Western Washington Stormwater Effectiveness Studies

Quality Assurance Project Plan (QAPP)

The effects of mulch on stormwater treatment and maintenance effort in bioretention systems

The effects of mulch on stormwater treatment and maintenance effort in bioretention systems

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1.0 Table of Contents

2.0 Executive Summary

This 2-year study seeks to evaluate the role that mulch plays in the performance of bioretention best management practices, specifically in terms of removal of pollutants from stormwater runoff when used as a top layer in bioretention cells. Additionally, we aim to see how different kinds of mulch attenuate stormwater flows through bioretention systems, alter soil moisture conditions, and provide dissolved carbon to the bioretention ecosystem. Three types of mulch, medium bark mulch, button bark mulch, and arborist chips, will be compared to a no-mulch control within replicated bioretention cells located at Washington State University's Puyallup Research and Extension Center. With this test facility of 16 bioretention cells, each of the three mulch types will be replicated four times and their performances compared against those of four no-mulch cells. We define treatment performance as the ability of a bioretention cell to remove/sequester stormwater pollutants, store water in the form of soil moisture, and reduce runoff volume. Additionally, weeding effort and plant growth will also be quantified to measure success of planted vegetation over time. All the cells will be dosed with a synthetic blend stormwater during 6 artificially generated storm events. Artificial stormwater will be applied to each cell with a network of pumps and pipes, using water that has been dosed artificially with 7 common analytes. Changes in water quality between influent and effluent will be measured by comparing event mean concentrations of the dosed analytes between inflow and outflow. Changes in water quantity will be evaluated by examining reductions to runoff volume between inflow and outflow, and changes in soil moisture within each bioretention cell. Anticipated study outcomes from this work are a better understanding of what types of mulch in bioretention systems are best suited to treat stormwater, ensure plant success and limit weeding efforts. Together these outcomes will shed light on the potentially crucial role that mulch plays in the performance of a bioretention cell.

3.0 Introduction and Background

3.1 Introduction to the Mulch and Bioretention Study

Stormwater that flows into bioretention or rain garden systems first contacts the mulch layer before any other component in that system. However, effects of mulch in bioretention systems have not been evaluated. Mulch can prevent weeds and invasive species. Given that repeated weeding and invasive removal is a costly addition to operations and maintenance budgets for any municipality, we aim to provide information to optimize mulch choice to minimize maintenance efforts. In addition, mulch layer can provide carbon and nutrients in the bioretention soil layers, eventually helping plant survival and growth. The incremental benefit to stormwater treatment is unknown, but this study aims to determine if the mulch layer itself affects analyte removal from stormwater in bioretention systems by increasing adsorptive surfaces for stormwater analytes such as hydrocarbons, metals, fecal coliform, or nutrients. Three mulch types will be tested:

1. Medium bark mulch (fir and ash)
2. Button bark mulch (cedar and fir)
3. Arborist chips (mixed)

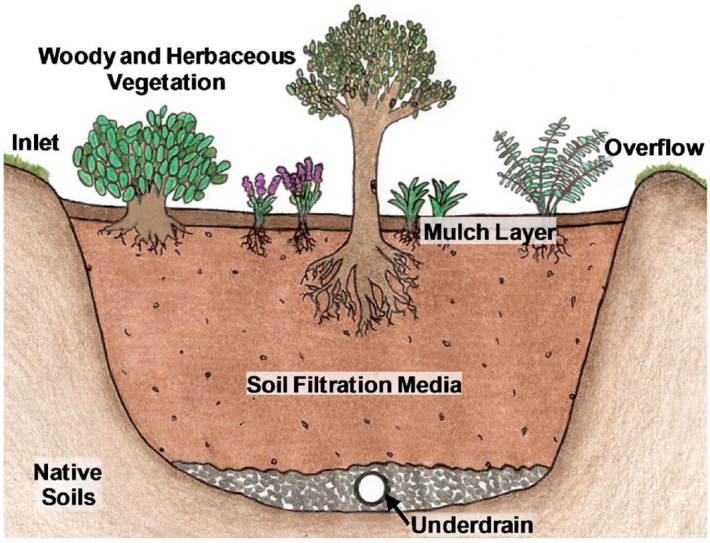

Figure 1: Schematic of a bioretention system with underdrain (from Roy-Poirier et al., 2010)

3.2 Problem Description

With the proliferation of rain gardens and bioretention systems in Western Washington designed to control and treat stormwater, there is a critical need to understand the role that mulch plays in treating stormwater and reducing maintenance effort. From a stormwater

treatment perspective there are five primary reasons that make cost effective choices regarding mulch for a bioretention system:

1. Stormwater that flows into bioretention or rain garden system first contacts the mulch layer before any other component in that system. By making an appropriate choice for this 'first responder' there is an opportunity for adding considerable treatment potential.
2. Mulch is an easily replenishable carbon source for critical biogeochemical processes that treat stormwater pollutants. Carbon sources in the BSM layer itself cannot be replaced without digging out the plants and BSM, however, mulch can be easily added on top.
3. We hypothesize that mulch is the most easily replaced component of a bioretention system if exposed to high and unexpected analyte loading. Its ease of replacement and status as the first substrate that stormwater encounters in the bioretention systems necessitates a greater understanding of its role in stormwater treatment.
4. The mulch layer ensures both soil moisture and nutrients from the mulch are retained in the upper layers of the BSM, where these are available to the plants for transpirative and phytoremediative processes, respectively. Note that transpirative processes affect stormwater control and phytoremediative processes affect stormwater treatment.
5. Mulch plays a critical role in preventing weeds and invasive species from outcompeting plants in a bioretention system. While this doesn't necessarily address stormwater treatment per se, there is sufficient evidence to show that weedy and unkempt bioretention systems are considered eyesores and tend to be undervalued by the public. Additionally, repeated weeding and invasive removal is a costly addition to operations and maintenance budgets for any municipality.

We believe that the multifold role that mulch plays in effective stormwater treatment and mitigation of maintenance effort needs a more complete understanding to guarantee the sustainability of the hundreds of bioretention facilities and rain gardens that will be installed in the coming years in the region.

3.3 Results of Prior Studies

With considerable recent effort to characterize stormwater pollutant removal by various types of bioretention soil media (BSM), a missing and critical aspect to these efforts is documenting the role of mulch for bioretention systems in western Washington. Sufficient evidence exists to show that mulch plays a critical role in stormwater pollution remediation. Some of this seminal work is outlined below:

Phosphorous and Mulch - Mei, Ying, et al. (2012) in a study on five types of mulch [bark of white poplar, bark of sophora japonica, haydite, pearlite, and vermiculite] showed that short term phosphorous sorption capacity was maximum when using vermiculite.

Metals and Mulch – Davis et al. (2001) identified the importance of a mulch layer in the removal of metals from influent stormwater. They showed that there was a significant uptake of metals an upper mulch layer, and that an inch-thick layer of mulch was sufficient to retain most the influent metals. This study was performed at a laboratory scale.

Oils, and Grease and Mulch – Hong et al. (2006) in a bench-scale infiltration study showed that a thin mulch layer was capable of trapping 80 to 95% of all oils and greases added to a synthetic stormwater influent load. Furthermore, 90% of the sorbed oils and greases biodegraded between 2 and 8 days, a biodegradation that was shown to be accompanied by increased microbial populations.

Heavy Metals, and Polycyclic Aromatic Hydrocarbons and Mulch – Ray et al. (2006) found that the sorption of heavy metals [copper, cadmium, chromium, lead, zinc] and PAHs [1,3 dichlorobenzene (DCB), naphthalene (NP), fluoranthene (FA), butylbenzylphthalate (BBP), and benzo(a)pyrene (B[a]P)] to a layer of hardwood mulch was dependent upon the pollutant species, contact time and initial concentrations. Sorption rates ranged from 20 to 100% with metals sorbing faster to the mulch than the PAHs. This study was also conducted at a laboratory bench-scale. Mulches can be effective in removing heavy metals from landscape and garden soils. Common urban contaminates such as lead and cadmium can be removed from the soil solution by mulched leaves of eucalyptus (*Eucalyptus spp.*), pine, poplar (*Populus spp.*), and arborvitae (*Thuja spp.*). Likewise, a mixture of compost and woodchips was found to decontaminate forest soils by complexing copper into a less toxic form (Chalker-Scott, 2007)

Microbial Rhizosphere and Mulch – Tiquia et al. (2002), in a field microcosm study that compared the application of several organic mulches to top soil against a bare soil control, showed that mulch treatment significantly affected organic matter content, soil respiration, microbial biomass N, soil pH, cation-exchange capacity, and concentrations of plant nutrients. The populations of certain bacterial populations in the rhizosphere was also significantly higher in the composted plots compare to the bare soil plots.

3.4 Regulatory Requirements

The data collected from this study is intended to provide more information on the performance of the mulch layer in a typical bioretention best management practice (BMP), and associated maintenance effort. Ultimately these results will inform Ecology's stormwater guidance, specifically bioretention design (BMP T7.30, "Bioretention Cells, Swales, and Planter Boxes," of Volume V of the 2012 SWMMWW as amended in 2014).

Urban jurisdictions use Green Stormwater Infrastructure (GSI) technology, such as bioretention, in new and re-developed infrastructure in order to comply with National Pollutant Discharge Elimination System (NPDES) regulations.

4.0 Project Overview

4.1 Study Goal

The goal of this project is to determine the benefits of three types of mulches in bioretention systems.

The study aims to quantify how well certain mulches remove specific pollutants from stormwater, impact hydrologic dynamics within a cell, and how some mulch types mitigate maintenance effort by suppressing the growth of weeds. As a result of this work, Phase I and II permittees will have a basis for mulch choice to in order to maximize stormwater pollution removal and minimize maintenance effort.

4.2 Study Description and Objectives:

This study will utilize sixteen replicated bioretention cells located at the WSU-Puyallup low impact development (LID) test facilities. All sixteen bioretention cells were retrofitted in Summer 2017 and replanted in November 2018 with a common plant palette. All sixteen cells were lined, re-plumbed, and instrumented to measure inflows and outflows. The bioretention cells are built with the default bioretention soil mix (BSM) which is 60:40 sand: compost)) as recommended by the Washington State Department of Ecology's.

Three types of mulch will overlay the standard BSM:

4. Medium bark mulch (fir and ash)
5. Button bark mulch (cedar and fir)
6. Arborist chips (mixed)

Each mulch type will be replicated four times and compared against a control of four bioretention cells with no mulch. Artificially dosed storm events comprising specific stormwater pollutants added to the dosing water will be applied to the 16 test cells, with influent and effluent pollutant concentrations measured through sampling and laboratory analyses. These influent and effluent concentrations will then be used to quantify pollutant removal efficiencies associated with these mulch choices.

Stormwater runoff will be collected from 72,084 ft^2 of impervious surface on the WSU Puyallup facility, and stored in a common dosing cistern. Stored stormwater will then be mixed with chemicals to meet the range of influent loading rates to represent urban stormwater pollutant concentrations.

We will test 7 stormwater analytes per storm event. These analytes are:

1. Nitrate – Nitrite
2. Total Phosphorous
3. Dissolved copper

4. Dissolved zinc
5. Total Petroleum Hydrocarbons
6. Total Suspended Sediments
7. Dissolved Organic Carbon

Pollutant removal rates will be quantified by measuring inflow and, outflow flow rates, as well as influent and effluent event mean analyte concentrations. Additionally, soil moisture, volumes of inflow and outflow will be used to characterize how mulch affects water retention in each cell.

The effects of mulch on weeding effort and plant survival will be quantified by measuring person-hours needed to remove weeds from the cells over the course of the study. Plant replacement costs will also be quantified, where plants will be replaced when there is 25% mortality of a particular species of plant. Weed proliferation, removal effort, and associated plant replacement costs, will give a more complete picture of which of the three mulches are best suited for weed suppression in Western Washington bioretention systems.

A listing of study objectives is:

1. Quantify pollutant removal efficiencies for 7 pollutants of concern, over two wet seasons.
2. Quantify stormwater fluxes in terms of inflow/outflow and soil moisture dynamics over two wet seasons.
3. Quantifying maintenance effort in terms of weed removal and plant replacement over the period of study.

4.3 Study Location

The work will be performed WSU's Puyallup Research and Extension Center in Puyallup, WA where 16 replicated and identical bioretention test cells have been retrofitted for this study. The test cells will be dosed with stormwater collected in a large 11,370-liter (3,000-gallon) cistern and then to each rain garden by gravity and at natural storm rates and volumes. Each test bioretention cell is hydraulically isolated from other cells, and inflow stormwater rates, as well as outflow stormwater rates can be quantified using sixteen 0.5L tipping gage flow meters. An additional flow meter that receives water directly from the influent cistern will give us the rate of influent flow to the 16 bioretention cells. Influent pollutant concentrations and effluent concentrations will be measured using compositing automated samplers that will be programmed to collect flow-paced water samples. Dosing of storm events will be managed by taking water samples directly out of the cistern prior to a dosed-storm event, and then adding target pollutants to the cistern to ensure that the dosed event falls within a range of desirable pollutant concentrations.

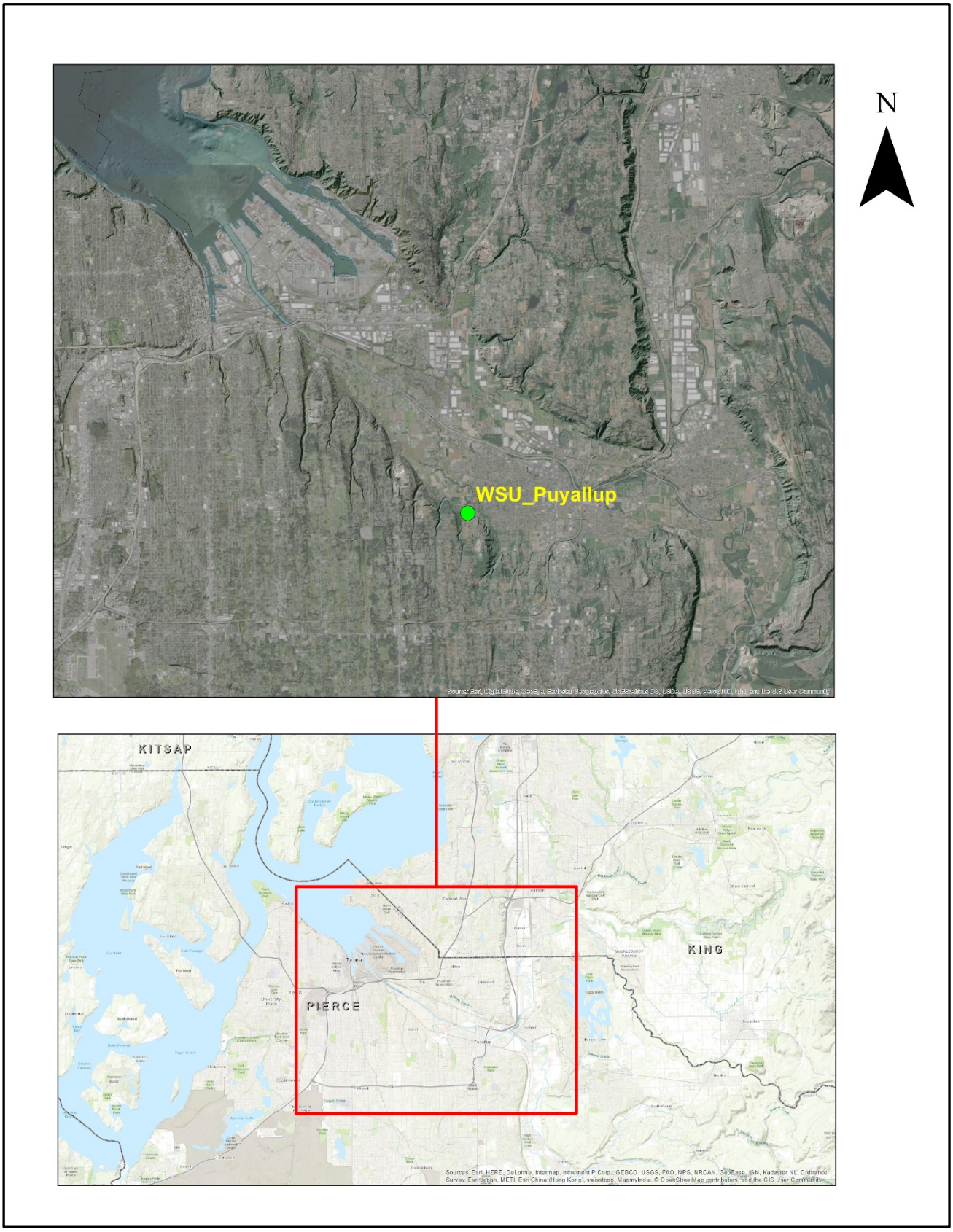

Figure 2: Location of WSU's Puyallup Research and Extension Center

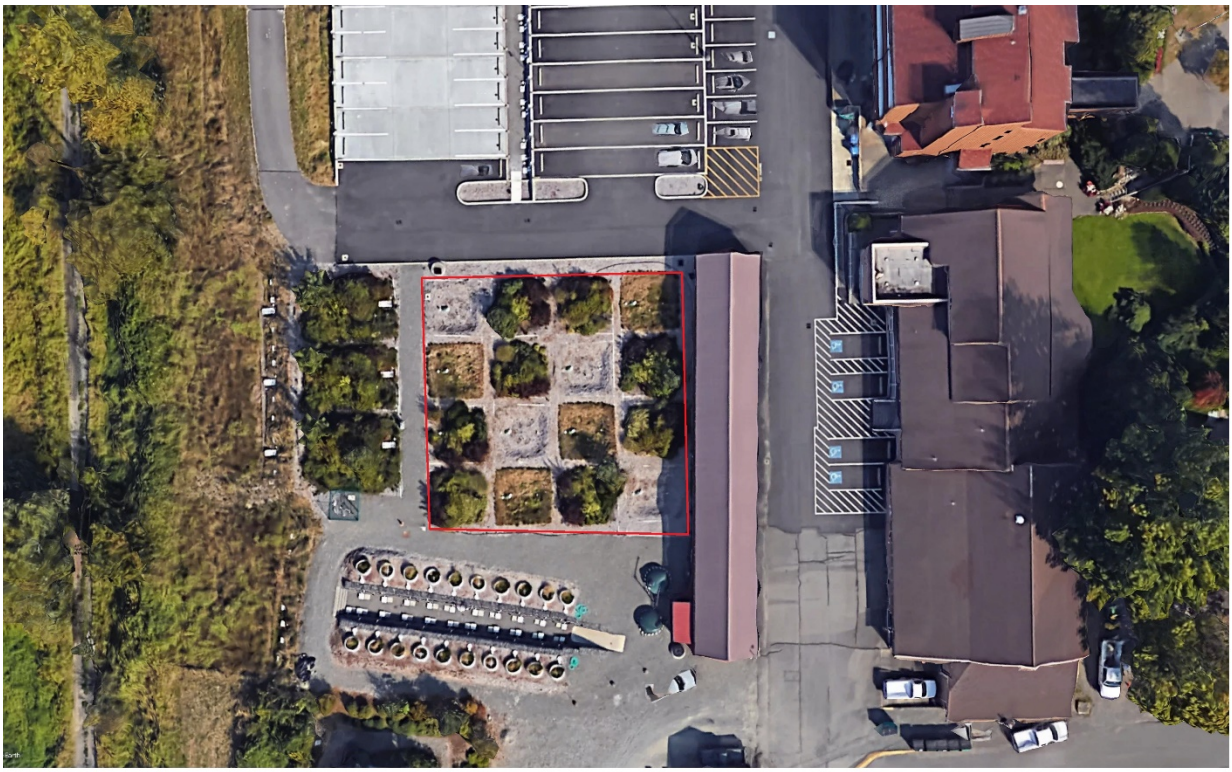

Figure 3: Layout of 16 bioretention test cells at WSU's Puyallup Research and Extension Center

4.4 Data Needed to Meet Objectives

Data collected during this study fall into two categories: A) mulch effect on plant growth and weed suppression; and B) mulch effect on water quality and water quantity, in a bioretention cell.

Mulch effects on plant and weed growth:

1. Quantifying time for system operational check (hours per month)
2. Quantify time needed to weed (hours per month)
3. Counting total number of weeds (count data)
4. Fresh and dry weight of weeds for weed biomass per treatment (mass)
5. Replacement cost and effort associated with replacing plants when around 25% of the species do not survive (value).

Mulch effects on water quality and quantity:

1. Flow rates in and out of the 16 bioretention cells (flow rate)
2. Event mean concentrations of 6 specific pollutants at the influent cistern and at the effluents of 16 bioretention cells, and (concentration data)
3. Dissolved organic carbon concentrations at effluent position for 16 bioretention cells.
4. Soil moisture conditions in the bioretention at two locations in the cells (volumetric soil moisture), one close to the influent, and one close to the effluent locations.

4.5 Tasks Required to Conduct Study

Task 1 Project management and administration

Project administration will be led by WSU staff and students. This includes initiating agreements, subcontracting with project partners, tracking progress of deliverables, reimbursing partner project work based on detailed reports on deliverables, and semi-annual reports to Ecology SAM program. WSU will provide updates and reporting to Ecology semi-annual or as requested and required by the contract.

Task 2 Quality Assurance and Project Protocol (QAPP) development

This document, the QAPP, describes the study design, Instrumentation, intended the type of data, how often data are collected, maintenance protocols for the system, how data will be managed, and lastly how data will be analyzed. Costs associated with QAPP development are related to time taken to write and revise this QAPP document.

Task 3 Bioretention system preparation and instrumentation

The bioretention cells are already built and instrumented with flow measuring instrumentation and weather sensors. Soil moisture sensors will be purchased for this project and owned by WSU. All 16 cells are already planted with a common plant palette.

Task 4 Quantifying maintenance effort and plant survival

Replicated maintenance protocols for each of the three mulch treatments such as pruning, weed removal will be compared to controls (no mulch). Maintenance effort will be measured in terms of person hours spent on an activity. Plant success will also be measured as an associated metric of maintenance effort. Plant survival and death rates will be monitored at least monthly. Growth rates will be measured bi-monthly by monitoring height and width of each plants using a quadrat. Visual assessment of crown health and common plant growth index will be used. All plant assessments will be carried out by a single individual.

Task 5 Quantifying mulch effects on water quality and water quantity

We will test 7 chemical parameters for each storm dosing event in both the influent and effluent from the bioretention cells.

1. Nitrate – Nitrite (target influent value: 0.3 mg/L)
2. Total phosphorous (target influent value: 0.3 mg/L)
3. Dissolved copper (target influent value: 0.1 mg/L)
4. Dissolved zinc (target influent value: 0.1 mg/L)
5. Total petroleum hydrocarbon (target influent value: TPH 15 mg/L)
6. Total suspended solids (target influent value: 150 mg/L)
7. Dissolved organic carbon (no target)

Pollutant removal efficiencies will be quantified by measuring inflow volume, outflow volume, initial analyte concentrations based on dosing of the cistern, and analyte concentration at the

bioretention cell outlet. Volumes of inflow and outflow will be used to characterize how mulch affects water retention in each cell. Results will represent full bioretention water quality and quantity treatment (not only the mulch layer). Soil moisture, and rainfall data will be used as additional explanatory variables in the interpretation of pollutant removal efficiencies.

Task 6 Communication

A final report of study findings will cover water quality treatment water quantity retention, soil moisture, maintenance effort, plant survival for the three mulch types tested, aa data quality review and usability statement, and recommendations for stormwater managers on the mulch types tested.

4.6 Potential Constraints

This work is dependent on rainfall events to charge the dosing system – so while storms will be artificially generated, the bulk of the stormwater for the actual artificial event will come from stormwater runoff stored after a natural storm event. We will therefore have to ensure that prior to an artificial event, we receive enough natural precipitation to fill our storage tanks.

5.0 Organization and Schedule

5.1 Key Project Team Members: Roles and Responsibilities

Table 5.1 Key project people and roles.

Key Team Members	Role	Responsibility
Ani Jayakaran, PhD PE Washington State University 253-445-4523 anand.jayakaran@wsu.edu	Lead Entity, proposal co-author and Quality Assurance Coordinator	Overall project management and ensuring that water quality and quantity objectives are met. Also responsible for deliverables.
Brandi Lubliner, PE WA Dept. of Ecology 360-407-7140 brwa461@ecy.wa.gov	SAM Project Manager	Reviews the project scope and budget, tracks progress, reviews and approves contract deliverables. Serves as the contact person for all communications, notifications, and billings questions regarding IAA No. 1800154.
Linda Chalker-Scott, PhD Washington State University lindacs@wsu.edu	Key Team Member, Proposal coauthor, and project collaborator	Responsible for evaluating weeding and plant related metrics.
Carly Thompson Washington State University carly.thompson@wsu.edu	Project Technician	Responsible for logistics associated with sampling storm events, and sensor maintenance.

5.2 Project Schedule

Table 5.2: Schedule Detail by Task Deliverables

Calendar Year	**2019**		**2020**				**2021**			
Task and Deliverables (Semi-annual basis)	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Project Management and Communication										
D1.1 to 1.4 Semi-annual Reports										
2. QAPP										
D2.1 Draft										
D2.2 Final										
3. Instrumentation										
D3.1 Memo indicating completion										
4. Quantifying Maintenance Effort										
D4.1 Monitoring Memo										
5. Quantifying Water Quality & Quantity Remediation by Mulch										
D5.1 Draft Analysis										
D5.2 Revised Analysis										
6. Communication										
D6.2 Draft Report on Whole Study										
D6.3 Final Report on Whole Study										
D6.3 Presentations										
D6.4 Fact Sheet										

5.3 Budget and Funding Sources

Table 5.3: Budget

Task Description		Salaries	Benefits	Supplies	Travel	Indirect	Total Task
Task 1	Project management and admin	$6,830	$1,763	-	-	$2,148	$10,741
Task 2	QAPP development	$7,165	$1,849	-	-	$2,254	$11,267
Task 3	Bioretention system preparation and instrumentation	-	-	$10,400	-	-	$10,400
Task 4	Quantifying maintenance effort and plant survival	$37,455	$7,994	-	$500	$11,362	$57,311
Task 5	Quantifying mulch effects on water quality & quantity	$11,684	$2,593	$72,690	$500	$3,569	$91,036
Task 6	Communication	$6,830	$1,763	-	-	$2,148	$10,741
	Total by Object	$69,964	$15,962	$83,090	$1,000	$21,481	$191,497

6.0 Quality Objectives

The data quality objectives for this project are to ensure that the measured data adequately represent water quantity and water quality fluxes associated with the 16 bioretention cells. To do this, field data will be collected to characterize water quantity flux, while laboratory analysis of influent and effluent samples will provide a characterization of how water quality is altered as stormwater passes through the mulch treatments. Data will be generated according to procedures outlined in Section 8.0. Data will be deemed acceptable in terms of data quality as outlined this section and only those data that meet and exceed our data quality requirements will be used for analyses.

BMP performance monitoring is expected to be scientifically accurate, useful for the intended analysis, and legally defensible. To achieve that goal, the collected data will be evaluated relative to the following indicators of quality assurance (QA).

Precision: A measure of the variability in the results of replicate measurements due to random error

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)

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 QA indicators. The MQOs are described below in separate subsections for hydrologic and laboratory data.

6.1 MQOs for water quantity or field data

Hydrologic monitoring will involve measurement of outflow using tipping bucket flow meters, soil moisture, and precipitation depth. Inflow will be calculated by assessing flow at the Influent sampling station, with the assumption flow at the location is representative of all inflows to the 16 bioretention cells. Flow measurement and soil moisture errors can be introduced through improper installation procedures, as well as though faulty sensor functioning over the period of study. Similarity, errors associated with precipitation depth data can be introduced from the placement and/or improper functioning of the rain gauge.

The data quality indicators for these measurements are expressed in terms of precision, bias, representativeness, completeness, and comparability. Assessments of precision and bias will be conducted before equipment is deployed in the field and again at the end of the project when the monitoring equipment is retrieved from the field. The MQOs for field data are defined below.

Precision

The precision of the flow meters will be measured by pouring water at known increments onto each flowmeter until the bucket tips. The quantity of water needed to tip the bucket will be recorded for 20 tips per flow meter. The process will be repeated three times, and the resultant coefficient of variation (C_v) will be calculated. The MQO for rain gauge precision will be a C_v of no more than 5 percent. C_v will be calculated using the following equation:

$$C_v = \frac{\sigma}{\mu} \times 100\%$$

Where:

C_v	=	Coefficient of variation
σ	=	Standard deviation
μ	=	The average volume increment needed to tip bucket

Rain gauge precision will be assessed by repeatedly releasing a known volume of water into the rain gauge to cause the tipping bucket mechanism to tip at least 20 times and recording the volumes required to tip it. The process will be repeated three times, and the resultant C_v will be calculated using the above equation.

Soil moisture precision will be assessed by installing the soil moisture sensors in a well graded well mixed 1′ X 1′ X 1′ sand box covered with foil with some water added to the sand. The soil moisture readings will be recorded on a 5-minute time step for 4 hours. The MQO for soil moisture precision will be 5 percent of the calculated measurement based on the mass of sand and added water.

Bias

Bias will be assessed based on a comparison of monitoring equipment readings to an independently measured "true" value. To assess bias associated with the flow gauges, each gauge will have known volumes of water added to determine the how much more (or less) water is needed to tip the bucket, and how different this volume is from manufacturer's specification of a tip per 0.5 Liters (L) of water. This test involves 20 repeated trials per flowmeter and will be conducted at the beginning and end of the study period. The MQO for level measurements will be a difference of no more than 5 percent between the average volume needed to tip the bucket, and the manufacturer's specification of 0.5 L.

Bias in precipitation depth data collected through this study will be assessed based on a comparison of the rain gauge's actual readings to its theoretical accuracy as specified by the

manufacturer. The rain gauge's actual readings will be determined by measuring the volume of water required to initiate one tip of the associated tipping bucket mechanism by adding incremental drops of water with a pipette. The resultant value will then be compared to the manufacturer's specifications for this volume. The MQO for precipitation depth will be a difference of no more than 5 percent between the rain gauge's actual reading and the volume specified by the manufacturer.

Bias associated with the soil moisture sensors will be determined by installing the soil moisture sensors in a well graded well mixed 1' X 1' X 1' sand box covered with foil with a known mass of water added to a known mass of oven dried sand. Soil moisture sensor readings will be collected over a two-day period and compared to the calculated soil moisture based on the mass of sand and added water. The MQO for these measurements is a difference of no greater than 5 percent between calculated and the measured soil moisture over the two-day period.

Representativeness

The representativeness of the hydrologic data will be ensured by the proper calibration and installation of all monitoring equipment, as well as adding the representative amount of water to each bioretention cell in a manner that conforms with rainfall totals common to this area, as well as the drainage area to treatment area ratio – for this study, that ratio is 10:1. Storm events that will be simulated are listed in Table 8.2.

Completeness

Completeness will be assessed based on occurrence of gaps in the data record for all monitoring equipment. The associated MQO is less than 10 percent of the total data record missing due to equipment malfunctions or other operational problems. 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. All the cells were built to design standards and the amount of stormwater applied to them will follow the sizing standard therefore users of this information can presume that results we find in this study are comparable to real world conditions.

6.2 MQOs for water quality sampling and laboratory analyses

QA indicators for laboratory data are expressed in terms of precision, bias, representativeness, completeness, and comparability. The specific MQOs that have been identified for this project are described below and summarized for the water and quality data in Table 6.1. Note that the term **"**reporting limit" in this document refers to the practical quantification limit established by the laboratory, not the method detection limit.

Precision

In this study, overall project data quality will be based on analytical precision and total precision. The following sections describe the MQOs associated with each type of precision.

Total Precision

Total precision will be estimated for laboratory split samples separately. Laboratory precision will be determined by the analytical lab and reported to us. Overall project data quality will be based on total precision; but part of the process of determining data suitability will depend on analytical precision (see below) objectives being met.

For duplicate values that are both greater than 5 times the reporting limit, the pooled relative standard deviation (RSD_p) of laboratory duplicates will meet MQOs identified in Table 6.1.

The RSD_p of duplicate samples will be calculated using the following equation:

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

Where:

S_p	=	Pooled standard deviation
RSD_p	=	Pooled relative standard deviation
Ci_1 and Cj_2	=	Concentration values
m	=	Number of pairs

Since there is no advantage to randomly selecting samples for replication, all available information and professional judgment will be used to select samples or measurements likely to yield results above five times the reporting limit (Ecology 2004). For example, when effluent concentrations are expected to be low, especially at or below five times the reporting limit, duplicate samples should be preferentially obtained from the influent station and effluent stations.

Table 6.2: Laboratory and Field Data Quality Indicators (DQIs) and Measurement Performance Criteria (MPC) for analytes of the mulch effectiveness study.

Analyte	Method	MDL	RL	Lab and Feld replicates RPD[a]	LCS (%R)	MS/MSD (%R)	Laboratory Duplicate RSD_p[b]
Nitrate + Nitrite-N	EPA 353.2	0.0100 mg/L	0.0100 mg/L	≤25% or ± 2 × RL	90-110%	75-125%	≤10%
Total Phosphorous	SM 4500-P E-99	0.00800 mg-P/L	0.00800 mg-P/L	≤20% or ± 2 × RL	90-110%	75-125%	≤10%
Dissolved Copper	EPA 200.8 UCT-KED	0.340 µg/L	0.500 µg/L	≤20% or ± 2 × RL	80-120%	75-125%	≤10%
Dissolved Zinc	EPA 200.8 UCT-KED	0.820 µg/L	4.00 µg/L	≤20% or ± 2 × RL	80-120%	75-125%	≤10%
Total Petroleum Hydrocarbons, (low level)	NWTPH-Dx	*0.0330 mg/L, ^0.0560 mg/L	*0.100 mg/L, ^0.200 mg/L	≤30% or ± 2 × RL	*56-120%, ^30-160%	*56-120%, ^30-160%	≤10%
Total Suspended Solids	SM 2540 D-97	1.000 mg/L	1.000 mg/L	≤25% or ± 2 × RL	90-110%	NA	≤15%
Dissolved Organic Carbon	SM 5310 B-00	0.5000 mg/L	0.5000 mg/L	≤20% or ± 2 × RL	90-110%	75-125%	≤15%

*- Diesel Range Organics (C12-C24)
^- Motor Oil Range Organics (C24-C38)

[a] The relative percent difference must be less than or equal to the indicated percentage for values greater than 5 times the reporting limit. *RPD* must be and ± 2 times the reporting limit for values less than or equal to 5 times the reporting limit.

[b] RSD_p will only be calculated for values that exceed 5 times the RL.

Analytical Precision

Analytical precision will be assessed by laboratory splits of samples, matrix spikes, and laboratory control samples (see below, under Bias).

The relative percent differences (RPD) of laboratory split samples will meet MQOs identified in Table 6.1.

The RPD will be calculated using the following equation:

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

Where:

RPD	=	Relative percent difference
C_1 and C_2	=	Concentration values

Bias

Sampling bias will be assessed based on analyses of field and laboratory samples. For details regarding remedial steps if contamination from any field equipment is detected, refer to the *Verification and Validation* section.

Field Bias

Field contamination during sampling could occur from the tubing or activities of field staff. The tubing will be used for one season then cleaned. To assess the cleaning effectiveness an equipment blank sample will be made by running lab supplied blank water thru tubing after cleaning. The values for field blanks are not to exceed the reporting limit, if they do the tubing will be discarded and new tubing used for the second sampling season.

Laboratory Bias

Laboratory contamination of samples will be assessed using method blanks, matrix spikes, and laboratory control samples (LCS). Method blank samples are expected to be below the reporting limit identified in Table 6.1. The percent recovery of matrix spikes and LCS will meet the MQOs identified in Table 6.1.

Percent recovery for matrix spikes will be 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

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

Percent recovery for LCS will be calculated using the following equation:

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

Where:

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

Representativeness

The sampling design will provide samples that represent a wide range of water quality conditions during storm events. Sample representativeness will be ensured by adequate sample size over a sufficient time span, and by employing consistent and standard sampling procedures.

One of the objectives of this project is to collect flow-weighted composite samples with pollutant concentrations that represent an event-mean concentration (EMC) for the sampled event. To ensure composite samples meet this objective, the following guidelines for sampling criteria will be used:

1. At least **10 flow-weighted sub-samples** (or aliquots) must be collected during the duration of the event.
2. Samples shall be collected for at least **75 percent of the storm event hydrograph** as measured by volume.
3. Maximum sampling duration: **36** hours
4. **Synthetic storms** – natural storm events will provide stormwater that will be stored in large cisterns. These cisterns will be dosed with chemical reagents to meet specific pollutant concentrations prior to dosing of the 16 bioretention cells. The dosing will be the basis for performing water quality testing and will be conducted in the form of synthetic storms that range from 0.2 inch to 1-inch rainfall over a 24-hour period.
5. Data from a minimum of 6 synthetic storms will be considered adequate to meet the objectives of this performance monitoring project.

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 that has been assigned a *J* qualifier. A qualitative assessment will be made as to which *J* flagged data may need to be excluded from this calculation before the production of the TER. 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. The results will be tabulated in standard spreadsheets to facilitate analysis and comparison.

7.0 Experimental Design

7.1 Study Design Overview

The study will be conducted at Washington State University's Research and Extension Station in Puyallup, WA. The site comprises three basic physical components to the experimental design:

1. **Cistern and flow distribution system** will be used as a source for stormwater associated with synthetic storm events.
2. **Bioretention cells (16)** with 60:40 BSM, two soil moisture sensors per cell, a common plant palette, and three mulch treatments (replicated four times). Four cells with no mulch will serve as control.
3. **Sampling stations (17)** – 16 measuring bioretention effluent, and one measuring influent directly from the cistern. Each sampling station comprises a water quantity sampling flowmeter, and an automated water quality sampler.

Cistern and Flow Distribution System

To facilitate monitoring of the bioretention cells, stormwater will be collected from a 72,084 square foot impervious drainage area on the WSU campus. Runoff from approximately 75 percent of this area (54,063 ft2) will be routed to two 11,370-liter (L) (3,000 gallon) cisterns for storage and delivery to the cells. The cistern locations on the campus and associated drainage area are shown in Figure 4. Stormwater from the cisterns can be routed via gravity flow to the cells during **natural storms**; alternatively, water can also be pumped from the cistern at specific flow rates, and pollutant concentrations, to produce **synthetic storms**. In both cases, weir boxes constructed at the water surface elevation inside the cistern distribute uniform volumes of stormwater to each bioretention cell, with one distribution line bypassing the bioretention cells and terminating at a separate Influent sampling station (Figure 5). Influent flows and chemistry for all the cells will be generalized based on representative data that are collected at this station.

For this study, synthetic storm events will be generated using the pump system and will move stormwater dosed with reagent grade chemicals to simulate a more potent stormwater mix, from the cistern to the bioretention cells. Based on prior experience the natural stormwater collected in the cisterns does not contain high enough concentrations of pollutants to provide a representative influent to the BMPs, therefore we add chemicals to become more representative of published stormwater concentrations draining urban centers (See Section 7.6 for targeted influent concentrations). The cistern will be kept full during the study using natural storms; therefore, any stormwater that enters the cisterns from the associated drainage basin will flow directly to the cells and Influent sampling station without attenuation.

1. By directing undosed stormwater associated with natural storm events to the cells, we will be able to measure just the water quantity dynamics of the system – flow rates and soil moisture fluxes.
2. By directing dosed synthetic storms to the cells, we will be able to quantify the water quality dynamics of the system – pollutant removal efficiencies.

Furthermore, eductors[1] to agitate the water in the cistern that are 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 bioretention cells. This will minimize any pretreatment that might occur in the cistern that would bias the results.

Figure 4: Image showing layout of facilities at WSU's Puyallup Research and Extension Center. Stormwater captured from a drainage area (purple) will be stored in a cistern, that in turn will be used to dose 16 bioretention cells (red area)

Bioretention Cells

Sixteen bioretention cells arranged in a 4 by 4 grid pattern were planted with a common plant pallet within a uniform planting area of 100 ft^2. The plants that were chosen are:

1. Primary deciduous woody element: *Physocarpus opulifolius* 'Tiny Wine' -- A dwarf ninebark with disease resistance and capacity to withstand both summer drought and some winter flooding.

[1] Eductors are a kind of jet-type pump that do not require any moving parts to be able to pump out a liquid or gas. These pumps make use of their structure to transfer energy from one fluid to another via the Venturi effect.

2. Primary evergreen woody element: *Mahonia aquifolium* 'Compacta' -- A dwarf cultivar of our native tall Oregon-grape that has a tidy habit and grows about 2-2.5 feet. Very tough in all conditions (as long as it's in full to mostly full sun).
3. Bunching grasses/grass-like plants*: Pennisetum a. 'Burgundy Bunny' Carex testacea*
4. Non-aggressive rhizomatous species:
   i. *Iris tenax* (evergreen)
   ii. *Juncus ensifolius*

The arrangement of those cells containing a particular mulch type, and cells containing no mulch [control] are depicted below in Figure 5. The figure also shows the arrangement of pipes and locations of the 16 effluent sampling station, and the single influent sampling station.

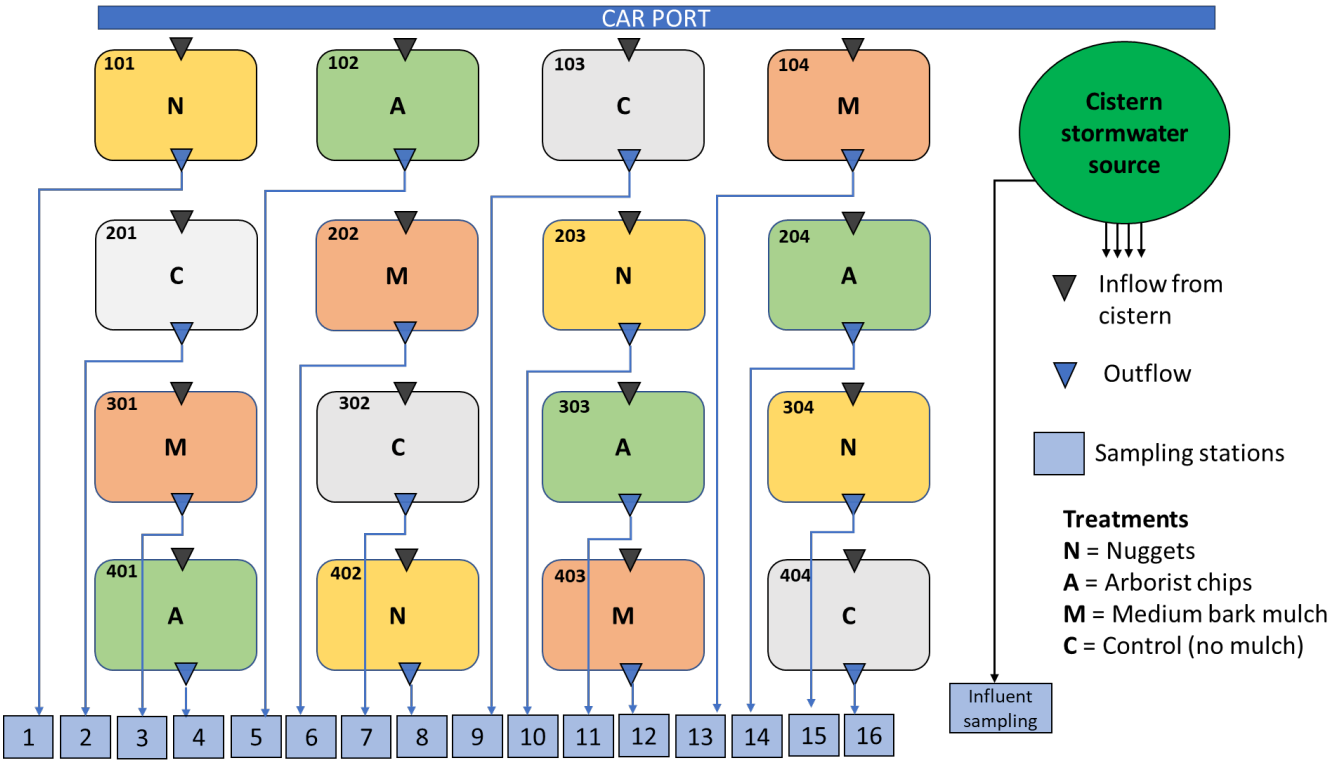

Figure 5: Schematic showing arrangement of cells with three kinds of mulch, with no mulch [control], and arrangement of piping system. Sampler stations are also shown.

Each bioretention test cell will comprise bioretention soil media of the 60:40 sand-compost mix, a common plant palette, and one of the three experimental mulches, or no mulch (control). Within each cell, a section close to the inflow, and one close to the outflow will have soil moisture sensors inserted to a depth of 1 foot below the ground surface. A vertical drain outlet has been installed within each cell to carry effluent from the cell to the downstream sampling location. The vertical drain outlet is designed to allow for varying the depth of outlet flow. For this project, that depth is set at **20 inches** below the top of the mulch layer, or **18 inches** below

the top of BSM where no mulch (control). The planted area of 100 ft^2 will be considered as the bioretention treatment areas.

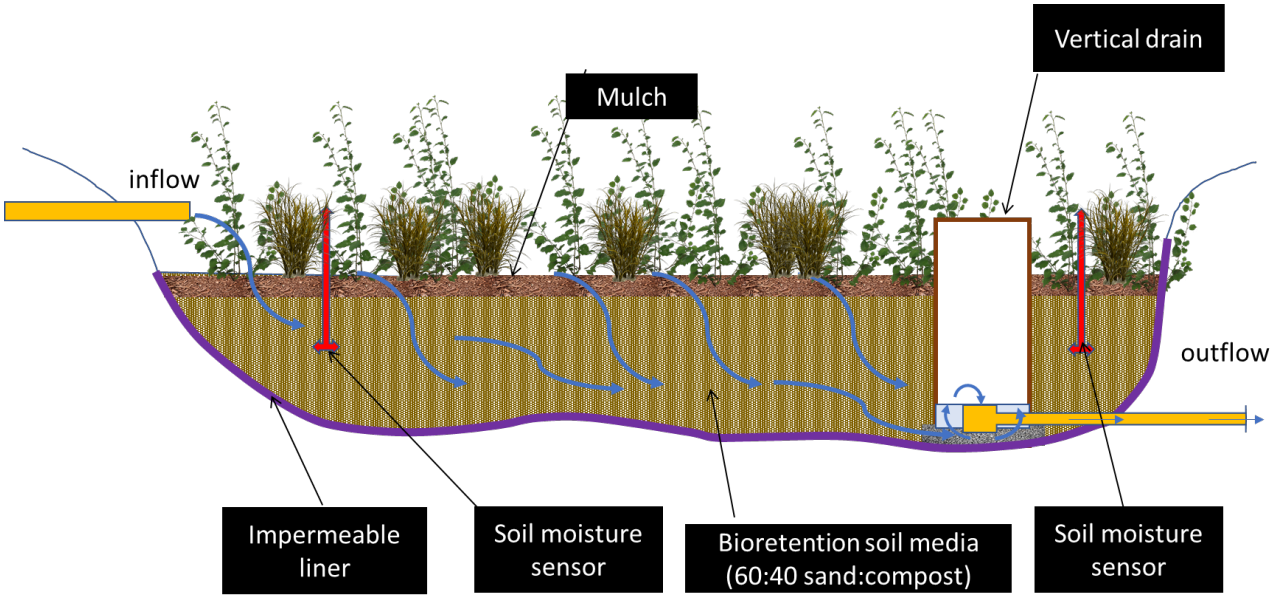

Figure 6: Cross-section of a single bioretention test cell

7.3 The Structural BMP System Sizing

Each bioretention cell is approximately 11ft by 11ft. The planted footprint in each cell is about 100 ft^2. The level of the outflow is approximately 20 inches below the top of mulch, and 18 inches below the top of the BSM mix. Per the Washington Stormwater Management Manual for Western Washington. Dosed synthetic storms will be routed to each cell, and each cell will receive a volume of runoff equivalent to 10:1 contributing:treatment area. Therefore, to simulate a 1-inch 24-hour rainfall event, 10 inches of dosed stormwater will be applied per unit treatment area of cell, or $\frac{10in}{12(in/ft)} * 100ft^2 = 83ft^3 = 2{,}360\ Liters$ of dosed stormwater will be needed to be applied to each cell for a simulated 1 inch storm.

7.4 Types of Data Being Collected

Table 7.4: Type and frequency of data collected for targeted parameters.

Parameter	Sample type for collection (I= influent, E=effluent)	Frequency of collection
Nitrate + Nitrite	I, E	6
Total phosphorous	I, E	6
Dissolved copper	I, E	6
Dissolved zinc	I, E	6
Total petroleum hydrocarbon	I, E	6
Total suspended solids	I, E	6
Dissolved organic carbon	I, E	6
Inflow volume	I	15 minute
Outflow volume	E	15 minute
Soil moisture	two locations per cell	15 minute
Plant success	within each cell	Weekly
Weeding effort	within each cell	Weekly
Precipitation	one location on campus	15 minute

See Figure 4 for contributing drainage area for cistern (influent) water, and Figures 5 and 6 for bioretention cell inflow and outflow locations. All effluent sample parameters will be measured in 3 field bioretention cell replicates per treatment and control.

Refer Table 9.5 for number of samples collected

7.5 Flow Monitoring

As described in the Experimental Design section, water is distributed to each bioretention cell and the Influent sampling station (Figure 5) via weir boxes placed at a uniform height within the cistern. 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 are not to be used as primary flow measurement devices; instead, their sole purpose will be to ensure an even distribution of water to each bioretention cell and the Influent sampling station. To this end, the height of the weir boxes will be checked on a monthly basis during the first year of monitoring to ensure the weirs are at the same elevation (see Quality Control section below). In the second year of monitoring, the height of the weir boxes will be checked at a minimum on a quarterly basis.

The volume of dosed stormwater routed to each bioretention cell will be estimated by routing water through a Hydrological Services TB0.5-L tipping bucket flow gauge (see detailed specifications in Appendix) is be installed at the Influent sampling station (Figure 3). The tipping bucket flow gauge is connected to a Campbell Scientific CR1000 datalogger. The datalogger measures each tip of the flow gauge bucket mechanism and convert the signal to a volume estimate. The volume estimates are 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 is 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 sampling station is used to estimate influent discharge rates to all of the bioretention cells. These discharge estimates will be valid so long as flow is uniformly distributed to each bioretention cell 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 bioretention cell.

Effluent discharge rates are measured at the point of discharge for each bioretention cell's outlet flow control structure (Figures 5 and 6). Flow from each outlet flow control structure is routed into a separate Hydrological Services TB1-L tipping bucket flow gauge for each bioretention cell. These flow gauges are connected to the same Campbell Scientific CR1000 datalogger described above, in connection with the Influent sampling station. The discharge measurements from these flow gauges are stored and downloaded using procedures described above for the Influent sampling station.

7.6 Soil Moisture Monitoring

Two soil moisture sensors (HOBOnet Soil Moisture EC-5 Sensors) will be installed within every bioretention cell at a depth of 12 inches below the ground surface. One sensor will be placed close to the inflow, the other close to the outflow of the cell. The data from each sensor is transmitted wireless to a receiving station (RX3000 WiFi Remote Monitoring Station), from which it will be downloading periodically to a central database.

7.7 Water Quality Sampling

Flow weighted composite samples will be collected during six synthetic storm events for characterizing influent and effluent pollutant concentrations for each bioretention cell. Influent samples will be collected using an Isco Model 6700 series automated sampler (see detailed specification in Appendix E) that are installed in association with the Influent Sampling Station and each bioretention cell (Figures 5). The automated sampler intake for the Influent sampling station will be located just upstream of the station's tipping bucket flow gauge (see description in previous section). The automated sampler intake for each bioretention cell 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.

7.8 Cistern Dosing

Given that stormwater emanating from the WSU Puyallup Research and Extension site is fairly low in pollutants, the cistern will be augmented with reagent grade metal and nutrient compounds, Sil-co-Sil 106 ground silica (for TSS), motor oil, diesel fuel, to achieve target ranges. This synthetic stormwater will then be transferred from the cistern stormwater to the 16 bioretention cells through a series of pumped pulsed events, where a series of pulsed events would mimic a single storm event. For this method, pollutant concentrations are anticipated to be relatively consistent throughout storm.

Addition of chemicals will be done to achieve the following influent targets.

1. Nitrate – Nitrite (target influent value: 0.3 mg/L)
2. Total phosphorous (target influent value: 0.3 mg/L)
3. Dissolved copper (target influent value: 0.1 mg/L)
4. Dissolved zinc (target influent value: 0.1 mg/L)
5. Total petroleum hydrocarbon (target influent value: TPH 15 mg/L)
6. Total suspended solids (target influent value: 150 mg/L)
7. Dissolved organic carbon (measured only in effluent)

To achieve these concentrations consistently in influent delivery, the amount of reagent added would need to account both for the water already in the cistern (V_1) as well as the additional

stormwater (V_2) that will be pumped into the cistern to simulate a synthetic storm. If C_1 is the desired influent concentration that will be delivered to the bioretention cells, then the reagent concentration (C_2) within the cistern just before additional stormwater is pumped into the full cistern, is given by:

$$C_2 = C_1(\frac{V_1 + V_2}{V_1})$$

7.9 Weeding Effort and Plant Success

The effect that mulch plays on mitigating weeds will be measured through monthly logging of person-hours needed to remove weeds or plants not planted in the cells, from each of the 16 bioretention cells.

Plant success will be measured by monitoring plant health and mortality on a monthly basis. We will also monitor plants for damage not associated with treatment (e.g., herbivore damage and other environmental factors). We will measure the success of plant establishment by measuring the total spread of the above ground parts. We will note whether growth is so vigorous that there is a risk of the area becoming a monoculture of that species.

8.0 Sampling Procedures

8.1 Standard Operating Procedures

Precipitation, Flow, and Soil Moisture Monitoring

No SOPs are prescribed for these activities as they will all be conducted using continuous sensor technology, with data logged using a telemetric network that transmits data to a central server.

Water Quality Sampling

Synthetic Storm Events

Pre-determined synthetic stormwater volumes and rates will be delivered from cisterns through pumps and flow meters. Accordingly, estimates for influent EMC will be determined from known volumes. If working with natural stormwater that has been in the cistern for less than 10 days, existing concentrations will be assumed from previous natural stormwater testing. If working with natural stormwater that has been in the cistern for more than 10 days, the cistern water will be tested for total nitrogen, phosphorus, zinc and copper. Estimates for influent EMC will then be determined given pre-determined storm volume and cistern water quality. Reagent grade ACS chemicals will be used to make Standard Solutions of each analyte. Concentrations of Standard Solutions will be below maximum concentrations achievable for cold water. Reagents to be used are listed in Table 8.1. Volume of Standard solutions will be added to the cistern in proportions to achieve target concentrations for total metals and total nutrient concentrations identified in above.

Table 8.1: Target primary pollutants and reagents for synthetic stormwater.

Target Pollutant	**Reagent**
TSS	Sil-co-Sil 106
Total P	Potassium Phosphate mono basic (KH_2PO_4)
NO_2+NO_3	Potassium nitrate (KNO_3)
Cu (total and dissolved)	Copper sulfate ($CuSO_4$)
Zn (total and dissolved)	Zinc Chloride ($ZnCl_2$)
Total Petroleum Hydrocarbons	Petrol and Diesel

Before a synthetic storm is applied water quality sampling equipment will be deployed following procedures detailed previously. Selected concentrations of metals and nutrients, Sil-co-Sil 106 ground silica (for TSS), diesel fuel, and motor oil will be added to the cistern. Eductors will be turned on for a minimum of one hour before adding chemicals and continue through storm delivery to create a well-stirred condition in the tank.

Pre-determined storms ranging from small (0.2 inches) to larger (1.0 inches) of rainfall will be delivered to bioretention cells from the cisterns. The existing contributing area to bioretention cell area ratio will be used to determine total synthetic storm volume. Stormwater from the cisterns will be continuously mixed and delivered using existing pumps and metered through high accuracy flow meters (Endress Hauser Promag 50) at pre-determined rates. Technicians will monitor flow delivery and adjust pumps and meters to attain desired synthetic storm delivery. Flow rates will roughly mimic typical storm hydrograph starting off at slower rates, increasing to a peak flow and then receding to the storm end (see Storm Volume and Rates for Synthetic Stormwater Delivery below).

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:

1. Flush sample line for each automated sampler with dilute (1:100) Liquinox detergent solution and then deionized water.
2. Attach sample line to automated sampler and position the associated intake in the respective sampling locations described above for the Influent sampling station and bioretention cells.
3. Place a clean 20-L glass sample bottle into the automated sampler and pack ice around each sample bottle.
4. Attach the automated sampler head to its base.
5. 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-mL sample aliquots at preset flow increments with the goal of collecting at least 29 sample aliquots, covering at least 90 percent of each storm's total runoff volume. Sample pacing for the automated samplers will be determined based on the total volume of water that will be used to dose the systems. The total volume of water used to dose the system will in turn be calculated based on the rainfall event that is being simulated (0.2 to 1 inch, 24-hr rainfall), assuming that all rainfall runs off the contributing area. Again, the contributing area is assumed to be 10 times the planted area of each bioretention cell (96 ft^2). The resultant runoff volume (cubic feet) will then be divided by 24 (the median number of 400 mL aliquots that a 20-L bottle will hold) to estimate the sample pacing (liters) 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 sampling station reaches a user customizable threshold. This alarm will notify field personnel that an event is underway. As needed, additional grab samples may also be collected to verify the data from the Influent sampling station are indeed representative of the influent to each of the bioretention cells (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 sampling event, 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 synthetic 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 Experimental Design section.

Storm Volume and Rates for Synthetic Stormwater Delivery

Storm volumes and the range of six synthetic storm events that will be generated are presented in the table below:

Table 8.2: Storm volumes for synthetic storm events.

24-hr Rainfall (in)	**0.2**	**0.4**	**0.5**	**0.6**	**0.8**	**1**
Volume per cell (ft^3)	17	33	42	50	67	83
Volume per cell (L)	472	944	1,180	1,416	1,888	2,360
Volume to all 16 cells + influent station (L)	8,023	16,046	20,058	24,069	32,092	40,116
Flow pacing for each sampler (L of effluent stormwater per 400mL-aliquot)	12.5	25.0	31.0	37.5	49.5	62.0

Prior to a beginning of a synthetic storm event, the stormwater cisterns will be filled to the point that water just starts flowing across the weir boxes at which point filling of the cistern will stop. Once all flow across weir boxes has ceased, eductors will be turned on for 60 minutes, after which dosing of the cistern will take place. Dosing concentrations will be based on the targeted influent concentration and dependent on the sums of the volume of water in the cisterns and anticipated stormwater that will be added to the cistern for the synthetic storm event [*See Section 7.8 Cistern Dosing*].

Once the cisterns have been dosed, water will be pumped into the cistern while the eductors are running to ensure a fully mixed system. Pumping will occur as 9 pulsed events, with each pulse

taking 20 minutes, and each pulse separated from the next pulsing event by a 20-minute period of no pumping. The intermittent pumping is to ensure that there is some parity in terms of delivery times for the nearest and the furthest cell, and that they are loaded similarly over the course of the entire synthetic storm event. This 20-minute pulsing is illustrated for two storm events in Figure 7 – that 0.2-inch and 1.0-inch storm events. Each storm event will take 340 minutes to complete. Delivery rates for the 0.2-inch and 1.0-inch storm events, and the number of sample aliquots collected per pulse are also shown in Figure 7.

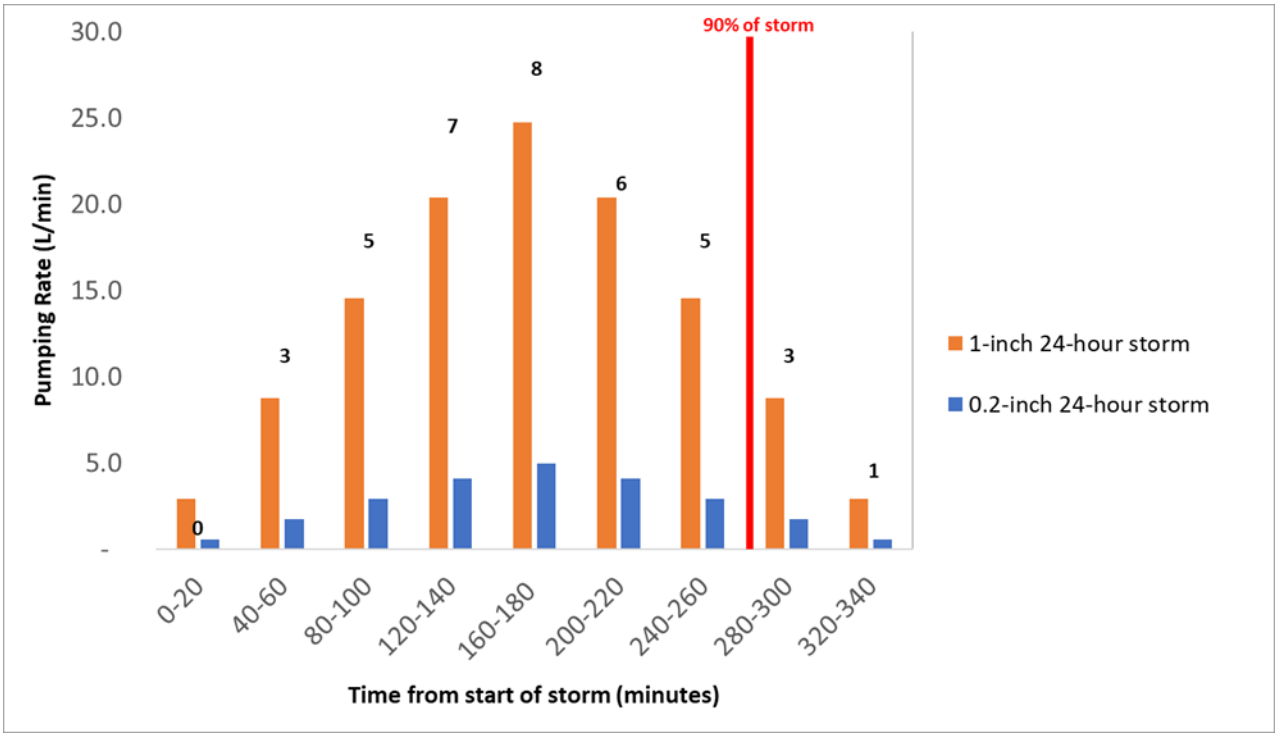

Figure 7: Pumping rates for two artificially generated storm events

Monitoring Weeding Effort

The amount of time taken to identify and remove weeds will be recorded for each bioretention cell. This activity will be performed once every month over the course of the study. The time weeding effort begins, when it ends, and the identifying label for the bioretention cell will be recorded. Additionally, annual and perennial weed counts, as well as wet and dry weights of weed biomass will be recorded.

Monitoring Plant Success

Plant success will also be measured as an associated metric of maintenance effort. Plant spread and vigor will be monitored weekly. Plant spread will be measured by assessing the circumference of spread. Vigor will be assessed by a visual assessment of crown health and plant growth and quantified using the following scale:

- 1 = No damage associated with treatment, good color, vigorous growth

- 2 = 1-25% damage associated with treatment. Color and growth are not as robust as those rated a "1" but are still acceptable and growing well.
- 3 = 26-50% damage. Plants show obvious signs of stress associated with the treatment but still show new growth and may recover.
- 4 = 51-75% damage. Plants show significant signs of stress associated with the treatment with little new growth.
- 5 = 76-100% damage. Plant is dead or is expected to die soon.

8.2 Containers, Preservation Methods, Holding Times

Automated samplers will be filled with ice before each sampled storm event. Ice will not be allowed to sit within autosamplers 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.

Clean, decontaminated sample bottles will be placed in the automatic sampler in advance of each storm event. All sample bottles (grab sample bottles and 20-liter composite bottles) will be transported in coolers with ice and kept below 6 degrees Celsius until delivery to the laboratory. 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 sampler carboy to precleaned sample bottles for the required analyses. The carboy will be vigorously agitated through a splitter into separate bottles for analysis. This transfer process will ensure the sample is well mixed before filling the individual sample bottles. 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 US EPA (1996) for the low-level detection of metals.

8.3 Equipment Decontamination

New sample bottles will be provided by the analytical laboratory prior to each sample collection event. Equipment used for intermediate storage and collection of samples (glass carboys, etc.) will be decontaminated for target parameters prior to each sampling event following SOPs described in Friese et al. 2014. Chemical waste will be disposed of following WSU Environmental Health and Safety SOPs for chemical waste disposal.

After samples are processed, laboratory personnel will clean the sample bottles with a four-step process: 1) Liquinox detergent rinse, 2) reagent grade water rinse, 3) two molar nitric acid rinse, and 4) reagent grade water rinse. Automatic sampler intake lines will also be cleaned using a Liquinox detergent rise after every sampling event.

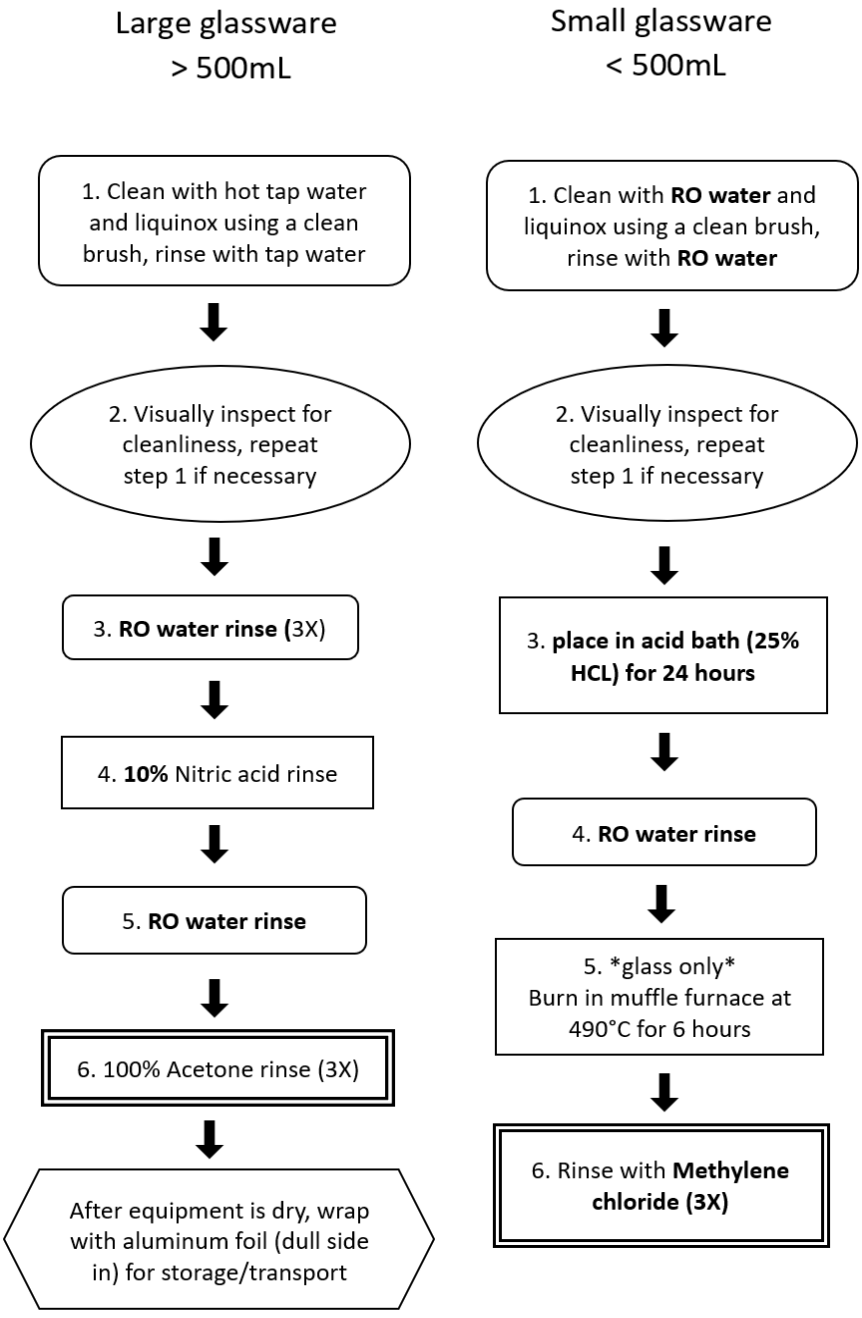

Figure 8. Decontamination SOPs for various types of equipment that will be used in the collection and storage of contaminated samples. This figure is adapted from the Ecology decontamination SOPs (Friese et al. 2014).

8.4 Sample Identification

All sample containers will be labeled with the following information using indelible ink and labeling tape:

- Sampling station name (e.g., 104 or INFL)
- Date of sample collection (year/month/day: yyyy/mm/dd)
- Time of sample collection (international format [24 hour])
- Field personnel initials (e.g., DSA)

QA samples (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.

Waterproof labels will be placed on dry sample container lids by self-adhesion or with tape. Waterproof labeling tape may be employed. Any written marks will be made with waterproof ink.

8.5 Chain of Custody

https://www.arilabs.com/sampling-and-custody-forms/

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.

8.6 Field Log Requirements

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 Appendix 2).

- Site name
- Date/time of visit and last sample collected
- Name(s) of field personnel present
- Weather and flow conditions
- Rain gauge condition
- Desiccant condition
- Number of aliquots (if sampled)
- Sampling errors? (if sampled)
- Sample duplicated? (if sampled)
- Estimated sample volume (if sampled)
- Presence of obstructions in weir, or sample tubing and remedial actions taken
- Unusual conditions (e.g., oily sheen, odor, color, turbidity, discharges or spills, and land disturbances)
- Modifications of sampling procedures

Field notes will be included as an appendix in the final report produced for this project.

9.0 Measurement Procedures

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

9.1 Procedures for Collecting Field Measurements

Precipitation Measurement

Two rain gages are installed on the Puyallup Research and Extension campus as outlined in Section 7.5. Data is logged on a local C1000 datalogger. The stored data is 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 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).

Soil Moisture Measurement

Each bioretention cell will have two soil moisture sensors installed (HOBOnet Soil Moisture EC-5 Sensors) at a depth of 12 inches, one at the inflow and the other at the outflow of the cell. Soil moisture measurements will be logged at a 15-minute frequency on a central datalogger that is 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 check the soil moisture sensors for proper position in the soil profile. On an annual basis, the calibration of the gauge will be checked and adjusted if necessary (see Quality Control section below).

Flow Measurement

Performed continuously and data sent on a wireless network to a central database.

Weeding Effort and Plant Success Measurement

Performed on a weekly basis, with data recorded on field data sheets and data entered into a digital database once a month.

9.2 Laboratory Procedures

Water Quality Measurement

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 analytical methods, and reporting limits for all water quality parameters to be evaluated in this study are presented in Table 9.2.

The Federal Register indicates that dissolved metals 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. Samples will be taken within 3 hours of the culmination of the synthetic storm event to the laboratory where samples will be split-churned for subsampling, and then filtered.

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 (See Table 6.1)

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.

9.3 Sample Preparation Methods

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 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. Samples will be delivered within 3 hours of the culmination of the synthetic storm to the laboratory for analysis.

9.4 Special Method Requirements

NA

9.5 Lab(s) Accredited for Methods

The laboratory identified for this project (Analytical Resources Incorporated) is certified by Ecology and participates in audits and inter-laboratory 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.

Table 9.5: Anticipated number of samples and quality assurance requirements for each water quality parameter.

Parameter	Storms	No of Stations	Total No. of Samples	Laboratory Method Blanks	Rinsate Blanks	Laboratory Control Standard	Matrix Spike	Lab Duplicates[a]	Distribution Systems Checks	Total No. of Samples[b]
Total suspended solids	6	17	102	1/storm[a]	NA	1/storm[a]	NA	2/storm[a]	3	129
Total phosphorus	6	17	102	1/storm[a]	2	1/storm[a]	1/storm[a]	2/storm[a]	3	135
Nitrate + nitrite nitrogen	6	17	102	1/storm[a]	NA	1/storm[a]	1/storm[a]	2/storm[a]	NA	132
Copper, dissolved	6	17	102	1/storm[a]	2	1/storm[a]	1/storm[a]	2/storm[a]	NA	132
Zinc, dissolved	6	17	102	1/storm[a]	2	1/storm[a]	1/storm[a]	2/storm[a]	NA	132
Total petroleum hydrocarbons (diesel + motor oil)	6	17	102	1/storm[a]	NA	1/storm[a]	1/storm[a]	2/storm[a]	NA	132
Dissolved Organic Carbon	6	17	102	1/storm[a]	NA	1/storm[a]	1/storm[a]	2/storm[a]	NA	132

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 - Total annual number of samples includes project samples, rinsate blanks, and distribution system checks.
NA - not applicable.

10.0 Quality Control

Quality control (QC) procedures are identified in separate subsections below for field and laboratory activities. The overall objective of these procedures is to ensure that data collected for this project are of a known and acceptable quality.

10.1 Field QC Required

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 Table 9.5 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 dataloggers 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 weir boxes, including debris removal
- Inspection of outlet flow control structures (see Figure 5), including level of upper and upper outlets

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 0.5 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 Experimental

Design section. The flow from the cistern will be measured with a magnetic flow meter; 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 5 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.

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):

- Bioretention cell 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

Equipment Rinsate Blanks

Equipment rinsate blanks will be collected at the Influent Sampling Station (Figure 5) 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
- Copper, dissolved
- Zinc, dissolved
- Nitrite + Nitrate
- Dissolved Organic Carbon
- Total Petroleum Hydrocarbons
- Total Suspended Solids

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 Experimental Design section, stormwater from the cistern (Figures 4 and 5) will be routed via gravity flow or pumped to the Influent Sampling Station (Figure 5) and individual bioretention cells during testing related to the bioretention cell research. In either case, weir boxes constructed at the water surface elevation inside the cistern will distribute flows evenly to each bioretention cell, with one distribution line bypassing the bioretention cells and terminating at the Influent sampling station. Using this design, influent flows and chemistry for all the bioretention cells will be generalized based on representative data that are collected at the Influent sampling station.

To verify that flow and chemistry data collected at the Influent sampling station are indeed representative of the influent entering each of the bioretention cells, the following checks will be performed:

- Weir box elevation checks
- Influent sampling station and bioretention cell flow checks
- Influent sampling station and bioretention cell chemistry checks.

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

<u>Weir Box Elevation Checks</u>

To ensure there is an even distribution of flow to each bioretention cell and the Influent sampling station, the height of the weir boxes will be checked on a monthly basis during the first year of monitoring 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 sampling station and Bioretention cell Flow Checks

To verify there is an even distribution of flow to each bioretention cell and the Influent sampling station, manual measurements of flow will be made at each bioretention cell during storm events and compared to the flow measured at the Influent sampling station. Flow measurements at each bioretention cell will be made by recording the amount of time it takes to collect a known volume of water from the inlets to each bioretention cell. These data will then be compared to the flow recorded by the automated equipment at the Influent sampling 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 bioretention cell deviates by more than 25 percent from the flow measured at the Influent sampling station.

Influent sampling station and Bioretention cell Chemistry Checks

To verify the chemistry data from the Influent sampling station are sufficiently representative of the influent to each of the bioretention cells, grab samples for total suspended solids (TSS) and Total Phosphorous will be simultaneously collected from the Influent sampling station and one randomly selected bioretention cell during at least three storm events. 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 sampling stations and bioretention cells. Dissolved zinc was also selected as a representative parameter for evaluating differences in dissolved constituent concentrations between the Influent sampling station and bioretention cells. Modifications to the flow distribution system may be considered if these measurements show the concentrations at each bioretention cell deviate by more than 35 percent from the flow measured at the Influent sampling station.

10.2 Laboratory QC Required

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 Table 9.5.

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 are shown in Tables 9.5 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 9.5 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 Table 9.5 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 Table 9.5 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
- Copper, dissolved
- Zinc, dissolved
- Nitrite + Nitrate
- Dissolved Organic Carbon
- Total Petroleum Hydrocarbons
- Total Suspended Solids

10.3 Corrective Action

Data from the lab and the field will be reviewed by all project personnel once every month to identify errors in instrumentation installation, sensor drift, sensor malfunction, and other issues that could water quality, quantity, and plant metrics. Corrective action in the form of sensor maintenance, repair, reinstallation, or simple cleaning will then be flagged for follow up corrective action. Options for corrective action might include:

1. Retrieving missing information
2. Re-calibrating the measurement system
3. Re-analyzing samples (must be done within holding time requirements)
4. Modifying the analytical procedures
5. Collecting additional samples or taking additional field measurements
6. Qualifying results

11.0 Data Management Plan Procedures

11.1 Data Recording & Reporting Requirements

Data from all dataloggers will be remotely uploaded on a 20-minute basis. The hydrologic data from each monitoring station, soil moisture, and rainfall data, will be imported into a database for subsequent analysis and archiving purposes. These data will be checked every week for evidence of an equipment malfunction or other operational problem. Gaps in flow data may need to be interpolated; if this occurs, data will be stored and presented in a manner that makes it clear which data are from measurement, and which have been interpolated. The database also will be used to produce event based hydrologic summary statistics (e.g., station runoff volume, storm precipitation total, storm duration) for each applicable station. These summary statistics will ultimately be stored in a Microsoft Excel database with other water quality data collected through the project (see description below).

11.2 Electronic Transfer Requirements

All data will be transmitted from individual flow gages, soil moisture sensors, and rain gage, via wireless ethernet from the location of the instrumentation, to a central computer located in a nearby building. Data uploads will occur on a 20-minute basis and will be logged locally on dataloggers in case there are interruptions in network connectivity.

11.3 Laboratory Data Package Requirements

The laboratory will report the analytical results within 30 days of receipt of the samples. The laboratories will provide sample and QC data in standardized reports that are suitable for evaluating the project data. These reports will include all raw data including results from QA samples, and all QC results associated with the data. The reports will also include a case narrative summarizing any problems encountered in the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers. Laboratory analytical and QA results will be delivered from the laboratory in both electronic and hardcopy form. 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 data entry to ensure that sample values were transcribed without error. Results from these reviews will be documented on standardized forms.

11.4 Procedures for Missing Data

1. Missing data will be filled in when appropriate through interpolation techniques such linear or spline fitting to fill in the gaps. However, data missing over a 24-hour period is unlikely to be suitable for this type of gap filling. When appropriate, missing climatic data can be filled in using data from other proximal weather stations.
2. All missing data will be coded appropriately to show that the data are "filled" through interpolation or matching from local sensors.
3. Missing data will be reported with results.

11.5 Acceptance Criteria for Existing Data

No existing data will be used

11.6 Environmental Information Management (EIM) Data Upload Procedures

Data will not be uploaded to EIM. The final data package will be sent to Ecology's SAM coordinator.

12.0 Audits

Audits will be performed to detect potential deficiencies in the hydrologic and water quality data collected for this project. Audits of hydrologic data will occur following each storm event. In connection with these audits, data collected from each monitoring station over the sampled storm events will be compared to data from prior storms and data from the rain gauge station to identify potential data quality issues. This audit will specifically include an examination of the data record for gaps, anomalies, or inconsistencies between the discharge measurements from previous monitoring events. Any data generated from calibration checks that were performed at a particular monitoring station will also be entered into control charts and reviewed to detect potential instrument drift or other operational problems. In addition, sample collection and hydrologic data will be reviewed to assess whether MQOs have been met.

In the event that QA issues are identified based on these audits, measures will be taken to troubleshoot the problem(s) and to implement corrective actions if possible. Corrective actions will be documented in the database for the hydrologic data and in a flow QA memorandum, which will be included in the final report.

Audits performed for water quality data will occur within 7 business 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 QC information has been provided. Specific QC elements for the data and raw data will also be examined to determine if the MQOs for the project have been met. Results from these audits will be documented in QA worksheets that will be prepared for each batch of samples.

In the event that a potential QA issue is identified through these audits, the program lead will review the data to determine if any response actions are required. Response actions in this case might include the collection of additional samples, reanalysis of existing samples if not yet past holding time or advising the laboratory that methodologies or QA/QC procedures need to be improved.

12.1 Technical System Audits

Audits of the technical system include:

1. Verifying that field staff are following the SOPs for sensor maintenance, sensor calibration, and field measurements (plant metrics)
2. Verify the data management procedures are followed including field data recording.

12.2 Proficiency Testing

ARI labs have a well proven track record of proficiency – we will therefore not carry out proficiency testing of this lab.

13.0 Data Verification and Usability Assessment

Data verification will be performed by WSU 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.

13.1 Field Data Verification

The verification 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. The available soil moisture data from each soil moisture sensor will be verified based on comparisons of soil moisture variations associated with individual natural and synthetic 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.
4. Metrics of plant growth and weeding effort will be reviewed to identify significant changes over short periods to ascertain if those metrics reflect real world conditions or if they are errors in measurement.
5. 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).
6. If minor quality assurance issues are identified in any portion of the discharge, soil moisture, or plant metrics record, 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.

13.2 Laboratory Data Verification

Water quality data obtained for the study will be reviewed by WSU 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 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 13.2 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 13.2: 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 verification 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 reviewed 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 10 and 11. 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 or r).

Holding Times

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 5 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 Table 6.1). 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 ½ of the reporting limit, the associated data will be labeled with a B (in essence increasing the reporting limit for the affected samples), and associated project samples within five times the de facto reporting limit will be flagged with a J (G. Grepogrove, Manchester Laboratory, personal communication, September 4, 2007). In each of these cases, the de facto reporting limit for that analyte will be recorded along with the raw data, equipment will be decontaminated, and samples will be rerun if possible.

Rinsate Blanks

Rinsate blank values for total phosphorus, orthophosphorus, and total and dissolved copper and zinc, and total suspended solids will be compared to the MQOs that have been identified for this project (see Table 6.1). If metals or phosphorus are detected in the rinsate blanks at concentrations that exceed two times the reporting limit, then associated sample tubing will be cleaned or replaced and associated samples collected since the previous rinsate blank that are within five times the new reporting limit will be flagged with a J. At the monitoring stations where corrective actions (e.g., replacement or cleaning of sample tubing) were taken, a follow-up rinsate blank will be collected and analyzed for any parameters exceeding two times the reporting limit.

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 9.2.

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).

13.3 Data Usability Assessment

Based on the results from the processes described in the Data Verification 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.

14.0 Data Analysis Methods

The sections below present data analysis procedures that will be used to compare the growth of plants, weeding effort, flow control and water quality treatment performance of three mulch types that will be evaluated through this study (see *Project Description* section).

14.1 Data Analysis Methods

All data analyses will be performed using open source software (R Core Team 2019)

Effects of mulch on plant and weed growth

The null hypothesis that will be tested is that there are no differences in plant growth metrics or weeding effort in bioretention cells with a mulch type, compared to bioretention cells without mulch. An additional null hypothesis that weeding effort and plant growth metrics are similar across all three mulch types. Testing for statistical significance will be effected using the non-parametric Mann-Whitney-Wilcoxon test, with metrics of plant growth and weeding effort treated as a dependent variables, and mulch type as an independent variable. All statistical testing will be evaluated at the a = 0.05 level of significance.

Effects of mulch on water quantity or flow control

The null hypothesis that will be tested is that there are no differences in average monthly soil moisture, peak outflow rate, and total outflow volume from bioretention cells with a mulch type, compared to bioretention cells without mulch. An additional null hypothesis that will be tested is that peak outflow rate, and total outflow volume are similar across all three mulch types. Testing for statistical significance will use non-parametric Mann-Whitney-Wilcoxon test, with soil moisture, peak outflow rate, and total outflow volume treated as dependent variables, and mulch type as an independent variable. All statistical testing will be evaluated at the a = 0.05 level of significance.

Effects of mulch on water quality treatment

The null hypothesis that will be tested is that there are no differences in median pollutant removal efficiency for a particular analyte in bioretention cells with a mulch type, compared to bioretention cells without mulch. An additional null hypothesis that will be tested is that the median pollutant removal efficiency for a particular analyte is similar across all three mulch types.

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

$$\Delta C = 100 \times \frac{(C_{in} - C_{out})}{C_{in}}$$

Where:

C_{in} = Flow-weighted influent pollutant concentration

C_{out} = Flow-weighted effluent pollutant concentration

Testing for statistical significance will be affected using the non-parametric Mann-Whitney-Wilcoxon test, with soil moisture, peak outflow rate, and total outflow volume treated as dependent variables, and mulch type as an independent variable. All statistical testing will be evaluated at the α = 0.05 level of significance.

14.2 Data Presentation

Chemical and hydrologic data for mulch effectiveness will be presented in a combination of tables, charts, and graphs in the final reports to illustrate trends, relationships, and anomalies with the data.

15.0 Reporting

Study findings will be sent to the SAM project manager in the form of a draft fact sheet and final report, which will explain the results for stormwater managers, NPDES permit coordinators, and others involved in stormwater management. In addition, two presentations will be created to share findings of the project with stormwater managers, including a presentation to the Stormwater Workgroup and one regional stormwater conference/workshop.

15.1 Final Reporting

A draft report will be submitted to the SAM Project Manager and to the Technical Advisory committee for review. A final report will be compiled based on feedback of the draft report, presenting all data collected, analysis results, and major study conclusions. The report shall include all monitoring data collected during study period. 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 bioretention cell
- Results from water quality and soil sampling performed in connection with each bioretention cell
- 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)

15.2 Dissemination of Project Documents

All project documents including this QAPP will be hosted electronically on the SAM website [https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Stormwater-monitoring/Stormwater-Action-Monitoring] and the Washington Stormwater Center's website [https://www.wastormwatercenter.org/].

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17.0 Appendices

APPENDIX 1

Standard Operating Procedures (SOP)

Bioretention Cell WQ Sampling SOP:

Sampling procedures for sampling influent and effluent from bioretention cells and Influent sampling station

Purpose

The standard operating procedures below are setup, sampling and transport guidelines necessary for consistent sampling and achieve quality assurance goals.

Materials

- Auto samplers (17).
- 20 liter auto sampler bottles (17).
- 20 liter bottle slings (17).
- Batteries (17).
- Clear Teflon-lined auto sampler tubing with quick connects (17).
- Pre-labeled amber glass bottles 500ml (2each treatment) (34).
- ??.
- Nitrile latex cloves.
- 6, 88 kg bags of ice for ISCO bases.
- Ice hammer.
- Parafilm for securing intakes tubes to reservoir ports
- Garbage cans, lids and straps for garbage can lids (17).

Preparation

- Plan synthetic storms around natural storm forecasts.
- Prepare/wash auto sampler bottles, caps and clear Teflon-lined tubing.
- Label bottles with the following:

- Sample log number.
- Treatment cell identification number (e.g., meso 35).
- Treatment cell sampling location (mid-drain: MD or under-drain: UD).
- Date of sample collection (year/month/day: yyyy/mm/dd).
- Time of sample collection (international format [24 hour]).
- Field personnel names.
- Alert labs to proposed sampling schedule (Analytical Resources Inc. 206-695- 6200 and Spectra lab (253-272-4850).
- Check weather station rain gauges for debris.
- Check tipping buckets and drains for debris.
- Place locks and cables at each station.
- Place auto samplers, 20 L bottles, intake tubes and batteries at sampling stations. **Do not place bottle caps or other sampling gear directly on gabion wire (Zn contamination). Sampler top can be placed on gabions and sampling gear placed in sampler top.**
- Place bottles in in slings and in samplers with lid on.

Place about 1/3 bag of ice in each sampler base. Ice should be placed around bottle no more than 24 hours before event with the goal of keeping sample temperatures

≤ 6 degrees C during sampling period.

With gloves on remove bottle lid, place lid in Tupperware container and place ISCO midsection on and secure. Do these steps before placing batteries or suction lines. **Do not touch rim or inside of sampling bottles.**

Place batteries and attached to power cable **(pay close attention to attaching the correct wires to battery terminals…i.e. red to positive terminal)**.

Attach signal cable.

With gloves:

Connect Teflon-lined sampling tube to auto sampler and secure other end in under-drain reservoir with parafilm.

Start sampler program.

Initiate sampler and program pacing.

Sampler pacing will be based on the collection of at least 38, 400 milliliter aliquots covering at least 75% of the storm's runoff volume for the first 24 hours of the event.

Sample collection

Rinsate blanks: collect rinsate blanks twice annually at Influent sampling station (once at the first storm event of the monitoring year and once midway through the monitoring year). Bottles should be labeled QA1, QA2…etc. and a crosscheck of sample station and sample type maintained by field personnel.

- With gloves, place Influent sampling station auto sampler line in carboy of reagent grade water.
- Program sampler to draw 10 liters of reagent grade water into the sampler's 20 liter glass bottle.
- Place bottle on ice and deliver to lab with other samples as separate blind sample.
- Remove ISCO lid and mid-section.
- Record pH before replacing sample bottle lid.
- Replace sample bottle lid and weigh samples.
- Deliver bottles to lab immediately in covered garbage cans with ice to level of sample.
- Alert ARI receiving that dissolved metals must be slit and filtered immediately and with ortho-phosphate.
- Split samples.

A minimum of 39 aliquots constitutes an acceptable sample for the full complement of analytes.

A minimum of 15 L is necessary to perform analysis on the full complement of analytes.

Synthetic Storm Setup

EMC Dosing Total Flow to MS for all flow going to Bioretention cells. This is controlled by closing all outlet valves on RG Cistern. Note: we are Dosing with Flow going to both RG and MS so all valves are open on outside of both MS and RG cisterns as well as Valves at pump labeled to and from MS and RG (only valve closed at pump is one labeled to MS distribution ring).

DOSING BIORETENTION CELLS

Go to either:

PrcFS>LID>Station5 (Bioretention cell)>Dosing>Dosing>EMC DOSING **FLOW to MS & RG.**xlxs for **2014-2015 Water year**.

PrcFS>LID>Station5(Bioretention cells)>Dosing>Dosing>EMC Dosing **Total flow to MS**

Open each analyte worksheet labeled Phos; NO3-N; NH3-N; Cd; Cr; Cu; Pb; Zn.

Follow directions at top of page:

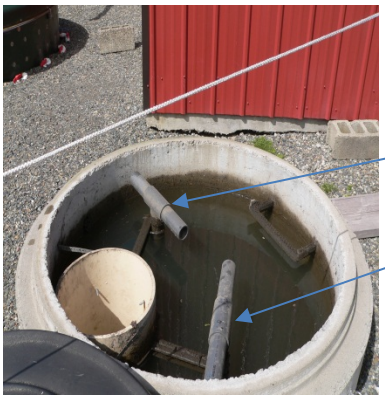
DOSING RATES FOR BIORETENTION CELLS

Find predicted Rainfall Row 7 then in same column on row 13 Enter the Target Event Mean Concentration (EMC) in cells colored blue. This will populate cell highlighted in Yellow, which will give amount of STD solution of each analyte to add to Cisterns. ** Before Dosing Turn on pump put Main breaker switch in up position then turn lower switch to Manual and let water circulate for at least 30min. Check and remove any debris on weirs or floating in tank. Take PreDose Samples 4ea. 500ml amber bottles 2 for PAH and 2 for Motor oil. Remove caps invert bottles and submerge into tank tip bottles upright below water surface remove bottles when completely full. Next fill PreDose container using cistern water rinsed pitcher; then dip water from as far as you can reach out into cistern and fill PreDose container as full as possible. Put all samples on ice and into cooler behind Allmendinger.

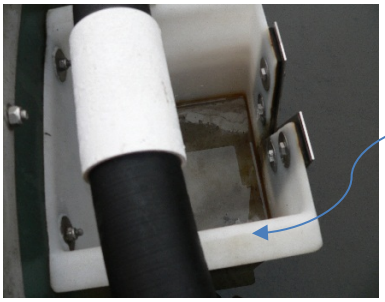
Before Storm turn on pump 30 minutes before adding Dosing then add ½ of Total dosing amount to each Cistern. Add 200g Sil-Co-Sil (TSS) to each MS weir box just under V notch, leave out any MS not sampling (MS15,24,34,42). Leave pump on an additional 30 minutes to circulate after dosing. Then turn Manual switch to Auto. Go up to Lab and connect to LoggerNet Station 6 open Numeric Table one and change Pump Master Switch from False to True.

Setting Computer Pacing

In lab's Storm Setup and Programming binder. Follow instructions under **Bioretention cell Storm Setup Operating Procedure**

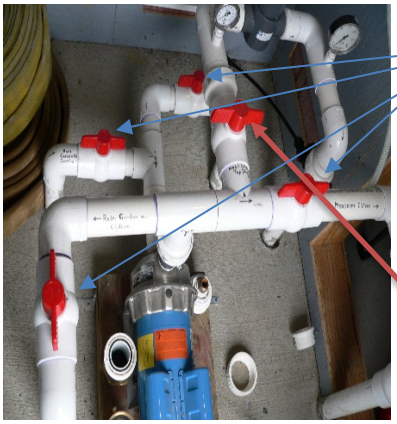


Catch Basin Valve to isolate MS Cistern Drain Valve RG cistern can't be isolated: Isolate flow to RG by closing individual RG valves



Weir Box Place Sil-co-Sil (TSS) Here

Pump Breaker Box Main Breaker switch Manual/Auto switch



Circulation Valves to and from RG & MS

MS Ring Valve Always closed

APPENDIX 2

Example Data Collection Forms

Sampling Event Checklist: Bioretention Cells

Date:_____ Time:_____

Personnel:_____

Weather:_____

Cell phone on and accessible:_____

Weather Station (station 1)

Rain gauge (elevated)		Clean screens		Check gauge level		Level gauge
Rain gauge (ground)		Clean screens		Check gauge level		Level gauge
Precipitation		Predicted		Recorded		
Anemometer		In place and intact		Check wiring		
Pyranometer		In place and intact		Check wiring		
Humidity		In place and intact		Check wiring		
Solar panel		In place and intact		Check wiring		
Battery		Volts		Check wiring		
Change desiccant		Yes		No		
Instruments recording		Yes		No		

Bioretention Cells (station 6): tipping buckets and datalogger

Tipping Buckets		Clear of debris		Level		
Tipping bucket drain		Clear of debris				
Battery		Volts				
Change desiccant		Yes		No		
Datalogger		Pacing		Manual start		Start of flow
Cistern pump		Pump breaker switch on		Pump on auto		

Bioretention Cells (station 6): samples

Cell	101	102	103	104	201	202	203	204
Samplers								
Sample ID								
Time bottle placed and iced								
Clean reservoirs								
Control cable connected								
Sampler on								
# of samples (sample count)								
# of samples (pulse count)								
Sample volume collected (bottle)								
Sample pH								
Begin sample date/time								
End sample date/time								
Sample error(s)								

Bioretention Cells (station 6): samples

Cell	301	302	303	304	401	402	403	404	INF
Samplers									
Sample ID									
Time bottle in place and iced									
Clean reservoirs									
Control cable connected									
Sampler on									
# of samples (sample count)									
# of samples (pulse count)									
Sample volume collected (bottle)									
Sample pH									
Begin sample date/time									
End sample date/time									
Sample error(s)									

Notes:_____

_____

_____

_____

_____

_____

Signature:_____

WSU Puyallup LID Research Program

Bioretention cell SOP: Influent sampling station and bioretention cell chemistry check

Personnel: _____

Date: _____ Time: _____

Weather conditions: _____

Purpose

The purpose of this distribution check is to confirm that the chemistry data from the Influent sampling station are sufficiently representative of the influent chemistry to each bioretention cell.

Procedure

- With gloves two field staff will simultaneously collect grab samples from the Influent sampling station and one randomly selected bioretention cell.
- Grab samples will be collected in washed glass bottles. Volume required: 1500 milliliters.
- Record time required to collect approximately 1500 milliliters and flow rate from both stations (determine exact volume by weighing).
- Place samples on ice immediately, deliver to lab and complete chain of custody.
- The grab samples will be collected for a least five storm events during each monitoring year.

Record bioretention cell identification, identification for both samples and flow rate.

Influent sampling station
Flow rate:_____
Sample ID:_____
Photo #/ID: _____
Notes: _____
_____

Bioretention cell ID: _____
Flow rate:_____
Sample ID:_____
Photo #/ID: _____
Notes: _____
_____

Miscellaneous notes

Monthly Plant Metrics

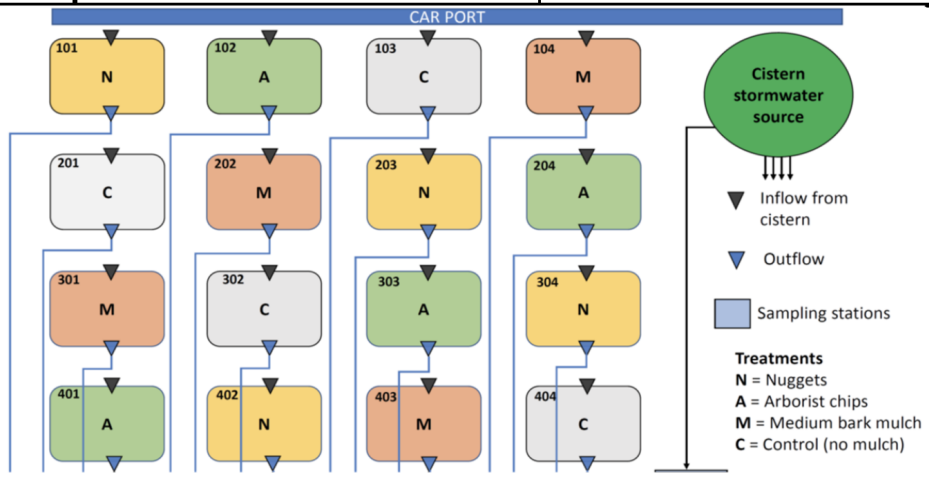
Plant metrics Field Data Sheet: Bioretention Cells

Date: Time:

Personnel: Weather:

Weeding Effort (hrs)	**Cell number:**							
	Start time				End time			
	time spent (min)							
	Quadrant 1				**Quadrant 2**			
	Weeds				Weeds			
Annual								
Perrrenial								
	Quadrant 3				**Quadrant 4**			
	Weeds				Weeds			
Annual								
Perrrenial								

	Total wet wt (g)	Total dry wt (g)
Annual		
Perrrenial		



Plant Sucess Field Data Sheet: Bioretention Cells

Date:

Personnel:

Time:

Weather:

Bioretenion Cell #

Plant Species	Plant Spread (Circumfrence, cm)	Plant Vigor (1-5)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
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APPENDIX 3

Equipment Specification Sheets

6712
Full-size Portable Sampler

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

Wide range of bottle configurations, plug-in flow and parameter monitoring

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.

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.

With eleven bottle choices, the 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).

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.

Teledyne 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.

Applications:

- Wastewater effluent
- Stormwater monitoring
- CSO monitoring
- Permit compliance
- Pretreatment compliance

Standard Features:

- SDI-12 interface provides "plug and play" connection with multi-parameter water-quality sondes and other compatible devices
- Choice of 11 different glass and plastic bottle configurations ranging from 24 x 1liter to 1 x 5.5 gallon
- NEMA 4X, 6 (IP67) controller enclosure
- Rugged ABS plastic shell
- Foam-insulated base holds up to 30 pounds (13.5 kg) of ice to preserve samples even in extreme conditions
- Sample delivery at the EPA-recommended velocity of 2 ft/sec., even at head heights of 26 feet
- Pump revolution counter and patented liquid detection sensor ensure accurate sample volumes—and tells you when tubing should be replaced

ISCO

TELEDYNE ISCO
Everywhereyoulook™

6712 Full-size Portable Sampler

Size (H x Dia):	27 x 20 in (68.6 x 50.7 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 VDC (Supplied by battery or AC power converter.)

Pump

Suction Tubing:	
-Length:	3 to 99 ft (1 to 30 m)
-Material:	Vinyl or Teflon
-Inside Dimension:	3/8 in (1.0 cm)
Pump Tubing Life:	Typically 1,000,000 pump counts
Maximum Lift:	28 ft (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) head height: 3.0 ft/s (0.91m/s) @10 ft (3.1 m) head height: 2.9 ft/s (0.87 m/s) @15 ft (4.6 m) head height: 2.7 ft/s (0.83 m/s)
Liquid Presence Detector:	Non-wetted, nonconductive sensor detects when liquid sample reaches the pump to automatically compensate for changes in head heights.

Controller

Dimensions (HxWxD):	10.3 x 12.5 x 10.0 in (26.1 x 31.7 x 25.4 cm)
Weight (dry):	13 lbs (5.9 kg)
Operating 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
Real Time Clock Accuracy:	1 minute per month, typical

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 9,999 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

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

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 Teledyne ISCO, or your local representative for pricing and additional information.

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

Teledyne ISCO
P.O. Box 82531, Lincoln, Nebraska, 68501 USA
Toll-free: (800) 228-4373 • Phone: (402) 464-0231 • Fax: (402) 465-3091

teledyneisco.com

TELEDYNE ISCO
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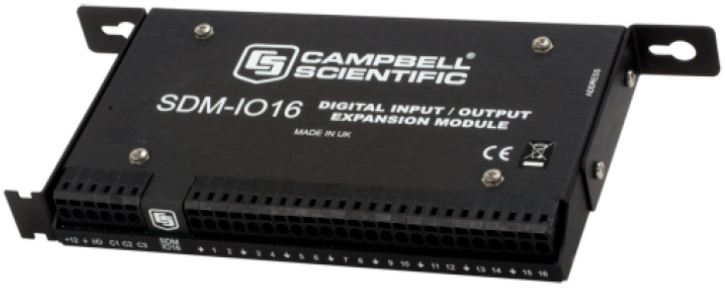
L-1107 Rev 2.0
9/18

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

SDM-IO16

16-Channel Input/Output Module



Expands Data Logger Digital Input/Output Capability

Overview

The SDM-IO16 expands the digital input and output channel count of Campbell Scientific data loggers.

Benefits and Features

- Provides 16 digital I/O ports
- When configured as an input, each port can monitor logic state, count pulses, measure signal frequency, and determine duty cycle

Detailed Description

The SDM-IO16 expands the digital input and/or output capability of Campbell Scientific data loggers. When a port is 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 data logger 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 data logger. A boost circuit allows an output that is set HI to source a current of up to 100 mA (at a reduced output voltage) for controlling external devices such as low voltage valves or relays.

Up to 15 SDM-IO16 modules can be addressed allowing up to 240 ports to be controlled by the data logger.

Data Logger Connection

The SDM Jumper Wire Kit (pn 32505) connects up to four SDMs to the data logger. This kit is recommended when multiple SDMs are connected to one data logger or for extremely short distances between the SDM and data logger. The CABLE5CBL-L cable is recommended for connecting a single SDM to the data logger, and for longer distances between the SDM and data logger.

Specifications

Operating Temperature	-25° to +50°C
SDM & I/O Port	0/5 V logic level ports (for connecting to the datal ogger's control/SDM ports)
EMC Status	Complies with EN 61326:1997.
Operating Voltage	12 Vdc (nominal 9 to 18 V)
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	±0.01%, worst case (-25° to +50°C)
Maximum Pulse Measurement Interval	15.9375 s
Dimensions	23.0 x 10.0 x 2.4 cm (9 x 4 x 1 in.)
Weight	350 g (12 oz)

Maximum Frequency (with 50/50 duty cycle)

Switch Debounce-Mode Turned Off	2.0 kHz on all channels simultaneously
Default Switch Debounce-Mode Enabled	150 Hz on all channels

Current Drain

-NOTE-	*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.*
Typical Standby	600 µA (all ports high, no load, excludes pulse counting)
Maximum	3 µA (active with all 16 ports counting pulses at 2 kHz and no output load)

Output

ON/HI Voltage (no load)	4.5 V (minimum) 5 V (nominal)
OFF/LO Voltage (no load)	0.1 V (maximum) 0 V (nominal)
Sink Current	Output will sink 8.6 mA from a 5 V source.
Source Current	133 mA short-circuited to ground 42 mA (@ 3 V)

Input

Voltage	1.0 V maximum threshold (low) 4.0 V minimum threshold (high)
Protection	Input clamped at -0.6 V and ±5.6 V relative to ground (via a 33 Ω 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)

For comprehensive details, visit: www.campbellsci.com/sdm-io16

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every two years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE

10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)

8 differential (DF) or 16 single-ended (SE) individually configured. Channel expansion provided by 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.

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% on all ranges guarantees 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 (-XT only)

[3]Accuracy does not include the sensor and measurement noise. Offsets are defined as:
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

ANALOG MEASUREMENT SPEED:

Integration Type/ Code	Integration Time	Settling Time	Total Time[5]	
			SE w/ No Rev	DF w/ Input Rev
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[4]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[4]	20.00 ms	3 ms	~25 ms	~50 ms

[4]AC line noise filter.

[5]Includes 250 µs for conversion to engineering units.

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

INPUT LIMITS: ±5 Vdc

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 (Vx1-Vx3)

3 switched voltage, sequentially active only during measurement.

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

V_x 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)

V_x FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

CURRENT SOURCING/SINKING: ±25 mA

RESISTANCE MEASUREMENTS

MEASUREMENT TYPES: Ratiometric measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Precise, dual polarity excitation for voltage excitations eliminates dc errors. Offset values are reduced by a factor of two when excitation reversal is used.

VOLTAGE RATIO ACCURACY[6]: Assuming excitation voltage of at least 1000 mV, not including bridge resistor error.

±(0.04% of voltage reading + offset)/V_x

[6]Accuracy does not include the sensor and measurement noise. The offsets are defined as:
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

PERIOD AVERAGE

Any of the 16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	Input Range (±mV)	Signal (peak to peak)[7]		Min Pulse Width (µV)	Max[8] Freq (kHz)
		Min. (mV)	Max (V)		
1	250	500	10	2.5	200
10	25	10	2	10	50
33	7.5	5	2	62	8
100	2.5	2	2	100	5

[7]With signal centered at the datalogger ground.

[8]The maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

PULSE COUNTERS (P1-P2)

2 inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

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 Vdc.
Input Hysteresis: 12 mV RMS @ 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 (C1-C8)

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

HIGH-FREQUENCY MAX: 400 kHz

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

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

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kohm with inputs <6.2 Vdc
220 ohm with inputs ≥6.2 Vdc

SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

SWITCHED 12 VDC (SW-12)

1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

CE COMPLIANCE

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

COMMUNICATIONS

RS-232 PORTS:
9-pin: DCE (not electrically isolated) for battery-powered computer or non-CSI modem connection.
COM1 to COM4: Four independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART
Baud Rates: selectable from 300 bps to 115.2 kbps.
Default Format: 8 data bits; 1 stop bits; no parity
Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with CSI telecommunication peripherals

SDI-12: Digital control ports 1, 3, 5, and 7 are individually configured and meet SDI-12 Standard version 1.3 for datalogger mode. Up to ten SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, Modbus, DNP3, FTP, HTTP, XML, POP3, SMTP, Telnet, NTCIP, NTP, SDI-12, SDM

SYSTEM

PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core RUNNING AT 7.3 MHz)

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

RTC CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

RTC CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc

EXTERNAL BATTERIES: 12 Vdc nominal (power connection is reverse polarity protected)

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

TYPICAL CURRENT DRAIN:
Sleep Mode: 0.7 mA typical; 0.9 mA max.
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 16.2 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 27.6 mA
Optional Keyboard Display On (no backlight): add 7 mA to current drain
Optional Keyboard Display On (backlight on): add 100 mA to current drain

PHYSICAL

DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in.); additional clearance required for cables and leads.

WEIGHT (datalogger + base): 1 kg (2.1 lb)

WARRANTY

3 years against defects in materials and workmanship.

Printed October 2012

Designed For Reliability...

TIPPING BUCKET FLOW GAUGE

MODELS TB1L & TB0.5L

WATER LEVEL

General

The HyQuest Solutions Tipping Bucket Flow Gauge is used for measuring water flow coming from a pipe or a drain. The unit comes with a dual reed switch, thus, when connected to a data logger, the data can be stored and collected when required. In addition, the flow gauge can be telemetered by connecting a compatible modem.

Features

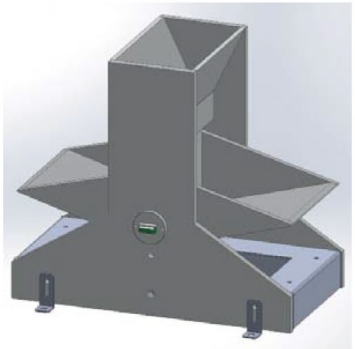
- Non-Corrosive, Robust PVC & Stainless Steel Construction
- Dual Reed Switch
- Suitable for Pipe Flow Measurement and water drain measurement
- Bucket Tip Volumes factory calibrated at either 0.5 Litre up to 1.0 Litre
- Suitable for Harsh Environments

Specifications

- Material: PVC Plastic and Stainless Steel
- Reed Switch: Dual output reed switch potted in soft silicon rubber with varistor protection.
- Max Capacity: 24 VDC (0.5 amp max.)
- Resistance: Initial contact resistance 0.1 Ω
- M.T.B.F: 10^8 to 10^9 Operations
- Flow Rate: Maximum 25 litres/minute
- Dimensions: Length 390mm, Width 235mm, Height 345mm
- Accuracy:

Flow Rate	%Error
0.5 litre/min	-2%
1.0 litre/min	-6%
5.0 litre/min	-10%
10.0 litre/min	-14%
15.0 litre/min	-18%
20.0 litre/min	-20%
25.0 litre/min	-22%

Tipping Bucket Flow Gauge Model TB1L or TB0.5L in field of use



Tipping Bucket Flow Gauge Model TB1L or TB0.5L

N.B. Specifications are subject to change at any time without notice.

Contact Us

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bsi. ISO 9001 Quality Management

HSA HYDROLOGICAL SERVICES AMERICA

Edition2: 22/9/16

Tipping Bucket Rain Gauge

METEOROLOGY | PRECIPITATION | RAINFALL

General Description

HyQuest Solutions' TB3 is a **high-quality tipping bucket rain gauge** for measuring rainfall and precipitation in urban and rural locations. Due to the integrated syphon, the gauge delivers **high levels of accuracy across a broad range of rainfall intensities** With the optional heater the TB3 is the ideal device for **cold climates**.

The TB3's tried and proven design ensures **long-term, accurate and repeatable results**. It is manufactured from high quality, **durable materials ensuring long-term stability in the harshest of environments**. It consists of a robust powder-coated aluminium enclosure, an aluminium base, and stainless steel finger filter and fasteners.

TB3 provides a **finger filter** that ensures the collector catch area remains unblocked when leaves, bird droppings and other debris find their way into the catch.

The TB3's base incorporates **two water outlets at the bottom** allowing for water collection and data verification.

Maintenance of the TB3 is easy, because removal of the outer enclosure and access to the tipping bucket mechanism and finger filter assembly is made easy with quick release fasteners.

Output options

TB3 includes a **dual output 24 V DC reed switch** allowing for output redundancy or the addition of a second data logger. The second output could also be used for connecting HyQuest Solutions' current meter counter CMCbt paired with the free FCD application that allow for easy and accurate field calibration even in noisy (urban) environments. The reed switch incorporates **varistor protection against surges** that may be induced on long, inappropriately shielded signal cables.

Main Features

- Long-term stable calibration
- Accuracy not affected by rainfall intensity
- Minimal maintenance required
- Robust design for all environments
- Expandability: Optional **autonomous real-time rain monitoring and reporting system** RainTrak Undercover with in-built telemetry and logging (see flip side)

Applications

- Classical Meteorology and Climatology
- Hydrometeorology
- Environmental, Hydrological and Air Quality Monitoring
- Road Traffic Infrastructure
- Water Treatment Plants, Dams, Reservoirs
- Agrometeorology
- Airports and Airfields
- Water Resources Management

HSA HYDROLOGICAL SERVICES AMERICA | HS HYQUEST SOLUTIONS KISTERS GROUP

Technical Specifications

Resolution	0.1 mm, 0.2 mm, 0.5 mm, 1.0 mm, 0.01 inch
Accuracy	■ 0-250 mm per hour; +/-2 % ■ 250-500 mm per hour; +/-3 %
Range	700 mm per hour
Material	■ Enclosure and base: anodised and powder-coated aluminium ■ Bucket: painted brass or chrome plated ABS
Pivots	Round sapphire pivots with hard stainless steel shaft
Dimensions & Mass	■ 200 mm diameter catch ■ 3.3 kg ■ 330 mm height
Environmental Conditions	■ Operating Temperature Range: -4 °F to +158 °F (heater recommended below +39 °F) ■ Humidity: 0-100 %

Accessories

Autonomous System RainTrak Undercover: TB3 can be used as a component of the RainTrak to provide a reliable and autonomous real-time rain monitoring and reporting system. Features: turnkey operation, battery operated with solar panel, integrated IP-capable data logger, periodic or event-driven data communication, wireless communication, incl. antenna, custom designed for harsh environments.

Pole Mount Bracket: Pole mount bracket with stainless steel bolts, nuts and washers to suit TB3, TB4 or TB6 base. Suits 50 mm NB galvanised pipe with 2" BSP thread.

Bird Guard: The bird guard prevents wild or feral birds from perching or roosting and thus increases accuracy by stopping bird feces from dropping inside the gauge funnel.

Portable Field Calibration Device (FCD): The FCD effectively enables field technicians to run functional tests and calibrations of any given rain gauge in the field avoiding dismantling of TBRG's, reducing TBRG downtime and thereby saving time and money.

iRIS dataloggers and data modems:

- Robust housing
- IP over one or two channels of your choice: xG / GPRS, satellite, IoT
- I/O: analog, digital, SDI-12, Modbus
- iLink software
- Telemetry or cloud app

Pulse Counter CMCbt: The CMCbt is a Bluetooth Pulse Counter that provides an interface between the TBRG's Reed Switch output and the FCD-App calibration software used in conjunction with HyQuest Solutions' Field Calibration Device FCD.

Heater Kits: A thermostatically controlled heating element raising the temperature of the interior of the rain gauge, funnel and catch to avoid the freezing of the gauge in cold climates with subsequent loss of precipitation records. Option: Low-power version with snow sensor

Please ask for details.

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HOBO® RX3000 Data Logger

RX3000 Remote Monitoring Station Data Logger

The HOBO RX3000 is Onset's next-generation remote data logging station that provides instant access to site-specific environmental data anywhere, anytime via the internet. The new station combines the flexibility and sensor quality of more expensive systems, an onboard LCD display, and the convenience of plug-and-play operation. The RX3000 has four configurable systems, that can be configured below, that consist of the following part numbers: RX3001-00-01, RX3002-00-01, RX3003-00-01 and RX3004-00-01.

The RX3000 station is the basis for the cost-effective and scalable HOBOnet Field Monitoring System for crop management, environmental research, and greenhouse operations.

Supported Measurements:

4-20mA, AC Current, AC Voltage, Air Velocity, Amp Hour (Ah), Amps (A), Barometric Pressure, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Differential Pressure, Event, Gauge Pressure, Kilowatt Hours (kWh), Kilowatts (kW), Leaf Wetness, Light Intensity, Power Factor (PF), Pulse Input, Rainfall, Relative Humidity, Soil Moisture, Temperature, Volatile Organic Comp., Volt-Amp Reactive, Volt-Amp Reactive hour, Volt-Amps (VA), Volts (V), Water Flow, Water Level, Watt Hours (Wh), Watts (W) and Wind

Key Advantages:

- Flexible support for a broad range of sensors
- LCD display for easy field deployment
- Cloud-based data access through HOBOlink
  - Get 24/7 web access to your data via web browser
  - Verify RX3000 system status remotely
  - Set up and manage alarm notifications over the web
  - Schedule automated delivery of data
- Plug-and-play operation
- Alarm notifications via text, email
- Rugged double-weatherproof enclosure
- Cellular, Wi-Fi and Ethernet Option are available
- Configure & check on your RX3000 monitoring station from your mobile devices
- Optional Analog Input and Relay Modules
- Optional third-party sensor can be purchased for Remote Water Level Monitoring
- Access to NEWA plant disease risk and insect pest models

HOBO RX3000 Data Logger Specifications

Operating Range	-40° to 60°C (-40° to 140°F); no remote communications for battery voltage less than 3.9 V DC
Smart Sensor Connectors	10
Smart Sensor Network Cable Length	100 m (328 ft) maximum
Smart Sensor Data Channels	Maximum of 15 (some smart sensors use more than one data channel; see sensor manual for details)
Module Slots	2
Logging Rate	1 second (RX3001 and RX3002) or 1 minute (RX3003 and RX3004) to 18 hours
Time Accuracy	±8 seconds per month in 0° to 40°C (32°F to 104°F) range; ±30 seconds per month in -40° to 60°C (-40° to 140°F) range
Battery Type/Power Source	4 Volt, 10 AHr, rechargeable sealed lead-acid; external power required using one of these options: AC power adapter (AC-U30), solar panel (SOLAR-xW), or external power source 5 V DC to 17 V DC with external DC power cable (CABLE-RX-PWR)
Rechargeable Battery Service Life	Typical 3–5 years when operated in the temperature range -20° to 40°C (-4°F to 104°F); operation outside this range will reduce the battery service life
Memory	32 MB, 2 million measurements, continuous logging
Alarm Notification Latency	Logging interval plus 2–4 minutes, typical
Enclosure Access	Hinged door secured by two latches with eyelets for use with user-supplied padlocks
LCD	LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Materials	Outer enclosure: Polycarbonate/PBT blend with stainless steel hinge pins and brass inserts; Inner enclosure: Polycarbonate; Gaskets: Silicone rubber; Cable channel: EPDM rubber; Cable opening cover: Aluminum with ABS plastic thumb screws; U-Bolts: Steel with zinc dichromate finish
Size	18.6 x 18.1 x 11.8 cm (7.3 x 7.1 x 4.7 in.); see diagrams on next page
Weight	2.2 kg (4.85 lb)
Mounting	3.8 cm (1.5 inch) mast or wall mount
Environmental Rating	Weatherproof enclosure, NEMA 4X (requires proper installation of cable channel system)
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU)
FC	**RX3002:** FCC ID R68XPICOW, IC ID 3867A-XPICOW **RX3003:** FCC ID QIPEHS6, IC ID 7830A-EHS6; approved for use in Taiwan and Japan **RX3004:** FCC ID QIPPLS62-W, IC ID:7830A-PLS62W
Wireless Radio	**RX3003:** GSM/GPRS/EDGE: Quad band 850/900/1800/1900 MHz, UMTS/HSPA+: Five band 800/850/900/1900/2100 MHz **RX3004:** GSM/GPRS/EDGE: Quad band 850/900/1800/1900 MHz UMTS/HSPA+: Seven band 800/850/900/1800/1900/2100 MHz LTE: Twelve Band 700/800/850/900/1800/1900/2100/2600 MHz
Antenna	**RX3003:** Penta band **RX3004:** 4G LTE

Ethernet (RX3001)	
Connector	One RJ45/100BaseT
Wi-Fi (RX3002)	
Network Standards	IEEE 802.11b/g/n

Frequency Range	2.412–2.484 GHz
Antenna Connector	1, no diversity supported
Data Rates	1, 2, 5.5, 11 Mbps (802.11b); 6, 9, 12, 18, 24, 36, 48, 54 Mbps (802.11g); 802.11n, HT20 MCS0 (6.5 Mbps) to HT20 MC87 (65 Mbps)
Number of Selectable Radio Subchannels	Up to 14 channels; profiles available will include USA, France, Japan, Spain, Canada, and "Other" (multiple countries)
Radio Modulations	OFDM, DSSS, DBPSK, DQPSK, CCK, 16QAM, 64QAM
Security	WEP 64/128, WPA-PSK, AES end-to-end encryption
Maximum Receive Level	-10 dBm (with PER <8%)
Receiver Sensitivity	-72 dBM for 54 Mbps, -87 dBm for 11 Mbps, -89 dBm for 5.5 Mbps, -90 dBm for 2.0 Mbps, -92 dBm for 1.0 Mbps
Cellular (RX3003 and RX3004)	
Wireless Radio	**RX3003:** GSM/GPRS/EDGE: Quad band 850/900/1800/1900 MHz, UMTS/HSPA+: Five band 800/850/900/1900/2100 MHz **RX3004:** GSM/GPRS/EDGE: Quad band 850/900/1800/1900 MHz UMTS/HSPA+: Seven band 800/850/900/1800/1900/2100 MHz LTE: Twelve Band 700/800/850/900/1800/1900/2100/2600 MHz
Antenna	**RX3003:** Penta band **RX3004:** 4G LTE

Contact Us

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- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
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- Call 1-508-759-9500
- In U.S. toll free 1-877-564-4377

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RXW-SMC-xxx Sensor

HOBOnet Soil Moisture EC-5 Sensor

The HOBOnet Wireless Soil Moisture Sensor integrates the field-proven ECH2O™ EC5 Sensor and provides readings directly in volumetric water content. The sensor's high-frequency design minimizes sensitivity to salinity and textural effects, and gives it a wide measurement range. HOBOnet Wireless Sensors communicate data directly to the RX3000 weather station or pass data through other wireless sensors back to the central station. They are preconfigured and ready to deploy, and data is accessed through HOBOlink, Onset's innovative cloud-based software platform.

Supported Measurements:

Soil Moisture

Key Advantages:

Sensor Features

- ±3% accuracy in typical soil conditions, and ±2% accuracy with soil-specific calibration
- Measures a 0.3-liter volume of soil for taking readings at a specific depth or in a container
- High-frequency (70 MHz) circuit provides good accuracy even in high-salinity and sandy soils

Wireless Features

- 900 MHz wireless mesh self-healing technology
- 450 to 600 meter (1,500 to 2,000 feet) wireless range and up to five hops
- Up to 50 wireless sensors per RX3000
- Simple button-push to join the HOBOnet wireless network
- Onboard memory to ensure no data loss
- Powered by rechargeable AA batteries and built-in solar panel

RXW-SMC-xxx Sensor Specifications

Sensor

Measurement Range	In soil: 0 to 0.550 m /m (volumetric water content)
Extended Range	-0.401 to 2.574 m /m
Accuracy	±0.031 m /m (±3.1%) typical 0 to 50°C (32° to 122°F) for mineral soils up to 8 dS/m and ±0.020 m /m (±2%) with soil specific calibration; see Notes 2 and 3
Resolution	0.0007 m /m (0.07%)
Volume of Influence	0.3 liters (10.14 oz)
Sensor Frequency	70 MHz
Sensor Operating Temperature Range	0° to 50°C (32° to 122°F). Although the sensor probe and cable can safely operate at below-freezing temperatures (to -40°C/F), the soil moisture data collected at these extreme temperatures is outside of the sensor's accurate measurement range.

Wireless Mote

Operating Temperature Range	-25° to 60°C (-13° to 140°F) with rechargeable batteries -40 to 70°C (-40 to 158°F) with lithium batteries
Radio Power	12.6 mW (+11 dBm) non-adjustable
Transmission Range	Reliable connection to 457.2 m (1,500 ft) line of sight at 1.8 m (6 ft) high Reliable connection to 609.6 m (2,000 ft) line of sight at 3 m (10 ft) high
Wireless Data Standard	IEEE 802.15.4
Radio Operating Frequencies	RXW-SMC-900: 904–924 MHz RXW-SMC-868: 866.5 MHz RXW-SMC-922: 916–924 MHz
Modulation Employed	OQPSK (Offset Quadrature Phase Shift Keying)
Data Rate	Up to 250 kbps, non-adjustable
Duty Cycle	<1%
Maximum Number of Motes	50 motes per one RX Wireless Sensor Network
Battery Type/ Power Source	Two AA 1.2 V rechargeable NiMH batteries powered by built-in solar panel or two AA 1.5 V lithium batteries for operating conditions of -40 to 70°C (-40 to 158°F)
Battery Life	With NiMH batteries: Typical 3–5 years when operated in the temperature range -20° to 40°C (-4°F to 104°F) and positioned toward the sun (see Deployment and Mounting), operation outside this range will reduce the battery service life With lithium batteries: 1 year, typical use
Memory	16 MB
Dimensions	Cable length: 5 m (16.4 ft) Mote: 16.2 x 8.59 x 4.14 cm (6.38 x 3.38 x 1.63 inches)
Weight	Mote: 223 g (7.87 oz)
Materials	Sensor: Weatherproof Mote: PCPBT, silicone rubber seal
Environmental Rating	Mote: IP67, NEMA 6
Compliance Marks	RXW-SMC-900 RXW-SMC-868 RXW-SMC-922

APPENDIX 4

Chain of Custody Forms

Chain of Custody Record & Laboratory Analysis Request

ARI Assigned Number:	Turn-around Requested:	Date:	
ARI Client Company:	Phone:	Page:	of
Client Contact:		No. of Coolers:	Cooler Temps:
Client Project Name:		Analysis Requested	
Client Project #:	Samplers:		

Sample ID	Date	Time	Matrix	No. Containers									Notes/Comments
Comments/Special Instructions	Relinquished by: (Signature)		Received by: (Signature)		Relinquished by: (Signature)		Received by: (Signature)						
	Printed Name:		Printed Name:		Printed Name:		Printed Name:						
	Company:		Company:		Company:		Company:						
	Date & Time:		Date & Time:		Date & Time:		Date & Time:						

Analytical Resources, Incorporated
Analytical Chemists and Consultants
4611 South 134th Place, Suite 100
Tukwila, WA 98168
206-695-6200 206-695-6201 (fax)

Limits of Liability: *ARI will perform all requested services in accordance with appropriate methodology following ARI Standard Operating Procedures and the ARI Quality Assurance Program. This program meets standards for the industry. The total liability of ARI, its officers, agents, employees, or successors, arising out of or in connection with the requested services, shall not exceed the Invoiced amount for said services. The acceptance by the client of a proposal for services by ARI release ARI from any liability in excess thereof, not withstanding any provision to the contrary in any contract, purchase order or co-signed agreement between ARI and the Client.*

Sample Retention Policy: Unless specified by workorder or contract, all water/soil samples submitted to ARI will be discarded or returned, no sooner than 90 days after receipt or 60 days after submission of hardcopy data, whichever is longer. Sediment samples submitted under PSDDA/PSEP/SMS protocol will be stored frozen for up to one year and then discarded.

Figure A-1. COC form for Analytical Resources, Inc.

QAPP Template References

1. Ecology, Technical Guidance Manual for Evaluationg Emerging Stormwater Treatment Technologies. 2011: Olympia.
2. EPA, Guidance on Systematic Planning Using the Data Quality Objectives Process. 2006: Washington, D.C. p. 120.
3. Guba, E.G., Criteria for assessing the trustworthiness of naturalistic inquiries. ECTJ, 1981. **29**(2): p. 75-91.
4. Ecology, Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. 2004, Washington State Department of Ecology: Olympia, WA.
5. Erickson, A.J., P.T. Weiss, and J.S. Gulliver, *Optimizing Stormwater Treatment Practices.*
6. United States Environmental Protection Agency, E., *Guidance for Quality Assurance Project Plans*. 2002, United States Environmental Protection Agency: Washington, DC.
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8. EPA, Guidance on Environmental Data Verification and Data Validation, in U.S. Environmental Protection Agency Quality System Series. 2002: Washington, DC.