automated equipment at the Influent Monitoring Station at the corresponding date and time. Modifications to the flow distribution system may be considered if these measurements show the flow at an individual mesocosm deviates by more than 25 percent from the flow measured at the Influent Monitoring Station. These checks will be made during at least five storm events in each monitoring year.

Influent Monitoring Station and Mesocosm Chemistry Checks

To verify the chemistry data from the Influent Monitoring Station are sufficiently representative of the influent to each of the mesocosms, grab samples for total suspended solids (TSS) and dissolved zinc will be simultaneously collected from the Influent Monitoring Station and one randomly selected mesocosm during at least five storm events in each monitoring year. The results from each location will then be compared and evaluated for inconsistencies.

Total suspended solids was specifically selected for these checks because it is expected to be strongly influenced by differential settling within the respective distribution systems for the Influent Monitoring Stations and mesocosms. Dissolved zinc was also selected as a representative parameter for evaluating differences in dissolved constituent concentrations between the Influent Monitoring Station and mesocosms. Modifications to the flow distribution

system may be considered if these measurements show the concentrations at each mesocosm deviate by more than 35 percent from the flow measured at the Influent Monitoring Station.

Concurrent Field Duplicate Samples – Water

Concurrent field duplicate samples will be collected at a sufficient frequency to represent 5 percent of the total number of project samples analyzed. The specific number of field duplicates to be collected during the sampling season is listed in Table 8. Water quality concurrent field duplicate split samples will be collected by deploying an additional duplicate automated sampler at a randomly selected station. This duplicate sampler will be stationed adjacent to the primary samplers and controlled by the data logger in an identical manner to the primary samplers. The sampler intakes will be placed next to each other in the outlet flow control structure.

All duplicate samples will be submitted to the laboratory and labeled as separate (blind) samples. The resultant data from these samples will then be used to assess variation in the analytical results that is attributable to environmental (natural), sub-sampling, and analytical variability (see *Quality Objectives* section).

Field Duplicate Split Samples – Soil

Field duplicate split samples will be collected at a sufficient frequency to represent 5 percent of the total number of project samples analyzed. The number of field duplicates to be collected during the sampling season is listed in Table 9. Soil sample field duplicate split samples will be collected by mixing the sample in a pre-cleaned stainless steel bowl with a pre-cleaned stainless steel spoon until the mixture is homogenous. The sample will subsequently be split in two and placed in separate soil bags. Duplicate sampling stations will be selected randomly.

All duplicate samples will be submitted to the laboratory and labeled as separate (blind) samples. The resultant data from these samples will then be used to assess variation in the analytical results that is attributable to environmental (natural), sub-sampling, and analytical variability.

Sample Handling, Delivery, and Processing

Ice will be placed around the 20 L glass bottles in each automated sampler before each sampled storm event. Ice will not be allowed to sit for more than 24 hours before the initiation of an event (with the goal of keeping sample temperatures below 6 degrees Celsius). After each targeted storm event, all samples will be minimally processed in the field to prevent potential contamination from trace pollutants in the atmosphere. During delivery to the laboratory, all water quality sample containers (i.e., 20 L glass bottles from automated samplers and grab sample bottles) will be transported in coolers with ice and kept below 6 degrees Celsius. The volume of ice should be equal to or greater than the volume occupied by samples (twice the volume of ice to samples is recommended during warm temperatures) (USGS 2003). The

temperature of the samples will be measured upon sample delivery and recorded on the chain of custody form.

Once in the laboratory, the composite samples will be transferred from the 20 L glass bottle from the automated sampler to pre-cleaned sample containers for the required analyses. Composite samples will be split into separate sample containers with the use of a 22 L churn splitter. During the churn splitting, one individual will first agitate the sample and pour the entire contents into the churn. This same individual will then operate the churn handle while another individual operates the spigot at the bottom of the churn. To minimize exposure of the samples to human, atmospheric, and other potential sources of contamination, laboratory staff will process the samples using "clean" techniques pursuant to protocols developed by the U.S. EPA (1996).

Soil samples will be placed in soil bags, labeled, and dried on-site in a drying oven set to 40°C. Once samples are fully desiccated, they will be transferred to the laboratory for further processing and analysis.

Sample Identification and Labeling

Each water and soil sample will be identified with a unique label. Bottles from water quality monitoring will be labeled with the following information using indelible ink and labeling tape:

- Mesocosm ID number (see Figure 3)
- Sample type (grab [G] or flow weighted composite [FWC] sample)
- Date of sample collection (year/month/day: yyyy/mm/dd)
- Time of sample collection (international format [24 hour])
- Field personnel initials

For flow weighted composite samples, the sample collection date and time will be defined based on the data and time the last sample aliquot was collected.

All bags from soil monitoring will be labeled with the following information using indelible ink and labeling tape:

- Mesocosm ID number (see Figure 3)
- Soil column horizon (e.g., 0 to 7.6 cm)
- Date of sample collection (year/month/day: yyyy/mm/dd)
- Time of sample collection (international format [24 hour])
- Field personnel initials

QA samples (field duplicates and rinsate blanks) will only be labeled as QA1, QA2, etc. for delivery to lab, but field staff will maintain a cross-check list of which stations and sample types the QA samples represent. When results from these samples are returned from the laboratory, the station name and QA sample type will referenced to the associated result in the data management system for the study.

Sample Containers and Preservation

Clean, decontaminated sample containers will be obtained from the analytical laboratory in advance of each storm event. Spare sample containers will be carried by the sampling team in case of breakage or possible contamination. Sample containers and preservation techniques will follow U.S. EPA (2007) guidelines. After samples are processed, laboratory personnel will clean the 20 L glass bottles used in the automated samplers with a five step process:

1. Liquinox detergent rinse
2. Reagent grade water rinse
3. 10 percent hydrochloric acid rinse
4. Reagent grade water rinse
5. Rinse with ultra-grade acetone and allow to air dry

All soil samples will be stored in soil bags that will be provided by the laboratory.

Chain-of-Custody Record

A chain-of custody record will be maintained for each sample batch listing the sampling date and time, sample identification numbers, analytical parameters and methods, persons relinquishing and receiving custody, dates and times of custody transfer, and temperature of sample upon delivery.

Laboratory Quality Control Procedures

Quality control procedures that will be implemented in the laboratories are described in the following subsections. The frequency and type of quality control samples to be analyzed by the laboratories are also summarized in Tables 7 and 8.

Method Blanks

Method blanks consisting of de-ionized and micro-filtered pure water will be analyzed with every laboratory sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. The total number of method blanks anticipated for this study is shown in Tables 8 and 9 by parameter. Blank values will be presented in each laboratory report.

Control Standards

Control standards for each parameter will be analyzed by the laboratory with every sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. The total number of control standards anticipated for this study is shown in

Tables 8 and 9 by parameter. Raw values and percent recovery (see formula in the *Quality Objectives* section) for the control standards will be presented in each laboratory report.

Matrix Spikes

For applicable parameters, matrix spikes will be analyzed by the laboratory with every sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. The total number of matrix spikes anticipated for this study is shown in Tables 8 and 9 by parameter. Raw values and percent recovery (see formula in the *Quality Objectives* section) for the matrix spikes will be presented in each laboratory report.

Laboratory Duplicate Split Samples

Laboratory split-sample duplicates for each parameter will be analyzed for specifically labeled QA samples submitted with every sample batch. This will represent no less than 10 percent of the project submitted samples. The total number of laboratory duplicates anticipated for this study is shown in Tables 8 and 9 by parameter. Raw values and relative percent difference (see formula in the *Quality Objectives* section) of the duplicate results will be presented in each laboratory report.

Churn Splitter Rinsate Blanks

Rinsate blanks will be collected from the churn splitter used to process samples for this study in order to verify it is not a source of contamination. At a minimum, two rinsate blanks will be collected for this purpose; the first prior to sampling the first storm event in any given monitoring year, and the second midway through the monitoring year. Each rinsate blank will be collected from churn splitter after it has been cleaned in accordance with standard laboratory procedures. The rinsate blanks will be analyzed for the following subset of parameters:

- Total phosphorus
- Orthophosphorus
- Cadmium, dissolved
- Cadmium, total
- Copper, dissolved
- Copper, total
- Zinc, dissolved
- Zinc, total
- Polycyclic aromatic hydrocarbons

Data Management Procedures

Data from the datalogger associated with the rain gauge, flow gauges, and TDR probes (see description in *Sampling Procedures* section) will be remotely transferred on a daily basis and/or at the beginning and end of each targeted storm event. These data will be immediately checked for evidence of an equipment malfunction or other operational problem. The hydrologic data from each monitoring station will then be imported directly into a database for subsequent analysis and archiving purposes. The database will be used to produce event-based hydrologic summary statistics (e.g., station runoff volume, storm precipitation total, storm duration) for each applicable monitoring location.

Analytical data for the project will be stored in a database with related event-based hydrologic summary statistics from each storm. Electronic data deliverables (EDDs) that are received from the laboratory will be imported directly into the database to prevent data entry errors. For data that must be entered manually, the project Quality Assurance Coordinator will perform an independent review of the date entry to ensure that sample values were transcribed without error. Results from these reviews will be documented on standardized forms (see example in Appendix F).

Audits and Reports

During this study, routine audits of the compiled data will be performed to ensure this QAPP is being implemented correctly. In addition, the data from this study will be summarized in annual reports. The activities are described in more detail in the following subsections.

Audits

Audits will be performed to detect potential deficiencies in the hydrologic, water quality, and soil data that will be collected for this project. Audits for hydrologic data will occur at least monthly and following each sampled storm event. In connection with these audits, the project Quality Assurance Coordinator will examine the new data collected from each monitoring location in relation to data from prior monitoring to identify potential QA issues. This audit will specifically include an examination of the data record for gaps, anomalies, or inconsistencies in the flow data. Any data generated from calibration checks that were performed at a particular monitoring location will also be entered into control charts and reviewed to detect potential instrument drift or other operational problems. In the event that QA issues are identified on the basis of these audits, the Quality Assurance Coordinator will immediately perform a site visit to troubleshoot the problem and to implement corrective actions if possible. Any QA issues that are detected through these audits will be documented in the electronic data record.

Audits performed for water quality and soil data will occur within seven days of receiving results from the laboratory. This review will be performed to ensure that all data are consistent, correct, and complete, and that all required quality control information has been provided. Results from these audits will be documented in standardized quality assurance worksheets (see example in Appendix F) that will be prepared for each batch of samples. In the event that a potential quality assurance issue is identified through these audits, the Quality Assurance Coordinator for the study will review the data to determine if any response actions are required. Response actions might include the collection of additional samples or the reanalysis of existing. Any QA issues that are detected through these audits will be documented in the quality assurance worksheets.

Reports

Annual reports will be prepared through the course of this study to present compiled data, analysis results, and major study conclusions. Each report shall include all monitoring data collected during the preceding water year (October 1 – September 30). Each report will also integrate data from earlier years into the analysis of results, as appropriate. The reports will be submitted in both paper and electronic form (PDF) and include the following specific information:

- Results from hydrologic monitoring performed in connection with each mesocosm
- Results from water quality and soil sampling performed in connection with each mesocosm
- Graphical and tabular summaries for the collected data
- Results from any statistical analyses that are performed on the data
- Major conclusions from monitoring performed over the water year
- Appendices with tabular compilations of all raw monitoring data, field data sheets, laboratory analytical reports, chain of custody documentation, and the Data Quality Assurance Memorandum (see *Data Quality Assessment* section)

Finally, relevant raw water quality chemistry data from study will be submitted to Ecology in an electronic format (Excel file) that is suitable for upload to the Information Management System (EIM) database.

Data Verification and Validation

Data verification and validation will be performed to determine the quality of the compiled data. This process involves a detailed examination of the associated quality control results to determine if the MQOs specified in the *Quality Assurance* section have been met. The specific procedures that will be used to verify and validate hydrologic and chemistry data are described in the following sections.

Hydrologic Data Verification and Validation

The verification and validation process for hydrologic data will involve the following steps:

1. Precipitation data from the study will be reviewed to identify any significant gaps. If possible, these gaps will be filled using data obtained from a nearby rain gauge.

2. The available discharge data from each tipping bucket flow gauges will be verified based on comparisons of the associated hydrographs to the hyetographs for individual storm events. Gross anomalies (e.g., data spikes), gaps, or inconsistencies that are identified through this review will be investigated to determine if there are quality assurance issues associated with the data that limit their usability.

3. Results from field calibration checks (see *Quality Assurance* section) will be reviewed to determine if specific MQOs for the hydrologic data have been met (see *Quality Objectives* section).

4. If minor quality assurance issues are identified in any portion of the discharge record from a particular station and storm event, the data from that station and event will be considered as an estimate and assigned a (j) qualifier. If major quality assurance issues are identified in any portion of the data from a particular station and /or storm event, the data from that station and event will be rejected and assigned an (r) qualifier. Estimated values will be used for evaluation purposes while rejected values will not.

Water Quality and Soil Data Verification and Validation

Water quality data obtained for the study will be reviewed by the Quality Assurance Coordinator to verify that all samples were collected in accordance with the procedures identified in this QAPP and that all required quality assurance/quality control (QA/QC) information was provided by the laboratory. The Quality Assurance Coordinator will then examine the data to determine if there were any errors or emissions. Finally, the Quality Assurance Coordinator will validate the

data by comparing the laboratory quality QA/QC results to the specific MQOs that were established for the study (see *Quality Objectives* section).

For soil data, values associated with minor quality control problems will be considered estimates and assigned *J*. Values associated with major quality control problems will be rejected and qualified *R*. Estimated values may be used for evaluation purposes, while rejected values will not be used.

For water quality data, each flow-weighted composite sample is interpreted to represent the mean concentration for the sampled storm event. However, flow gauge or laboratory error can lead to compromised data which is not representative of the target population (i.e., the true flow-weighted mean concentration of the targeted storm hydrograph). Therefore, the water quality data collected for this study will be labeled with unique quality assurance flags for both laboratory and field data QA issues. Table 10 presents the flagging scheme that will be used in reports produced for this project. Again, estimated values may be used for evaluation purposes, while rejected values will not be used.

Table 10. Data qualifiers and definitions for water quality parameters.

Data Qualifier	Definition	Criteria for Use
J	Value is an estimate based on analytical results.	MQOs for field duplicates, laboratory duplicates, matrix spikes, laboratory control samples, holding times, or blanks have not been met.
R	Value is rejected based on analytical results.	Major quality control problems with the analytical results.
j	Value is an estimate based on storm sampling criteria.	Hydrograph is compromised from gage error, but is still deemed an adequate estimate.
r	Value is rejected based on storm sampling criteria.	Hydrograph is compromised from gage error, and has rendered the EMC non-representative.
Jj	Value is an estimate based on analytical results and storm sampling criteria.	Analytical and storm sampling criteria have not been met, but data is still usable.
Jr	Value is an estimate based on analytical results and rejected based on storm sampling criteria.	Analytical criteria have not been met but data still usable; Hydrograph is compromised from gage error, and has rendered the EMC non-representative.
U	Value is below the reporting limit.	Based on laboratory method reporting limit.
UJ	Value is below the reporting limit and is an estimate based on analytical results.	Based on laboratory method reporting limit; MQOs for analytical results have not been met.
Ur	Value is below the reporting limit and is rejected based on storm sampling criteria.	Based on laboratory method reporting limit; Hydrograph is compromised from gage error, and has rendered the EMC non-representative.
Uj	Value is below the reporting limit and is an estimate based on storm sampling criteria.	Based on laboratory method reporting limit; Analytical and storm sampling criteria have not been met, but data is still usable.

EMC: event mean concentration
MQO: measurement quality objective

The following sections describe in detail the data validation procedures for these specific quality control elements:

- Completeness
- Methodology
- Holding times
- Blanks
- Reporting limits
- Duplicates
- Matrix spikes and matrix spike duplicates
- Calibration and control standards

Completeness

Completeness will be assessed by comparing valid sample data with the data collection goals identified in this QAPP. Completeness will be calculated by dividing the number of valid values by the total number of expected values. Additional samples may be collected if completeness does not meet the specified MQO in the *Quality Objectives* section.

Methodology

Methodologies for analytical procedures will follow U.S. EPA approved methods specified in Tables 6 and 7. Field procedures will follow the methodologies described in this quality assurance project plan. Any deviations from these methodologies must be approved by Ecology and documented in an addendum to this QAPP. The project database will include a field for identifying analytical method. Deviations that are deemed unacceptable will result in rejected values (*R*) and will be corrected for future analyses.

Holding Times

Holding times for each analytical parameter in this study are summarized in Tables 6 and 7. Filtration and analysis dates and times will be reported by the laboratory. Holding times will be assessed by comparing the filtration and analysis dates and times to the sample collection dates and times. For flow weighted composite samples, the sample collection date and time will be defined based on the data and time the last sample aliquot was collected.

The following guidelines will be applied when evaluating analysis holding times for parameters with holding times in excess of 7 days:

- Data from samples that exceed the specified maximum post-filtration holding times by less than 48 hours will be considered estimates (*J*)

- Data from samples that exceed the maximum post-filtration holding times by more than 48 hours will be rejected values (*R*)

The following guidelines will be applied when evaluating holding times for parameters with holding times that are less than 7 days:

- Data from samples that exceed the specified maximum post-filtration holding times by less than 24 hours will be considered estimates (*J*)
- Data from samples that exceed the maximum post-filtration holding times by more than 24 hours will be rejected values (*R*)

Method Blanks

Method blank values will be compared to the MQOs that have been identified for this project (see *Quality Objectives* section). If an analyte is detected in a method blank at or below the reporting limit, no action will be taken. If blank concentrations are greater than the reporting limit, the concentration measured in the blanks will become the de facto reporting limit for that analyte. Any sample concentrations below this de facto limit will be flagged with a *U*, while sample concentrations within 5 times this de facto reporting limit will be flagged with a *J* (Grepogrove 2007). In each case, the de facto reporting limit for that analyte will be recorded with the raw data instead of the method reporting limit.

Rinsate Blanks

Rinsate blank values will be compared to the MQOs that have been identified for this project (see *Quality Objectives* section). If an analyte is detected in a rinsate blank at concentrations that exceed 2 times the reporting limit, the concentration measured in the blank will become the de facto reporting limit for that analyte for all samples collected at that station since the last rinsate blank was collected. Any sample concentrations below this de facto limit will be flagged with a *U*, and sample concentrations within 5 times this de facto reporting limit will be flagged with a *J* (Grepogrove 2007). In each case, the de facto reporting limit for that analyte will be recorded with the raw data instead of the method reporting limit. In addition, the sampling lines for all automated samplers will be cleaned or replaced. Protocols for cleaning sampling lines will be reviewed and augmented if necessary to target contamination from the specific pollutant detected in the rinsate blank. Finally, the laboratory will be contacted to evaluate the adequacy of bottle cleaning procedures.

Reporting Limits

Both raw values and reporting limits will be presented in each laboratory report. If the proposed reporting limits are not met by the laboratory, the laboratory will be requested to reanalyze the samples and/or revise the method, if time permits. Proposed reporting limits for this project are summarized in Tables 6 and 7.

Duplicates

Duplicate results exceeding the MQOs for this project (see *Quality Objectives* section) will be recorded in the raw data tables, and noted in the quality assurance worksheets (see example in Appendix F); and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (e.g., more than twice the objective), then associated values will be rejected (*R*).

Matrix Spikes

Matrix spike results exceeding the MQOs for this project (see *Quality Objectives* section) will be noted in the quality assurance worksheets (see example in Appendix F), and associated values will be flagged as estimates (*J*). However, if the percent recovery exceeds the MQOs and a value is less than the reporting limit, the result will not be flagged as an estimate. Non-detected values will be rejected (*R*) if the percent recovery is less than 30 percent.

Control Standards

Control standard results exceeding the MQOs for this project (see *Quality Objectives* section) will be noted in the quality assurance worksheets (see example in Appendix F), and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (e.g., more than twice the objective), then associated values will be rejected (*R*).

Data Quality Assessment

The subsection below describes the process for determining whether the data meet project objectives once the data results are compiled. Data analysis procedures that will be used to meet these objectives are then summarized in the following subsection.

Data Usability Assessment

Based on the results from the processes described in the *Data Verification and Validation* section, the Quality Assurance Coordinator will prepare annual Data Quality Assurance Memoranda to summarize quality control results, identify when data quality objectives were not met, and discuss the resulting limitations, if any, on the use or interpretation of the data. Specific QA information that will be noted in each data validation memorandum is as follows:

- Changes in the monitoring and quality assurance plan
- Results of performance and/or system audits
- Significant quality assurance problems and recommended solutions
- Data quality assessment results in terms of precision, bias, representativeness, completeness, comparability, and reporting limits
- Discussion of whether the quality assurance objectives were met, and the resulting impact (if any) on decision-making
- Limitations on use of the measurement data

These Data Quality Assurance Memoranda will establish the usability of data and will be included as an appendix to data reports (see *Audits and Reports* section) that are prepared for each water year.

Data Analysis Procedures

The sections below present data analysis procedures that will be used to compare the flow control and water quality treatment performance of four bioretention soil mixes that will be evaluated through this study (see *Project Description* section). (Note that Appendix A also presents data analysis procedures that are specific to the four mesocosms that are being monitored pursuant to the requirements of the City of Seattle's Phase I Municipal Stormwater Permit.)

Flow Control Performance

To evaluate the flow control performance of the bioretention soil mixes, the following information will be compiled for each storm that occurred during each water year:

- Storm precipitation depth
- Storm duration
- Storm average precipitation intensity
- Storm peak precipitation intensity
- Storm antecedent dry period
- Peak discharge at each mesocosm and the Influent Monitoring Station
- Runoff volume at each mesocosm and the Influent Monitoring Station
- Flow duration at each mesocosm and the Influent Monitoring Station

Once this information is compiled, additional analyses will be performed to identify a subset of storms that had sufficient precipitation totals and/or intensities to produce measurable runoff into the mesocosms. Specifically, any storm event that produced a measurable flow volume at the Influent Monitoring Station will be flagged as runoff-producing.

Statistical analyses will then be performed on the data from the runoff-producing storms to compare flow control performance of the various bioretention soil mixes. The specific null hypotheses (H_o) and alternative hypotheses (H_a) for these analyses is as follows:

Hypothesis 1:

H_o: Effluent volumes from all four bioretention soil mixes are equal.

H_a: Effluent volumes from one or more of the bioretention soil mixes are significantly different from the others.

Hypothesis 2:

H_o: Peak effluent flow rates from all four bioretention soil mixes are equal.

H_a: Peak effluent flow rates from one or more of the bioretention soil mixes are significantly different from the others.

Hypothesis 3:

H_o: Effluent flow durations from all four bioretention soil mixes are equal.

H_a: Effluent flow durations from one or more of the bioretention soil mixes are significantly different from the others.

To evaluate these hypotheses, the data for each measure of treatment performance (i.e., flow duration, peak flow rate, and flow duration) will be analyzed using Analysis of Variance (ANOVA) tests (or a non-parametric analogue) to determine if the there are significant differences between the bioretention soil mixes. Where significant differences are detected

through these tests, follow-up multiple range tests will be applied to the data to determine which specific bioretention soil mixes are different from the others. In all tests, statistical significance will be assessed based on an alpha (α) level of 0.05.

Water Quality Treatment Performance

Data analyses will be performed to evaluate the water quality treatment performance of each of the bioretention soil mix following procedures identified by Ecology (2008). The specific goal of these analyses will be to evaluate the performance of the bioretention soil mixes relative to the following treatment goals that are identified in Ecology (2008):

- **Basic Treatment** – 80 percent removal of TSS for influent concentrations that are greater than 100 milligrams/liter (mg/L), but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L TSS.
- **Enhanced Treatment** – Provide a higher rate of removal of dissolved metals than most basic treatment facilities. The performance goal assumes that the facility is treating stormwater with dissolved copper typically ranging from 0.003 to 0.02 mg/L, and dissolved zinc ranging from 0.02 to 0.3 mg/L. Data collected for an "enhanced" best management practice (BMP) should demonstrate significantly higher removal rates than basic treatment facilities.
- **Phosphorus Treatment** – 50 percent removal of TP for influent concentrations ranging from 0.1 to 0.5 mg/L.
- **Oil Treatment** – No ongoing or recurring visible sheen, a daily average total petroleum hydrocarbon concentration no greater than 10 mg/L, and a maximum of 15 mg/L for a discrete (grab) sample.

These treatment goals are to be evaluated with a 95 percent statistical confidence and 80 percent power. The specific procedures that will be used in the evaluation of these goals are as follows:

- Statistical comparison of influent and effluent pollutant concentrations and loads
- Calculation and evaluation of pollutant reduction efficiencies
- Evaluation of pollutant reduction efficiencies relative to efficiencies for representative basic treatment facilities
- Evaluation of effluent concentrations
- Correlation analysis to examine the influence of storm characteristics on treatment performance

Each of these procedures is described in more detail in the following subsections.

Statistical Comparisons of Influent and Effluent Pollutant Concentrations and Loads

Statistical analyses will be performed to assess significance of differences in influent and effluent pollutant concentrations and loads for the various bioretention soil mixes. The specific null hypothesis (H_o) and alternative hypothesis (H_a) for these analyses are as follows:

Ho: Effluent pollutant concentrations and loads are equal to or higher than influent concentrations and loads.

Ha: Effluent concentrations and loads are lower than influent concentrations and loads.

To evaluate these hypotheses, a Wilcoxon signed rank test (Helsel and Hirsch 2002) will be used to compare influent and effluent concentrations and loads for each of the bioretention soil mixes across all sampled storm events in the monitoring period of interest. The Wilcoxon signed rank test is a non-parametric analogue to the paired t-test. Through the use of a paired test, differences in the performance data for each monitoring station can be more efficiently assessed, because the noise (or variance) associated with monitoring over a range of storm sizes are blocked out of the statistical analyses (Helsel and Hirsch 2002). In all tests, statistical significance will be assessed based on an alpha (α) level of 0.05.

Calculation and Evaluation of Pollutant Reduction Efficiencies

Pursuant to guidance from Ecology (2008), pollutant reduction efficiencies for each bioretention soil mix will be estimated using the three methods described below.

Method #1: Individual Storm Reduction in Pollutant Concentration

The reduction (in percent) in pollutant concentration during each individual storm (ΔC) will be calculated as:

$$\Delta C = 100 \times \frac{\left(C_{in} - C_{eff}\right)}{C_{in}}$$

Where: C_{in} = flow-weighted influent pollutant concentration

C_{eff} = flow-weighted effluent pollutant concentration.

For TSS and total phosphorus, the median percent reduction in concentrations and associated 95 percent confidence interval about the median will be estimated using a bootstrapping approach (Helsel and Hirsch 2002). The lower confidence interval about the median for each parameter will then be used to determine whether the treatment goals identified above for basic and phosphorus treatment have been met. Specifically, if the lower confidence limit is higher than the specified removal efficiency goals for each treatment category, it can be concluded that

the treatment goal was met with the required 95 percent confidence that is specified in Ecology (2008).

Method #2: Aggregate Pollutant Loading Reduction

The aggregate reduction (in percent) in pollutant load for all storms (ΔL_{agg}) will be calculated as:

$$\Delta L_{agg} = 100 \times \frac{\left(\sum_{i=1}^{n} \left(C_{i,in} * V_i \right) - \sum_{i=1}^{n} \left(C_{i,eff} * V_i \right) \right)}{\sum_{i=1}^{n} \left(C_{i,in} * V_i \right)}$$

Where: $C_{i,in}$ = influent pollutant concentration for storm *i*

V_i = volume of storm *i*

$C_{i,eff}$ = flow-weighted effluent pollutant concentration

n = number of storms

Method #3: Individual Storm Reduction in Pollutant Loading

Pollutant load reduction (in percent) in individual storms (ΔL) will be calculated as:

$$\Delta L = 100 \times \frac{\left(\left(C_{in} \times V \right) - \left(C_{eff} \times V \right) \right)}{\left(C_{in} \times V \right)}$$

Where: C_{in} = flow-weighted influent pollutant concentration

V_i = volume of storm *i*

C_{eff} = flow-weighted effluent pollutant concentration

Like the Method #1 calculations above, the median percent reduction in loads for TSS and total phosphorus will be estimated using a bootstrapping approach along with the associated 95 percent confidence interval about the median (Helsel and Hirsch 2002). The lower confidence interval about the median will then be compared to the treatment goals identified above for basic and phosphorus treatment to determine if they have been met with the required 95 percent confidence that is specified in Ecology (2008).

Evaluation of Pollutant Reduction Efficiencies Relative to Efficiencies for Representative Basic Treatment Facilities

As described above, the Ecology (2008) indicates that the data collected for an "enhanced" BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment facilities. To determine if any of the bioretention soil mixes meet this goal with a specific level

of statistical confidence, a one-tailed Mann Whitney U test will be used to compare reduction efficiencies for dissolved zinc and dissolved copper to the representative reduction efficiencies for basic treatment facilities that are in the International Stormwater Best Management Practices Database (ASCE 2009). The specific null and alternate hypotheses that will be assessed in these tests are as follows:

H_o: Bioretention soil mix pollutant reductions efficiencies are equal to or lower than those for basic treatment facilities

H_a: Bioretention soil mix pollutant reductions efficiencies are greater than those for basic treatment facilities.

Pursuant to the guidelines in Ecology (2008), statistical significance in these tests will be evaluated at an alpha (α) level of 0.10.

Evaluation of Effluent Concentrations

To evaluate the treatment goals identified above for TSS and oil control that are based on target effluent concentrations, the median effluent concentration for the associated parameters will be estimated using a bootstrapping approach (Helsel and Hirsch 2002) along with the 95 percent confidence interval about the median. The upper confidence interval about the median for each parameter will then be used to determine whether the treatment goals identified have been met. Specifically, if the upper confidence limit is lower than the specified effluent concentration goals for each treatment category, it can be concluded that the treatment goal was met with the required 95 percent confidence that is specified in Ecology (2008).

Correlation Analysis to Examine Influence of Storm Characteristics

Kendall's tau correlation coefficients will be used to evaluate whether the following storm event characteristics influence the treatment performance of the various bioretention soil mixes:

- Storm precipitation depth
- Storm average intensity
- Storm peak intensity
- Storm antecedent dry period
- Storm duration
- Peak influent discharge
- Average influent discharge
- Sample date

These tests will specifically examine potential relationships between these storm event characteristics and the following variables that either directly measure or indirectly influence system performance: influent concentration, effluent concentration, and pollutant removal efficiency estimates. In all cases, the statistical significance of these tests was evaluated at an alpha level (α) of 0.05.

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APPENDIX A

Description of Monitoring Activities to be Performed Pursuant to City of Seattle Phase I Municipal Stormwater Requirements

Monitoring Activities to be performed pursuant to City of Seattle Phase I Municipal Stormwater Permit Requirements

As described in the *Introduction* section to this Quality Assurance Project Plan (QAPP), monitoring to be performed on a subset of the mesocosms constructed for the Low Impact Development (LID) Research Program will also be used to meet requirements specified in Section S.8.F of the City of Seattle's Phase I Municipal Stormwater Permit (Permit). Specifically, this monitoring will be performed on a subset of 4 mesocosms out of the 20 that will be constructed for the LID Research Program. These four mesocosms that will be constructed with the bioretention soil mix consisting of 60 percent aggregate and 40 percent compost. In accordance with a Memorandum of Agreement (MOA) between the City of Seattle and Washington State University (WSU), monitoring activities for this subset of mesocoms will conform to requirements identified in the permit and Washington State Department of Ecology (Ecology) guidelines for monitoring emerging stormwater treatment technologies (Ecology 2008).

This appendix evaluates the mesocosms' sizing and operational configuration relative to Seattle Public Utilities' (SPU) design criteria for bioretention systems; it then outlines specific monitoring activities within this QAPP that will be performed pursuant to these requirements. This information is presented herein under the following subheadings:

- Monitoring Schedule
- Mesocosm Sizing
- Mesocosm Operating Configuration
- Flow Monitoring
- Water Quality Monitoring
- Sediment Monitoring
- Sampling and Analysis Goals
- Reporting

Monitoring Schedule

Permit required monitoring will begin October 1, 2010. The goal will be to collect five flow weighted composite samples annually from the four replicate mesocosms that are being monitored pursuant to the MOA between the City of Seattle and WSU. Over a two year period of monitoring, this will yield approximately 40 paired influent and effluent samples for evaluating the treatment effectiveness of the associated bioretention soil mix (4 mesocosoms × 5 samples/year × 2 years of monitoring = 40 samples). Pursuant to guidance presented in Ecology (2008), the reasonable maximum sampling effort for evaluating the performance of emerging stormwater treatment technologies is 35 samples. However, as described below, the data obtained from this monitoring may be analyzed after a minimum of 12 samples has been collected to determine if additional sample collection is warranted.

Mesocosm Sizing

The mesocosm performance monitoring program will be implemented on the WSU campus in Puyallup, Washington (see vicinity map in Figure 1 of main text). As described in the *Sampling Process Design* section within the main body of this QAPP, stormwater will be collected from a 72,084 square feet (ft^2) impervious drainage area on the WSU campus for studies to be conducted through the LID Research Program. Runoff from approximately 25 percent of this area (18,021 ft^2) can be routed via gravity flow to the 20 mesocosms and Influent Monitoring Station that will be constructed for the testing facility. Each mesocosm has a surface area of 19.63 ft^2. Given flows from the impervious drainage area will be distributed equally to the 20 mesocosms and the Influent Monitoring Station, the ratio of contributing basin area to surface area for the mesocosm is 2.3 percent ([19.63 $ft^2 \times 21$]/18,021 ft^2 = 0.023 = 2.3 percent).

For reference, SPU sizing criteria for water quality treatment using bioretention require the bottom area of the treatment system to represent 2.6 percent of the contributing area for 6 inches of ponding, and 2.0 percent of the contributing area for 12 inches of ponding. To meet SPU's flow volume reduction standard for Green Stormwater Infrastructure (GSI) (i.e., infiltration of 95 percent of the total annual runoff volume), the treatment system must be sized to represent 6.0 percent of the contributing area. Finally, to meet SPU's standard for peak flow control, the treatment system must be sized to represent 6.5 percent of the contributing area.

In general, these data indicate the mesocosms are appropriately sized for assessing the performance of systems that were constructed to meet SPU's sizing criteria for water quality treatment. However, the mesocosms are undersized by a factor of approximately 3 relative to SPU's sizing criteria for GSI and peak flow control. Given this consideration, flow will enter the mesocosom through a manifold constructed of plastic piping perforated with drilled holes that distributes water across the surface of the tank. This system will prevent the mobilize soils within the mesocosms that might otherwise bias data obtained for characterizing water quality treatment performance.

Mesocosm Operating Configuration

Pursuant to SPU design criteria, the maximum ponding depth for bioretention cells is 12 inches; in high density right-of-way applications, the ponding depth shall be no greater than 6 inches, Furthermore, bioretention cells must be installed in soils with infiltration rates that are adequate to meet maximum pool drawdown times; alternatively, bioretention cells must be installed with an underdrain.

As described, the *Sampling Process Design* section within the main body of this QAPP, the mesocosms are equipped with an outlet flow control structure that can be used to adjust the saturated zone level, hydraulic residence time, and ponding depth within the media tank for each mesocosm. However, the outlet flow control structures will not be utilized for monitoring that is performed to meet the City of Seattle's permit requirements; rather, the four associated

mesocosms will be operated with bypass valves for the outlet flow control structures set to remain open. With these bypass valves open, the flow of water through the bioretention soil mixes will not be subject to any artificial controls and will essentially mimic the natural drainage condition. Furthermore, the mesocosms will be constructed to allow at least 12 inches of ponding over the associated bioretention soil mix. When operated in this configuration, the mesocosms should provide representative data for assessing bioretention soil mix treatment performance based on SPU's design criteria.

Flow Monitoring

Stormwater inflows and outflows to the four mesocosms that will be monitored for the City of Seattle's permit requirements will be measured continuously. Although the mesocosms are sized for water quality only, the flow data will then be analyzed to evaluate the flow reduction effects of the bioretention soil mix, including its effects on reducing and/or delaying flow peaks, volume, and duration. In conjunction with the water quality monitoring described below, these data will also facilitate event-based pollutant loading analyses for characterizing water quality treatment performance. The specific procedures that will be used collect flow monitoring data are described in the *Sampling Procedures* section within the main body of this QAPP.

Water Quality Monitoring

As described in the Sampling Process Design section within the main body of this QAPP, monitoring of the mesocosms for the LID research program will be conducted in three phases: Baseline monitoring, Phase 1 monitoring, and Phase 2 monitoring. Baseline monitoring will characterize the physical and chemical properties of the various bioretention soil mixes prior to the onset of monitoring activities that are performed to quantify their treatment performance. Phase 1 monitoring will involve quantifying the treatment performance of the mesocosms using stormwater that is generated during natural storms and routed by gravity to the individual mesocosms via a 11,370 liter (L) (3,000 gallon) cistern. Phase 2 will involve quantifying treatment performance of the mesocosms using stormwater that is stored in the cistern and pumped to mesocosms at specific flow rates, volumes, and pollutant concentrations to generate synthetic storms.

It is anticipated that <u>all</u> monitoring for the City of Seattle's permit requirements will occur during the Phase 1 monitoring period. During this period, the cistern will not be drained between storms; therefore, any stormwater that enters the cistern from the associated drainage basin will flow directly to the mesocosms without attenuation. Furthermore, eductors installed inside the cistern will be activated during sampled storm events to keep particulate bound pollutants from settling out in the cistern prior to reaching the mesocosms. This will minimize any pretreatment that might occur in the cistern that would bias the results from the mesocosm monitoring. If settling of solids does occur within the cistern (pretreatment), the result will be to lower the influent concentration of stormwater distributed to all the mesocosms and the Influent

Monitoring Station. The influent versus effluent comparison will not be compromised by the effect of pretreatment, but the calculated performance efficiency of the mesocosms may be more conservative compared to using "untreated" or higher concentration influent stormwater.

During the Phase 1 monitoring, flow weighted composite effluent samples will be collected from each mesocosm and used to characterize effluent chemistry. Similarly, one flow weighted composite sample will be collected from the Influent Monitoring Station and used to generalize influent chemistry across all the mesocosms. Based on guidance presented in Ecology (2008), the following criteria will be used to determine the acceptability of individual storm events for monitoring:

- Target storm depth: A **minimum of 0.15 inches** of precipitation over a 24 hour period.
- Antecedent conditions: A period of **at least 6 hours** preceding the event **with less than 0.04 inches** of precipitation.
- Minimum duration: Target storms must have **a duration of at least 1 hour**.
- End of storm: A continuous **6-hour period with less than 0.04 inches of precipitation**.

During each event, the following sampling criteria will also be adopted from Ecology (2008) to determine the acceptability of flow weighted composite samples:

- Samples shall be collected for at least **75 percent of the storm event hydrograph** as measured by volume.
- The maximum time period over which samples are to be collected is **36 hours**.
- A minimum of **10 sample aliquots** is collected for compositing during each storm event.

The collected flow weighted composite samples will be submitted to an accredited laboratory where they will be analyzed using the analytical methods identified in Appendix 9 of the Permit for the following parameters:

- pH
- Particle size distribution
- Hardness
- Total suspended solids
- Total phosphorus
- Orthophosphorus
- Total and dissolved copper and zinc

The specific procedures that will be used during water quality monitoring are described in the *Sampling Procedures* section within the main body of this QAPP. The associated analytical methods are described in the *Measurement Procedures* section and summarized in Table 6.

Sediment Monitoring

In general, monitoring of sediment accumulation rates is advised in Ecology (2008) to help demonstrate facility performance and design a maintenance plan. However, because sediment accumulation rates within the mesocosms are expected to be very low, implementation of monitoring to meet this goal will not be practical in this study. In lieu of this monitoring, the total amount of sediment removed by the mesocosms will be estimated using a mass balance approach based on comparisons of influent and effluent total suspended solids and suspended sediment loads. In addition, the predominant size fraction of the sediment removed by the mesocosms will be estimated based on comparisons of particle size distributions that are measured in influent and effluent samples.

Sampling and Data Analysis Goals

Pursuant to section S8.F of the permit, sampling and data analysis must be performed to "determine mean effluent concentration and mean percent removals for each BMP type with 90 to 95% confidence and 75 to 80 percent power." On August 19, 2010, representatives from Herrera Environmental Consultants (Herrera), SPU, Ecology, and WSU met to discuss the interpretation of this requirement. Based on these discussions, the following considerations will be applied to meet the sampling and data analysis goals for the four mesocosms that are being monitored pursuant to the permit:

- A minimum of 12 qualifying samples from the four mesocosms combined will be collected to evaluate the water quality treatment performance of the bioretention soil mix for any given parameter. Each qualifying sample must meet the storm, sampling, and influent concentration criteria that are specified in Ecology's guidelines for monitoring emerging stormwater treatment technologies (Ecology 2008).

- After this minimum number of qualifying samples has been collected, an appropriate paired statistical test can be performed at any time to determine if influent concentrations are significantly different from effluent concentrations for each parameter. Specifically, a Wilcoxon signed-rank test will be used for parameters that are found to have a non-normal distribution, while a paired t-test will be used for parameters that exhibit a normal distribution. If these tests indicates there is a significant difference for a given parameter, it can be assumed an adequate number of samples have been collected to demonstrate removal with the required

confidence and power; therefore, no further sampling for that parameter is required. In these instances, the actual treatment performance for the parameter will be quantified based on the calculated mean effluent concentration and removal efficiency from the available data.

- If the test indicates there is no significant difference between the influent and effluent concentrations for a given parameter, then an assessment can be made to determine if additional sampling for that parameter is warranted prior to reaching the reasonable maximum sampling effort of 35 samples. Specifically, if it can be reasonablely argued that the collection of additional samples will not have a meaningful impact on the conclusions of the study, then the City of Seattle can request sampling be terminated after the minimum of 12 qualifying samples has been collected.

Specific issues that might be used to justify the termination of sampling for any given parameter include:

- Treatment performance for a parameter cannot be evaluated because influent concentrations are consistently at levels that are considered irreducible.
- Effluent data indicate a particular pollutant is being exported on a consistent basis from the bioretention soil mix.
- Influent and effluent concentrations that are consistently similar; hence, additional sampling up to the reasonable maximum sampling effort of 35 samples will likely not be sufficient to demonstrate any significant difference in these concentrations.

Reporting

Pursuant to requirements identified in section S8.H of the permit, data obtained from the mecososm performance monitoring will be summarized in annual reports to Ecology. The first report will be submitted in March 2011 and provide an overview of mesocosm project and construction schedule from water year 2010. Monitoring reports with then be prepared in March 2012 and March 2013 (if necessary) to summarize data from water years 2011 and 2012, respectively. These reports will present the following information:

- The current status of the monitoring program
- A comprehensive data and QA/QC report, with an explanation and discussion of the results
- Water quality treatment and flow reduction performance data from the mesocosms

In addition to the annual monitoring reports, monitoring data pertinent to fulfilling the National Stormwater BMP Data Base input requirements will also be collected as described in section 3.4.3 of USEPA publication number 821-B-02-001, *Urban Stormwater BMP Performance Monitoring*.

APPENDIX B

Detailed Compost and Mineral Aggregate Specifications for Bioretention Soil Mixes

WSU LID Research Program

Mesocosms bioretention soil mix

A total of 20 mesocosm tanks will be used with five treatments (below) replicated four times. The fifth treatment will depend on initial column tests to determine suitability of biosolids or other material for use in bioretention applications. The five treatments include:

1. 60 percent mineral aggregate and 40 percent compost by volume (approximately 8 percent organic matter by weight).

2. 80 percent mineral aggregate and 20 percent compost by volume (approximately 4 percent organic matter by weight).

3. 60 percent mineral aggregate, 15 percent compost, 15 percent shredded cedar bark, and 10 percent water treatment residuals (alum sludge or new alum) by volume.

4. 60 percent mineral aggregate, 30 percent compost, and 10 percent water treatment residuals (alum sludge or new alum) by volume.

5. 60 percent mineral aggregate, 15 percent biosolids, 15 percent shredded cedar bark, and 10 percent water treatment residuals (alum sludge or new alum) by volume. This is a proposed mix and is subject to change based on preliminary testing.

The mineral aggregate will meet the below gradation:

Sieve Size	Percent Passing
3/8”	100
#4	95-100
#10	75-90
#40	25-40
#100	4-10
#200	2-5

The compost will meet the following specifications:

- Material must be in compliance with WAC chapter 173-350 section 220, and be made from Type 1, 2, or 3 feedstock. Type 1 feedstock is recycled plant waste, including agricultural, yard, pre-consumer food, and cardboard; Type 2 is manure and bedding; Type 3 is post-consumer food, biosolids (sewage sludge), and other materials judged low in contaminants but potentially high in pathogens. Type 4 feedstock is mixed municipal solid waste, industrial solid wastes and other materials judged high risk for toxics, contaminants or pathogens.
- Organic matter content between 45% and 65% as determined by loss of ignition test method.
- pH between 5.5 and 8.0.

- Carbon:nitrogen ratio between 20:1 and 25:1 for most landscapes. A CN ratio of 30:1 to 35:1 is preferred for native woody plantings, especially in restoration projects, because it supports these plants and minimizes weed growth.
- Maximum electrical conductivity of 6 mmhos/cm (or 4 mmhos/cm for sites east of the Cascades where there is less rainfall to leach salts from BSM).
- Moisture content range between 35 and 50%.
- No viable weed seeds.
- Manufactured inert material (plastic, concrete, ceramics, etc.) should be less than 1% on a dry weight or volume basis (as required by WAC 173-350-220).

- Metals should not be in excess of limits in the following table (from WAC 173-350-220).

Metal	Limit (mg/kg dry weight)
Arsenic	≤ 20 ppm
Cadmium	≤ 10 ppm
Copper	≤ 750 ppm
Lead	≤ 150 ppm
Mercury	≤ 8 ppm
Molybdenum	≤ 9 ppm
Nickel	≤ 210 ppm
Selenium1	≤ 18 ppm
Zinc	≤ 1400 ppm

APPENDIX C

Project Funding Details

Puyallup Research and Extension Center Stormwater Retrofit		
ELEMENTS (Tasks or Objects)	**TOTAL PROJECT COST (TPC)**	**TOTAL ELIGIBLE COST (TEC)**
1 - Project Management	$133,500	$95,000
2 – Environmental Assessment and Project Design	$84,107	$84,107
3 – Plans and Specifications	$100,000	$100,000
4 – Construction Management	$40,000	$40,000
5 – Construction of LID Integrated Management	$844,140	$785,726
6 – LID Monitoring and Analysis; Training, Education and Outreach	$228,500	$228,500
Total	$1,430,247	$1,333,333
The DEPARTMENT's Fiscal Office will track to the Total Eligible Cost.		
MATCHING REQUIREMENTS		
DEPARTMENT Share: maximum 75% of TEC		$1,000,000
RECIPIENT Share: minimum 25% of TEC		$333,333
RECIPIENT Share of ineligible project costs: Funding source: Cash		$96,914

APPENDIX D

Elevation of Stormwater Conveyance Structures in Drainage Basin to the Mesocosm Cistern

SW 1/4, SECTION 29, TOWNSHIP 20 NORTH, RANGE 4 EAST, W.M.

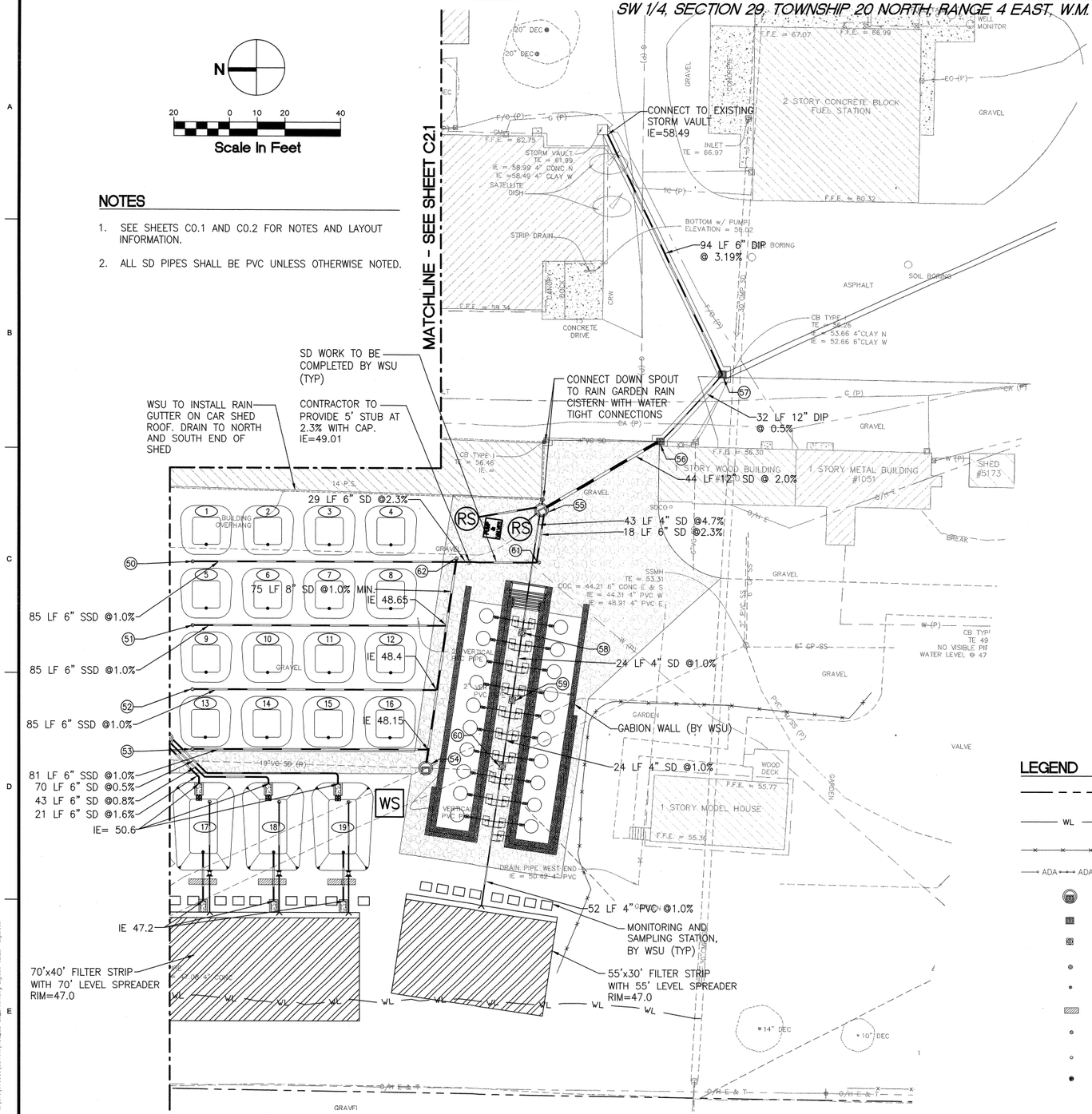
N

20 0 10 20 40

Scale In Feet

NOTES

1. SEE SHEETS C0.1 AND C0.2 FOR NOTES AND LAYOUT INFORMATION.
2. ALL SD PIPES SHALL BE PVC UNLESS OTHERWISE NOTED.



BIORETENTION FACILITY TABLE

NO.	TOP	BOTTOM	OVERFLOW RIM	OVERFLOW IE	NOTES
1	54.0	52.5	53.25	50.33	RAIN GARDEN "TEST CELL"–DETAIL 5/C4.3
2	54.0	52.5	53.25	50.33	"
3	54.0	52.5	53.25	50.33	"
4	54.0	52.5	53.25	50.33	"
5	53.75	52.25	53.0	50.08	"
6	53.75	52.25	53.0	50.08	"
7	53.75	52.25	53.0	50.08	"
8	53.75	52.25	53.0	50.08	"
9	53.5	52.0	52.75	49.83	"
10	53.5	52.0	52.75	49.83	"
11	53.5	52.0	52.75	49.83	"
12	53.5	52.0	52.75	49.83	"
13	53.25	51.75	52.5	49.58	"
14	53.25	51.75	52.5	49.58	"
15	53.25	51.75	52.5	49.58	"
16	53.25	51.75	52.5	49.58	"
17	52.0	50.0	50.5	47.56	RAIN GARDEN "HYDRAULIC CELL"–DETAIL 4/C4.3
18	52.0	50.0	50.5	47.56	"
19	52.0	50.0	50.5	47.56	"

STORM STRUCTURE TABLE

NO	RIM	IE	NOTES	NORTHING/EASTING
50	53.75	49.75 (S)	CLEANOUT	N 681920.00 E 1185375.09
51	53.50	49.50 (S)	CLEANOUT	N 681920.02 E 1185352.09
52	53.25	49.25 (S)	CLEANOUT	N 681920.04 E 1185329.09
53	53.00	49.00 (S)		N 681920.05 E 1185307.79
54	52.70	47.0± (N/S/E)	CONNECT TO EX 10" SD VERIFY IE (N/S)	N 681836.11 E 1185301.04
55	57.30	51.50 (12"SE) 50.00 (6"&4"W)	RIM TO BE ABOVE ADJACENT GRADE, SEE CISTERN DETAILS D2.1	N 681788.92 E 1185398.65
56	56.40	54.84 (SE) 52.40 (NW) 53.70 (N EX)	CONNECT TO EX 4" SD CAP EX 4" SD OUTFALL	N 681751.62 E 1185419.90
57	56.75	55.50 (NE) 55.00(NW)		N 681729.26 E 1185444.26
58	50.50	48.00		N 681801.33 E 1185349.84
59	50.50	47.76		N 681804.89 E 1185301.89
60	50.50	47.52		N 681808.44 E 1185301.89
61	51.1	49.58	CLEANOUT	N 681795.19 E 1185375.14
62	54.4	48.90 (N/S/W)	CLEANOUT	N 681824.94 E 1185376.47

(BY WSU)

LEGEND

- PROPERTY LINE
- WL — 50' WETLAND BUFFER LINE PER PACIFIC RIM SOIL AND WATER, INC.
- TREE PROTECTION (5 / L2.0)
- ADA — ADA ADA ROUTE OF TRAVEL
- CATCH BASIN, TYPE II
- WSDOT CATCH BASIN, TYPE 1
- AREA DRAIN (6 / C4.7)
- DOWNSPOUT (5 / C4.7)
- OBSERVATION PORT (4 / C4.6)
- TRENCH DAM (2 / C4.6)
- CLEANOUT (5 / C4.3) OR (8 / C4.6) OR (1 / C4.7)
- SOIL SAMPLING PORT (9 / C4.6)
- GRAVEL POCKETS (3 / C4.7)
- STORM DRAIN (1 / C4.6)
- RETAINING WALL (1 / S1.0) OR (2 / S1.0)
- GABION WALL (BY WSU) (6 / L2.0)
- FILTER STRIP (7 / C4.6)
- MESOCOSM MONITORING (BY WSU) SEE SHEET D1.0
- RS — RAIN GARDEN RAIN CISTERN (BY WSU) SEE SHEET D1.0
- WS — WEATHER STATION (BY WSU)
- SSD — SLOTTED STORM DRAIN

APPROVED

BY _____ CITY OF PUYALLUP ENGINEERING SERVICES

DATE 6-29-09

NOTE: THIS APPROVAL IS VOID AFTER 1 YEAR FROM APPROVAL DATE. THE CITY WILL NOT BE RESPONSIBLE FOR ERRORS AND/OR OMISSIONS ON THESE PLANS. FIELD CONDITIONS MAY DICTATE CHANGES TO THESE PLANS AS DETERMINE BY THE CITY ENGINEER.

REV.	APPD.	DATE	DESCRIPTION

SvR DESIGN COMPANY
1205 SECOND AVE, SUITE 200
SEATTLE, WA 98101
T 206.233.0326
F 206.233.9135
www.svrdesign.com

WASHINGTON STATE UNIVERSITY
Department of Facilities Operations
Maintenance Shop
509-335-9003
Pullman, Wa. 99164-1150
FAX 509-335-8070

CITY OF PUYALLUP
PUBLIC WORKS DEPARTMENT
330 3rd STREET
PUYALLUP, WA 98374
T (253) 841-5484
F (253) 841-5437

WSU - PUYALLUP RESEARCH AND EXTENSION CENTER
LID STORMWATER RETROFIT - PHASE 1

SHEET TITLE:
DRAINAGE PLAN - BIORETENTION AREA

DESIGN	KG, NC, RP
DRAWN	JR, AS
APP'D	
DATE	06/09/2009
F.F. NO.	1864-2006
FILE NO.	1000-G-15

C2.2b

SHEET OF

PERMIT

DERRY D. E. NAISH, STATE OF WASHINGTON, 28806, REGISTERED PROFESSIONAL ENGINEER 6-11-09

THOMAS R. VON SCHRADER, STATE OF WASHINGTON, 29842, REGISTERED PROFESSIONAL ENGINEER 6-11-09

QA/QC REVIEWER

PLEASE CALL
3 Working Days
BEFORE YOU DIG
1-800-424-5555

Plotted: Jun 11, 2009 – 12:08:28am By: matto
File: G:\0To1\0703B6\Current\WSU_C2-2b_DRAINLing Layout. C2.2b Layout:

APPENDIX E

Equipment Specification Sheet

Isco Product Data

Isco 6712 Full-size Portable Sampler

Isco's 6700 Series Portable Samplers have set the industry standard, providing the most comprehensive and durable performance available. With the introduction of our new 6712, Isco takes another step toward the ultimate by including SDI-12 interface capabilities.

This full-size portable lets you take full advantage of the advanced 6712 Controller, with its powerful pump, versatile programming, and optional plug-in modules for integrated flow measurement. Setup is fast and simple, with online help just a key stroke away.

The environmentally-sealed 6712 controller delivers maximum accuracy and easily handles all of your sampling applications, including:

- Flow-paced sampling with or without wastewater effluent
- stormwater monitoring
- CSO monitoring
- permit compliance
- pretreatment compliance

In the Standard Programming Mode, the controller walks you through the sampling sequence step-by-step, allowing you to choose all parameters specific to your application. Selecting the Extended Programming Mode lets you enter more complex programs.

Optional land-line and GSM and CDMA cellular telephone modems allow programming changes and data collection to be performed remotely, from a touch-tone phone. They also provide dial-out alarm.

Versatile and Convenient

With eleven bottle choices, Isco's 6712 Sampler lets you quickly adapt for simple or intricate sampling routines. Up to 30 pounds (13.5 kg) of ice fits in the insulated base, preserving samples for extended periods, even in extreme conditions. The 6712 with the “Jumbo Base” option holds bottles up to 5.5 gallon (21 liter).

Tough and Reliable

The 6712 Portable Sampler features a vacuum-formed ABS plastic shell to withstand exposure and abuse. Its tapered design and trim 20-inch (50.8 cm) diameter result in easy manhole installation and removal. Large, comfortable handles make transporting safe and convenient—even when wearing gloves.

Isco's 6712 Portable Sampler carries a NEMA 4X, 6 (IP67) enclosure rating.

Superior capability, rugged construction, and unmatched reliability make the 6712 the ideal choice for portable sampling in just about any application.

Bottle options are available for practically any sequential or composite application.

Specifications

Isco 6712 Full-size Portable Sampler	
Size (Height x Diameter):	27 x 20 inches (50.7 x 68.6 cm)
Weight:	Dry, less battery - 32 lbs (15 kg)
Bottle configurations:	24 - 1 Liter PP or 350 ml Glass 24 - 1 Liter ProPak Disposable Sample Bags 12 - 1 Liter PE or 950 ml Glass 8 - 2 Liter PE or 1.8 Liter Glass 4 - 3,8 Liter PE or Glass 1 - 9,5 Liter PE or Glass 1 - 5.5 gallon (21 Liter)PE or 5 gallon (19 Liter) Glass, (with optional Jumbo Base)
Power Requirements:	12 V DC (Supplied by battery or AC power converter.)
Pump	
Intake suction tubing:	
Length	3 to 99 feet (1 to 30 m)
Material	Vinyl or Teflon
Inside dimension	3/8 inch (1 cm)
Pump tubing life:	Typically 1,000,000 pump counts
Maximum lift:	28 feet (8.5 m)
Typical Repeatability	±5 ml or ±5% of the average volume in a set
Typical line velocity at Head height: of	
3 ft. (0.9 m)	3.0 ft./s (0.91 m/s)
10 ft. (3.1 m)	2.9 ft./s (0.87 m/s)
15 ft. (4.6 m)	2.7 ft./s (0.83 m/s)
Liquid presence detector:	Non-wetted, non-conductive sensor detects when liquid sample reaches the pump to automatically compensate for changes in head heights.

Controller	
Weight:	13 lbs. (5.9 kg)
Size (HxWxD)	10.3 x 12.5 x 10 inches (26 x 31.7 x 25.4 cm)
Operational temperature:	32° to 120°F (0° to 49°C)
Enclosure rating:	NEMA 4X, 6 (IP67)
Program memory:	Non-volatile ROM
Flow meter signal input:	5 to 15 volt DC pulse or 25 millisecond isolated contact closure.
Number of composite samples:	Programmable from 1 to 999 samples.
Clock Accuracy:	1 minute per month, typical, for real time clock
Software	
Sample frequency:	1 minute to 99 hours 59 minutes, in 1 minute increments. Non-uniform times in minutes or clock times 1 to 9,999 flow pulses
Sampling modes:	Uniform time, non-uniform time, flow, event. (Flow mode is controlled by external flow meter pulses.)
Programmable sample volumes:	10 to 9,990 ml in 1 ml increments
Sample retries:	If no sample is detected, up to 3 attempts; user selectable
Rinse cycles:	Automatic rinsing of suction line up to 3 rinses for each sample collection
Program storage:	5 sampling programs
Sampling Stop/Resume:	Up to 24 real time/date sample stop/resume commands
Controller diagnostics:	Tests for RAM, ROM, pump, display, and distributor

Ordering Information

***Note**: Power source, bottle configuration, suction line, and strainer must be ordered separately. Many options and accessories are available for 6712 Samplers; see separate literature for 700 Series Modules and other components to expand your monitoring capabilities. Contact Isco, or your Isco representative for pricing and additional information.*

Description	Part Number
6712 Portable Sampler, Full-size Includes controller with 512kB RAM, top cover, center section, base, distributor arm, instruction manual, pocket guide.	68-6710-070
6712 Portable Sampler, with Jumbo Base As described above	68-6710-082

The 6712 Controller is also an SDI-12 data logger, and has many optional capabilities. Please contact Isco or your Isco distributor for more information.

Water is life. Protect it.

Teledyne Isco, Inc.

4700 Superior Street
Lincoln NE 68504 USA
Phone: (402) 464-0231
USA and Canada: (800) 228-4373
Fax: (402) 465-3022
E-Mail: iscoinfo@teledyne.com
Internet: www.isco.com

Isco reserves the right to change specifications without notice.
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SDM-IO16

16-Channel I/O Expansion Module

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

The SDM-IO16's 16 digital I/O ports function similarly to the control ports included on the majority of our dataloggers. When configured as an input, each port can monitor logic state, count pulses, measure signal frequency, and determine duty cycle. An option in the pulse counting mode enables switch debounce filtering, allowing the SDM-IO16 to accurately count switch closures. The SDM-IO16 can also be programmed to send an interrupt signal to the datalogger when one or more input signals change state.

When configured as an output, each port can be set to 0 or 5 V by the datalogger. A 'boost' circuit allows an output that is set HI to source a current of up to 100 mA for controlling external devices such as low voltage valves or relays.

SDM Operation

The SDM-IO16 is a synchronously addressed datalogger peripheral. Three ports on the datalogger are used to address the SDM-IO16. Advanced error checking techniques ensure correct data transmission to and from the SDM-IO16. Up to sixteen SDM-IO16 modules can be addressed allowing up to 256 ports to be controlled by the datalogger.

Datalogger Connection

The CABLE5CBL-L is recommended for connecting the module to the datalogger. A 1-ft cable length should be sufficient when both datalogger and SDM-IO16 are housed within an ENC12/14 enclosure; a 2-ft length may be required if the datalogger and SDM-IO16 are housed at opposite ends of an ENC16/18 Enclosure.

The cable length should be as short as possible. Typically, the maximum cable length is 20 ft. Contact Campbell Scientific if the length needs to be longer.

Compatible Dataloggers

All of the functions are supported by our CR800, CR850, CR1000, CR3000, CR5000 CR10X (OS 1.17 or later) and CR23X (OS 1.14 or later) dataloggers. Several of our dataloggers support the output mode only. These dataloggers include our CR7, CR10, and 21X. Please note that the SDM-IO16 is not compatible with the CR200-series, CR9000(X), CR500, or CR510 dataloggers.

Software Requirements

Support for all the functions requires CRBasic's SDMIO16 instruction or Edlog's Instruction 188. Instruction 188 is available in Edlog templates that post date March 2002 (LoggerNet version 2.1 contains this template). Edlog templates that predate March 2002 can support only the output mode using Instruction 104. The SDMCD16AC instruction supports only the output mode in CRBasic.

Power Considerations

The datalogger's rechargeable power supply can power the SDM-IO16 for most pulse counting or status input applications. However, when driving loads, the SDM-IO16 power requirements may be large compared to most Campbell Scientific products. For these applications, an external power supply is recommended.

Mounting

Mounting brackets are provided for attaching the SDM-IO16 to the backplate of an ENC12/14 or larger enclosure.

Ordering Information

Synchronous Device for Measurement	
SDM-IO16	16-Channel I/O Expansion Module

SDM-to-Datalogger Cable	
CABLE5CBL-L	5-conductor, 24 AWG cable with drain wire and Santoprene jacket. Enter cable length, in feet, after the -L. Must choose a cable termination option (see below).

Cable Termination Options (choose one)	
-PT	Cable terminates in stripped and tinned leads for direct connection to a datalogger's terminals.
-PW	Cable terminates in connector for attachment to a prewired enclosure.

Specifications

SDM and I/O Port: 0/5 V logic level ports for connecting to the data-logger's control/SDM ports

EMC Status: Complies with EN 61326:1997

Power

Operating Voltage: 12 Vdc (nominal 9 to 18 V)

Current Drain[1] @ 12 Vdc

Typical Standby: 600 µA (assumes all ports high, no load, excludes pulse counting)

Maximum: 3 mA (active with all 16 ports counting pulses at 2 kHz and no output load)

Output

Voltage (no load)

ON/HI: nominal 5 V, minimum 4.5 V

OFF/LO: nominal 0 V, maximum 0.1 V

Sink Current: Output will sink 8.6 mA from a 5 V source

Source Current: Output will source 42 mA at 3 V; 133 mA short-circuited to ground

Maximum Current (total all outputs): Limited by 12 V supply

Input

Voltage

High: 4.0 V minimum threshold

Low: 1.0 V maximum threshold

Protection: Input clamped at -0.6 V and ±5.6 V relative to ground via a 33 ohm resistor to withstand a continuous current flow of 200 mA

Source Current: Output will source 42 mA at 3 V; 133 mA short-circuited to ground

Impedance: Biased to +5 V relative to ground by a 100 kohm resistor

Pulse Counting

Maximum Frequency: 2.0 kHz on all channels simultaneously with switch debounce-mode turned off with a 50/50 duty cycle.
150 Hz on all channels with default switch debounce mode enabled and a 50/50 duty cycle.

Minimum frequency: 0 Hz is reported if there are less than two high-to-low signal transitions in the measurement interval.

Minimum Pulse Width: 244 µs

Default Switch Debounce Timing: Input and ground must remain closed for 3.17 ms then remain open for 3.17 ms to be counted as a closure

Internal Clock Accuracy (-25° to 50°C): ±0.01%, worst case

Max. Measurement Interval: 15.9375 s

Physical

Operating Temperature: -25° to +50°C

Dimensions: 9 in. x 4 in. x 1 in.; 23.0 cm x 10.0 cm x 2.4 cm

Weight: 12 oz (350 g)

[1]*Current consumption is roughly proportional to input signal frequency and number of ports used. Current drawn from any output must be added to the quiescent level to obtain the total current drain.*

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Campbell Scientific, Inc.
Printed October 2009

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C range unless otherwise specified; non-condensing environment required. To maintain electrical specifications, Campbell Scientific recommends recalibrating dataloggers every two years. We recommend that the system configuration and critical specifications are confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE

10 ms to 30 min. @ 10 ms increments

ANALOG INPUTS

8 differential (DF) or 16 single-ended (SE) individually configured. Channel expansion provided by AM16/32 and AM25T multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single conversion. **Resolution of DF measurements with input reversal is half the Basic Res.**

	Input Referred Noise Voltage	
Input Range (mV)[1]	*DF Res (µV)*[2]	*Basic Res (µV)*
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% exists on all ranges to guarantee that full-scale values will not cause over-range.

[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C

[3]The sensor and measurement noise are not included and the offsets are the following:

Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range; digital resolution dominates for higher ranges.

250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

MINIMUM TIME BETWEEN VOLTAGE MEASUREMENTS: Includes the measurement time and conversion to engineering units. For voltage measurements, the CR1000 integrates the input signal for 0.25 ms or a full 16.66 ms or 20 ms line cycle for 50/60 Hz noise rejection. DF measurements with input reversal incorporate two integrations with reversed input polarities to reduce thermal offset and common mode errors and therefore take twice as long.

250 µs Analog Integration: ~1 ms SE
1/60 Hz Analog Integration: ~20 ms SE
1/50 Hz Analog Integration: ~25 ms SE

COMMON MODE RANGE: ±5 V

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 Gohms typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT only)

ANALOG OUTPUTS

3 switched voltage, active only during measurement, one at a time.

RANGE AND RESOLUTION: Voltage outputs programmable between ±2.5 V with 0.67 mV resolution.

ACCURACY: ±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

CURRENT SOURCING/SINKING: ±25 mA

RESISTANCE MEASUREMENTS

MEASUREMENT TYPES: The CR1000 provides ratiometric measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Precise, dual polarity excitation using any of the 3 switched voltage excitations eliminates dc errors.

RATIO ACCURACY[3]: Assuming excitation voltage of at least 1000 mV, not including bridge resistor error.

$\pm(0.04\%$ of voltage reading + offset$)/V_x$

[3]The sensor and measurement noise are not included and the offsets are the following:

Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

Offset values are reduced by a factor of 2 when excitation reversal is used.

PERIOD AVERAGING MEASUREMENTS

The average period for a single cycle is determined by measuring the average duration of a specified number of cycles. The period resolution is 192 ns divided by the specified number of cycles to be measured; the period accuracy is ±(0.01% of reading + resolution). Any of the 16 SE analog inputs can be used for period averaging. Signal limiting are typically required for the SE analog channel.

INPUT FREQUENCY RANGE:

Input Range	*Signal (peak to peak)*[4] *Min*	*Max*	*Min. Pulse W.*	*Max*[5] *Freq.*
±2500 mV	500 mV	10 V	2.5 µs	200 kHz
±250 mV	10 mV	2 V	10 µs	50 kHz
±25 mV	5 mV	2 V	62 µs	8 kHz
±2.5 mV	2 mV	2 V	100 µs	5 kHz

[4]The signal is centered at the datalogger ground.

[5]The maximum frequency = 1/(Twice Minimum Pulse Width) for 50% of duty cycle signals.

PULSE COUNTERS

Two 24-bit inputs selectable for switch closure, high-frequency pulse, or low-level AC.

MAXIMUM COUNTS PER SCAN: 16.7×10^6

SWITCH CLOSURE MODE:
Minimum Switch Closed Time: 5 ms
Minimum Switch Open Time: 6 ms
Max. Bounce Time: 1 ms open w/o being counted

HIGH-FREQUENCY PULSE MODE:
Maximum Input Frequency: 250 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW-LEVEL AC MODE: Internal AC coupling removes AC offsets up to ±0.5 V.

Input Hysteresis: 16 mV @ 1 Hz
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine wave (mV RMS)	*Range (Hz)*
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

DIGITAL I/O PORTS

8 ports software selectable, as binary inputs or control outputs. C1-C8 also provide edge timing, subroutine interrupts/wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UART), SDI-12 communications, and SDM communications.

HIGH-FREQUENCY PULSE MAX: 400 kHz

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.8 to 5.3 V; low -0.3 to 1.2 V

INPUT HYSTERISIS: 1.4 V

INPUT RESISTANCE: 100 kohms

SWITCHED 12 V

One independent 12 V unregulated sources switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

SDI-12 INTERFACE SUPPORT

Control ports 1, 3, 5, and 7 may be configured for SDI-12 asynchronous communications. Up to ten SDI-12 sensors are supported per port. It meets SDI-12 Standard version 1.3 for datalogger mode.

CE COMPLIANCE

STANDARD(S) TO WHICH CONFORMITY IS DECLARED: IEC61326:2002

CPU AND INTERFACE

PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core)

MEMORY: 2 Mbytes of Flash for operating system; 4 Mbytes of battery-backed SRAM for CPU usage, program storage and data storage.

SERIAL INTERFACES: CS I/O port is used to interface with Campbell Scientific peripherals; RS-232 port is for computer or non-CSI modem connection.

PARALLEL INTERFACE: 40-pin interface for attaching data storage or communication peripherals such as the CFM100 module

BAUD RATES: Selectable from 300 bps to 115.2 kbps. ASCII protocol is one start bit, one stop bit, eight data bits, and no parity.

CLOCK ACCURACY: ±3 min. per year

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc (reverse polarity protected)

TYPICAL CURRENT DRAIN:
Sleep Mode: ~0.6 mA
1 Hz Scan (8 diff. meas., 60 Hz rej., 2 pulse meas.)
w/RS-232 communication: 19 mA
w/o RS-232 communication: 4.2 mA
1 Hz Scan (8 diff. meas., 250 µs integ., 2 pulse meas.)
w/RS-232 communication: 16.7 mA
w/o RS-232 communication: 1 mA
100 Hz Scan (4 diff. meas., 250 µs integ.)
w/RS-232 communication: 27.6 mA
w/o RS-232 communication: 16.2 mA

CR1000KD CURRENT DRAIN:
Inactive: negligible
Active w/o backlight: 7 mA
Active w/backlight: 100 mA

EXTERNAL BATTERIES: 12 Vdc nominal

PHYSICAL SPECIFICATIONS

MEASUREMENT & CONTROL MODULE SIZE: 8.5" x 3.9" x 0.85" (21.6 x 9.9 x 2.2 cm)

CR1000WP WIRING PANEL SIZE: 9.4" x 4" x 2.4" (23.9 x 10.2 x 6.1 cm); additional clearance required for serial cable and sensor leads.

WEIGHT: 2.1 lbs (1 kg)

WARRANTY

Three years against defects in materials and workmanship.

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Australia | Brazil | Canada | England | France | Germany | South Africa | Spain | USA (headquarters)

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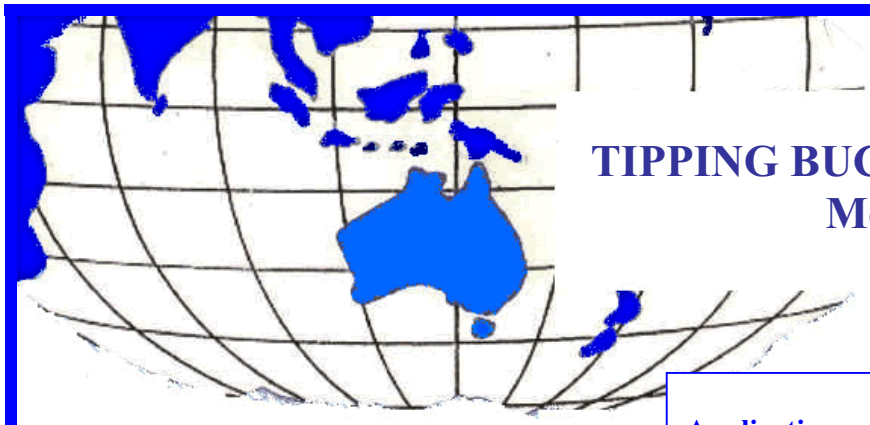
BULLETIN 75,
Edition 1



TIPPING BUCKET FLOW GAUGE
Model TB1L

Features

- Non-Corrosive, Robust PVC & Stainless Steel Construction
- Dual Reed Switch
- Suitable for Pipe Flow Measurement and water drain measurement
- Bucket Tip Volumes can be between 0.5 Litre up to 1.0 Litre
- Suitable for Harsh Environment

Description

The Hydrological Services Flow Gauge is considered to be one of the most accurate flow gauges used for measuring water flow coming out of a pipe or a drain. The unit comes with a dual reed switch, thus, when connected to a Hydrological Services data logger, the data can be stored and collected when required. In addition, the flow gauge can be telemetred by connecting one of the hydrological services data loggers to a GSM or PSTN modem

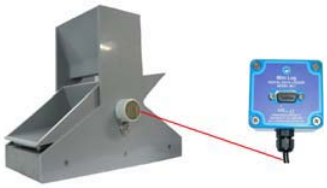
CERTIFIED QUALITY MANAGEMENT SYSTEM
ISO9001

Hydrological Services Pty Ltd
Sydney, Australia

48-50 Scrivener St, Warwick Farm
2170 Sydney, Australia
A.B.N. 37 000 732 954
Box 332 Liverpool BC 1871
Ph: +612 9601 2022
Fax: +612 9602 6971
Email: sales@hydrologicalservices.com
Web: www.hydrologicalservices.com

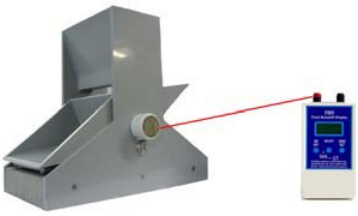
Applications

- Connected to a data logger for collection and storage



- Connected to a data logger and a modem for telemetry

- Connected to a TRD (Total Rainfall Display)



Specifications

Material: PVC Plastic and Stainless Steel

Reed Switch: dual reed switches potted in soft silicon rubber with varistor protection.

- Max Capacity: 12 VA (0.5 amp max.) (24VDC are available on request)
- Resistance: Initial contact resistance 0.1 Ω
- M.T.B.F: 10^8 to 10^9 Operations

Flow Rate: 25 litres/minute.

Accuracy: ±2%

Dimensions: Length 390mm, Width 180mm, Height 345mm.

Accessories

a. Minilog Digital Data Logger
b. WinComLog
c. Modem (GSM or 3G or PSTN)
d. TRD Counter

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TIPPING BUCKET RAINGAUGE

Model TB3

Special points of interest:

- World standard 200mm catch
- Accuracy not affected by rainfall intensity
- Bucket sizes: 0.01 inch/ 0.2mm/ 0.5mm/ 1.0mm
- Long term stable calibration
- Leaf filter resists blocking
- Optional internal Data Logger, with no external power requirement
- In-built discharge outlets at base for water collection and analysis
- Dual output signal for data collection and transmission
- World class meteorological instrument
- Easy to service with low maintenance requirement

Inside this issue:

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INTRODUCTION

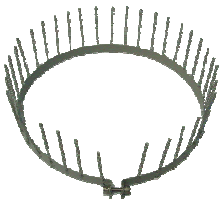
The Hydrological Services Tipping Bucket Raingauge is recognised as the world standard for measuring rainfall and precipitation in remote and unattended locations.
The integrated syphon mechanism delivers high levels of accuracy across a broad range of rainfall intensities.
Each unit consists of a collector funnel with leaf filter, an integrated syphon control mechanism, an outer enclosure with quick release fasteners, and base which houses the tipping bucket mechanism.
The unit includes dual output reed switches with varistor protection as well as dual rainfall discharge outlets for water collection and/or analysis.

TB3 Raingauge

Pole Mount Bracket Model TB334

Field Calibrator Model FCD

ML1 Data Logger



Bird Guard Model TB333

Designed & Manufactured By Hydrological Services Pty Ltd

Address:

48-50 Scrivener Street

Liverpool, NSW, 2170, Australia

Ph. 61 2 9601 2022 Fax. 61 2 9602 6971

Web: www.hydrologicalservices.com

Email: sales@hydrologicalservices.com

NCS INTERNATIONAL CERTIFIED QUALITY MANAGEMENT SYSTEM ISO9001

Distributed By:

Operation

The bucket tips when precipitation of 0.01 inch, 0.2mm, 0.5mm or 1.0mm has been collected. A pulse from each tip is sensed by the reed switch and logged to a data logger. The dual reed switch can also transmit the pulse to a telemetry system.

The Tipping Bucket Raingauge can be used in conjunction with Hydrological Services data logger model ML1. The logger is rugged and compact, it records the date and time of occurrence of tips from the raingauge up to 100,000 events with 1 Second Resolution can be stored in the ML1's memory. The data is stored in a flash EPROM.

TB3 Base with optional ML1-FL

The ML1 fits inside the model TB3 Raingauge. Its compact design makes it ideal for incorporation into any piece of equipment where intelligent data acquisition and logging are required.

Accessories

Description	***Part No.***
Data Logger	ML1/ML1-FL
RS232 to USB Converter	DL307
Field Calibration Device	TB320 / FCD
TB3 Heater Kit	TB323
TB3 Bird Guard	TB333
TB3 Pole Mounting Bracket	TB334

Specifications

Receiver: 200 mm ± 0.3 diameter heavy duty cast aluminium, Powder coated.

Bucket capacity: 0.2 mm, 0.5 mm,1.0 mm, 0.01 inch of rainfall.

Sensitivity: one tip.

Maximum intensity: 700 mm / hr.

Calibration accuracy:

TB3 bucket capacity	Intensity	Accuracy
0.1mm, 0.2mm & 0.01”	0-250mm/hr	± 2 %
	250-400 mm/hr	± 3 %
0.5mm & 1.0 mm	0-500 mm/hr	± 2 %

Long term stable calibration.

Humidity: 0 to 100 %

Temperature: - 20 to +70•€

Contact system: dual reed switches potted in soft silicon rubber with varistor protection.

- Max Capacity: 24 Volts (0.5 amp max.)
- Resistance: Initial contact resistance 0.1 OHMS
- M.T.B.F: 10^8 to 10^9 Operations

Syphon: 0.4 mm capacity of rainfall - made from brass with a non hydroscopic outer case.

Bucket: two types of buckets, synthetic ceramic coated brass bucket balanced to ±0.05 gms, and injection moulded non hydroscopic plastic ABS UV stabilised balanced ±0.05 gms.

Base: Cast aluminium.

Level: bulls eye level adhered to aluminium base.

Mounting holes: three 10 mm diameter mounting holes with 117 mm p.c.d. cast in feet attached to outside diameter of base.

Drain fittings: to attach 12 mm inside diameter tubing, to catch rainfall after passing through buckets.

Pivots: ground sapphire pivots with hard stainless steel shaft.

Insect covers: stainless steel mesh on all openings to prevent insects and ants entering gauge.

Outer enclosure: keyed to enable the release of the outer enclosure without the need for the removal of the three securing screws.

Height / Weight: 330mm / 3 kg

Packed Dimensions: 5 kg 0.03m^3

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APPENDIX F

Example Field and Quality Assurance Auditing Forms

HERRERA
ENVIRONMENTAL
CONSULTANTS

Automatic Sampler Field Notes

Date _____ Page _____

Project/Field Tech: _____

Purpose: _____

Weather: _____

Routine Data	Station:	Station:	Station:	Station:
Watch Time (military)				
Staff Gauge (ft)				
Creek Clarity				
Battery Change? (yes/no)				
Flow Measurement? (yes/no)				

Flow Meter Data				
FM Display Time				
FM Time OK? (yes/no)				
Level (ft)				
Flow Rate (cfs)				
Total Flow (cf)				
Flow Totalizer Reset (yes/no)				
Flow Totalizer Reset Time (Military)				
Data Set No.				
Max. Head (ft)				
Interval/Pulse (cf)				
Data Download? (yes/no)				

Sampler Data				
Sampler Display Time (Military)				
Sampler Time OK? (yes/no)				
No. of Samples (actual/attempted)				
Sample Volume Collected				
Begin Sample Date/Time (Military)				
End Sample Date/Time (Military)				
Program Halted Date/Time (Military)				
Tubing Replaced? (yes/no/rotate)				

Notes:

HERRERA
ENVIRONMENTAL
CONSULTANTS

2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
(206) 441-9080
FAX (206) 441-9108

CHAIN OF CUSTODY RECORD

PROJECT NAME:	PROJECT NUMBER:	CLIENT:
REPORT TO:		COPY TO:
SAMPLED BY:		DELIVERY METHOD:
LABORATORY:	REQUESTED COMPLETION DATE:	TOTAL # OF CONTAINERS:
LAB USE:		

ANALYSES REQUESTED

SAMPLE ID:	DATE:	TIME:	SAMPLE DESCRIPTION	# OF CONTAINERS:																

REMARKS:

RELINQUISHED BY (NAME/CO.):	SIGNATURE:	DATE/TIME:	RECEIVED BY (NAME/CO.):	SIGNATURE:	DATE/TIME:
RELINQUISHED BY (NAME/CO.):	SIGNATURE:	DATE/TIME:	RECEIVED BY (NAME/CO.):	SIGNATURE:	DATE/TIME:

Data Quality Assurance Worksheet

By _____

Project Name/No./Client: _____ Date _____ Page ____ of ____

Laboratory/Parameters: _____ Checked: initials _____

Sample Date/Sample ID: _____ date _____

Parameter	Completeness/ Methodology	Holding Times	Blanks/ Detection Limit	Matrix Spikes/ Surrogate Recoveries	Lab Duplicates	Field Duplicates	Lab Control Samples	Instrument Calibration/ Performance	ACTION

Mesocosm Infiltration Test Field Form

Start Date: _____
Start Time: _____

Conditions: _____

Field Personnel: _____

Notes:

			Water Level		
Rec. #	Time (hr:min)	Δ Time (min.)	Staff Gauge (ft.)	Δ Staff Gauge (ft.)	Comments

Mesocosm Soil Sampling Log

Date ______________________________

Field Personnel: ______________________________

Conditions: ______________________________

Notes

Mesocosm ID	Soil Depth	Sample Time	Sample ID after Compositing	Comments

Page _____ of ______