QUALITY ASSURANCE PROJECT PLAN

Low Impact Development Research Program: Rain Garden Performance Monitoring

Prepared for

Washington State University
Puyallup Research and Extension Center

July 2010  Draft
Note:
Some pages in this document have been purposefully skipped or blank pages inserted so that this document will copy correctly when duplexed.
QUALITY ASSURANCE PROJECT PLAN
Low Impact Development Research Program: Rain garden Stormwater Treatment
Performance Monitoring

July 2010

Approved by:

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</table>
## Contents

Introduction ..................................................................................................................................... 1
Background ..................................................................................................................................... 5
Project Description .......................................................................................................................... 7
Organization and Schedule ............................................................................................................. 9
Quality Objectives ........................................................................................................................ 13
  Bias ........................................................................................................................................ 13
  Precision ................................................................................................................................ 15
  Representativeness ................................................................................................................. 16
  Completeness ........................................................................................................................ 16
  Comparability ......................................................................................................................... 16
Sampling Process Design .............................................................................................................. 17
  Rain Garden Design ............................................................................................................... 17
    Cistern and Flow Distribution System ........................................................................... 17
    Rain Garden Bioretention Soil Mix and Plant Treatments .............................................. 17
    Outlet Flow Control Structure ....................................................................................... 28
  Monitoring Design ................................................................................................................. 28
    Baseline Monitoring ........................................................................................................ 29
    Phase 1 Monitoring .......................................................................................................... 30
Sampling Procedures .................................................................................................................... 33
  Baseline Monitoring .............................................................................................................. 33
  Phase 1 Monitoring ................................................................................................................ 33
    Vegetation Monitoring ....................................................................................................... 33
    Precipitation Monitoring ................................................................................................. 35
    Infiltration Testing ............................................................................................................ 35
    Soil Chemistry Monitoring .............................................................................................. 35
Measurement Procedures .............................................................................................................. 37
Quality Control Procedures ........................................................................................................... 41
  Field Quality Control Procedures ......................................................................................... 41
    Instrument Maintenance and Calibration ........................................................................ 41
    Field Notes ........................................................................................................................ 41
    Distribution System Checks .............................................................................................. 43
    Field Duplicate Split Samples – Soil ............................................................................... 43
    Sample Handling, Delivery, and Processing ................................................................... 44
    Sample Identification and Labeling ................................................................................ 44
    Sample Containers and Preservation ............................................................................... 44
    Chain-of-Custody Record ................................................................................................. 44
  Laboratory Quality Control Procedures ............................................................................... 44
    Method Blanks .................................................................................................................... 45
    Control Standards .............................................................................................................. 45
Tables

Table 1. Key personnel for the rain garden research component of the Low Impact Development Research Program................................................................. 10
Table 2. Schedule of key milestones for the rain garden research component of the Low Impact Development Research Program........................................ 12
Table 3. Measurement quality objectives for soil data.............................................................................................................................. 14
Table 4. Rain garden plant treatment, potential plant species, and likely hydro-zone locations ........................................................................ 27
Table 5. Methods and detection limits for soil analyses ........................................................................................................................ 39
Table 6. Anticipated annual number of samples and associated quality assurance requirements for each soil parameter.............................................. 42

Figures

Figure 1. Vicinity map of Washington State University LID research center, Puyallup, WA. ........................................................................................................ 2
Figure 2. Plan view of Washington State University low impact development research facility. .................................................................................. 19
Figure 3. Plan view of rain garden test facility........................................................................................................................................... 21
Figure 4. Cross-section view of rain garden cistern and pump system ..................................................................................................................... 23
Figure 5. Cross-section of typical rain garden ........................................................................................................................................... 25
Figure 6. Cross-section and plan view of the outlet flow control structure for a rain garden cell........................................................................... 26
Introduction

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

Initially, the LID Research Program will focus on two practices: permeable pavement and bioretention. To facilitate performance evaluations of these practices, the largest parking area on campus (impervious asphalt) was removed and replaced with pervious asphalt and concrete. A 0.24 hectare (0.6 acre) gravel area adjacent to the parking lot was also removed and replaced with 39 bioretention cells. Sixteen of the cells are conventional rain garden installations in the ground, and 20 are deep tanks or “mesocosms” for performing more controlled testing on different bioretention soil mixes (BSMs).

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

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

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

- **Background** – An explanation of why the project is needed
- **Project Description** – Project goals and objectives, and the information required to meet the objectives
Figure 1. Vicinity map of the Washington State University LID research center, Puyallup, WA.
Quality Assurance Project Plan—LID Research Program: Rain Garden Performance Monitoring

- **Organization and Schedule** – Project roles and responsibilities, and the schedule for completing the work

- **Quality Objectives** – Performance (or acceptance) thresholds for collected data

- **Sampling Process Design** – The sampling process design for the study, including sample types, monitoring locations, and sampling frequency

- **Sampling Procedures** – A detailed description of sampling procedures and associated equipment requirements

- **Measurement Procedures** – Laboratory procedures that will be performed on collected samples

- **Quality Control** – Quality control (QC) requirements for both laboratory and field measurements

- **Data Management Procedures** – How data will be managed, from field or laboratory recording to final use and archiving

- **Audits and Reports** – The process that will be followed to ensure this QAPP is being implemented correctly and the quality of the data is acceptable

- **Data Verification and Validation** – The data evaluation process, including the steps required for verification, validation, and data quality assessment

- **Data Quality (Usability) Assessment** – The procedures that will be used to determine if collected data are of the right type, quality, and quantity to meet project objectives
Background

An extensive body of monitoring and research suggests that land development and the resulting stormwater are primary causes of fresh and marine water degradation. Increased runoff volume and peak flow rates accelerate sediment delivery, scour stream channels, reduce habitat complexity, and change hydroperiods in affected wetlands.

A wide range of pollutants are associated with stormwater flows, including heavy metals, oil and grease, pesticides, polycyclic aromatic hydrocarbons, sediment, and nutrients (nitrogen and phosphorus). In some land use settings, pollutant concentrations in stormwater runoff can exceed levels that are considered acutely toxic. Pollutant concentrations can also exceed chronic toxicity levels in urbanized streams. Little is known about the impacts of mixtures of pollutants on aquatic biota, but recent research indicates synergism or increased toxicity for mixtures of some pesticides. Suspended sediment and nutrients in stormwater also impact aquatic biota through various mechanisms.

The current structural approach to stormwater management cannot fully mitigate the flow and water quality impacts from urban development. Increasingly, stormwater engineers and designers explore and implement distributed LID strategies that seek to preserve the natural hydrologic regime of watersheds by managing stormwater as close to its source as possible. In western Washington, LID will be required in all Phase I communities (cities and counties with populations greater than 100,000) by 2011. Low impact development will likely be required in all Phase II communities (cities and counties with populations greater than 10,000) in the next 4 to 5 years.

This year, WSU and project partners will complete construction of the first university LID research program in the western U.S. The program will focus on permeable pavement and bioretention initially, and use full-scale replicated research plots to test the water quality treatment and flow control performance of these systems.
Project Description

The primary objective of the rain garden research is to examine the performance of various plants and the influence of different plant treatments on rain garden soil properties. The same soil mix will be used for all rain gardens: a mixture of 60 percent aggregate and 40 percent compost by volume (approximately 8 percent organic matter by weight). The plant treatments will include managed meadow (all grasses), shrubs and small trees, shrub and grass mix, and unplanted control area. The cells will be arranged in a 4-plot by 4-plot square and the four plant treatments randomized within each row.

During Phase 1 of the research program, stormwater will be delivered to a 3,000 gallon cistern and then to each rain garden by gravity and at natural storm rates and volumes. Plant growth and vigor, infiltration rates, and soil chemistry will be assessed each year. After an establishment period, Phase 2 of the project will begin, and will involve controlled experiments to test the influence of fine sediment on infiltration rates. For this testing, sediment will be mixed in the cistern and delivered to the rain gardens at specific loads and rates.

The following information will be collected through the rain garden research:

- Subgrade soil and BSM physical and chemical properties at baseline and overtime
- Plant growth and quality over time
- Transpiration rates for selected plants
- The influence of plants on infiltration rate of the BSM
Organization and Schedule

WSU is collaborating with the City of Puyallup and other project partners to implement the LID Research Program. Funding for the program was obtained through a grant from Ecology’s Stormwater Management Implementation Grant Program. WSU is also providing significant in-kind resources to fund major elements of the program.

Key personnel for the rain garden research component of the program are shown in Table 1.
### Table 1. Key personnel for the rain garden research component of the Low Impact Development Research Program.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Role</th>
<th>Responsibilities</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtis Hinman</td>
<td>Washington State University</td>
<td>Program Director</td>
<td>Ensures tasks and other requirements of this QAPP are executed on time. Verifies the QAPP is followed and the study is producing data of known and acceptable quality. Ensures adequate training and supervision of all monitoring and data collection activities. Supervises all assigned study personnel. Tracks project schedule and budgets.</td>
<td>Office: (253) 445-4590</td>
</tr>
<tr>
<td>Andy Barry</td>
<td>Washington State University</td>
<td>Compost Science Technical Lead</td>
<td>Coordinates project technical issues related compost chemistry and analysis.</td>
<td>Office: (253) 445-4500</td>
</tr>
<tr>
<td>Rita Hummel</td>
<td>Washington State University</td>
<td>Plant Science Technical Lead</td>
<td>Coordinates project technical issues related to plant growth and development.</td>
<td>Office: (253) 445-4524</td>
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<tr>
<td>Eric Miltner</td>
<td>Washington State University</td>
<td>Plant Science Technical Lead</td>
<td>Coordinates project technical issues related to plant growth and development.</td>
<td>Office: (253) 445-4594</td>
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<tr>
<td>Brent Thyssen</td>
<td>Soiltest Farm Consultants</td>
<td>Laboratory Manager for Soil Analyses</td>
<td>Supervises laboratory personnel involved in generating soil analytical data for this study. Ensures that laboratory personnel involved in generating analytical data have adequate training and a thorough knowledge of the QAPP and all SOPs specific to the analyses or task performed and/or supervised. Oversees all operations, ensuring that all QA/QC requirements are met, and documentation related to the analysis is completely and accurately reported. Enforces corrective action, as required. Develops and facilitates monitoring systems audits.</td>
<td>Office: (509) 765-1622</td>
</tr>
</tbody>
</table>
Table 1 (continued). Key personnel for the rain garden research component of the Low Impact Development Research Program.

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Role</th>
<th>Responsibilities</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Lenth</td>
<td>Herrera Environmental Consultants</td>
<td>Contractor Project Manager for QAPP Development</td>
<td>In coordination with WSU staff, oversees preparation of the QAPP. Ensures monitoring procedures specified in the QAPP meet requirements that are specified in the grant for the LID Research Program and Section S.8.F of the City of Seattle’s Phase I Municipal Stormwater Permit.</td>
<td>Office: (206) 441-9080 x144 Mobile: (206) 245-7539</td>
</tr>
<tr>
<td>Deborah Cornett</td>
<td>Washington State Department of Ecology</td>
<td>Grant Manager</td>
<td>Acts as the grant manager for the Ecology. Ensures the grant requirements for the project are met. Approves QAPP for grant.</td>
<td>Office: (360) 407-7269</td>
</tr>
<tr>
<td>To be determined</td>
<td>Washington State University</td>
<td>Quality Assurance Coordinator</td>
<td>Oversees review of all water quality and hydrologic data to verify they meet quality objectives specified in this QAPP.</td>
<td>Office: (253) 445-4500</td>
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</table>

LID: low impact development  
QAPP: quality assurance project plan  
SOP: standard operating procedures  
WSU: Washington State University
Key milestones for the rain garden component of the LID Research Program are summarized in Table 2.

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

<table>
<thead>
<tr>
<th>Project Milestone</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft QAPP Submitted</td>
<td>July 2010</td>
</tr>
<tr>
<td>Final QAPP</td>
<td>August 2010</td>
</tr>
<tr>
<td>Rain Garden Construction and Baseline Monitoring</td>
<td>Spring-Summer 2010</td>
</tr>
<tr>
<td>Phase 1 Monitoring Initiation</td>
<td>October 2010</td>
</tr>
<tr>
<td>Phase 2 Monitoring Initiation</td>
<td>No earlier than October 2011</td>
</tr>
</tbody>
</table>
Quality Objectives

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

- **Bias**: The systematic or persistent distortion of a measurement process that causes errors in one direction (i.e., the measured mean is different from the true value).

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

- **Representativeness**: The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency and duration, and sampling methods.

- **Completeness**: The amount of data obtained from the measurement system.

- **Comparability**: The ability to compare data from the current study to data from other similar studies, regulatory requirements, and historical data.

Measurement quality objectives (MQOs) are performance or acceptance criteria that are established for each of these quality assurance indicators. Specific MQOs identified for this project are described below and summarized in Table 3. The term “reporting limit” in this document refers to the practical quantification limit established by the laboratory, not the method detection limit.

**Bias**

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

\[
\%R = \left( \frac{S - U}{C_{sa}} \right) \times 100\%
\]

Where:  
\(\%R\) = Percent recovery  
\(S\) = Measured concentration in spike sample  
\(U\) = Measured concentration in unspiked sample  
\(C_{sa}\) = Actual concentration of spike added
### Table 3. Measurement quality objectives for soil data.

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

a Reference sample recovery will be based on North American Proficiency Testing Program sample statistics.
b Reference sample recovery will be based on Environmental Resource Associates QC sample statistics.
DTPA = Diethylenetriamine penta-acetic acid.
ISV: internal standard verification.
RPD = relative percent difference.
RSDp = pooled relative standard deviation.
TBD = to be determined.
If the analyte is not detected in the unspiked sample, then a value of zero will be used in the equation. The specific MQOs for the percent recovery in matrix spikes are defined in Table 3 for each soil parameter.

Bias in LCS will also be evaluated based on their percent recovery. In this case, percent recovery will be calculated using the following equation:

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

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

The specific MQOs for the percent recovery in LCS are defined in Table 3 for each soil parameter.

**Precision**

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

$$S_p = \sqrt{\frac{\sum (C_i - C_j)^2}{2m}}$$

and

$$RSD_p = \frac{S_p}{\bar{x}} \times 100\%$$

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

When one or both values are less than or equal to 5 times the reporting limit, they will not be included in the $RSD_p$ calculation. The specific MQOs for total precision are defined in Table 3 for each soil parameter.

Analytical precision is the measure of the variability in the results of replicate measurements due to random error that is introduced from just the laboratory analytical procedure. Analytical
precision will be assessed based on the relative percent difference (RPD) of laboratory duplicates that are run with each batch of samples. The RPD of these samples will be calculated using the following formula:

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

Where:  
$\text{RPD}$ = Relative percent difference  
$C_1$ and $C_2$ = Concentration values

The specific MQOs for analytical precision are defined in Table 3 for each soil parameter. For all parameters, the RPD must be ±2 times the reporting limit if the duplicate concentrations are both within 5 times the reporting limit. If either of the duplicate concentrations is at or below the reporting limit, the RPD cannot be calculated.

**Representativeness**

Sample representativeness will be ensured by employing a sampling design that will adequately capture the variability in soil chemistry across all the rain garden experimental treatments. Representativeness will also be ensured by employing consistent and standard sampling procedures, as identified in this QAPP.

**Completeness**

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

**Comparability**

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

The primary objective of the rain garden research is to examine the performance of various plants and the influence of different plant treatments on rain garden soil properties. This section describes the sampling process design that will be used to meet this goal, including a general description of the monitoring site, detailed information about rain garden components, and descriptions of monitoring activities performed during each phase of the monitoring program.

Rain Garden Design

The rain garden performance monitoring program will be implemented on the WSU campus in Puyallup, Washington (see vicinity map in Figure 1). Figure 2 shows a general site plan for the campus, and Figure 3 provides a detail of the campus area devoted to the rain garden research. Sixteen rain garden cells will be constructed on the campus. The sampling process design will rely on four replicate rain garden cells for each of the four plant treatments described in the Project Description section above.

There are three basic physical components to the rain garden design:

- Cistern and flow distribution system
- Rain garden cell BSM and plant treatments
- Outlet flow control structure.

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

Cistern and Flow Distribution System

To facilitate monitoring of the rain garden cells, stormwater will be collected from a 34,012 square foot impervious drainage area on the WSU campus and routed to an 11,370 liter (L) (3,000 gallon) cistern for storage. The cistern’s location on the campus and associated drainage area are shown in Figure 3. Elevations of stormwater conveyance structures in the drainage area to the cistern are provided in Appendix A. Stormwater from the cistern can be routed via gravity flow to the rain garden cells to assess treatment performance during natural storms; alternatively, water can be pumped from the rain garden cells at specific flow rates, volumes, and pollutant concentrations to produce synthetic storms for testing rain garden performance. In either case, weirboxes constructed at the water surface elevation inside the cistern will distribute flows evenly to each rain garden cells. Figure 4 provides a more detailed cross-section view of the cistern, associated weirboxes, pump system, and distribution lines.

Rain Garden Bioretention Soil Mix and Plant Treatments

As described above, 16 replicated rain garden cells will be installed to facilitate the rain garden research. The rain garden cells will be sized using the Western Washington Hydrology model
based on a 5:1 ratio of contributing area to rain garden surface area. Each cell will have approximately 300 square feet of surface area, and 18 inches of BSM. Figure 5 shows a cross-section view of a typical rain garden cell.

The same BSM will be used for all the rain garden cells. This BSM will be composed of 60 percent aggregate and 40 percent compost by volume (approximately 8 percent organic matter by weight).

Four experimental plant treatments will be evaluated in the rain garden research as follows:

- Managed grassland (MG)
- Shrub and tree (ST)
- Mixed landscape planting (ML)
- Unplanted control (UC)

Each plant treatment will be replicated in four separate rain garden cells. Plant selection and performance will be considered as it relates to the various hydro-zones in the rain garden. Hydro-zones are defined as wet (floor of rain garden), transitional (sloped sides), and dry (highest elevation of rain garden).

Plants under consideration for planting in each rain garden treatment are listed in Table 4. Not all plant species will be planted in all hydro-zones. If, based on known adaptations, a species is not expected to survive in a particular zone, it will not be planted there. However, most species will be planted in at least two of three hydro-zones to test the limits of their adaptations. Table 4 indicates hydro-zone locations for each potential plant species. Plant selection will also depend on commercial availability.

Planting procedures for each plant treatment will be as follows:

- **Grasses in MG Treatment.** Grasses in the MG treatment only will be planted from seed, using rates recommended for reclamation or low-maintenance lawns. Seed will be applied to the surface of the BSM, followed by light raking to incorporate and ensure adequate seed/soil contact. Mulch will not be applied to the surface of the BSM in the MG treatment.

- **Woody Plants and Herbaceous Plants in ML and ST Treatments.** Plants will be obtained from reputable nurseries or grown from seed or cuttings at WSU Puyallup. Uniform plant material will be obtained whenever possible; however, all plants will be sorted for quality and size before planting to allow for maximum uniformity within a replication. Within a plant community treatment, the placement of the plants in each replicate plot will be identical and chosen with careful consideration as to maximize area for root and shoot growth. Plants will be transplanted according to recommended practice: roots at the periphery of the root ball will be cut and spread, the planting holes will be twice the diameter of the
Figure 2.
Plan view of Washington State University low impact development research facility.
Figure 3.
Plan view of rain garden test facility.

Legend
- MESocosm Gistern
- Weather Station
- Managed Grassland
- Shrub and Tree
- Mixed Landscape Planting
- Unplanted Control
- Drainage Basin

RAIN GARDEN DRAINAGE
BASIN AREA = 68,124 SQ. FT.

Pump and Valves
Figure 4.
Cross-section view of rain garden cistern and pump system.
Figure 5.
Cross section of typical rain garden.
Figure 6. Cross section and plan view for the outlet flow control structure of a rain garden cell.
### Table 4. Rain garden plant treatment, potential plant species, and likely hydro-zone locations.

<table>
<thead>
<tr>
<th>Plant Treatment</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Hydro-Zone§</th>
</tr>
</thead>
<tbody>
<tr>
<td>Managed grassland</td>
<td>Festuca arundinacea</td>
<td>Tall fescue</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Agrostis capillaris</td>
<td>Colonial bentgrass</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Deschampsia cespitosa</td>
<td>Tufted hairgrass</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Festuca rubra</td>
<td>Fine-leaf fescue</td>
<td>t, d</td>
</tr>
<tr>
<td>Tree and shrub: Trees</td>
<td>Arbutus unedo</td>
<td>Strawberry tree</td>
<td>t, d</td>
</tr>
<tr>
<td></td>
<td>Magnolia virginiana</td>
<td>Sweetbay magnolia</td>
<td>w, t</td>
</tr>
<tr>
<td>Tree and shrub: Shrubs</td>
<td>Clethra alnifolia</td>
<td>Summersweet</td>
<td>w, t</td>
</tr>
<tr>
<td></td>
<td>Cornus sericea (LPDC1Y)</td>
<td>Yellow dogwood</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Leucothoe axillaris</td>
<td>Coast leucothoe</td>
<td>t, w</td>
</tr>
<tr>
<td></td>
<td>Mahonia aquifolium 'Compacta'</td>
<td>Compact Oregon grape</td>
<td>t or d</td>
</tr>
<tr>
<td></td>
<td>Myrica californica</td>
<td>Pacific wax myrtle</td>
<td>w,t,d</td>
</tr>
<tr>
<td></td>
<td>Physocarpus opulifolius 'Center Glow'</td>
<td>Center Glow ninebark</td>
<td>w,t,d</td>
</tr>
<tr>
<td>Tree and shrub: Sub-shrubs or Groundcovers</td>
<td>Gaultheria shallon</td>
<td>Salal</td>
<td>w or t</td>
</tr>
<tr>
<td></td>
<td>Illex vomitoria 'Nana'</td>
<td>Dwarf yaupon holly</td>
<td>t or d</td>
</tr>
<tr>
<td></td>
<td>Mahonia nervosa</td>
<td>Longleaf mahonia</td>
<td>t or d</td>
</tr>
<tr>
<td></td>
<td>Mahonia repens</td>
<td>Creeping mahonia</td>
<td>w,t,d</td>
</tr>
<tr>
<td>Mixed landscape: Grasses</td>
<td>Deschampsia cespitosa</td>
<td>Tufted hairgrass</td>
<td>w,t,d</td>
</tr>
<tr>
<td></td>
<td>Helichtotrichon sempervirens</td>
<td>Blue oat grass</td>
<td>t</td>
</tr>
<tr>
<td></td>
<td>Miscanthus sinensis 'Little Kitten'</td>
<td>Japanese silvergrass</td>
<td>w,t</td>
</tr>
<tr>
<td></td>
<td>Molinia caerulea 'Moor Flame'</td>
<td></td>
<td>w, t</td>
</tr>
<tr>
<td>Mixed landscape: Sedges/Rushes</td>
<td>Carex obnupta, C. stipata</td>
<td>Slough sedge, Saw-toothed sedge</td>
<td>w, t</td>
</tr>
<tr>
<td></td>
<td>Juncus effusus, J. ensifolius, J. tenuiss</td>
<td>Common, Dagger-leaf, Slender rush</td>
<td>w,t,d</td>
</tr>
<tr>
<td>Mixed landscape: Herbaceous Perennials</td>
<td>Hemiocallis hybrid</td>
<td>Daylily</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Xerophyllum tenax</td>
<td>Beargrass</td>
<td>d</td>
</tr>
<tr>
<td>Mixed landscape: Trees</td>
<td>Taxodium distichum 'Shawnee Brave'</td>
<td>bald cypress</td>
<td>w, t</td>
</tr>
<tr>
<td></td>
<td>Taxodium distichum (weeping)</td>
<td>bald cypress</td>
<td>t</td>
</tr>
<tr>
<td>Mixed landscape: Shrubs</td>
<td>Cornus sericea (LPDC2R)</td>
<td>Red-osier dogwood</td>
<td>t or d</td>
</tr>
<tr>
<td></td>
<td>Diervilla sessifolia 'Cool Splash'</td>
<td>Cool Splash bush-honeysuckle</td>
<td>t,d</td>
</tr>
<tr>
<td></td>
<td>Physocarpus capitatus</td>
<td>Pacific Ninebark</td>
<td>w, t, d</td>
</tr>
<tr>
<td></td>
<td>Physocarpus opulifolius 'Center Glow'</td>
<td>Center Glow ninebark</td>
<td>w,t,d</td>
</tr>
<tr>
<td></td>
<td>Salix integra 'Hakuro-nishiki'</td>
<td>Dappled willow</td>
<td>w or t</td>
</tr>
<tr>
<td>Mixed landscape: Sub-shrubs or Groundcovers</td>
<td>Cornus sericea 'Kelseyi'</td>
<td>Dwarf red-osier dogwood</td>
<td>w,t,d</td>
</tr>
<tr>
<td></td>
<td>Diervilla lonicera</td>
<td>Dwarf bush-honeysuckle</td>
<td>t, d</td>
</tr>
</tbody>
</table>

§ Hydro-zones: w = wet; t = transitional; d = dry.
root ball, and the surface of the rootball will be approximately 3 cm above grade (Watson and Himelick 1997; Maleike and Hummel 1994). During transplanting, care will be taken to keep BSM and mulch layers separate and out of the planting pit.

Outlet Flow Control Structure

As shown in Figure 5, an underdrain pipe will be installed in the drain rock underlying BSM for each rain garden cell. The underdrain pipe will connect to a vertically oriented outlet flow control structure with upper and lower outlets (Figure 6). Discharge from the lower outlet is regulated by an orifice that can be set at different heights within the outlet flow control structure. This outlet can be used to control the saturated zone level and hydraulic residence time within the rain garden cell, thereby affecting denitrification processes (conversion of nitrate to nitrogen gas) that are mediated by anaerobic bacteria. The upper outlet serves as a bypass weir that can also be set at different heights within the outlet flow control structure. Adjustment of this weir can be used to control hydraulic residence time and ponding depth within the rain garden cell.

The outlet flow control structures will not be used in the first 1 to 2 years of monitoring; instead, the rain garden will be operated with bypass valves for the outlet flow control structures set to remain open. With these bypass valves open, the flow of water through the rain garden cells will not be subject to any artificial controls and will essentially mimic the natural drainage condition. Once the performance of the rain garden cells has been evaluated under this “baseline” condition, the outlet flow control structures will then be brought on-line to evaluate performance under other hydraulic scenarios of interest.

Monitoring Design

Monitoring activities will occur in three phases that are herein referred to as Baseline monitoring, Phase 1 monitoring, and Phase 2 monitoring. Baseline monitoring will characterize the physical and chemical properties of the various bioretention soil mixes prior to the onset of monitoring activities in the rain garden cells. Phase 1 monitoring will involve studies to quantify plant health and quality in the rain garden cells over time. In addition, monitoring during Phase 1 monitoring will also be performed to quantify physical and chemical changes in the BSM over time. Phase 2 monitoring will involve controlled experiments to test the influence of fine sediment on infiltration rates; however, this monitoring will occur at a later date and will be described in a separate QAPP.

Baseline monitoring will be performed in the spring and summer of 2010 during construction of the rain gardens. Phase 1 monitoring will then initiate at the start of water year 2011 and be ongoing thereafter. The specific activities that will be performed during these monitoring phases are described in the following subsections.
Baseline Monitoring

The goal of the Baseline monitoring is to characterize the physical and chemical properties of the BSM used in the rain garden cells before it is altered by subsequent stormwater inputs or interactions with the various plant treatments. To meet this goal, samples of the BSM used to construct the individual rain garden cells will be collected and analyzed for representative soil parameters. Specifically, nine individual samples will be collected from different locations within the BSM used to construct each individual rain garden cell; these samples will then be composited into a single sample. This process will be repeated for each rain garden cell to obtain a total of 16 composite samples. These composite samples will then be submitted to an accredited laboratory where they will be analyzed for the following parameters:

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

In addition to the above parameters, WSU will perform the following soil analyses on the composite samples at a non-accredited laboratory located on the WSU Puyallup campus:
Phase 1 Monitoring

The goal of Phase 1 monitoring will be to determine which plants perform best under specific hydroperiods and to characterize how various plant palettes affect rain garden soil properties.

Vegetation Monitoring

During Phase 1, vegetation monitoring will occur on an annual basis. Monitoring of vegetation will focus on two primary types of measurements:

- Plant growth and aesthetic quality measurements
- Plant water relations measurements

Plant growth will be assessed by measuring plant dimensions while plant aesthetics will be assessed by professional botanists using a graduated scale based on color, density, and uniformity. Plant water relations measurements will consist of xylem pressure potential measurements and transpiration measurements. Details on all of these procedures are provided in the Sampling Procedures section below.

Precipitation and Evapotranspiration Monitoring

To facilitate rain garden monitoring, a weather station with two tipping bucket rain gauges will be used to continuously monitor precipitation totals at the monitoring site (Figure 3). The weather station will also monitor wind speed and direction, solar radiation and relative humidity. Evapotranspiration is calculated using these data and the Penman-Montieth equation. These data will be used during the vegetation analysis to determine to what extent meteorological factors affected plant health.

Infiltration Testing

During Phase 1 monitoring, the infiltration rate in each rain garden will be assessed on an annual basis. Infiltration testing will be conducted following a falling head procedure described in the Sampling Procedures section. Testing will occur immediately after planting and then on an annual basis from that date forward. The results from these tests will be used to assess how soil compaction, rhizosphere (root system) development, and sediment loading impact infiltration rates over time.

Soil Chemistry Monitoring

The goal of soil chemistry monitoring will be to track changes in the chemistry of the BSM in each rain garden cell over time as the associated plant communities develop. These samples will
be collected once yearly and submitted to an accredited laboratory where they will be analyzed for the following parameters:

- Total carbon
- Total nitrogen
- Total phosphorus
- Bray phosphorus
- Water soluble phosphorus
- Oxalate phosphorus
- pH
- Oxalate iron and aluminum
- Calcium, magnesium, and potassium
- Ammonium and nitrate
- Cation exchange capacity

In addition to the above parameters, WSU will perform the following analyses on samples of the BSM from each rain garden cell at a non-accredited laboratory located on the WSU Puyallup campus:

- Total carbon by loss on ignition
- Bulk density

Finally, the soil compaction in each rain garden will be documented annually at the same time the soil samples are collected.
Sampling Procedures

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

Baseline Monitoring

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

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

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

Phase 1 Monitoring

Vegetation Monitoring

As described in the Sampling Process Design section, vegetation monitoring will focus on two primary types of measurements:

- Plant growth and aesthetic quality measurements
- Plant water relations measurements

The procedures that will be used for these measurements are described below.
Plant Growth and Aesthetic Quality Measurements

Separate measurement procedures will be used to assess the growth and aesthetic quality of grasses and woody and herbaceous plants as follows:

- **Grasses.** In order to assess relative establishment rates of seeded grasses, the plantings will be visually assessed using a 1 to 5 scale (1 = no establishment, 5 = best establishment). Percent ground cover will be visually assessed at the end of the first growing season. Growth measurements of bunch grasses will include heights, widest and narrowest diameters, and above-ground biomass of plants cut back annually. For full canopy grasses, heights, % ground cover, and above-ground biomass will be measured from a uniform area. Aesthetic quality will be assessed on a scale of 1 to 5 (1 = dead, 3 = acceptable, 5 = optimal quality), taking into account plant color, density, and uniformity of growth.

- **Woody and Herbaceous Plants.** Shoot growth, plant survival and aesthetic quality of trees, shrubs, woody ground covers and herbaceous perennials will be measured at transplant and at the end of the growing season. Shoot growth measurements will include plant height measured from the soil line to tallest terminal bud, flower cluster, or leaf extension, canopy diameter at two locations, and for trees only, trunk caliper. A shoot growth index (SGI) will be calculated from the plant growth data as follows: \(((\text{diameter } A + \text{diameter } B)/2 + \text{height})/2\) (Hummel et al. 2000).

Plant survival will be visually assessed by estimating the percent of canopy dieback. Plant aesthetic quality will be rated on a visual scale of 1 (poor quality) to 5 (outstanding quality) with a rating of 3 considered acceptable performance in the rain garden environment (Hummel et al. 2000). In rating the plants, foliage color, condition and density, and plant form, height, and attractiveness will be considered.

Plant Water Relations Measurements

A Scholander pressure chamber will be used to measure mid-day xylem pressure potential (XPP) of at least one leaf collected from representative red-osier dogwood plants in midsummer. When pressure chamber measurements are used to estimate the water potential existing in the xylem, they can be referred to as xylem pressure potential, as recommended by Ritchie and Hinckley (1975). A straight cut will be made with a sharp blade across the petiole of a mature, fully expanded leaf at node 3 or 4 from the shoot apex. Once severed, the leaf blade will be enclosed in a plastic bag and quickly placed in the pressure chamber, which was previously lined with moist paper towels, leaving the cut end of the petiole protruding through a hole in the sealed gasket. Pressure will be increased slowly until water appears on the cut surface of xylem vessels visible at the cut end of the petiole and the pressure recorded (Hummel 1979).

Transpiration of mature, fully expanded leaves on red-osier dogwood, and a representative broad-leaved evergreen will be measured, while attached to the plant, with a porometer (Li-Cor...
Model LI-1600, Li-Cor, Inc. Lincoln, Nebraska). Measurements will be made concomitant with XPP in midsummer. Transpiration of the representative broad-leaved evergreen will also be measured in midwinter. Sunlight in μE s⁻¹ m⁻² and relative humidity will be recorded at the time of measuring XPP and transpiration.

**Precipitation Monitoring**

To monitor precipitation, two Hydrological Services TB3 tipping bucket rain gauge (see detailed specifications in Appendix B) will be installed in an area adjacent to the rain gardens that is unobstructed by buildings or trees (Figure 3). One gauge will be mounted on a 5 foot pole and one at ground level. Each will be leveled upon installation. Data from the gauge will be recorded on an alternating current (AC) powered Campbell Scientific CR1000 datalogger (see detailed specifications in Appendix B). The datalogger will be programmed to scan every 10 seconds and record totalized rainfall on a 5-minute interval. The stored data will be automatically downloaded on a daily basis via radio telemetry to a central server located in an adjacent campus building. On at least a monthly basis, field personnel will check the rain gauge to ensure it is still level. On an annual basis, the calibration of the gauge will be checked and adjusted if necessary (see Quality Control section below).

**Infiltration Testing**

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

1. Closing the 1.5 inch knife valve at the end of the underdrain.
2. Releasing water into the rain garden until there is 6 inches of standing water.
3. To assure saturation, the water will be allowed to stand for 1 hour. Water levels will be checked again after the hour and adjusted to 6 inches of standing water if necessary.
4. Opening the knife valve and recording the time needed for the 6 inches of water to infiltrate.

Field personnel will record all the pertinent information on standardized field forms which will be scanned and stored in the project database.

**Soil Chemistry Monitoring**

Samples of the BSM in each rain garden cell will be collected on an annual basis to assess soil fertility, chemistry, and physical properties. To collect these samples, a 2-inch diameter push probe will be used to collect the BSM samples at randomly selected locations within each rain garden cell; these samples will then be composited into a single sample for laboratory analyses.
This process will be repeated for each rain garden cell to obtain a total of 16 composite samples. The composite samples from each rain garden cell will be labeled in the field, placed in a cooler with ice, and transported to the laboratory within the allowable limits for sample holding times and with the appropriate chain of custody documentation. Once at the laboratory, the samples will be analyzed for the suite of parameters that were identified in the Sampling Process Design section for Phase 1 soil chemistry monitoring.

After sampling is complete, voids left in the rain garden cells from the push probe will be filled with stockpiled bioretention soil mix retained from the initial rain garden cell construction. The new soil mix will be packed into the void left by the push probe so that water introduced during subsequent storm events will not bypass the bioretention soil mix and flow directly to the underdrain with minimal treatment. Finally, the sampling location will be marked so that subsequent samples are not collected in the same location.

In addition to the soil sampling described above, the soil compaction in each rain garden cell will be measured annually. These measurements will be made with a Rimik recording penetrometer to a depth of 30 cm at nine locations per rain garden cell (Cogger et al. 2008).
Measurement Procedures

Laboratory analytical procedures for BSM samples collected from each rain garden cell are identified in Table 5 with associated preservation methods, analytical methods, reporting limits, and sample holding times. The WSU-Puyallup campus is an agricultural research center that has non-accredited laboratory facilities capable of processing and analyzing soil samples. Consequently, the following parameters will be analyzed on campus:

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

The remainder of the soil parameters will be analyzed at Soiltest Farm Consultants, Inc. This laboratory is certified by Ecology and participates in audits and 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 QA/QC procedures.

The laboratory will report the analytical results within 30 days of receipt of the samples. These reports will provided in both a hardcopy and electronic format, and contain the same information as described above for water quality parameters.
Table 5. Methods and detection limits for soil analyses.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Analytical Method</th>
<th>Method Number</th>
<th>Volume Required for Analysis</th>
<th>Field Sample Container</th>
<th>Pre-processing Holding Time</th>
<th>Total Holding Time</th>
<th>Field Preservation</th>
<th>Laboratory Preservation</th>
<th>Reporting Limit/Resolution Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Electrometric</td>
<td>S -2.20 b</td>
<td>0.5 g</td>
<td>NA</td>
<td>48 hours *</td>
<td>NA</td>
<td>Room temperature</td>
<td>NA</td>
<td>Standard units</td>
</tr>
<tr>
<td>Total carbon by loss on ignition</td>
<td>Gravimetric</td>
<td>S -9.20 b</td>
<td>0.5 g</td>
<td>NA</td>
<td>48 hours *</td>
<td>NA</td>
<td>Maintain &lt; 6°C</td>
<td>0.10</td>
<td>%</td>
</tr>
<tr>
<td>Percent total solids</td>
<td>Gravimetric</td>
<td>P -1.10 b</td>
<td>50 g</td>
<td>NA</td>
<td>48 hours</td>
<td>NA</td>
<td>Maintain &lt; 6°C</td>
<td>0.10</td>
<td>%</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>Sieve/Hydrometer</td>
<td>ASTM D422</td>
<td>500 g</td>
<td>NA</td>
<td>6 months</td>
<td>NA</td>
<td>Room temperature</td>
<td>NA</td>
<td>lb/ft³</td>
</tr>
<tr>
<td>Bulk density</td>
<td>Volumetric</td>
<td>TMECC 03.01-A</td>
<td>200 g</td>
<td>NA</td>
<td>7 days</td>
<td>NA</td>
<td>Room temperature</td>
<td>NA</td>
<td>mg CO₂-C/g OM/day</td>
</tr>
<tr>
<td>Compost stability</td>
<td>Respiration</td>
<td>TMECC 02.05-B</td>
<td>500 g</td>
<td>NA</td>
<td>48 hours</td>
<td>NA</td>
<td>Room temperature</td>
<td>0.8</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>Na replacement</td>
<td>S -10.10 b</td>
<td>2 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>0.7</td>
<td>mg/kg</td>
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<tr>
<td>Total carbon</td>
<td>Combustion</td>
<td>ASTM D5737</td>
<td>0.5 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>4.3</td>
<td>mg/kg</td>
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<tr>
<td>Total nitrogen</td>
<td>Combustion</td>
<td>ASTM D5737</td>
<td>0.5 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>0.1</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Water soluble phosphorus</td>
<td>ICP</td>
<td>EPA 3050A/6010B</td>
<td>0.5 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>0.7</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Oxalate phosphorus</td>
<td>ICP</td>
<td>SSSA Mono.9 6-2.3</td>
<td>0.125 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>TBD</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>ICP</td>
<td>SSSA Mono.9 6-2.3</td>
<td>0.125 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>1.0/1.0</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Calcium, magnesium, and potassium</td>
<td>NH₄OAc/ICP</td>
<td>S -5.10 b</td>
<td>2 g</td>
<td>48 hours *</td>
<td>NA</td>
<td>NA</td>
<td>Room temperature</td>
<td>Ca 0.2/Mg 0.1/K 11</td>
<td>mg/kg; K mg/kg</td>
</tr>
</tbody>
</table>

* ASTM method numbers are from ASTM (2003); EPA method numbers are from U.S. EPA (1983, 1984).
* From Gavlak et al. 2003.
* From Test Methods for the Examination of Composting and Compost; A joint project of the United States Department of Agriculture and the U.S. Composting Council.
* From Test Method from the Soil Science Society of America.
* Samples will be dried on-site at 40°C. Once samples are transferred to the laboratory they will be pulverized using a hammer mill apparatus, and sieved through a 2 millimeter mesh screen (from Brown [1998]; Recommended Chemical Soil Test Procedures for the North Central Region).
* C = Celsius.
* DTPA = Diethylenetriamine penta-acetic acid.
* lb/ft³ = pounds per cubic foot.
* g = grams.
* g OM/day = grams organic matter per day.
* ICP = inductively coupled plasma.
* Meg/100g = milli-equivalents per 100 grams.
* mg/kg = milligrams per kilogram.
* mg = milligrams.
* NA = not applicable.
* TBD = to be determined.
Quality Control Procedures

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

Field Quality Control Procedures

Quality control procedures 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 6 for soil parameters.

Instrument Maintenance and Calibration

Routine maintenance and operational inspections will be performed monthly to ensure that required monitoring equipment is functioning properly. Maintenance activities and operational inspections will include:

- Inspection of the rain gauge, including level check and debris removal
- Inspection of weirboxes (see Figure 4), including debris removal
- Inspection of outlet flow control structures (see Figure 5), including level of upper and upper outlets

Field Notes

During each soil sampling field visits, the following information will be recorded on a waterproof standardized field form:

- Rain garden cell identification
- Date/time of visit
- Name(s) of field personnel present
- Weather and flow conditions
- Number of samples collected/composited
- Sample depth
Table 6.  Anticipated annual number of samples and associated quality assurance requirements for each soil parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Samples per Rain Garden</th>
<th>Number of Rain Gardens</th>
<th>Total Number of Samples</th>
<th>Laboratory Method Blanks</th>
<th>Laboratory Control Standard</th>
<th>Matrix Spike</th>
<th>Lab Duplicates</th>
<th>Field Duplicates</th>
<th>Total Annual Number of Samples b</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>NA</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Total carbon by loss on ignition</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>NA</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Percent total solids</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>NA</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Compost stability</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Cation exchange capacity</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Total carbon</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>NA</td>
<td>NA</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Nitrate</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Bray phosphorus</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Water soluble phosphorus</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Oxalate phosphorus</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Oxalate iron and aluminum</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>NA</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Calcium, magnesium, and potassium</td>
<td>1</td>
<td>16</td>
<td>16</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>1/batch</td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

a  Field duplicates will be collected and analyzed for at least 5 percent of the total number of submitted samples.
b  Total annual number of samples includes project samples and field duplicates.
BSM: bioretention soil mix.
NA: not applicable.
Unusual conditions (e.g., oily sheen, odor, color, turbidity, discharges or spills, and land disturbances)

Modifications of sampling procedures

Distribution System Checks
As described in the Sampling Process Design section, stormwater from the cistern (Figures 3 and 4) will be routed via gravity flow or pumped to the individual rain gardens during testing related to the rain garden research. In either case, weirboxes constructed at the water surface elevation inside the cistern will distribute flows evenly to each rain garden.

Weirbox elevation and rain garden flow will be checked to verify that flow is being evenly distributed among the rain gardens. These checks are described in more detail in the following subsections.

Weirbox Elevation Checks
To ensure there is an even distribution of flow to each rain garden, the height of the weirboxes will be checked on a monthly basis during the first year of monitoring using a laser level to assure they are at the same elevation. In all subsequent years of monitoring, the height of the weirboxes 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.

Rain Garden Flow Checks
To verify there is an even distribution of flow to each rain garden, manual measurements of flow will be made at each rain garden during storm events. Flow measurements at each rain garden will be made by recording the amount of time it takes to collect a known volume of water from the inlets to each rain garden. Modifications to the flow distribution system may be considered if these measurements show the flow at an individual rain garden deviates by more than 25 percent from the average flow rate to all the rain gardens. These checks will be made during at least five storm events in each monitoring year.

Field Duplicate Split Samples – Soil
Field duplicate split samples will be collected at a sufficient frequency to represent 5 percent of the total number of project samples analyzed. The number of field duplicates to be collected during the sampling season is listed in Table 6. Soil sample field duplicate split samples will be collected by mixing the sample in a pre-cleaned stainless steel bowl with a pre-cleaned stainless steel spoon until the mixture is homogenous. The sample will subsequently be split in two and placed in separate soil bags. Duplicate sampling stations will be selected randomly.
All duplicate samples will be submitted to the laboratory and labeled as separate (blind) samples. The resultant data from these samples will then be used to assess variation in the analytical results that is attributable to environmental (natural), sub-sampling, and analytical variability.

**Sample Handling, Delivery, and Processing**

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

**Sample Identification and Labeling**

Each sample from each rain garden will be identified with a unique label following the numbering system identified in Figure 3. All soil bags will be labeled with the following information using indelible ink and labeling tape:

- Sample number
- Date of sample collection (year/month/day: yyyy/mm/dd)
- Time of sample collection (international format [24 hour])
- Field personnel initials

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

**Sample Containers and Preservation**

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

**Chain-of-Custody Record**

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

**Laboratory Quality Control Procedures**

Quality control procedures that will be implemented in the laboratories are described in the following subsections. The frequency and type of quality control samples to be analyzed by the laboratories are also summarized in Table 6.
Method Blanks

Method blanks consisting of de-ionized and micro-filtered pure water will be analyzed with every laboratory sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. The total number of method blanks anticipated for this study is shown in Table 6 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 Table 6 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 6 by parameter. Raw values and percent recovery for the matrix spikes (see formula in the Quality Objectives section) 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 6 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.
**Data Management Procedures**

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

Analytical data will be stored in a database with related event-based hydrologic summary statistics from each storm. Electronic data deliverables (EDDs) received from the laboratory will be imported directly into the database to prevent data entry errors. For data that must be entered manually, the project Quality Assurance Coordinator will perform an independent review of the date entry to ensure that sample values were transcribed without error.
Audits and Reports

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

Audits

Audits will be performed to detect potential deficiencies in collected data. Audits of the meteorological data obtained from the weather station will occur at least monthly. The project Quality Assurance Coordinator will compare the new data collected from the weather station to data from prior monitoring to identify potential QA issues. This audit will specifically include an examination of the data record for gaps, anomalies, or inconsistencies in the data. Any data generated from calibration checks will also be entered into control charts and reviewed to detect potential instrument drift or other operational problems. If these audits identify QA issues, the Quality Assurance Coordinator will immediately perform a site visit to troubleshoot the problem and to implement corrective actions if possible. Any QA issues that are detected through these audits will be documented in the electronic data record.

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

Reports

Annual reports will be prepared through the course of this study to present compiled data, analysis results, and major study conclusions. Each report will summarize data from a specific water year (i.e., October through September) and include the following specific information:

- Meteorological data results
- Results from soil sampling performed in connection with each rain garden cell
- Results from the vegetation monitoring in each rain garden 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)
Data Verification and Validation

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

Meteorological Data Verification and Validation

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

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

2. Review of results from field calibration checks (see Quality Assurance section) to determine if specific MQOs for the hydrologic data have been met (see Quality Objectives section).

3. If minor quality assurance issues are identified in any portion of the meteorological record, the data from the affected period will be considered as an estimate and assigned a (j) qualifier. If major quality assurance issues are identified in any portion of the data, the data will be rejected and assigned an (r) qualifier. Estimated values will be used for evaluation purposes while rejected values will not.

Soil Data Verification and Validation

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

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

The following sections describe in detail the data validation procedures for these specific quality control elements:
Completeness will be assessed by comparing valid sample data with the data collection goals identified in this QAPP. Completeness will be calculated by dividing the number of valid values by the total number of expected values. Additional samples may be collected if completeness does not meet the specified MQO in the Quality Objectives section.

Methodology
Methodologies for analytical procedures will follow U.S. EPA approved methods specified in Table 5. Field procedures will follow the methodologies described in this quality assurance project plan. Any deviations from these methodologies must be approved by Ecology and documented in an addendum to this QAPP. The project database will include a field for identifying analytical method. Deviations that are deemed unacceptable will result in rejected values (R) and will be corrected for future analyses.

Holding Times
Holding times for each analytical parameter in this study are summarized in Table 5. Filtration and analysis dates and times will be reported by the laboratory. Holding times will be assessed by comparing the preservation and analysis dates and times to the sample collection dates and times.

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

- Data from samples that exceed the specified maximum post-preservation holding times by less than 48 hours will be considered estimates (J).
- Data from samples that exceed the maximum post-preservation 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-preservation holding times by less than 24 hours will be considered estimates (J).

Data from samples that exceed the maximum post-preservation holding times by more than 24 hours will be rejected values (R).

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

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 Table 5.

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; 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, 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, and associated values will be flagged as
estimates ($J$). If the objectives are severely exceeded (e.g., more than twice the objective), then associated values will be rejected ($R$).
Data Quality Assessment

This section describes the process for determining whether the data meet project objectives once the data results are compiled, and summarizes data analysis procedures that will be used to meet these objectives.

Data Usability Assessment

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

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

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

Data Analysis Procedures

Analyses will then be performed on the compiled data from this study to examine the performance of various plants in rain gardens and the influence of the different plant treatment on BSM properties.
References


APPENDIX A

Elevation of Stormwater Conveyance Structures in Drainage Basin to the Rain Garden Cistern
APPENDIX B

Equipment Specification Sheet
CR1000 Specifications

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

PROGRAM EXECUTION RATE
10 ms to 30 min. @ 10 ms increments

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

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

### Input Referred Noise Voltage
- **Input**
- **DF**
- **Basic**

<table>
<thead>
<tr>
<th>Range (mV)</th>
<th>Res (µV)</th>
<th>Res (µV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±5000</td>
<td>667</td>
<td>1333</td>
</tr>
<tr>
<td>±2500</td>
<td>333</td>
<td>667</td>
</tr>
<tr>
<td>±250</td>
<td>33.3</td>
<td>66.7</td>
</tr>
<tr>
<td>±25</td>
<td>3.33</td>
<td>6.7</td>
</tr>
<tr>
<td>±7.5</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>±2.5</td>
<td>0.33</td>
<td>0.67</td>
</tr>
</tbody>
</table>

1. Range overhead of ±9% exists on all ranges to guarantee that full-scale values will not cause over-range.
2. Resolution of DF measurements with input reversal.

ACCURACY:

- ±(0.06% of reading + offset), 0° to 40°C
- ±(0.12% of reading + offset), -25° to 100°C
- ±(0.16% of reading + offset), -55° to 85°C

The sensor and measurement noise are not included and the offsets are the following:
- Offset for DF w/input reversal = 1.5 Basic Res + 1.0 µV
- Offset for DF w/o input reversal = 3 Basic Res + 2.0 µV
- Offset for SE = 3 Basic Res + 3.0 µV

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±25 mV input range; digital resolution dominates for higher ranges.
- 250 µs Integration: 0.34 µV RMS
- 50/60 Hz Integration: 0.19 µV RMS

MINIMUM TIME BETWEEN VOLTAGE MEASUREMENTS: Includes the measurement time and conversion to engineering units. For voltage measurements, the CR1000 integrates the input signal for 0.25 ms or a full 16.66 ms or 20 ms line cycle for 50/60 Hz noise rejection. DF measurements with input reversal incorporate two integrations with reversed input polarities to reduce thermal offset and common mode errors and therefore take twice as long.
- 250 µs Analog Integration: ~1 ms SE
- 1/60 Hz Analog Integration: ~20 ms SE
- 1/50 Hz Analog Integration: ~25 ms SE

COMMON MODE RANGE: ±5 V

DC COMMON MODE REJECTION: >100 dB

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

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

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

INPUT RESISTANCE: 20 Kohms typical

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

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

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

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

CURRENT SOURCING/SINKING: ±25 mA

### RESISTANCE MEASUREMENTS

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

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

### PERIOD AVERAGING MEASUREMENTS

The average period for a single cycle is determined by measuring the average duration of a specified number of cycles. The period resolution is 192 ns divided by the specified number of cycles to be measured; the period accuracy is ±(0.01% of reading + resolution).

### PULSE COUNTERS

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

MAXIMUM COUNTS PER SCAN: 16.7x10^5

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

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

OUTPUT RESISTANCE: 330 ohms

INPUT SE: 3.8 V ± 0.3 to 5.3 V; low -0.3 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 ohms

SWITCHED 12 V

One independent 12 V unregulated switched output, not configured.

### SDI-12 INTERFACE SUPPORT

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

### CE COMPLIANCE

(Standard(s) to which CONFORMITY is DECLARED: IEC61156:2002)

### CPU AND INTERFACE

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

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

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

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

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

CLOCK ACCURACY: ±3 min. per year

### SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc (reverse polarity protected)

TYPICAL CURRENT DRAW:
- Sleep Mode: ~0.6 mA
- 1 Hz Scan (8 diff. meas., 60 Hz rej., 2 pulse meas.) w/RS-232 communication: 19 mA
- 1 Hz Scan (8 diff. meas., 250 µs integ., 2 pulse meas.) w/RS-232 communication: 16.7 mA
- 100 Hz Scan (4 diff. meas., 250 µs integ.) w/RS-232 communication: 16.7 mA
- 250 µs Scan (3 diff. meas., 500 µs integ.) w/RS-232 communication: 16.2 mA

CR1000D CURRENT DRAW:
- Inactive: negligible
- Active w/backlight: 7 mA
- Active w/backlight: 100 mA

EXTERNAL BATTERIES: 12 Vdc nominal

### PHYSICAL SPECIFICATIONS

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

CR1000D Wiring Panel Size:
- 9.4” x 4” x 2.4”
- Additional clearance required for serial cable and sensor leads.

WEIGHT: 2.1 lbs (1 kg)

### WARRANTY

Three years against defects in materials and workmanship.
**INTRODUCTION**

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

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

**Special points of interest:**

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

**Inside this issue:**

1. Special points of interest
2. Specifications
3. Operation
4. Photos
5. Introduction

**Designated & Manufactured By**
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Email: sales@hydrologicalservices.com

**Distributed By:**

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**TB3 Raingauge**

**Pole Mount Bracket Model TB334**

**Bird Guard Model TB333**

**Field Calibrator Model FCD**

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**ML1 Data Logger**
**Operation**

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

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

**TB3 Base with optional ML1-FL**

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

**Specifications**

<table>
<thead>
<tr>
<th>TB3 bucket capacity</th>
<th>Intensity</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1mm, 0.2mm &amp; 0.01”</td>
<td>0-250mm/hr</td>
<td>± 2 %</td>
</tr>
<tr>
<td>250-400 mm/hr</td>
<td></td>
<td>± 3 %</td>
</tr>
<tr>
<td>0.5mm &amp; 1.0 mm</td>
<td>0-500 mm/hr</td>
<td>± 2 %</td>
</tr>
</tbody>
</table>

Long term stable calibration.

- **Humidity:** 0 to 100 %
- **Temperature:** -20 to +70°C
- **Contact system:** dual reed switches potted in soft silicon rubber with varistor protection.
- **Max. Capacity:** 24 Volts (0.5 amp max.)
- **Resistance:** Initial contact resistance 0.1 OHMS
- **M.T.B.F.:** $10^8$ to $10^9$ Operations
- **Syphon:** 0.4 mm capacity of rainfall - made from brass with a non hydroscopic outer case.
- **Bucket:** two types of buckets, synthetic ceramic coated brass bucket balanced to ±0.05 gms, and injection moulded non hydroscopic plastic ABS UV stabilised balanced ±0.05 gms.
- **Base:** Cast aluminium.
- **Level:** bulls eye level adhered to aluminium base.
- **Mounting holes:** three 10 mm diameter mounting holes with 117 mm p.c.d. cast in feet attached to outside diameter of base.
- **Drain fittings:** to attach 12 mm inside diameter tubing, to catch rainfall after passing through buckets.
- **Pivots:** ground sapphire pivots with hard stainless steel shaft.
- **Insect covers:** stainless steel mesh on all openings to prevent insects and ants entering gauge.
- **Outer enclosure:** keyed to enable the release of the outer enclosure without the need for the removal of the three securing screws.
- **Height / Weight:** 330mm / 3 kg
- **Packed Dimensions:** 5 kg 0.03 m³

**Accessories**

<table>
<thead>
<tr>
<th>Description</th>
<th>Part No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Logger</td>
<td>ML1/ML1-FL</td>
</tr>
<tr>
<td>RS232 to USB Converter</td>
<td>DL307</td>
</tr>
<tr>
<td>Field Calibration Device</td>
<td>TB320 / FCD</td>
</tr>
<tr>
<td>TB3 Heater Kit</td>
<td>TB323</td>
</tr>
<tr>
<td>TB3 Bird Guard</td>
<td>TB333</td>
</tr>
<tr>
<td>TB3 Pole Mounting Bracket</td>
<td>TB334</td>
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</tbody>
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