Performance Monitoring Report

Geneva Bioretention Pilot Project

Prepared for
Whatcom County Public Works Department

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA
Science + Planning + Design

Performance Monitoring Report

Geneva Bioretention Pilot Project
Whatcom County, Washington

Prepared for
Whatcom County Public Works Department
322 North Commercial Street, Suite 224
Bellingham, Washington 98225
Telephone: 360-778-6200

Prepared by
Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206-441-9080

January 23, 2026

Contents

Appendices

Tables

Figures

Executive Summary

Lake Whatcom, the primary drinking water source for more than 100,000 residents in Whatcom County, Washington, has experienced significant water quality degradation over recent decades, largely due to increased residential development within its watershed. In response, Whatcom County, as part of a collaborative, multi-jurisdictional effort, has implemented a range of stormwater retrofits and water quality improvement projects. This Report presents the results of a comprehensive monitoring program focused on the Austin South bioretention swales, a key stormwater treatment system reconstructed in 2021 to reduce nutrient and bacteria loads entering Lake Whatcom.

The Austin South bioretention swales were retrofitted with High Performance Bioretention Soil Media (HPBSM), a lined underdrain system, and an inflow dosing mechanism to optimize the removal of pollutants from stormwater runoff. The project's primary objective was to evaluate the effectiveness of these improvements in reducing concentrations of total phosphorus and bacteria—specifically, parameters linked to the lake's 303(d) listing for impaired water quality.

Extensive post-construction monitoring was conducted in accordance with the Washington State Department of Ecology's Technology Assessment Protocol – Ecology (TAPE) guidelines and a Quality Assurance Project Plan. Over the course of the monitoring period, paired influent and effluent samples were collected during storm events and analyzed for total suspended solids (TSS), total phosphorus (TP), orthophosphate, and bacteria (e.g., *E. coli*), among other parameters. Due to instrumentation issues, the degree of bypass (i.e., the amount of stormwater runoff that overflows the facility and is not treated) could not be quantified. Bypass was observed during several storm events but could not be confidently quantified over the monitoring period. Though bypass could not be assessed, the study resulted in accurate treated flow rates and chemistry results. The system was highly effective at treating phosphorus and bacteria:

- Total Phosphorus Reduction: The Austin South bioretention swales demonstrated a median influent total phosphorus concentration of 0.061 mg/L and a median effluent concentration of 0.013 mg/L, resulting in a 79 percent median reduction in total phosphorus levels and matching forested conditions.
- Bacteria Reduction: Monitoring results indicated a median influent fecal coliform concentration of 145 colony-forming units (CFU) per 100 milliliters (mL), with a median effluent concentration of 7 CFU per 100 mL. This corresponds to a median reduction of 97 percent in fecal coliform, highlighting the effectiveness of the HPBSM and engineered swale design for bacterial removal.

In addition to phosphorus and bacteria, the bioretention system also provided substantial reductions in TSS and trace metals, further enhancing the quality of stormwater discharged to Lake Whatcom. The observed performance closely aligned with, and in some cases exceeded, laboratory-based expectations for the HPBSM media.

This page intentionally left blank

1. Introduction

Lake Whatcom, the drinking water source for over 100,000 Whatcom County residents, has seen a marked decline in water quality due to residential development in its watershed. In 1998, Lake Whatcom was added to the Clean Water Act's 303(d) list due to inadequate dissolved oxygen levels. Lake Whatcom is listed with a Total Maximum Daily Load (TMDL) for phosphorus and bacteria. Studies have identified the conversion of land from a “forested condition” to a “developed condition” as the primary driver of this decline. Whatcom County is part of a multi-jurisdictional effort to restore the Lake Whatcom watershed and has been planning and implementing projects and programs aimed at reducing phosphorus loads from stormwater runoff. These efforts include retrofitting existing stormwater infrastructure to maximize nutrient-removal opportunities.

In 2021, a comprehensive evaluation of the existing stormwater treatment infrastructure was completed in the Geneva neighborhood, located in Whatcom County on the southern shore of Lake Whatcom’s western end (Figure 1). As part of this evaluation, the bioretention swales and filter cartridge vaults currently installed in the Geneva neighborhood were assessed to determine how effectively they removed total suspended solids (TSS), total and dissolved copper, total and dissolved zinc, as well as total phosphorus and orthophosphate (Herrera 2021). It was recommended that a series of underutilized bioretention swale cells on Austin Street between Cable and Morgan Streets (the “Austin South” bioretention swales) be reconstructed to improve the water quality of runoff flowing into Lake Whatcom.

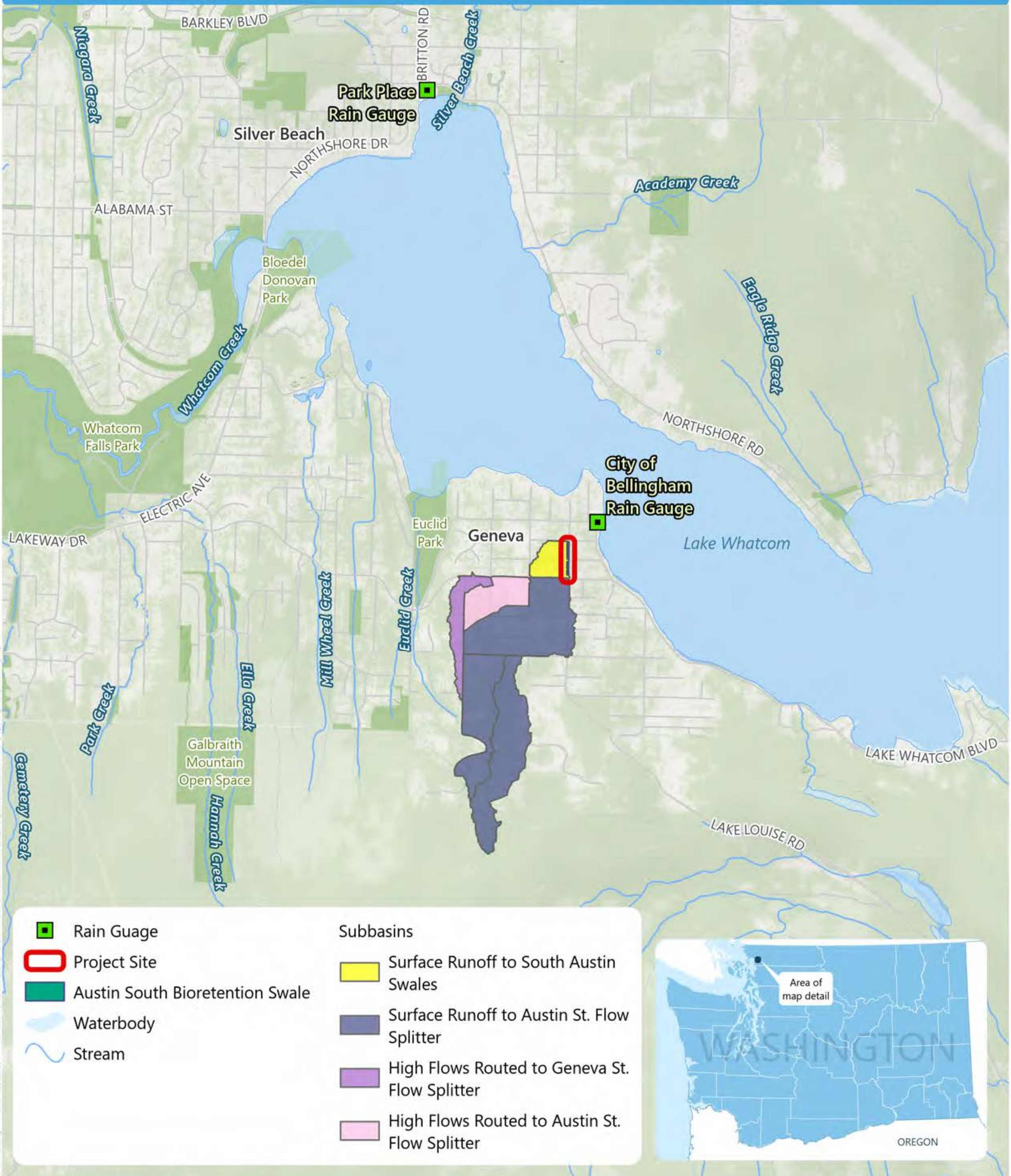
A majority of the Austin South bioretention swale cells were previously taken offline using an overland bypass pipe shortly after their construction due to sedimentation and local flooding issues. As part of rebuilding, the Austin South bioretention swales underwent excavation to remove current soil media and obstructions. The reconstruction also involved installing a liner, underdrain, swale cell weirs, and High Performance Bioretention Soil Media (HPBSM). The Austin South bioretention swales utilize an inflow dosing system that increases the overall capacity of the bioretention facilities by regulating inflow rates while allowing the treatment media to dry intermittently. The dosing system includes a pretreatment vault, dosing vault, dosing siphon, and regulating valve; two flow splitters; and associated drainage piping. The Austin South bioretention swales are referred to as the Project herein.

The Project was monitored to verify treatment performance following a Quality Assurance Project Plan (QAPP) (Herrera 2023) developed in accordance with the Washington State Department of Ecology (Ecology) (Ecology 2004) and the Technology Assessment Protocol – Ecology (TAPE) guidelines (Ecology 2018). The QAPP and associated Addendum are included in Appendix A.

The Project is funded by a grant from Ecology. Monitoring results presented in this Report follow TAPE reporting guidelines on preparing a Technical Evaluation Report (Ecology 2018). Analysis of samples collected for this Project will assess whether the performance of the HPBSM observed in laboratory experiments can be replicated in a large-scale treatment facility using the same specifications. In addition, this Project is intended to function as a case study for implementation of the HPBSM specification.

HERRERA
Science + Planning + Design

Figure 1.
Vicinity Map of the Geneva Bioretention Pilot Project.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: ESRI (Basemap), City of Bellingham

This Report documents monitoring and sampling activities, deviations from procedures described in the QAPP, and results of the HPBSM performance analyses. The Report also includes the following:

- Introduction
- Technology description
- Sampling procedures
- Data summaries and analysis
- Operation and maintenance information
- Discussion
- Conclusions
- Appendices

2. Technology Description

This section describes the physical Project, the Project treatment processes, the site requirements for Project installation, and the sizing methodology of the Project.

2.1. Physical Description

The Geneva Bioretention Pilot Project is an aboveground stormwater filtration system that consists of three bioretention swale "Cascades" (a Cascade consists of six or seven bioretention cells with zero longitudinal slope), which are described in detail in this section of the Report and represented in Figure 2. The Project is designed to treat 92.1 percent of the average annual inflowing runoff volume before the Cascade weirs are overtopped and the bypass discharges via the bioretention swale overflow structures. For influent runoff not treated by the Project (i.e., runoff that bypasses the swales via overflow), an existing bioretention swale ("Austin North" swale) and filter cartridge vault are located downstream to provide additional runoff treatment. The Austin North swale is not part of the Project design or monitoring and is therefore not detailed in this Report.

A pretreatment device with a General Use Level Designation (GULD) (Contech Vortechs) was included in the design to reduce the sediment load on the swale media and therefore reduce its maintenance frequency. Sediment and debris maintenance occurs primarily in the pretreatment device and dosing vault (discussed below), which are relatively easy locations to perform sediment removal. The dosing siphon located downstream of the dosing vault also captures some sediment that is not retained in the pretreatment device or dosing vault.

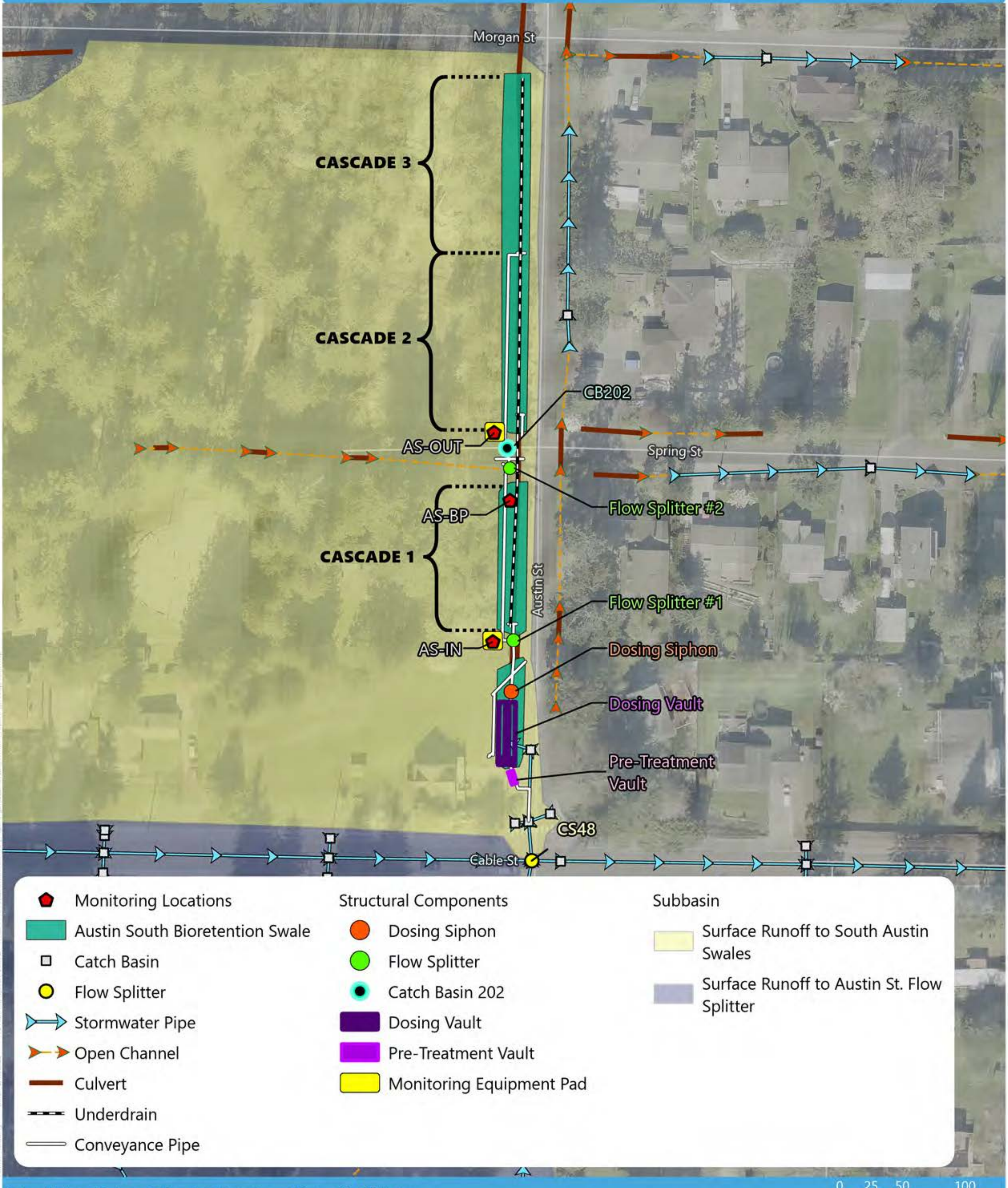
The bioretention swale media includes a primary HPBSM layer (18-inch depth) and polishing media layer (12-inch depth) to maximize phosphorus treatment performance. The HPBSM with polishing media was approved by Ecology for phosphorus-sensitive receiving waters in 2021 (Ecology 2021). A 6-inch ponding depth, compared to the existing as-designed depth of 2 inches, increases the total ponded volume and therefore increases the total runoff volume receiving treatment. The reconstructed bioretention swales were lined with an impermeable liner to prevent infiltration to native soils due to local basement flooding concerns. An underdrain collects treated runoff and routes it to an existing pipe for treated runoff under the Austin North swale.

The Project consists of three bioretention swale Cascades (Figure 2). Cascade 1 is the southernmost and receives the first 28 percent of runoff; flow is then split to Cascade 2 (which receives 37.4 percent of runoff) and, finally, Cascade 3 (which receives 34.6 percent of runoff). Cascades 1 and 3 have six bioretention cells separated by weirs, while Cascade 2 has seven bioretention cells.

Monitoring and automated sampling equipment were installed at the Project inlet, bypass, and underdrain outlet as described in the QAPP. Equipment locations are presented in Figure 3. Design drawings are included in Appendix B.

HERRERA
Science + Planning + Design

Figure 2.
Site Map.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: City of Bellingham

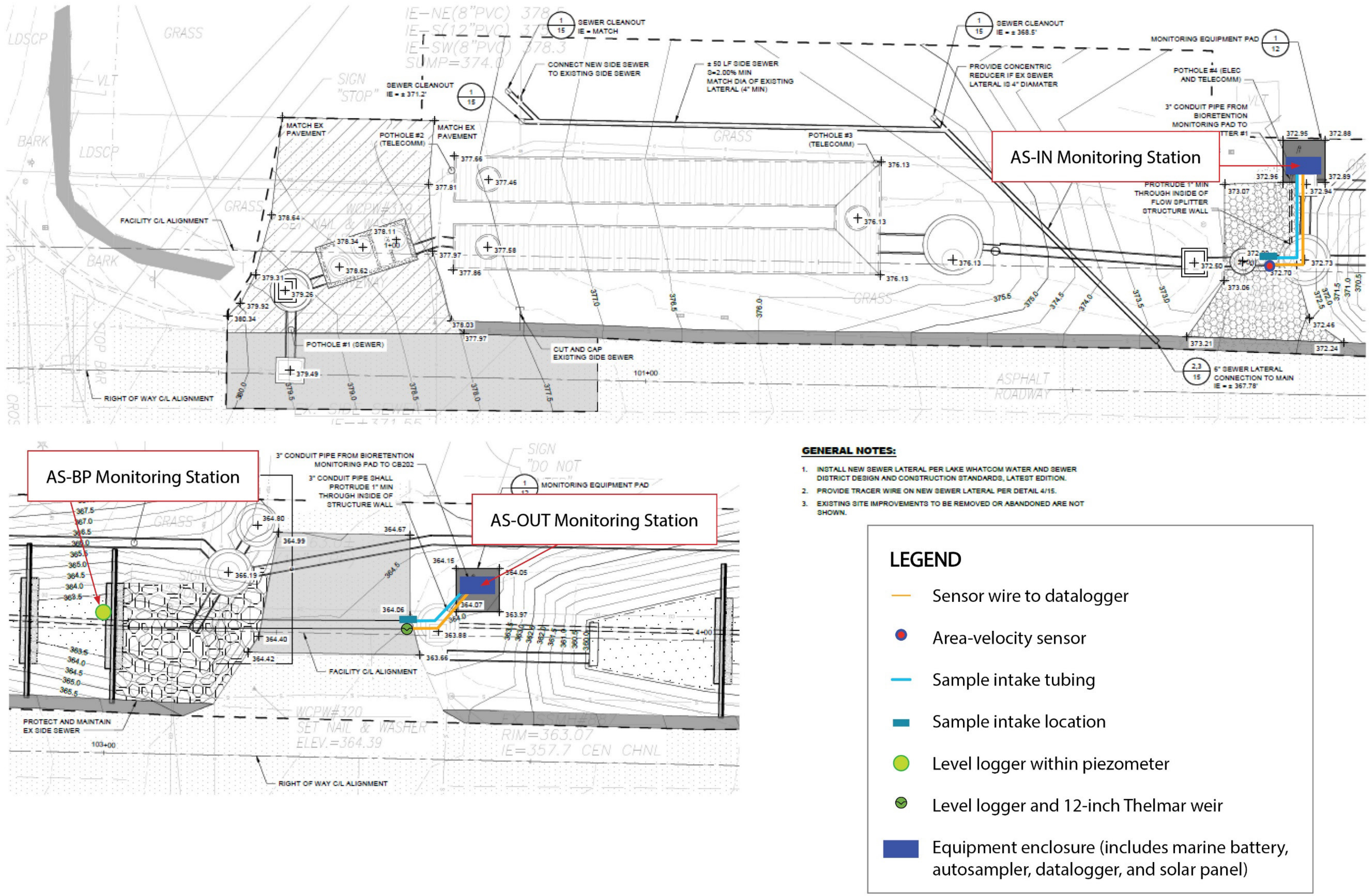


Figure 3. Austin South Monitoring Equipment Configuration.

2.2. Treatment Processes

Treatment of runoff that enters the Project occurs within the pretreatment vault, dosing vault, bioretention swale surfaces, and bioretention swale HPBSM. The treatment processes that occur in these Project components are detailed below.

2.2.1. Settling

Runoff from the contributing subbasins' storm drain network (Figure 4) first enters the Project's Contech Vortechs pretreatment vault, which settles larger debris out of the Project influent and reduces the sediment load to the bioretention swale media. The dosing siphon upstream of the bioretention swales allows for settling and capture of some TSS that is not captured by the pretreatment vault. Solids settling from direct runon also occurs behind the weirs that are placed perpendicularly along the length of the bioretention swales.

2.2.2. Adsorption

Based on chemical reactions involving positive and negative particle attraction within the organic and nonorganic matrix of the HPBSM, adsorption and sequestration may take place, rendering pollutants immobile and/or potentially bioavailable (Hua et al. 2012).

2.2.3. Filtration

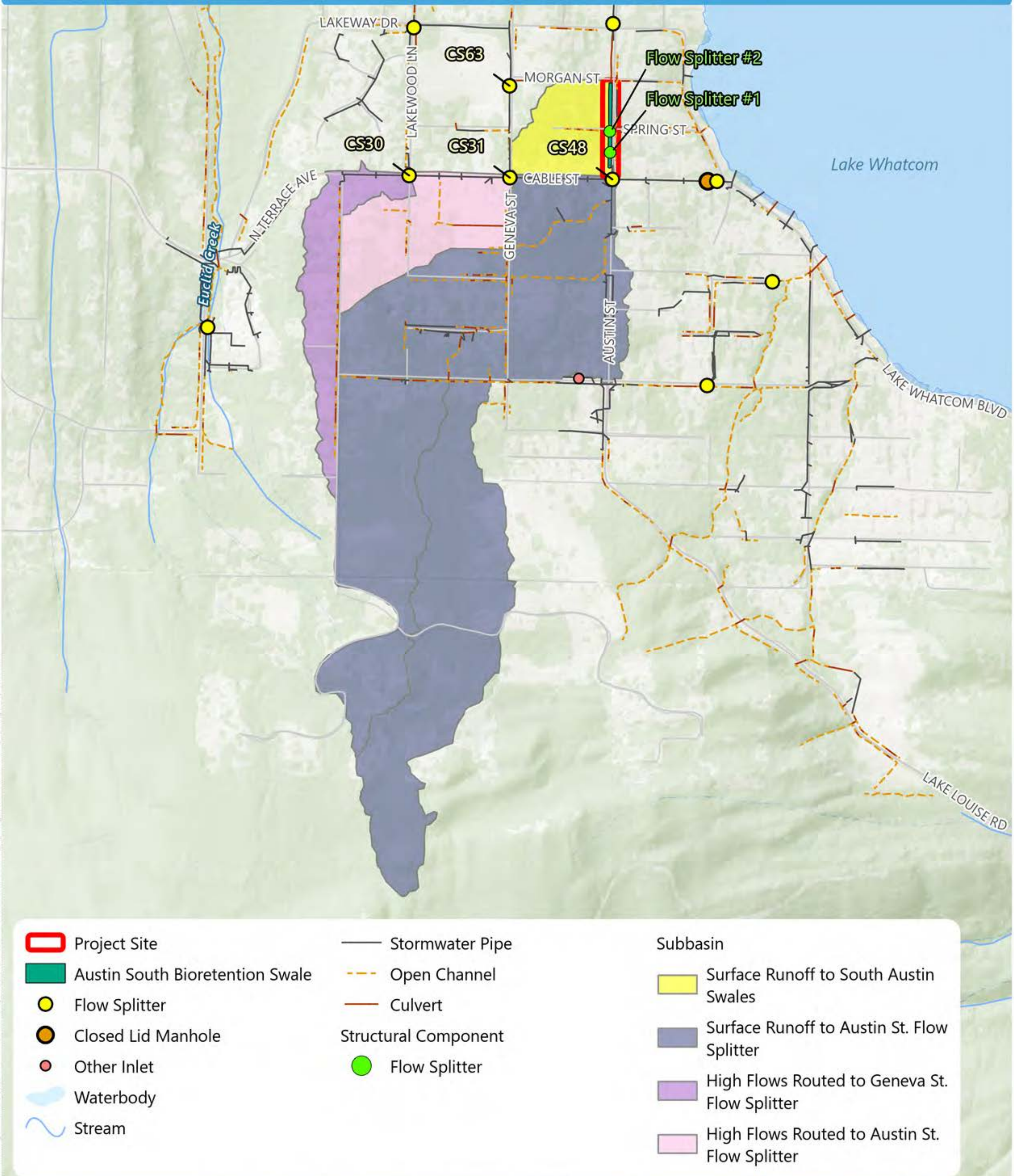
Filtration occurs as runoff travels through the HPBSM, which consist of an 18-inch-deep primary media layer and a 12-inch-deep polishing media layer. The primary media layer is composed of approximately 70 percent sand, 20 percent coconut coir fiber, and 10 percent biochar (Ecology 2021). The polishing media layer is composed of 90 percent sand, 7.5 percent activated alumina, and 2.5 percent iron. On the surface of the HPBSM is a 2-inch-deep hardwood mulch layer. As flow passes through the HPBSM, finer particulate material is removed by filtration through the multi-gradation particles. Some of these particles may be held in suspension or broken down further and/or made bioavailable.

2.2.4. System Discharge

The Project discharges its untreated bypass flows aboveground to an existing 18-inch culvert that routes flow to another bioretention swale (Austin North swale) and filter cartridge vault. The Project discharges treated runoff below ground in a 12-inch underdrain. Both above- and belowground discharge eventually routes to an existing 24-inch outfall, which discharges to Lake Whatcom, located at the north end of Austin Lane.

HERRERA
Science + Planning + Design

Figure 4.
Subbasins Contributing to the Project.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: City of Bellingham

2.3. Site Requirements

2.3.1. Necessary Soil Characteristics

The Project bioretention swales are lined by an impervious liner and have an underdrain; therefore, in situ soil conditions are not relevant to the functionality of the Project.

2.3.2. Hydraulic Grade Requirements

Since this is a passive system, the design of the Project is based on the elevational difference between the inlet and outlet inverts. The difference in elevation between the pretreatment vault invert and the existing concrete culvert at the outlet end of the Project is approximately 30 feet at an average approximate slope of 5 percent.

2.3.3. Depth to Groundwater Limitations

The Project is installed at-grade, is lined by an impervious liner, and has an underdrain; therefore, groundwater limitations are not relevant to the functionality of the Project.

2.3.4. Utility Requirements

The Project is a passive system that requires no power and has a free-draining outlet.

2.4. Sizing Methodology

The Project was sized to maximize the treatment of inflowing runoff. The existing CS48 flow splitter (Figure 4) routes inflows up to 0.81 cubic feet per second (cfs) to the Project before the flow splitter high-flow weir is engaged. Additionally, the drainage basins directly contributing to the Project (connected via overland flow) have an online water quality flow rate of 0.28 cfs. The 3,000 square feet (sf) total bioretention bottom area within the bioretention swale cells can infiltrate at a rate of 0.57 cfs, based on a 12 inches per hour (in/hr) HPBSM infiltration rate with a saturated hydraulic conductivity (K_{sat}) safety factor of two (6 in/hr effective infiltration rate).

The Project is designed to treat 70.1 percent of the average annual influent runoff volume from the contributing basin (inflows from tributary basins via CS48) and 92.1 percent of the runoff volume entering the pretreatment vault and bioretention swale before the bioretention swale Cascade weirs are overtopped and runoff discharges via downstream overflow of each Cascade section. This average annual influent runoff volume percent treatment was calculated using the Western Washington Hydrology Model (WWHM) (Ecology 2012) and accounts for the pulsed flows from the dosing vault and dosing siphon.

HPBSM facilities with a polishing layer that are designed according to the Ecology specifications are expected to achieve TSS reductions of at least 80 percent, a total phosphorus reduction of at least 50 percent, and dissolved copper and zinc reductions of at least 30 and 60 percent, respectively (Ecology 2021).

2.5. Operation and Maintenance Requirements

Proper maintenance and operation are necessary to ensure the ongoing function of the Project and all HPBSM installations. The following subsections summarize the necessary inspection and maintenance procedures for the Project. Detailed operation and maintenance requirements for all elements of the Project, including the pre-settling catch basin, flow splitters, and dosing vault, are presented in the Operations and Maintenance Manual (Appendix C).

2.5.1. Inspection

Routine inspection of the Project and similar HPBSM facilities is essential to inform maintenance frequency and ensure longevity of the facility. Pretreatment, flow splitter, and dosing mechanism inspection requirements are detailed in the Operations and Maintenance Manual (Appendix C). Critical inspection tasks for the main HPBSM facility includes twice per year inspections of diffuser tees and filter mulch for sediment accumulation and scour.

Inspection of the HPBSM and polishing layers is not a required routine component, but targeted inspection of underperforming cells is described in the Operations and Maintenance Manual. Assessment of underperforming HPBSM cells includes performing a falling head hydraulic conductivity assessment to determine if the design infiltration rate of 6 inches per hour is being met. Assessment of the polishing layer requires water quality screening of the facility effluent rather than a hydraulic assessment to determine if orthophosphate concentrations are within expected concentrations.

2.5.2. Maintenance

Maintenance frequency for the HPBSM facilities will vary depending on pollutant and sediment loads from the contributing basin. Routine inspections described in the Operations and Maintenance Manual (Appendix C) should be used to inform necessary maintenance and replacement schedules. Aside from inspection-driven maintenance tasks, the following maintenance should be expected for HPBSM facilities that are similar to the Project:

- Facility diffuser tees should be cleaned of debris and sediment twice per year and any associated scours repaired.
- Debris, weeds, and vegetation should be removed from the bioretention weirs and cobbles on an annual basis.

- Filter mulch should be replaced at minimum every 2 years or more frequently depending on sediment accumulation noted in inspections. Coir mats may be installed to mitigate filter mulch scouring.
- HPBSM and polishing layers require a full replacement on an approximately 10-to-15-year cycle depending on pollutant loading.

2.6. Reliability

Both the Project and HPBSM facilities more broadly are designed to treat a wide range of stormwater contaminants without release or export, unlike standard BSM facilities, which commonly export nutrients and copper. A pre-settling hydrodynamic separator was installed at the Project to reduce sediment loads and maintenance requirements for the facility. Pretreatment is generally recommended to improve performance and longevity of bioretention facilities. The Operations and Maintenance Manual (Appendix C) describes the expected lifespan of filter mulch, HPBSM, and polishing layers.

3. Sampling Procedures

This section describes the sampling process design for the field evaluation of the Project. This section begins with a description of the drainage area and Austin South bioretention swales. Separate sections describe the monitoring schedule, field data collection procedures, laboratory procedures, data management procedures, and data analysis procedures that have been implemented for this evaluation.

3.1. Monitoring Schedule

The sampling for this field testing was performed over a 16-month period, from December 2023 through April 2025.

3.2. Field Procedures

3.2.1. Hydrologic Data Collection Procedures

As described in the QAPP, influent and effluent flows from the Project were monitored continuously over the test period from December 2023 through April 2025. In addition, precipitation depths at a nearby station designated PP-RG were monitored continuously over the same period.

Flow rate at the influent monitoring station (AS-IN) was measured using a Starflow QSD AV sensor and a Campbell Scientific CR350 datalogger. The total flow to all three Cascades in the Project was measured at this station. Of this flow, 28 percent was designed to be delivered to the southernmost cell of Cascade 1 (Cascade 1 is between Flow Splitter #1 and Flow Splitter #2). Flow rate at the effluent monitoring station (AS-OUT) was measured using a Keller America AccuLevel pressure transducer, a 12-inch Thel-Mar weir, and a Campbell Scientific CR350 datalogger. This flow only captured what was filtered in Cascade 1. The dataloggers installed at both the inlet and outlet monitoring locations were programmed to record flow rates at each location and to trigger the automated samplers at predefined pacing intervals. The dataloggers used integrated digital cellular modems to download data automatically and send text message alarms to field technicians and the project manager. See Figure 3 for a diagram of the monitoring equipment configuration.

The influent and effluent monitoring equipment were installed to run on 12-volt deep-cycle marine batteries that were charged using a 100-watt solar panel installed at each station. The dataloggers, batteries, and samplers were stored in secure, aboveground environmental enclosures (Knaack Model 4836 or equivalent). Influent and effluent flows from the bioretention swales (AS-IN and AS-OUT, respectively) were monitored continuously over the monitoring period.

Additionally, an In-Situ TROLL 200 level logger was installed to measure representative bypass flows from the outlet of the southern section of the Austin South bioretention swales (AS-BP). A separate datalogger, In-Situ VuLink, was installed in association with, and at the location of, the bypass flow level logger (Figure 3). Bypassed flows at monitoring station AS-BP were not continuously monitored due to repeated performance issues with station instruments and sensors.

The level logger at the bypass station (AS-BP) experienced abnormal measurements in pressure, causing erroneous and unusable measurements in water level. The level logger was uninstalled in March 2024, sent back to the manufacturer, and was found to have no issues. It was concluded that an unknown interference, likely electrical, was sourced near the original location of the level logger. After moving the device to three different alternative locations, the spurious measurements continued and the level logger approach was discontinued. In lieu of measured bypass flow, treated effluent flow as well as visual inspection after each monitoring event were used to estimate bypass frequency. This alternate approach to bypass estimation is further described in the Bypass Frequency Evaluation section.

Precipitation depths at the Project site were monitored continuously using the Park Place rain gauge (PP-RG), located approximately 1.5 miles north-northwest of the Project. Precipitation depths were measured at PP-RG by a Texas Electronics TE-525 rain gauge. The rain gauge was installed on an 8-foot steel pole and interfaced with a separate Campbell Scientific CR1000X datalogger. The datalogger was programmed to scan every 10 seconds and record precipitation depth at the performance verification site on a 5-minute time step.

All discharge data and rainfall data stored on the dataloggers were remotely downloaded at least daily via digital cell phone link. These data were then processed and validated in accordance with procedures described later in this Report.

3.2.2. Water Quality Data Collection Procedures

To facilitate the collection of flow-weighted composite samples, two ISCO 6712 automated samplers were installed in association with the AS-IN and AS-OUT stations (Figure 3). Influent samples were collected at a monitoring station in the inlet pipe to Flow Splitter #1, conveying water into the first Cascade of the bioretention swales (AS-IN). The influent samples were taken downstream of the pretreatment device, dosing vault, and dosing siphon. For effluent water quality sample collection at the AS-OUT station, the sample intake was positioned inside the underdrain pipe behind the Thel-Mar weir just before entering CB202 (Figure 3). Effluent samples (AS-OUT) represent the treated flows from the southern section of the Austin South bioretention swales that extends between Flow Splitter #1 and Flow Splitter #2. In this manner, a representative section of the Project was monitored.

The water quality monitoring protocols followed the Automatic Sampling for Stormwater Monitoring Standard Operating Procedure (Ecology 2018) for collecting flow-weighted composite samples. Each sampler used a decontaminated 20-liter high-density polyethylene (HDPE) bottle to collect composite samples from each sampled storm event (Appendix A). Composite sample bottles were decontaminated by the laboratory with acid wash prior to each sampling event (Herrera 2023).

The dataloggers previously described in the Hydrologic Data Collection Procedures section also controlled the ISCO 6712 automated samplers. The Campbell Scientific CR350 dataloggers were programmed to trigger their respective automated samplers based on a predefined pacing volume.

Once triggered, both automated samplers collected a 220 mL sub-sample, or aliquot, to be composited into 20-liter HDPE bottles. Samplers were programmed to collect a sample at initiation to account for the volume of water that passed the monitoring stations before initiation. Pumped sub-sample volume was calibrated at installation and then calibrated thereafter approximately once per quarter. Equipment was inspected before and after a sampled storm event. Before a storm event, field staff inspected and cleared debris from the weir and velocity sensor to remove any blockages. Every time field staff calibrated this equipment, the date of calibration was recorded in the field notes for record management.

Both automated samplers were housed in aboveground environmental enclosures as described in the Hydrologic Data Collection Procedures section. Each automated sampler was powered by a 12-volt deep-cycle marine battery that was also housed in the enclosure. The dataloggers were programmed to record hydrological measurements and to trigger the inlet and outlet automated samplers at predefined pacing intervals (Walkowiak 2006).

Poly(tetrafluoroethylene) (PTFE)-lined sample tubing was installed to connect the AS-IN and AS-OUT stations to the automated samplers in the enclosures (Figure 3). The tubing was installed with a positive linear grade so that water completely drained through the sample tube during rinse, purge, and sampling cycles. The sampler intakes were carefully positioned at each station to achieve homogeneity and representativeness of the samples.

The following conditions serve as guidelines for defining the acceptability of specific storm events for water quality sampling:

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

Antecedent conditions and storm predictions were monitored via the internet, and a determination was made as to whether to target an approaching storm. Once a storm was targeted, field staff would visit each station prior to the sampling event to verify that the equipment was operational and to start the sampling program. A clean, 20-liter polyethylene carboy and ice were also placed in the automated samplers at this time. The speed and intensity of incoming storm events was tracked using internet-accessible Doppler radar images. Actual rainfall totals during sampled storm events were quantified based on data from the rain gauge at PP-RG.

During the storm event sampling, the datalogger was programmed to enable the sampling routine in response to a predefined increase in water level (stage) at AS-IN and AS-OUT. The automated samplers were then programmed to collect 220-mL sample aliquots at preset flow increments. Based on the expected size of the storm, the flow increment was adjusted to ensure that the following criteria for acceptable composite samples were met at each station:

- A minimum of **10** aliquots were collected for each event.
- Sampling was targeted to capture **at least 75 percent** of the hydrograph.
- Due to sample holding time considerations, the maximum duration of automated sample collection was **36 hours**.

After each targeted storm event, field personnel returned to each station, made visual and operational checks of the sampling equipment, and determined the total number of aliquots composited. Pursuant to the sampling goals identified above, the minimum number of aliquots that constitute an acceptable composite sample was 10. If the sample was determined to be acceptable, the carboy containing the flow-weighted composite sample was immediately capped, removed from the automated sampler, and kept below 6 degrees Celsius (°C) using ice during transport to the laboratory (Exact Scientific Services in Ferndale, Washington).

All samples were delivered to the laboratory with appropriate chain-of-custody documentation (Appendix D). Collected flow-weighted composite samples were then analyzed for the following:

- Total suspended solids (TSS)
- Total phosphorus
- Orthophosphate
- Total and dissolved copper
- Total and dissolved zinc

A subset of composite samples was also analyzed for the following

- Particle size distribution (PSD)
- Nitrate + Nitrite
- Hardness as $CaCO_3$

During select storms, grab samples were also collected and analyzed for fecal coliform bacteria, *Escherichia coliform* bacteria, and total petroleum hydrocarbons (NWTPH-Dx). pH was monitored *in situ* during three storm events on February 27, May 21, and June 3, 2024.

3.2.3. Vegetation Monitoring Procedures

Vegetation monitoring procedures outlined in the QAPP included visual assessment of the health and vigor of plantings at project construction completion, in the early summer of 2024, and in the spring of 2025. Specific QAPP-prescribed procedures included visual estimates of survival and cover within cover thresholds, estimates of dominant species presence, visual estimates of percent of bare ground, and visual estimates of vegetation health.

Vegetation monitoring procedures deviated from these QAPP-prescribed procedures as described below:

- Vegetation monitoring was not conducted on the schedule or frequency as described in the QAPP. One vegetation monitoring event was conducted upon the completion of the water quality monitoring period on July 30 and July 31, 2025. Photographs were therefore not taken from permanently marked points in each cell during multiple monitoring events.
- Plant survival and health were logged by planted area and plant type, including upland trees, upland shrubs, and zone 1 (cell bottom) instead of by cell top, side slope, and cell bottom.

Results and conclusions on plant health and vigor were based on one post-monitoring inspection, review of site photographs taken throughout the monitoring period, and comparison to planting plan counts.

3.2.4. Field Quality Assurance and Control Measures

Quality control procedures that were implemented for field activities are described in the following subsections. The results from quality assurance/quality control (QA/QC) procedures that were performed for the collection of water quality samples are reported in Appendix E, and QA/QC results of hydrologic data are discussed in the Hydrologic Data section. A complete database of laboratory and hydrologic results is presented in Appendix F.

3.2.4.1. Instrument Maintenance and Calibration

Before and after each targeted event, routine maintenance and operational inspections were performed to ensure that the equipment was functioning properly. Maintenance activities and operational inspections included the following:

- Inspection of battery and battery connections
- Replacement of desiccant for the dataloggers and autosamplers
- Inspection of the bioretention swale HPBSM surfaces
- Inspection of the Thel-Mar weir, including level check and debris removal
- Inspection of AV sensor, including zero check and debris removal

The calibration of the pressure transducer at AS-OUT was checked during most pre-storm site visits. The procedure for calibrating the Thel-Mar weir at AS-OUT entailed filling the space behind the Thel-Mar weir with water until the water level just reached the height of the weir crest. The stage was then recorded on field forms and the offset calibrated so that the stage was reset to zero. Calibrations only occurred when the offset differed by more than 0.01 foot. The AV sensor at AS-IN was checked during pre-storm site visits when no base flow was present at the station to ensure the stage was zero. The sensor was calibrated by damming water behind the sensor, measuring a known water level at the sensor's location, and comparing to the instrument's reading. The calibrations took place at the beginning and conclusion of the monitoring period. Instrument maintenance and calibration activities were documented on standardized field forms (Appendix G).

The rain gauge is a robust instrument that requires only annual calibration. On a semi-annual basis, the level of the rain gauge was checked. The rain gauge was calibrated annually following the procedure described in the QAPP (Herrera 2023).

3.2.4.2. Field Notes

During each pre- and post-storm site visit to each monitoring station, the following information was recorded on an electronic field form as applicable (Appendix G):

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

3.2.4.3. Equipment Rinsate Blanks

Field rinsate blanks were collected at the AS-IN and AS-OUT monitoring locations prior to monitoring on December 14, 2023; December 6, 2024; and July 3, 2025. The field rinsate blanks were collected by pumping reagent-grade water through the intake tubing into a precleaned sample container. The volume of reagent grade water pumped through the sampler for the field blank was similar to the volume of water collected during a typical storm event. All target contaminant concentrations in these rinsate blanks were below two times the reporting limit, resulting in no data qualifiers. The Chemistry Data Quality Worksheets are presented in Appendix E.

To help prevent cross-contamination from the tubing during routine sampling, the automated sampler tubing was rinsed with stormwater (using an automated double-rinse cycle) before the collection of each aliquot. In addition, laboratory-provided deionized water was backflushed through the sample tubing during the pre-storm site visit for each monitored event.

3.2.4.4. Field Duplicates

Field duplicates were collected for approximately 10 percent of the samples. To ensure high enough concentrations for the duplicate analysis to be meaningful, only the influent station samples were duplicated. To collect the composite sample field duplicates, the collected sample in the 20-liter carboy was split into sample collection bottles dedicated for collecting field duplicates using a 22-liter churn splitter during sample processing at the laboratory. The resultant data from the duplicate samples were used to assess variation in the results that were attributable to analytical variability combined with variability induced by field collection and transportation. The field duplicate collected on June 3, 2024, resulted in a J flag for TSS results, and the field duplicate collected on June 7, 2024, resulted in a J flag for fecal coliform and *E. coli* results. Results of the field duplicates are presented in the data Chemistry Quality Assurance Worksheets in Appendix E.

3.2.4.5. Sample Handling

The base of each automated sampler was filled with ice before each sampled storm event. Ice was not allowed to sit within autosamplers for more than 24 hours before the initiation of an event (with the goal of keeping sample temperatures below 6°C). After each targeted storm event, all samples were minimally processed in the field to prevent potential contamination from trace pollutants in the atmosphere.

All sample bottles (grab sample bottle, 20-liter composite bottles) were transported in coolers with ice and kept below 6°C until delivery to the laboratory. The temperature of the samples was measured upon sample delivery and recorded on the chain-of-custody form. Once in the laboratory, the composite samples were transferred from the sampler carboy to precleaned sample bottles for the required analyses. The carboy was vigorously agitated through a splitter into separate bottles for analysis. This transfer process ensured the sample was well mixed before filling the individual sample bottles. To minimize exposure of the samples to human, atmospheric, and other potential sources of contamination, laboratory staff processed the samples using "clean" techniques pursuant to protocols developed by the U.S. Environmental Protection Agency (US EPA 1996) for the low-level detection of metals.

3.2.4.6. Sample Identification and Labeling

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

- Site/station name (e.g., AS-IN or AS-OUT)
- Date of sample collection (year/month/day: yyyy/mm/dd)
- Time of sample collection (international format [24-hour])
- Field personnel initials (e.g., SG)

Quality assurance samples (field duplicates and blanks) were labeled as AS-IN-QA or AS-OUT-QA.

Waterproof labels were placed on dry sample container lids by self-adhesion or with tape. Any written marks were made with waterproof ink.

3.2.4.7. Sample Containers and Preservation

Clean, decontaminated sample bottles were obtained from the analytical laboratory in advance of each storm event. Spare sample bottles were brought to the site by the sampling team as backup in case of breakage or possible contamination of a sample. Sample containers and preservation techniques followed US EPA (2007) guidelines. After samples were processed, laboratory personnel cleaned the sample bottles with a four-step process:

1. Liquinox detergent rinse
2. Reagent grade water rinse
3. Two molar hydrochloric acid rinse
4. Reagent grade water rinse

3.2.4.8. Sample Packing and Shipping

Samples for the particle size distribution analysis were shipped by Exact Scientific Services (Exact) in Ferndale, Washington, to Environmental Technical Services (ETS) in Petaluma, California. Steps for packing and shipping samples included the following:

1. Fold the field-sampling sheets and chain-of-custody record form, and place them in plastic bags to protect the sheets during transport.
2. Clearly mark the analyses to be performed for each sample.
3. Pack samples to prevent breakage or leakage (samples should already be labeled).
4. Securely seal shipping containers, and affix identification labels to each shipping container.
5. Mark containers "THIS END UP" and number containers in a shipment.

3.2.4.9. Chain-of-Custody Record

A chain-of-custody record was maintained for each sample batch by 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 (Appendix D).

3.3. Laboratory Procedures

3.3.1. Analytical Methods

Laboratory analytical methods for this Project are summarized in Table 1. Exact in Ferndale, Washington, was used for all parameters except for total phosphorus, orthophosphate, and total and dissolved zinc, which were subcontracted to Analytical Resources, Inc. (ARI) in Tukwila, Washington. PSD was submitted to ETS in Petaluma, California.

Table 1. Water Quality Analysis Methods and Detection Limits.

Parameter	Analytical Method	Method Number[a]	Field Sample Container	Pre-Filtration Holding Time	Total Holding Time[b]	Field Preservation	Laboratory Preservation	Actual Reporting Limit/Resolution	Target Reporting Limit/Resolution	Units
Total suspended solids	Gravimetric[c]	SM 2540D	20-liter HDPE bottle	7 days	7 days	Maintain ≤6°C	Maintain ≤6°C	1.0	1.0	mg/L
Particle size distribution	Sieve	ASTM D422		7 days	7 days		Maintain ≤6°C	NA	NA	microns
Total phosphorus	Colorimetric	EPA 365.3/SM 4500		NA	28 days		Maintain ≤6°C, H_2SO_4 to pH <2	0.005	0.001	mg/L
Orthophosphate	Colorimetric	SM 4500P E		24 hours[d]	48 hours		Maintain ≤6°C	0.005	0.001	mg/L
Total Kjeldahl nitrogen	Micro-Kjeldahl	SM 4500-Norg D-97		NA	28 days		Maintain ≤6°C, H_2SO_4 to pH <2	0.5	1.0	mg/L
Nitrate + nitrite	Ion Chromatography	EPA 300.0		48 hours	28 days		Maintain ≤6°C, H_2SO_4 to pH <2	0.1	0.1	mg/L
Hardness as $CaCO_3$	ICP/MS+Calculation	200.8/SM 2340C		28 days	28 days		Maintain ≤6°C, HNO_3 to pH <2	0.8	1.0	mg/L $CaCO_3$
pH	Electrometric	SM 4500H+B		NA	NA		NA	0.01	0.01	pH units
Copper, dissolved	ICP-MS	EPA 200.8		24 hours[d]	6 months		Maintain ≤6°C, HNO_3 to pH <2 after filtration[e]	1	0.1	µg/L
Copper, total				NA			Maintain ≤6°C, HNO_3 to pH <2	1	0.1	
Zinc, dissolved	ICP-MS	EPA 200.8		24 hours[d]	6 months		Maintain ≤6°C, HNO_3 to pH <2 after filtration[e]	2.5	1	µg/L
Zinc, total				NA			Maintain ≤6°C, HNO_3 to pH <2	2.5	5	
Fecal coliform bacteria	Membrane filter	SM 9222D	2 x 125 bacteria bottle	6 hours	6 hours	Maintain ≤10°C	Maintain ≤10°C, sodium thiosulfate	1[f]	2/40,000[f]	CFU/100 mL
Escherichia coli bacteria		EPA Method 1604		24 hours	24 hours	Maintain ≤10°C	Maintain ≤10°C, sodium thiosulfate	1[f]	2/40,000[f]	CFU/100 mL
TPH (gasoline)	GC/MS	NWTPH-Gx	Two 40-mL glass vial	14 days (to extraction)	40 days (from extraction)	HCl to pH <2, maintain ≤6°C	Maintain ≤6°C	100	100	µg/L
TPH (diesel)	GC/FID	NWTPH-Dx[g]	Two 500-mL amber glass bottle	7 days (to extraction)	40 days (from extraction)	Maintain ≤6°C	Maintain ≤6°C, HCl to pH<2	50	50	µg/L
TPH (motor oil)		NWTPH-Dx[g]						100	100	µg/L

[a] SM method numbers are from APHA et al. (1998); EPA method numbers are from US EPA (1983, 1984); ASTM method numbers are from ASTM (2007). The 18th edition of Standard Methods for the Examination of Water and Wastewater (APHA et al. 1992) is the current legally adopted version in the Code of Federal Regulations.

[b] Holding time specified in US EPA guidance (US EPA 1983, 1984) or referenced in APHA et al. (1992) for equivalent method.

[c] A G4 glass fiber filter was used for the filtration.

[d] US EPA requires filtering for dissolved metals within 15 minutes of the collection of the last aliquot. This goal is exceedingly difficult to meet when conducting flow-weighted sampling. A more practical proxy goal of 24 hours was adopted for this study.

[e] A 0.45-micron fiber nylon filter was used for dissolved metals (copper and zinc) filtration.

[f] Reporting limit was dependent upon dilution used in the laboratory.

[g] Washington State Department of Ecology methods (Ecology 1997) include silica gel extract cleanup step.

°C = degrees Celsius
CFU/100 mL = colony-forming units per 100 milliliters
GC/FID = gas chromatography/flame ionization detection
GC/MS = gas chromatography/mass spectrometry
HDPE = high-density polyethylene
ICP-MS = inductively coupled plasma/mass spectrometry
mg/L = milligrams per liter
µg/L = micrograms per liter
NA = not applicable
TPH = Total Petroleum Hydrocarbons

3.3.2. Laboratory Quality Control Measures

The accuracy of the laboratory analyses was verified with blank analyses, duplicate analyses, laboratory control spikes, and matrix spikes, in accordance with the analytical methods employed. These are described in detail in the following subsections.

3.3.2.1. Method Blanks

Method blanks consisting of de-ionized and micro-filtered pure water were analyzed with every laboratory sample batch. Laboratory sample batches consisted of no more than 20 samples and may have included samples from other projects. Blank values were presented in each laboratory report.

3.3.2.2. Control Standards

Control standards for each parameter were analyzed by the laboratory with every sample batch. Laboratory sample batches consisted of no more than 20 samples and may have included samples from other projects. Raw values and percent recovery for the control standards were presented in each laboratory report.

3.3.2.3. Matrix Spikes

For applicable parameters, matrix spikes were analyzed by the laboratory with every sample batch. Laboratory sample batches consisted of no more than 20 samples and may have included samples from other projects. Raw values and percent recovery for the matrix spikes were presented in each laboratory report.

3.3.2.4. Laboratory Duplicates

Laboratory split sample duplicates for each parameter were analyzed with every sample batch. These represent no less than 10 percent of the Project submitted samples. Raw values and relative percent difference of the duplicate results were presented in each laboratory report.

3.4. Data Management Procedures

Data from the datalogger were remotely downloaded on a daily basis. The hydrologic data from each monitoring station were imported directly into a database (Aquarius data management software) for subsequent analysis and archiving purposes. These data were promptly checked for evidence of any equipment malfunction or other operational problems. Hydrologic data from the Aquarius database was used to produce event-based hydrologic summary statistics (e.g., station runoff volume, storm precipitation total, storm duration) for each applicable station. These summary statistics were ultimately stored in Herrera Environmental Consultant's (Herrera) data warehouse known as DRIP (Data Retention and Integration Platform) along with water quality data collected through the Project (see description below).

The laboratories reported the analytical results to Herrera within 30 days of receipt of the samples. The laboratories provided sample and quality control data in standardized reports that were suitable for evaluating the Project data. These reports included all raw data including raw quality assurance data and all quality control results associated with the data. The reports also included a case narrative summarizing any problems encountered in the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers. Laboratory analytical and quality assurance results were delivered from the laboratory in electronic form.

Analytical data for the Project were initially uploaded to ESdat, a commercially available cloud database for environmental data. ESdat provides basic laboratory electronic data deliverable validation and QA/QC tools. Following the initial processing in ESdat, Herrera's DRIP system paired the analytical chemistry and hydrologic data collected for each storm event. The Herrera quality assurance officer performed an independent review of the data to ensure that all sample values were entered without error as described in the QAPP (Herrera 2023). The review consisted of checking that all laboratory data were entered into the database correctly and all data in the database agree with the data presented in Individual Storm Reports (ISRs) (Appendix H). ISRs are one-page summaries consisting of a hydrologic and sampling statistics summary table, a hydrograph and hyetograph showing sample collection times, precipitation characteristics of an event, and a water quality data summary table.

Both the laboratory and Herrera will retain project-related data for 5 years after completion of the Project.

3.5. Data Analysis Procedures

Data analyses were performed to evaluate the water quality treatment performance of the test system following procedures identified by Ecology (2018) in G*uidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE)* and by the US EPA (2002) in *Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements*. The specific procedures used in these analyses are as follows:

- Statistical analysis to compare influent and effluent concentrations
- Calculation of pollutant removal efficiency
- Pollutant removal as a function of flow rate
- Comparisons of percent removal to treatment goals

Analysis of plant health and vigor was conducted as described below due to data collection deviations. Each of these procedures is described in more detail in the following subsections.

3.5.1. Statistical Comparisons of Influent and Effluent Pollutant Concentrations

Statistical analyses were performed to assess significance of differences in pollutant concentrations between the influent and effluent stations across individual storm events. The specific null hypothesis (H_o) and alternative hypothesis (H_a) for these analyses are as follows:

H_o: Effluent pollutant concentrations are equal to or higher than influent concentrations.

H_a: Effluent concentrations are lower than influent concentrations.

To evaluate these hypotheses, a Wilcoxon signed-rank test (Helsel and Hirsch 2002) was used to compare performance data from AS-IN and AS-OUT. The Wilcoxon test is a nonparametric analogue to the paired t-test. Statistical significance was assessed based on an alpha (α) level of 0.05. Values less than or equal to the reporting limit were set to negative 1 prior to the analysis so that they were ranked below reported values and were set to be equivalent in rank with one another.

3.5.2. Calculation of the Pollutant Removal Efficiency

Pursuant to guidance from the TAPE, the reduction (in percent) in pollutant concentration during each individual storm (ΔC) was calculated as:

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

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

C_{eff} = Flow-weighted effluent pollutant concentration

3.5.3. Pollutant Removal as a Function of Flow Rate

To assess system performance as a function of flow rate, the event-based percent pollutant reductions were regressed against the 90th percentile of the sampled effluent flow rates for each event. A linear regression model was developed using the 90th percentile of the sampled effluent flow rate as the independent variable and pollutant removal performance data (from the paired influent and effluent composite samples) as the dependent variable. The suitability of the regression equation should be evaluated using the diagnostics described in Helsel and Hirsch (2002).

3.5.4. Comparison of Percent Removal to Treatment Goals

In this Project, a statistically small number of storms were targeted for sampling. Rather than simply describing the population of event-based percent removal estimates by their mean and normal theory confidence interval, the mean and its confidence intervals were estimated by bootstrapping.

Bootstrapping offers a distribution-free method for estimates of confidence intervals of a measure of central tendency (Efron and Tibshirani 1993). The generality of bootstrapped confidence intervals means they are well-suited to non-normally distributed data and/or data sets not numerous enough for a powerful test of normality (Porter et al. 1997).

In its simplest form, bootstrapping a summary statistic of a data set of sample size n consists of drawing n elements from the data set randomly with replacement and equal probabilities of drawing any element. The statistic of interest is then calculated on this synthetic data set, and the process is repeated for many repetitions. Repetition generates a distribution of possible values for the statistic of interest. Quantiles of this distribution are confidence intervals of the statistic. For example, if the mean is replicated 10,001 times, after sorting the replications, the 50th and 9,950th elements form the 99 percent confidence interval of the mean.

For parameters with percent removal goals (e.g., influent TSS ≥100 mg/L), the bootstrapped 95 percent lower confidence interval for the mean percent removal was compared to the treatment goal. If the lower confidence limit is higher than the treatment goal, it can be concluded that the system met the treatment goal with the required 95 percent confidence.

For parameters with effluent concentration goals (e.g., influent TSS <100 mg/L), the bootstrapped 95 percent upper confidence interval for the mean effluent concentration was compared to the treatment goal. If the upper confidence limit is lower than the effluent concentration goal, it can be concluded that the system met the treatment goal with the required 95 percent confidence.

Values at or below the reporting limit were set equal to one-half the reporting limit prior to bootstrap analyses.

3.5.5. Analysis of Plant Health and Vigor

Data collected during the vegetation inspection on July 30 and July 31, 2025, were summarized based on vegetation species, surviving count, and health/vigor. The health/vigor of the vegetation was evaluated based on the following criteria:

- **Declining health:** Shows signs of irreversible decline due to drought stress and/or damage
- **Stunted:** Shows signs of drought stress, and/or damage, and/or some branch dieback
- **Established:** Shows minimal signs of drought stress and/or branch dieback

The vegetation inspection findings and site photographs from the water quality monitoring period were compiled into a summary of findings and key takeaways (Appendix G).

3.6. QAPP Deviations

3.6.1. Field Procedures

Field sampling and measurement procedures were generally consistent with the QAPP and Addendum with the following exceptions:

- Influent and effluent flow monitoring equipment was not calibrated at the frequency described in the QAPP. In addition, flow monitoring equipment at the bypass station malfunctioned and was unable to log for the duration of the monitoring period despite attempts to remedy. As a result, confidence in the evaluation of bypass frequency and magnitude was impacted as discussed in the Hydrologic Data section.
- Vegetation monitoring was not conducted at the frequency described in the QAPP. Conclusions and findings were based on one vegetation monitoring event at the end of the water quality monitoring period and from photos taken throughout the monitoring period.

3.6.2. Laboratory Procedures

Laboratory analytical methods, reporting limits, and quality assurance procedures were generally consistent with the QAPP and Addendum with the following exceptions:

- Rinsate blanks collected before the first event (December 14, 2023) were not analyzed for orthophosphate, nitrate+nitrite, copper, and zinc. Only total phosphorus was analyzed.
- Analytical methods described in the QAPP were not consistently used by the analytical laboratories but were replaced with comparable methods including SM 9222D for *E. coli* (versus the QAPP prescribed EPA 1604) and EPA 300.0 for orthophosphate (versus QAPP prescribed SM 4500-P).
- Analytical reporting limits exceeded QAPP prescribed limits and resulted in a non-detect for several parameters including those listed below. Specific reporting limit exceedances are described in the QA Review Memo (Appendix E).
    - TSS reporting limits ranged from 1.0 to 4.5 mg/L, exceeding the QAPP reporting limit of 1.0 mg/L.
    - Total phosphorus reporting limits ranged from 0.008 to 0.016 mg/L, exceeding the QAPP reporting limit of 0.005 mg/L.
    - Orthophosphate reporting limits ranged from 0.004 to 0.05 mg/L, often exceeding the QAPP reporting limit of 0.005 mg/L.
    - Dissolved zinc reporting limit was consistently 0.006 mg/L, exceeding the QAPP reporting limit of 0.0025 mg/L.

  These elevated reporting limits likely resulted in additional non-detect results which may have decreased the confidence in pollutant reduction and performance calculations. However, the elevated reporting limits were still below the lower influent concentration range for TAPE studies.

3.6.3. Data Analysis Procedures

Data analysis procedures were generally consistent with the QAPP and Addendum except for calculation of pollutant load reductions. Due to instrumentation failures at the bypass monitoring station, bypass frequency and quantity could not be accurately evaluated. In addition, large discrepancies between influent and effluent flow volumes that cannot be entirely attributed to bypass were observed. These are discussed in more detail in the Hydrologic Data Collection Procedures section. As a result of the lower confidence in flow totals, pollutant load reductions were not calculated. Pollutant concentration reductions were calculated in accordance with TAPE guidance.

4. Data Summaries and Analysis

This section summarizes data collected at the Project during the December 2023 through April 2025 monitoring period. The presentation of these data is organized under separate subsections for the hydrologic and water quality monitoring results, respectively. Appendix E presents results from the validation review that was performed on the water quality data.

4.1. Hydrologic Data

To provide some context for interpreting the data, this section compares rainfall totals measured during the monitoring period relative to historical data. The actual hydrologic monitoring results are then presented in a subsequent subsection.

4.1.1. Quality Assurance Review Results

The hydrologic data were assessed against method quality objectives in the project QAPP (Herrera 2023). Based on this assessment, some of the data collected were qualified as estimates; however, no data were rejected, and all individual values were carried forward into the analyses presented below with some additional qualifications.

Three flows comprise the hydraulics of this system: influent, effluent, and bypass flows. A dosing siphon delivered the influent flow to the facility as runoff filled the dosing tank (Appendix B). As a result, instead of a typical hydrograph with the rising limb, peak, and falling limb associated with the contributing drainage basin's runoff, the facility received sharp and brief pulses of flow that extended well beyond the end of a precipitation event. Due to the challenges of the inlet flow sensor position, calibrations for the inlet flow sensor did not occur on a regular basis throughout the monitoring period. However, the sensor was calibrated at the beginning and end of the monitoring period. The sensor was checked prior to a sampling event when no baseflow was present to determine the sensor read zero level.

At the effluent monitoring location, Herrera installed and calibrated a 12-inch Thel-mar weir with associated level sensor pressure transducer, allowing for the conversion of level readings to discharge via the weir manufacturer's published stage-discharge relationship. The treated effluent monitoring location was calibrated four times throughout the monitoring period.

The bypass station was monitored using a pressure sensor to monitor water level relative to the most downstream weir wall, calibrated to measure volume spilling over weir wall and engaging the bypass. However, for reasons explained in the Hydrologic Data Collection Procedures section, the pressure sensor was unable to accurately read water level. Data collected from the sensor was deemed unusable and the station was decommissioned within the first months of the monitoring period.

4.1.2. Historical Rainfall Data Comparison

An analysis was performed on rainfall data collected at the Park Place rain gauge (PP-RG) to determine if rainfall totals from the monitoring period (December 2023 through April 2025) were anomalous. The analysis involved a comparison of rainfall totals measured at the PP-RG and City of Bellingham Geneva rain gauge (Geneva-RG) over the monitoring period to averaged totals for the Bellingham International Airport rain gauge (BLI-RG) from the past 24 years. These data are summarized in Table 2.

Since PP-RG precipitation data were missing for the last 3 months, comparisons with Geneva-RG and historical BLI-RG are made over 14 months, while Geneva-RG and BLI-RG historical results are compared over the full 17 months. Results from this analysis (Table 2) show that the average 17-month rainfall total at BLI-RG from 2000 through 2024 was 51.47 inches. The total rainfall at this same station through the 17-month monitoring period was 60.25 inches, indicating that this was an above-average wet period when compared to long-term averages (17 percent greater). In comparison, the 14-month rainfall at the PP-RG and Geneva-RG stations were 42.64 and 50.11 inches, respectively, compared to 42.86 inches at the BLI-RG from 2000 through 2024. This indicates that the monitoring period was an above-average wet period when compared with long-term averages.

Measurements at the Geneva-RG are generally consistent with the BLI-RG readings during the monitoring period. Measurements at the PP-RG station varied more considerably, most visibly in October and December 2024. Due to the gaps in data at the end of the monitoring period at PP-RG and the proximity of Geneva-RG to the Project site, precipitation data from Geneva-RG should be considered the final representative source for the monitoring program and is included in ISRs and associated storm characteristic summaries.

Table 2. Monthly Precipitation Totals for December 2023 to April 2025 at the Test Site Compared to Park Place Rain Gauge and Historical Totals at Bellingham Int'l Airport.

Month	Monthly Rainfall (inches) (Geneva-RG)[a]	Park Place (PP-RG) Monthly Rainfall (inches)	Bellingham Int'l Airport (BLI-RG) Monthly Rainfall (inches)[b]	Historical Bellingham Int'l Airport (BLI_RG) Monthly Rainfall (inches) (2000–2024)[b]
December 2023	5.87	4.95	5.67	4.28
January 2024	5.90	5.07	6.72	4.25
February 2024	4.03	3.06	3.03	2.75
March 2024	3.62	3.08	2.68	3.41
April 2024	2.82	2.32	2.26	2.42
May 2024	2.48	2.61	3.24	2.20
June 2024	1.45	1.97	2.03	1.57
July 2024	0.27	0.95	1.02	0.67
August 2024	2.01	1.05	2.61	1.04
September 2024	1.89	2.26	2.00	2.33
October 2024	6.11	4.71	6.72	4.13
November 2024	5.26	4.83	4.81	5.28

Table 2 (continued). Monthly Precipitation Totals for December 2023 to April 2025 at the Test Site Compared to Park Place Rain Gauge and Historical Totals at Bellingham Int'l Airport.				
Month	**Monthly Rainfall (inches) (Geneva-RG)[a]**	**Park Place (PP-RG) Monthly Rainfall (inches)**	**Bellingham Int'l Airport (BLI-RG) Monthly Rainfall (inches)[b]**	**Historical Bellingham Int'l Airport (BLI_RG) Monthly Rainfall (inches) (2000–2024)[b]**
December 2024	6.02	3.38	5.36	4.28
January 2025	2.38	2.40	2.15	4.25
February 2025	3.48	NA	3.34	2.75
March 2025	5.56	NA	5.12	3.41
April 2025	2.47	NA	1.49	2.42
Total (14-month)	**50.11**	**42.64**	**50.30**	**42.86**
Total (17-month)	**61.62**	**NC**	**60.25**	**51.47**

[a] Source: City of Bellingham Rain Gauge – Geneva

[b] Source: Weather station KBLI, data accessed via NOAA National Centers for Environmental Information; located 6.9 miles northwest of the Project site

4.1.3. System Hydraulic Performance

The Quality Assurance Review Results section describes limitations of the monitored hydrologic data. While effluent flow was calibrated, uncertainty in influent flow measurement and the absence of direct bypass monitoring preclude a complete hydraulic mass balance for the system.

Figure 5 presents cumulative influent and effluent volumes over the monitoring period (December 2023 through April 2025). The effluent station measured an estimated 9,166,217 gallons of treated discharge, while the influent monitoring station recorded an estimated 16,193,122 gallons. Although these volumes differ by approximately 7 million gallons, this difference cannot be attributed solely to bypass. With the low confidence in the estimated influent flows and because bypass flows were unable to be measured (see the Hydrologic Data Collection Procedures section), the total amount of bypass of the system cannot reasonably be quantified.

Bypass occurrence was documented through visual observation during or immediately following monitored storm events. Four monitored events exhibited visible bypass (Figure 5). However, without direct bypass flow monitoring, cumulative bypass volume could not be quantified for the duration of the monitoring period. The treated effluent volume represents a confirmed minimum volume that passed through the Project, with true volume entering the Project likely being greater.

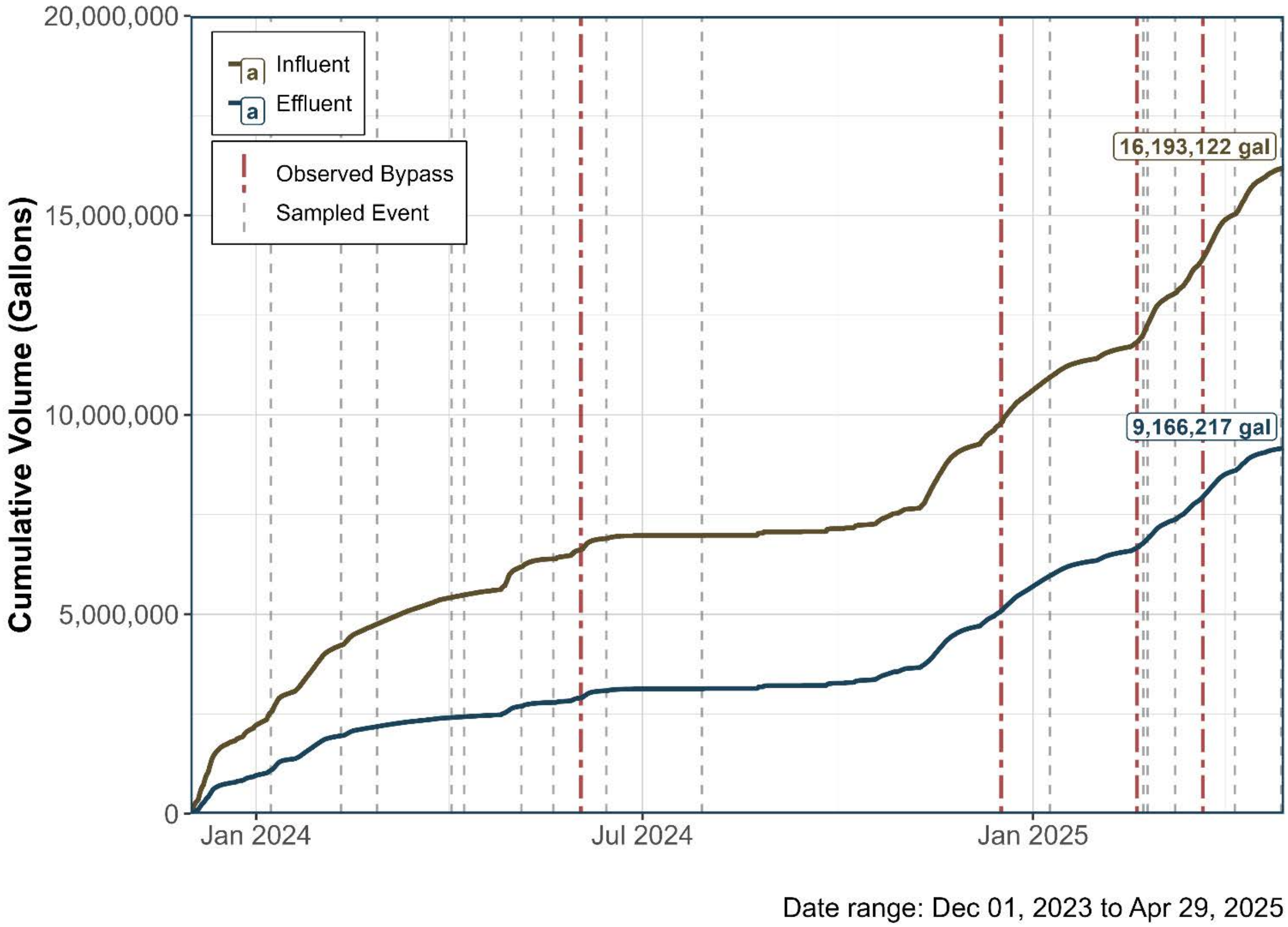


Figure 5. Cumulative Influent and Treated Effluent Volume of the System, With Note of Observed Bypass and Sampled Events.

4.2. Water Quality Data

Results from the 19 sampled composite storm events and three base flow events that occurred at the site between December 2023 to April 2025 are presented in this section. The section begins with a summary of results from quality assurance reviews of the data that were collected over this period. Storm event characteristics and sample collection procedures are then compared to criteria identified in the TAPE Technical Guidance Manual (Ecology 2018) for assessing the representativeness of collected samples for use in quantifying system performance. Finally, water quality data are compared to the specific performance goals from the TAPE Technical Guidance Manual (Ecology 2018). The field forms for each sampled event are provided in Appendix G. Appendix H provides ISRs for each sampled event. Finally, Appendix D provides laboratory reports for each sampled event, including chain-of-custody forms.

4.2.1. Quality Assurance Review Results

The water quality data were assessed against method quality objectives in the project QAPP (Herrera 2023). The results of this assessment are reported in Appendix E. Based on this assessment, some of the collected data were qualified as estimates; however, no data were rejected, and all individual values were carried forward into the analyses presented below.

4.2.2. Comparison to Criteria for Assessing Sample Representativeness

The TAPE guidance identifies criteria for assessing the representativeness of collected samples based on the characteristics of sampled storm events and sample collection procedures. The data collected through this monitoring effort were evaluated relative to these criteria and presented in the following subsections.

4.2.2.1. Storm Event Criteria

During the monitoring period, composite samples from 19 storms and two base flow events, in addition to grab samples from 15 storm and three base flow events, were sampled to characterize the water quality treatment performance of the Project. Precipitation data from the sampled storm events in this period were compared to the TAPE criteria for determining sample acceptability (i.e., minimum precipitation depth, minimum antecedent dry period, minimum storm duration, and minimum average storm intensity).

Summary data related to these criteria for each of the 19 sampled storm events are presented in Table 3. These data show the criterion for minimum precipitation depth (0.15 inch) was met during all storm events except for the April 8, 2024, event, which reached 0.13 inch. However, the April 8, 2024, event was included in the final data set for analysis due to other storm and sampling criterion being met. The minimum, median, and maximum precipitation depths across the 19 storm events were 0.13, 0.52, and 1.37 inches, respectively. The criterion for minimum antecedent dry period (6 hours) was also met for every event. Antecedent dry periods during the sampled storm events ranged from 6.5 to 338.8 hours, with a median value of 39.0 hours. The storm duration criterion (1 hour) was met for all events. Storm durations ranged 2.8 to 39.0 hours, with a median value of 11.8 hours (Table 3). Finally, a range of storm intensities were sampled. For the 19 sampled storm events, average rainfall intensity ranged from 0.01 to 0.12 in/hr (Table 3).

Table 3. Sampled Event Storm Characteristics and Sampling Criteria.

Storm Start Datetime	Sample Type[a]		Rainfall Depth (inches) Goal ≥0.15 in	Rainfall Duration (hours) Goal ≥1 hr	Antecedent Dry Period (hours) Goal ≥6 hr	Average Rainfall Intensity (in/hr) Goal: a range	Number of Aliquots Goal ≥10		Storm Coverage (%) Goal ≥75%		Sampling Duration (hours) Goal <36 hr		90th Percentile Sampled Effluent Flow (gpm)	Peak Inflow (gpm)
	Composite	Grab					IN	OUT	IN	OUT	IN	OUT		
2024-01-08 01:30	X		1.14	24.2	39.0	0.047	41	31	**70.3**	**64.7**	19.2	19.0	40.6	221.2
2024-02-10 15:45	X	X	0.75	20.2	48.8	0.037	45	85	89.8	91.2	17.9	18.2	22.9	229.2
2024-02-27 10:30	X	X	1.37	39.0	52.5	0.035	31	33	**51.2**	**43.1**	22.2	18.8	12.6	208.6
2024-04-02 11:15	X		0.21	4.5	120.0	0.047	16	28	**36.6**	**62.8**	0.7	10.1	11.5	223.6
2024-04-08 11:45	X		**0.13**	5.8	11.0	0.022	13	49	**12.0**	**44.3**	0.6	3.7	12.4	204.5
2024-05-05 05:30	X		0.47	9.0	169.2	0.052	75	57	88.1	**40.8**	13.9	5.0	33.2	218.4
2024-05-18	X	X	*NA – base flow event*											
2024-05-20 21:15	X	X	0.59	23.5	338.8	0.025	64	93	77.0	79.7	14.3	15.1	22.8	227.9
2024-06-02 02:35	D	D	0.31	6.4	17.8	0.048	28	26	**73.4**	75.5	5.7	7.4	37.0	185.2
2024-06-07		D	*NA – base flow event*											
2024-06-10	X	X	*NA – base flow event*											
2024-06-14 11:30	X		0.51	10.0	248.0	0.051	30	41	**52.6**	84.8	8.1	13.0	27.5	186.8
2024-07-28 20:15 [b]	X		0.27	12.5	1057	0.022	**6**	25	81.9	94.6	0.7	3.5	40.2	172.8
2024-12-17 01:45	D	D	1.20	20.0	24.5	0.060	84	89	91.0	91.6	22.1	23.0	45.9	268.1
2025-01-09 19:30	X	D	0.52	9.8	107.2	0.053	29	43	**71.8**	**71.3**	11.6	11.0	29.5	215.7
2025-02-15 11:00		X	0.46	19.5	222.2	0.024	*NA – grab samples only*							201.0
2025-02-19 05:45	D		0.33	2.8	8.8	0.118	28	35	95.4	83.7	7.4	7.8	42.8	240.8
2025-02-22 06:30	D	X	0.45	11.8	18.8	0.038	39	41	93.9	91.1	17.0	17.2	39.3	248.8
2025-02-24 06:15	D	X	0.68	23.8	19.5	0.029	85	99	**56.2**	**50.3**	16.2	14.8	40.4	255.2
2025-03-09 04:45	X		0.55	6.5	30.5	0.085	40	50	90.7	93.3	12.2	11.9	46.9	218.8
2025-03-22 11:45	X	X	0.97	33.5	24.0	0.029	69	79	76.7	**73.5**	24.9	24.7	44.1	254.1
2025-03-26 06:30		X	0.79	11.8	44.5	0.067	*NA – grab samples only*							272.5
2025-04-06 03:45	X	X	0.53	17.2	6.8	0.031	43	48	89.2	82.4	18.2	15.9	40.1	257.8
2025-04-08 08:45		X	0.16	5.0	6.5	0.032	*NA – grab samples only*							259.3
2025-04-28 07:00	X	X	0.15	13.8	174.0	0.011	12	18	85.8	87.3	14.6	17.0	13.9	235.8
SUMMARY – Valid Storm Sampling Events														
Maximum			1.37	39	1057	0.118	85	99	95.4	94.6	24.9	24.7	46.9	272.5
Median			0.5	12.2	41.8	0.038	39.0	43.0	77.0	79.7	14.3	14.8	37.0	225.8
Minimum			0.13	2.8	6.5	0.011	6	18	12	40.8	0.6	3.5	11.5	172.8

[a] "D" indicates that a field duplicate was collected for the associated suite of parameters.

[b] The sampling event on July 28, 2024, did not meet the criteria for number of aliquots at the influent station. However, due to sufficient storm coverage in a small window of active flow through the system, analytical results were included in the data set.

BOLD values indicate event did not meet TAPE storm criteria.

4.2.2.2. Sample Collection Criteria

As described in the Water Quality Data Collection Procedures section, automated samplers were programmed with the goal of meeting specific criteria for sampling acceptable storm events, as identified in the TAPE guidelines. The criterion for minimum number of sample aliquots (10) was met for all the flow-weighted composite samples except for the event on July 28, 2024, due to short flow duration. However, results from this event were included in the final data set due to other sample collection criteria being met (Table 3). The criterion for minimum portion of storm volume covered by sampling (75 percent) was met in the majority of the storm flow-weighted composite samples, but multiple events with storm volume coverage of below this goal were included in the final data set. Due to the dosing mechanism and baseflow, hydrographs did not have the typical shape or response to that of surface runoff. Additionally, the hydrographs were not indicative of beginning in tandem with a first flush of the storm event. Low storm volume coverage may have been due to dosing "pulses" that were not sampled and not actually associated with a storm event. Finally, the sampling duration did not exceed 36 hours for any of the flow-weighted composite samples (Table 3).

4.2.3. Water Quality Treatment Performance Evaluation

This section evaluates water quality data based on treatment goals identified in the TAPE guidelines. Particle size distribution (PSD) data are presented first to assess the representativeness of influent stormwater. Results from monitoring performed to evaluate the performance of the Project relative to the goals for basic, metals, and phosphorus treatment are then presented.

4.2.3.1. Particle Size Distribution

The TAPE guidelines indicate that stormwater in the Pacific Northwest typically contains mostly silt-sized particles and finer; therefore, results for PSD are reviewed to indicate whether the stormwater runoff analyzed is representative of regional conditions. The average D50 (the median particle diameter for a sample) of the influent water was 5 microns (Table 4), which was below the criterion of 62.5 microns (the silt-sand threshold), thus meeting the TAPE guidelines for influent PSD (Ecology 2018).

Table 4. Influent (AS-IN) Particle Size Distribution and Associated Total Suspended Solids Results.

Sample Date	Total Suspended Solids (mg/L)	Particle Size Distribution (µm)		
		D25	D50	D75
2024-02-29	16.2	2	3	12
2024-06-03	27.5	2	5	36
2024-12-17	29.2	2	7	31
SUMMARY (all data)				
Median	27.5	2	5	31
Mean	24.3	2	5	26

D25, D50, D75 = particle diameter at which 25, 50, and 75 percent of particles are finer; mg/L = milligrams per liter; µm = micrometers

4.2.3.2. Pollutant Removal Efficiency and Performance Goals

Total Suspended Solids

The basic treatment goal for TSS from the TAPE guidelines indicates two criteria:

- For influent concentrations ranging from 100 to 200 mg/L, the lower 95th percentile confidence limit (LCL95) of the mean TSS removal efficiency, calculated via bootstrapping, must be greater than or equal to 80 percent.
- For influent TSS concentrations less than 100 mg/L but greater than 20 mg/L, the upper 95th percentile confidence limit (UCL95) of the mean effluent concentration must be less than or equal to 20 mg/L.

There is no specified goal for influent TSS concentrations less than 20 mg/L; consequently, those sample pairs (influent and effluent) are not used to assess TSS removal performance. For influent concentrations greater than 200 mg/L, the influent is artificially capped at 200 mg/L for the purposes of calculating the removal efficiency. Finally, pollutant removals must represent a range of effluent flow rates up to and including the design flow rate.

Of the 21 sampled events, 19 of which were storm events, only 7 influent composite samples had TSS concentrations over 20 mg/L (Table 5). No influent TSS concentrations exceeded the 200 mg/L upper limit. In general, influent pollutant concentrations were consistently lower than the lower limit of the TAPE influent criteria, but TAPE-style performance evaluations were still conducted. Note that these results do not represent a formal TAPE study, and the HPBSM facility is not pursuing a GULD with Ecology.

For the seven events with qualifying TSS concentrations, the LCL95 mean TSS removal was 87 percent. For all storm events, the LCL95 mean removal rate was 79 percent (Table 5). Both the qualifying and all storm events had UCL95 mean effluent TSS concentrations less 20 mg/L at 4.8 and 3.0 mg/L, respectively. A one-tailed Wilcoxon test was performed on these data to determine if the TSS concentrations were significantly lower from the treated effluent station versus the influent. This analysis indicated that AS-OUT had statistically significantly lower TSS concentrations compared to AS-IN ($p < 0.001$; Figure 6).

To evaluate how TSS treatment efficiency may vary as a function of flow rate through the system, analyses were performed to determine the effluent flow rate at the time each aliquot was collected. The 90th percentile of the effluent aliquot flow rates was then calculated per TAPE guidelines for the entirety of the TSS data set, excluding baseflow results. Figure 7 displays treated effluent TSS concentration versus the 90th percentile sampled effluent flow rate for all qualifying events. Results from a simple linear regression indicated no significant relationship between treated TSS concentrations and effluent flow rate ($p = 0.485$). In other words, the facility demonstrated outstanding TSS removal during both minor and major storm events.

Table 5. Comparison of Austin South Bioretention Swale Composite Sample Data to TAPE Basic Treatment Requirements.						
Storm Date	Total Suspended Solids (mg/L)			90th Percentile Sampled Effluent Flow (gpm)	Peak Inflow (gpm)	Bypass Observed
	IN	OUT	Percent Reduction[a]			
2024-01-08	**22.1**	**1.6**	**93%**	40.6	221.2	–
2024-02-10	13.7	<4.5	67%	22.9	229.2	–
2024-02-27	16.2	<1.7	90%	12.6	208.6	–
2024-04-02	5.4	<2.0	63%	11.5	223.6	–
2024-04-08	5.3	<1.3	75%	12.4	204.5	–
2024-05-05	13.6	<2.0	85%	33.2	218.4	–
2024-05-18	*3.6*	*4.2*	*-17%*	*Baseflow*	*Baseflow*	*N/A*
2024-05-20	18.2	<2.0	89%	22.8	227.9	–
2024-06-02	**27.5**	**<2.5**	**91%**	37.0	185.2	True[c]
2024-06-10	*<2.0*	*<2.0*	*ND*	*Baseflow*	*Baseflow*	*N/A*
2024-06-14	**32.8**	**2.0**	**94%**	27.5	186.8	–
2024-07-28	**40.0**	**8.7**	**78%**	40.2	172.8	–
Maintenance 11/13 to 12/30/2024: Conducted infiltration tests to confirm HPBSM cells are infiltrating at design rate.						
Maintenance 12/10/2024: Top layers of mulch scarified, and new mulch added where needed. Coconut coir mats secured in cells 1.1, 2.1, 2.2, 3.1, and 3.2.						
2024-12-17	**29.2**	**<2.0**	**93%**	45.9	268.1	True
2025-01-09	**30.2**	**<2.0**	**93%**	29.5	215.7	–
Maintenance 1/14/2025: Mulch previously ordered replaced with proper coarser spec. Coconut coir mat installed along top of mulch layer.						
2025-02-19	**103**	**1.7**	**98%**	42.8	240.8	True
2025-02-22	17.4	<2.0	89%	39.3	248.8	–
2025-02-24	13.0	<2.0	85%	40.4	255.2	–
2025-03-09	14.0	<2.0	86%	46.9	218.8	–
2025-03-22	9.6	<2.0	79%	44.1	254.1	True
2025-04-06	9.8	<1.1	89%	40.1	257.8	–
2025-04-28	4.0	<2.0	50%	13.9	235.8	–
SUMMARY – All Data						
Maximum	103	8.7	98%	46.9	272.5	
Median	14	2	89%	38.1	227.9	
Minimum	2	1.1	-17%	11.5	22.0	
Total n-value	21	21	20	21	21	4
TAPE SUMMARY STATISTICS – Storm Event Data						
Criteria	-	<20	≥80%	-		
Total n-value	-	19	19			
UCL95 Mean	-	3.0	-			
LCL95 Mean	-	-	79%			

Table 5 (continued). Comparison of Austin South Bioretention Swale Composite Sample Data to TAPE Basic Treatment Requirements.						
Storm Date	Total Suspended Solids (mg/L)			90th Percentile Sampled Effluent Flow (gpm)	Peak Inflow (gpm)	Bypass Observed
	IN	OUT	Percent Reduction[a]			
TAPE SUMMARY STATISTICS – Qualifying Influent Concentration						
Criteria	-	<20	≥80%	-		
Qualifying n	-	7	7			
UCL95 Mean[b]	-	4.8	-			
LCL95 Mean[b]	-	-	87%			

[a] For sample pairs with non-detected effluent concentration, the reporting limit was used in calculating mean effluent concentrations and percent reduction. Actual concentrations in non-detected samples are typically lower than the reporting limits.

[b] Bootstrapping is typically only recommended for groups with an n-value of at least 10. Bootstrapped LCL95 and UCL95 results are presented for comparison to similar technologies only.

[c] Bypass was observed from June 1, 2024, until June 3, 2024.

Note: Grey shaded cells are baseflow events. Green shaded cells are maintenance events.

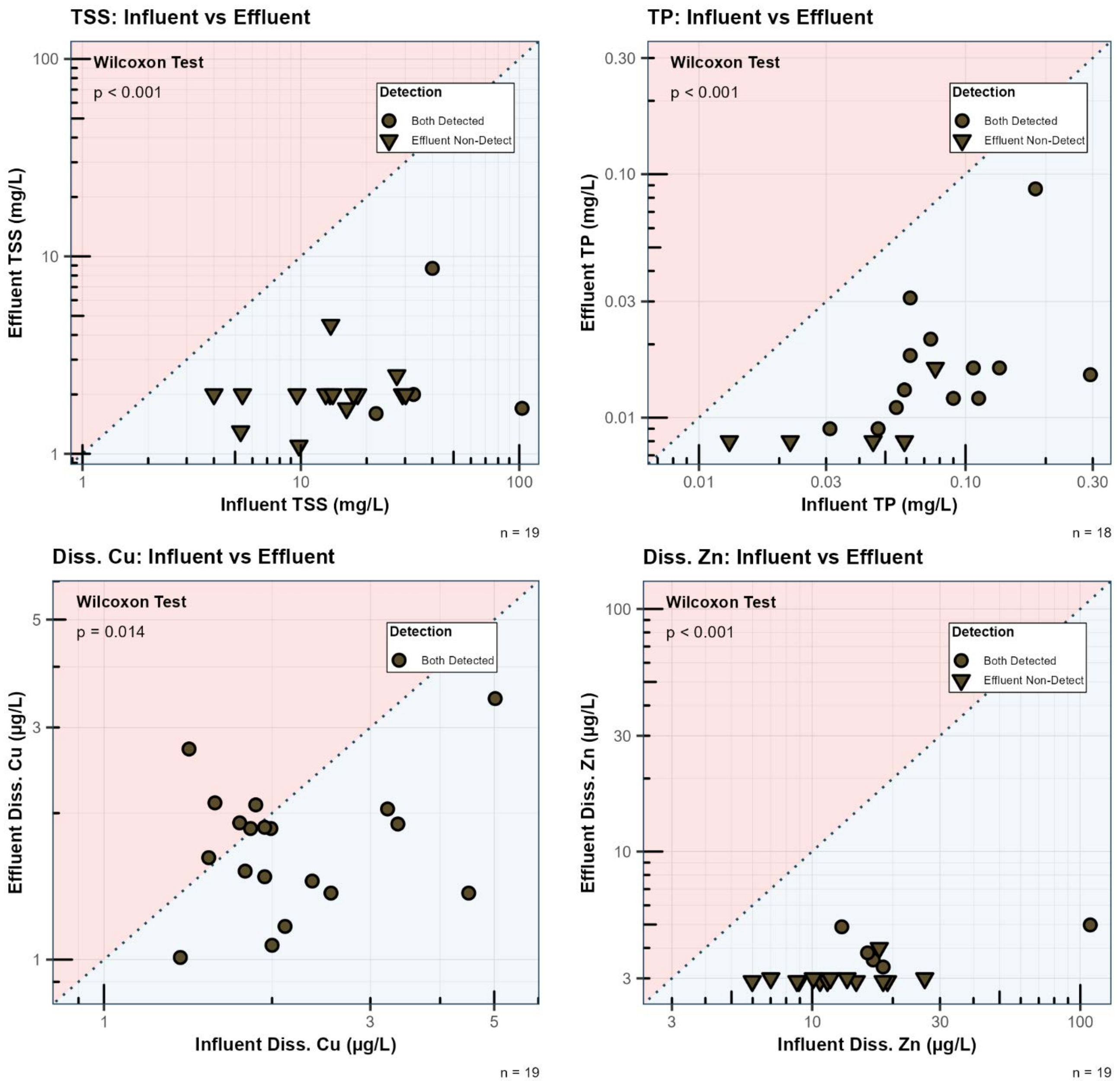
< = parameter was not detected in the sample at the reporting limit

gpm = gallons per minute

LCL95 = Lower 95th percentile confidence limit

mg/L = milligrams per liter

UCL95 = Upper 95th percentile confidence limit



Note that scales for each parameter differ. Wilcoxon signed-rank test p-value provided in upper left of each plot; sample size (n) provided below each plot at lower right. Points located below the dashed line indicated a reduction in concentration from the influent to the effluent; points above indicate an increase.

Figure 6. Paired Water Quality Sample Results for Total Suspended Solids (TSS), Total Phosphorus (TP), Dissolved Copper, and Dissolved Zinc.

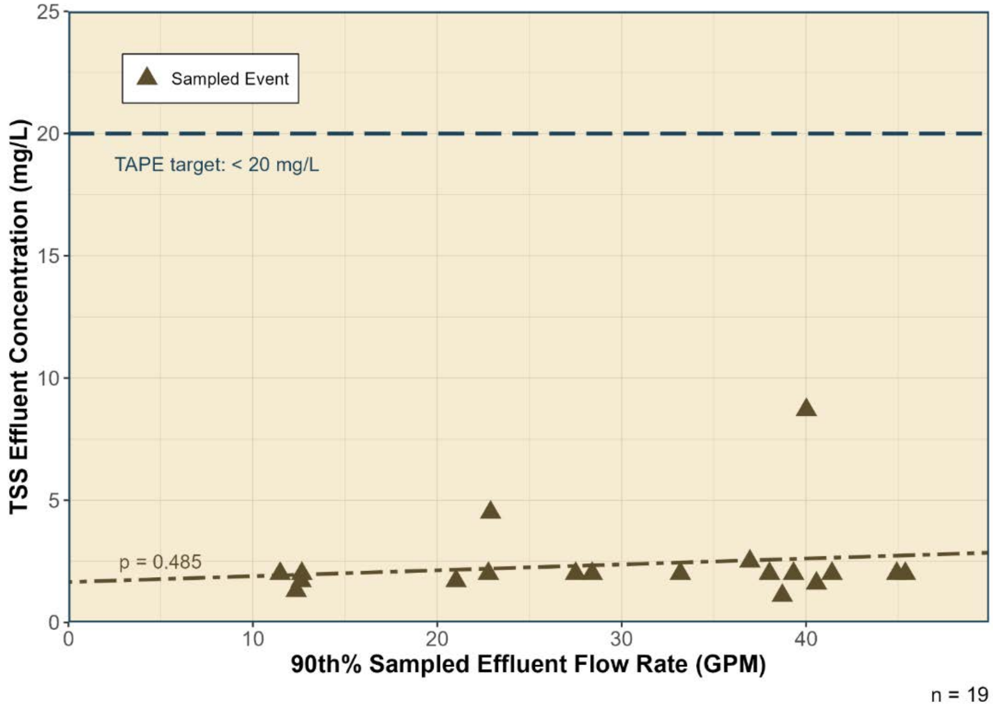


Figure 7. Total Suspended Solids (TSS) Effluent Concentration as a Function of 90th Percentile Sampled Effluent Flow Rate.

Total Phosphorus and Metals Treatment

The phosphorus treatment goal from the TAPE guidelines indicates the bootstrapped lower 95th percentile confidence limit (LCL95) of the mean total phosphorus removal efficiency must be greater than or equal to 50 percent for influent concentrations ranging from 0.1 to 0.5 mg/L. The metals treatment goal from the TAPE guidelines indicates the bootstrapped LCL95 of the mean dissolved copper and zinc removal efficiency must be greater than or equal to 30 and 60 percent, respectively, with influent ranges of 5 to 20 ug/L for dissolved copper and 20 to 300 ug/L for dissolved zinc. Finally, pollutant removals must represent a range of effluent flow rates up to and including the design flow rate.

Total Phosphorus

Of the 20 sampled events for total phosphorus (TP), 18 of which were storm events, only 4 influent composite samples had total phosphorus concentrations over 0.1 mg/L (Table 6). In general, influent pollutant concentrations were consistently lower than the lower limit of the TAPE influent criteria, but TAPE-style performance evaluations were still conducted. These results do not represent a formal TAPE study, and the HPBSM facility is not pursuing a GULD from Ecology.

For the four events with qualifying TP concentrations, the LCL95 mean TP removal was 86.6 percent. For all storm events, the LCL95 mean removal rate was 69 percent (Table 6). The overall median TP removal for all events was 79 percent. A one-tailed Wilcoxon test was performed on these data to determine if the TP concentrations were significantly lower from the treated effluent station versus the influent. This analysis indicated that AS-OUT had statistically significantly lower TP concentrations compared to AS-IN ($p < 0.001$; Figure 6).

To evaluate how TP treatment efficiency may vary as a function of flow rate through the system, analyses were performed to determine the effluent flow rate at the time each aliquot was collected. Figure 8 displays treated effluent TP concentration versus the 90th percentile sampled effluent flow rate for all qualifying events. Results from a simple linear regression indicated no significant relationship between treated TP concentrations and effluent flow rate ($p = 0.085$). In other words, the facility demonstrated excellent TP removal during both minor and major storm events.

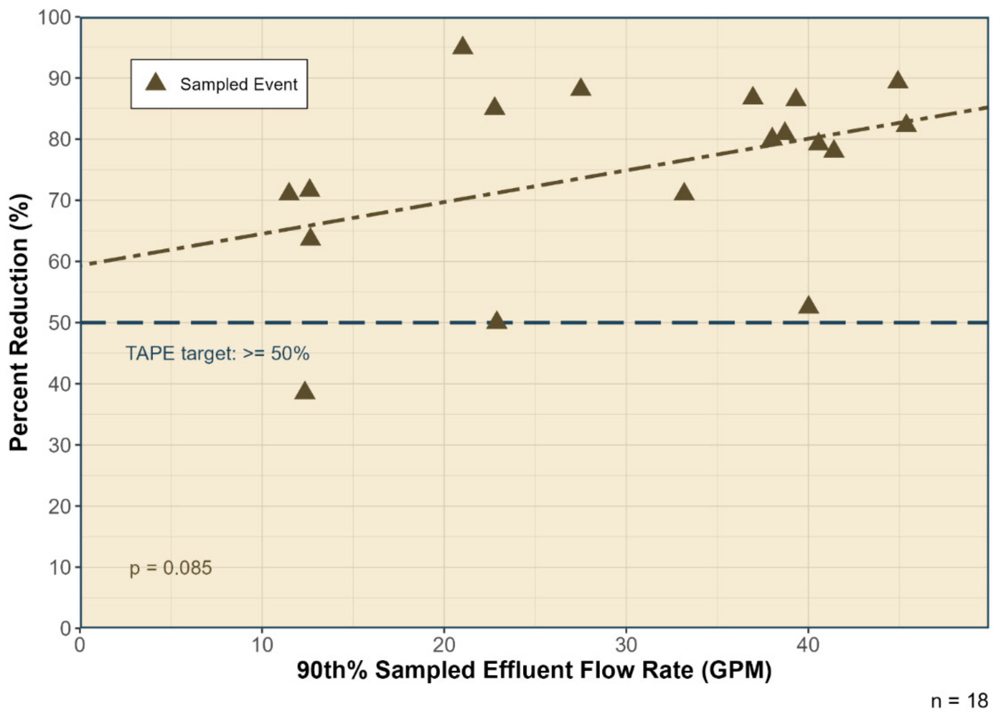


Figure 8. Total Phosphorus Effluent Concentration as a Function of 90th Percentile Sampled Effluent Flow Rate.

Metals

Of the 21 sampled events for copper and zinc, 19 of which were storm events, only one dissolved copper and two dissolved zinc influent concentrations were greater than their TAPE defined criteria, 5 and 20 ug/L, respectively (Table 6). As noted previously, in general, influent pollutant concentrations were consistently lower than the lower limit of the TAPE influent criteria, but TAPE-style performance evaluations were still conducted. These results do not represent a formal TAPE study, and the HPBSM facility is not pursuing a GULD from Ecology.

For the single event with qualifying dissolved copper concentrations, the copper removal was 31.5 percent. For all storm events, the LCL95 mean removal rate was 0.9 percent and the median removal was 15 percent (Table 6). A one-tailed Wilcoxon test was performed on these data to determine if the dissolved copper concentrations were significantly lower from the treated effluent station versus the influent. This analysis indicated that AS-OUT had statistically significantly lower dissolved copper concentrations compared to AS-IN ($p = 0.014$; Figure 6).

For the two events with qualifying dissolved zinc influent concentrations, the average dissolved zinc removal was 88.6 percent. For all storm events, the LCL95 mean removal rate was 70.7 percent and the median removal was 74 percent (Table 6). A one-tailed Wilcoxon test was performed on these data to determine if the dissolved zinc concentrations were significantly lower from the treated effluent station versus the influent. This analysis indicated that AS-OUT had statistically significantly lower dissolved zinc concentrations compared to AS-IN ($p < 0.001$; Figure 6).

To evaluate how metals treatment efficiency may vary as a function of flow rate through the system, analyses were performed to determine the effluent flow rate at the time each aliquot was collected. Figure 9 and Figure 10 display dissolved copper and zinc percent reduction versus the 90th percentile sampled effluent flow rate, respectively, for all qualifying events. Results from a simple linear regression indicated no significant relationship between treated metal concentrations and effluent flow rate (copper, $p = 0.739$; zinc, $p = 0.427$). Consequently, storm size did not have a clear impact of metals removal performance.

Table 6. Comparison of Austin South Bioretention Swale Composite Sample Data to TAPE Phosphorus and Metals Treatment Requirements.												
	Total Phosphorus (mg/L)			Dissolved Copper (ug/L)			Dissolved Zinc (ug/L)			90th Percentile Sampled Effluent Flow (gpm)	Peak Inflow (gpm)	Bypass Presence
Storm Date	IN	OUT	Percent Reduction[a]	IN	OUT	Percent Reduction[a]	IN	OUT	Percent Reduction[a]			
2024-01-08	0.077	<0.016	79.2%	4.50	1.37	69.6%	16.9	3.57	78.9%	40.6	221.2	–
2024-02-10	0.062	0.031	50.0%	1.37	1.01	26.3%	10.7	<2.92	72.7%	22.9	229.2	–
2024-02-27	0.074	0.021	71.6%	1.42	2.71	-90.8%	16.1	3.82	76.3%	12.6	208.6	–
2024-04-02	0.031	0.009	71.0%	1.79	1.52	15.1%	19.1	<2.92	84.7%	11.5	223.6	–
2024-04-08	0.013	<0.008	38.5%	2.00	1.07	46.5%	14.6	<2.92	80.0%	12.4	204.5	–
2024-05-05	0.062	0.018	71.0%	2.55	1.37	46.3%	8.93	<2.92	67.3%	33.2	218.4	–
2024-05-18	*0.015*	*0.019*	*-26.7%*	*0.82*	*1.29*	*-57.3%*	*10.6*	*<2.92*	*72.5%*	*Baseflow*	*Baseflow*	*N/A*
2024-05-20	**0.107**	0.016	**85.0%**	3.22	2.04	36.6%	11.4	<2.92	74.4%	22.8	227.9	–
2024-06-02	0.090	0.012	86.7%	2.36	1.45	38.6%	5.98	<2.92	51.2%	37.0	185.2	True[c]
2024-06-10	*0.015*	*0.010*	*33.3%*	*1.59*	*1.38*	*13.2%*	*8.59*	*<2.92*	*66.0%*	*Baseflow*	*Baseflow*	*N/A*
2024-06-14	**0.134**	0.016	**88.1%**	3.36	1.90	43.5%	8.78	<2.92	66.7%	27.5	186.8	–
2024-07-28	**0.183**	0.087	**52.5%**	**5.02**	3.44	**31.5%**	18.4	<2.92	84.1%	40.2	172.8	–
Maintenance 11/13 to 12/30/2024: Conducted infiltration tests to confirm HPBSM cells are infiltrating at design rate.												
Maintenance 12/10/2024: Top layers of mulch scarified, and new mulch added where needed. Coconut coir mats secured in cells 1.1, 2.1, 2.2, 3.1, and 3.2.												
2024-12-17	**0.112**	0.012	**89.3%**	1.87	2.08	-11.2%	17.8	<4.00	77.5%	45.9	268.1	True
2025-01-09	NA	NA	NC	2.11	1.17	44.5%	13.5	<3.00	77.8%	29.5	215.7	–
Maintenance 1/14/2025: Mulch previously ordered replaced with proper coarser spec. Coconut coir mat installed along top of mulch layer.												
2025-02-19	**0.294**	0.015	**94.9%**	1.94	1.48	23.7%	7.01	<3.00	57.2%	42.8	240.8	True
2025-02-22	0.059	0.013	78.0%	1.99	1.86	6.5%	10.1	<3.00	70.3%	39.3	248.8	–
2025-02-24	0.055	0.011	80.0%	1.54	1.62	-5.2%	**109**	4.98	**95.4%**	40.4	255.2	–
2025-03-09	0.059	<0.008	86.4%	1.94	1.87	3.6%	**26.3**	<3.00	**88.6%**	46.9	218.8	–
2025-03-22	0.045	<0.008	82.2%	1.58	2.10	-32.9%	18.4	3.34	81.8%	44.1	254.1	True
2025-04-06	0.047	0.009	80.9%	1.83	1.86	-1.6%	11.7	<3.00	74.4%	40.1	257.8	–
2025-04-28	0.022	<0.008	63.6%	1.75	1.91	-9.1%	12.9	4.89	62.1%	13.9	235.8	–
SUMMARY – All Data												
Maximum	0.294	0.087	95%	5.02	3.44	70%	109	4.98	95%	46.9	272.5	-
Median	0.0605	0.0125	79%	1.94	1.62	15%	12.9	3	74%	37.0	227.9	
Minimum	0.013	0.008	-27%	0.82	1.01	-91%	5.98	2.92	51%	11.5	172.8	
Total n-value	20	20	20	21	21	21	21	21	21	19	19	4
TAPE SUMMARY STATISTICS – Storm Event Data												
Criteria	-	-	50%	-	-	30%	-	-	60%			
Total n-value	-	-	18	-	-	19	-	-	19			
LCL95 Mean	-	-	69.0%	-	-	0.9%	-	-	70.7%			

Table 6 (continued). Comparison of Austin South Bioretention Swale Composite Sample Data to TAPE Phosphorus and Metals Treatment Requirements.												
Storm Date	Total Phosphorus (mg/L)			Dissolved Copper (ug/L)			Dissolved Zinc (ug/L)			90th Percentile Sampled Effluent Flow (gpm)	Peak Inflow (gpm)	Bypass Presence
	IN	OUT	Percent Reduction[a]	IN	OUT	Percent Reduction[a]	IN	OUT	Percent Reduction[a]			
TAPE SUMMARY STATISTICS – Qualifying Influent Concentrations (>0.1 mg/L TP; 5 ug/L Dissolved Copper; >20 ug/L Dissolved Zinc)												
Criteria	-	-	50%	-	-	30%	-	-	60%			
Qualifying n	-	-	4	-	-	1	-	-	2			
LCL95 Mean	-	-	86.6%	-	-	NC	-	-	88.6%			

[a] For sample pairs with undetected effluent concentration, the reporting limit was used in calculating mean effluent concentrations and percent reduction. Actual concentrations in non-detected samples are typically lower than the reporting limits.

[b] Bootstrapping is typically only recommended for groups with an n-value of at least 10. Bootstrapped LCL95 and UCL95 results are presented for comparison to similar technologies only.

[c] Bypass was observed from June 1, 2024, until June 3, 2024.

Note: Grey shaded cells are baseflow events. Green shaded cells are maintenance events.

< = Parameter was not detected in the sample at the reporting limit

LCL95 = Lower 95th percentile confidence limit

mg/L = milligrams per liter

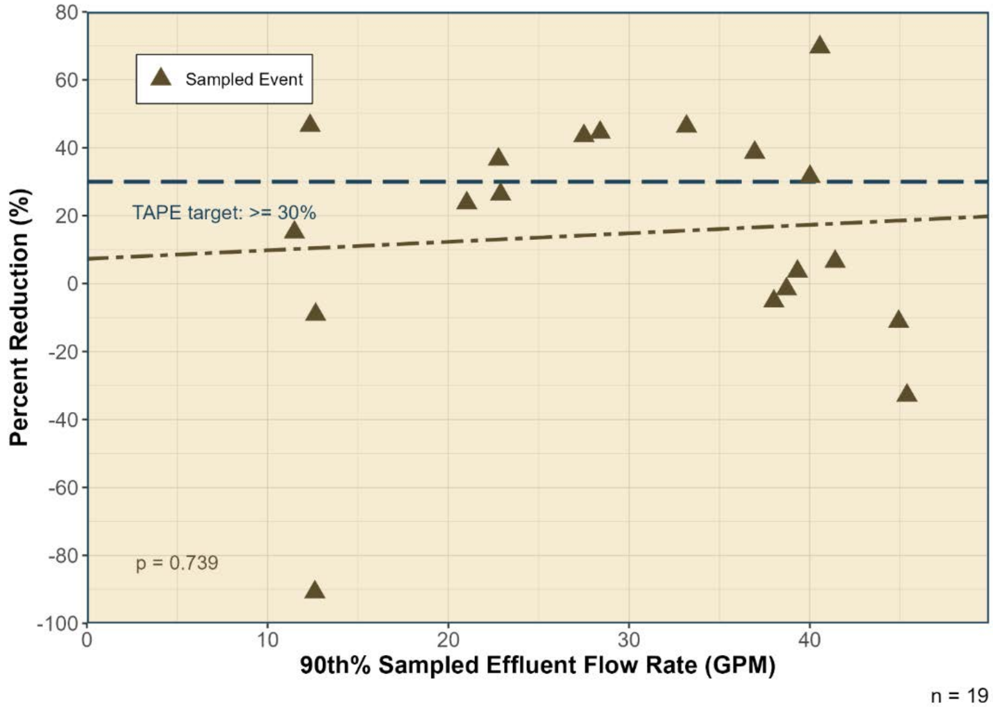


Figure 9. Dissolved Copper Effluent Concentration as a Function of 90th Percentile Sampled Effluent Flow Rate.

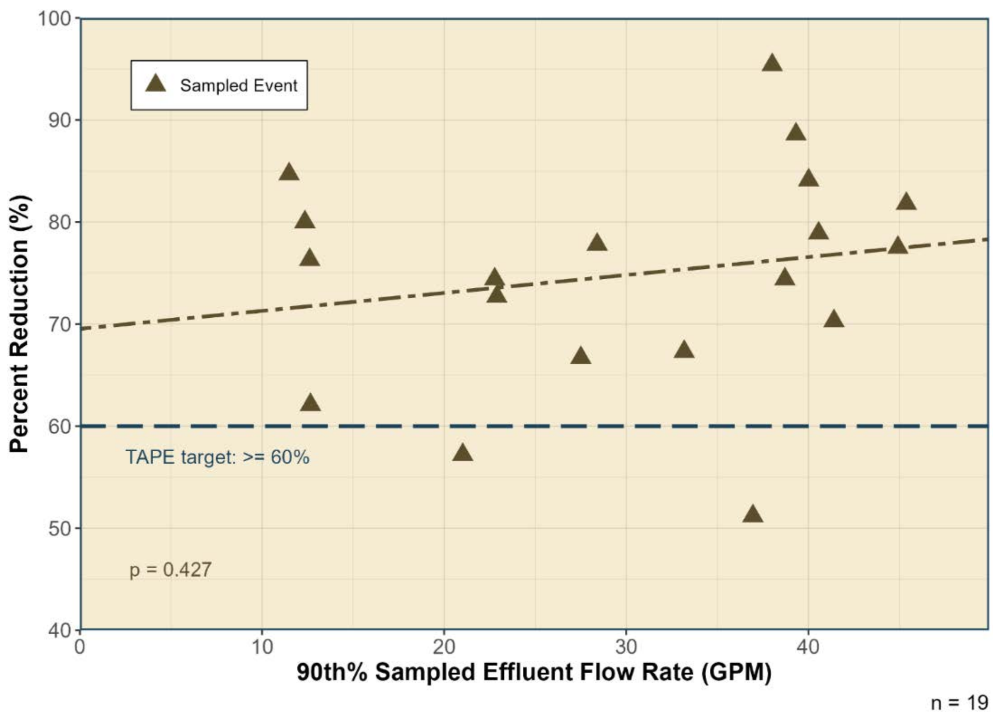


Figure 10. Dissolved Zinc Effluent Concentration as a Function of 90th Percentile Sampled Effluent Flow Rate.

4.2.3.3. Screening Parameters

In addition to the target parameters, the following screening parameters were required by TAPE to be analyzed during at least three events: orthophosphate, PSD, pH, hardness, total Kjeldahl nitrogen, nitrate+nitrite, fecal coliform, *E. coli*, total copper, and total zinc. Table 7 and Table 8 present the remaining results for composite and grab sample screening parameters, respectively. There are no performance goals associated with these additional analytes.

Table 7. Summary of Composite Screening Parameter Results from the Austin South Bioretention Swale.

Date	Total Copper (ug/L)			Total Zinc (ug/L)			Nitrate + Nitrite (mg/L)			Ortho-Phosphorus (mg/L)			Hardness (mg $CaCO_3$/L)		
	In	Out	%	In	Out	%	In	Out	%	In	Out	%	In	Out	%
2024-01-08	5.60	3.20	42.9%	30.1	4.05	86.5%	0.786	0.648	17.6%	0.005	<0.004	20.0%	40	40	0.0%
2024-02-10	2.80	1.90	32.1%	21.5	<2.92	86.4%	0.630	0.418	33.7%	0.004	<0.004	0.0%	40	36	10.0%
2024-02-27	3.44	3.71	-7.8%	25.2	3.17	87.4%	0.916	0.595	35.0%	<0.013	<0.013	NC	46	40	13.0%
2024-04-02	2.69	1.63	39.4%	26.3	<2.92	88.9%	-	-	-	0.006	0.004	33.3%	-	-	-
2024-04-08	2.68	1.49	44.4%	19.2	<2.92	84.8%	-	-	-	0.005	<0.004	20.0%	42	50	-19.0%
2024-05-05	3.95	1.82	53.9%	19.6	<2.92	85.1%	-	-	-	-	-	-	-	-	-
2024-05-18	1.08	1.63	-50.9%	11.7	3.36	71.3%	-	-	-	<0.013	<0.013	NC	-	-	-
2024-05-20	4.98	2.11	57.6%	25.3	<2.92	88.5%	-	-	-	-	-	-	-	-	-
2024-06-02	3.98	1.64	58.8%	21.4	<2.92	86.4%	0.229	0.109	52.4%	0.007	0.004	42.9%	42	46	-9.5%
2024-06-10	1.73	1.47	15.0%	10.6	<2.92	72.5%	-	-	-	0.004	<0.004	0.0%	-	-	-
2024-06-14	6.28	2.15	65.8%	31.4	<2.92	90.7%	-	-	-	<0.013	<0.013	NC	-	-	-
2024-07-28	9.04	4.71	47.9%	45.9	4.47	90.3%	0.295	0.447	-51.5%	0.010	0.006	40.0%	40	62	-55.0%
Maintenance 11/13 to 12/30/2024: Conducted infiltration tests to confirm HPBSM cells are infiltrating at design rate.															
Maintenance 12/10/2024: Top layers of mulch scarified, and new mulch added where needed. Coconut coir mats secured in cells 1.1, 2.1, 2.2, 3.1, and 3.2.															
2024-12-17	4.11	2.08	49.4%	43.2	<4.00	90.7%	-	-	-	0.015	<0.0056	62.7%	-	-	-
2025-01-09	4.13	1.32	68.0%	35.6	<3.00	91.6%	-	-	-	<0.009	<0.009	NC	-	-	-
Maintenance 1/14/2025: Mulch previously ordered replaced with proper coarser spec. Coconut coir mat installed along top of mulch layer.															
2025-02-19	10.6	1.82	82.8%	63.6	<3.00	95.3%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-02-22	4.15	2.09	49.6%	23.2	<3.00	87.1%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-02-24	4.09	1.69	58.7%	142.0	<3.00	97.9%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-03-09	3.64	1.97	45.9%	41.5	<3.00	92.8%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-03-22	2.85	2.28	20.0%	34.1	<3.00	91.2%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-04-06	2.92	2.13	27.1%	22.0	<3.00	86.4%	-	-	-	<0.009	<0.009	NC	-	-	-
2025-04-28	2.15	1.67	22.3%	17.4	3.60	79.3%	-	-	-	<0.009	<0.009	NC	-	-	-
SUMMARY (all data)															
n	21	21	21	21	21	21	5	5	5	19	19	8	6	6	6
Median	3.95	1.90	45.9%	25.3	<3.00	87.4%	0.630	0.447	33.7%	<0.009	<0.009	26.7%	41	43	-4.8%
SUMMARY (storm events only)															
n	19	19	19	19	19	19	5	5	5	17	17	7	6	6	6
Median	3.98	1.97	47.9%	26.3	<3.00	88.5%	0.630	0.447	33.7%	<0.009	<0.009	20.0%	41	43	-4.8%

Note: Grey shaded cells are baseflow events. Green shaded cells are maintenance events.

< = Sample was not detected by the laboratory at or above the detection limit. The analytical reporting limit is listed as an

– = Parameter not analyzed

µg/L = Micrograms per liter

mg/L = Milligrams per liter

NC = Not calculated. Percent reductions were not calculated for influent and effluent sample pairs that were both undetected.

Table 8. Summary of Grab Screening Parameter Results from the Austin South Bioretention Swale.									
	Fecal Coliform (CFU/100 mL)			*E. Coli* (CFU/100 mL)			pH (std. units)		
Date	**IN**	**OUT**	**% Red.**	**IN**	**OUT**	**% Red.**	**IN**	**OUT**	**% Red.**
2024-02-10 15:45	92	11	88%	92	11	88%			
2024-02-27 10:30	116	2	98%	116	2	98%	8.11	8.56	-6%
2024-05-18 03:12	<2	7	-250%	<2	7	-250%			
2024-05-20 21:15	350	21	94%	350	21	94%	10.42	8.49	19%
2024-06-02 02:35	2400	70	97%	2200	56	97%	6.04	6.26	-4%
2024-06-07 12:54	5	11	-120%	5	11	-120%			
2024-06-10 12:21	7	7	0%	7	7	0%			
Maintenance 11/13 to 12/30/2024: Conducted infiltration tests to confirm HPBSM cells are infiltrating at design rate.									
Maintenance 12/10/2024: Top layers of mulch scarified, and new mulch added where needed. Coconut coir mats secured in cells 1.1, 2.1, 2.2, 3.1, and 3.2.									
2024-12-17 01:45	370	2	99%	280	<2	99%			
2025-01-09 19:30	155	3	98%	155	3	98%			
Maintenance 1/14/2025: Mulch previously ordered replaced with proper coarser spec. Coconut coir mat installed along top of mulch layer.									
2025-02-15 11:00	91	2	98%	91	2	98%			
2025-02-22 06:30	430	10	98%	430	8	98%			
2025-02-24 06:15	145	5	97%	145	5	97%			
2025-03-22 11:45	200	10	95%	200	10	95%			
2025-03-26 06:30	500	<2	100%	200	<2	99%			
2025-04-06 03:45	26	2	92%	26	2	92%			
2025-04-08 08:45	230	8	97%	230	8	97%			
2025-04-28 07:00	127	5	96%	91	2	98%			
SUMMARY (all data)									
n	17	17	17	17	17	17	3	3	3
Median	145	7	97%	145	7	97%	8.11	8.49	-4%
SUMMARY (storm events only)									
n	14	14	14	14	14	14	3	3	3
Median	178	5.00	97%	177.50	4.00	98%	8.11	8.49	-4%

Note: Grey shaded cells are baseflow events. Green shaded cells are maintenance events.

CFU/100 mL = colony-forming units per 100 milliliters

4.3. Plant Health and Vigor

In November 2023, native plants were installed as part of the final construction phase of the bioretention pilot project. A Herrera landscape architect inspected all vegetation prior to plantings to ensure that they arrived in good condition and confirmed that they were planted at appropriate depths and spacing over several days. Due to smaller-than-anticipated clearance between the road prism and the edge of the bioretention swales, some plants intended for the bioretention swale side slopes were relocated to upland areas. The cell bottoms (Zone 1), where HPBSM was placed, were planted with species from the Zone 1 Planting list, as well as 67 *Rosa gymnocarpa* shrubs. The Zone 1 summary table provided in Appendix G reflect these adjusted counts and planting locations.

Photos taken by stakeholders, maintenance staff, and monitoring staff during construction and throughout the monitoring period (November 2023 to April 2025) are presented in a photo log in Appendix G.

On July 30 and July 31, 2025, Herrera's landscape architect conducted a site visit to count and assess the plantings. Conditions were dry, with no recent rainfall and with temperatures in the mid-70s degrees Fahrenheit. The bioretention cell bottoms were observed to have been modified with wood chips covered by jute netting secured with landscape staples. These materials appeared clean and free of silt, suggesting no significant runoff events had occurred since the installation. Additionally, rounded rock (2 to 4 inches in diameter) had been placed in the splash zones just downstream of the weir plates, displacing or covering any surviving vegetation in those areas. The site was largely free of weeds, with some weed presence limited to the southernmost (uphill) cell. Table 9 and Table 10 summarize the plant health and vigor results from the July 2025 site visit. The tables provided in Appendix G provide additional vegetation observations from the July 2025 site visit, including the sizes, counts, positions, and conditions of plants in the upland zones as well as the cell bottoms (Zone 1).

Table 9. Plant Health and Vigor Results – July 2025.

Plant Species	Quantity Planted	Percent Survival	Surviving Condition			
			Poor	Fair	Average	Excellent
Upland						
Acer circinatum	9	51 to 75%	44%	11%	-	-
Mahonia repens	100	11 to 30%	15%	-	-	-
Philadelphus lewisii	100	31 to 50%	-	8%	42%	-
Polystichum munitum	152	76 to 100%	-	79%	-	-
Rosa gymnocarpa	83	76 to 100%	-	19%	-	59%
Symphoricarpos albus	100	76 to 100%	-	5%	73%	-
Cell Bottom						
Carex obnupta	150	76 to 100%	-	-	-	95%
Carex stipata	100	76 to 100%	-	-	-	85%
Iris douglasiana	50	0 to 10%	4%	-	-	-
Juncus patens	150	31 to 50%	-	-	37%	-
Rosa gymnocarpa	67	51 to 75%	-	-	58%	-

Table 10. Austin South Bioretention Swale Cover and Establishment – July 2025.			
Facility Element	**Percent Weedy Species Cover**	**Percent Cover**	**Percent Bare Ground**
Upland Area	0 to 10%	0 to 25%	76 to 100%
Cell Bottom	0 to 10%	0 to 25%	76 to 100%

Throughout the monitoring period, flow conditions caused surface scouring of the bioretention cells, which led to the installation of the jute netting and wood chips on the cell bottoms circa January 2025. The vegetation's health and ability to successfully establish were negatively impacted by this surface scouring. Therefore, definitive conclusions about the performance of HPBSM as a media to establish and support healthy vegetation cannot be drawn for this Project.

5. Operation and Maintenance

System maintenance was conducted at the site on an as-needed basis during the duration of the monitoring period. General maintenance activities and observations are summarized in Table 11 and included in the field forms (Appendix G).

Table 11. Maintenance Activities Summary.

Date	Maintenance Activity
2023-12-15	Scheduled maintenance was performed on CS30. The crew reinstalled the control structure and vactored material out of the sump. Scheduled maintenance was performed for structure in the Cable and Geneva intersection.
2024-12-10	County performed maintenance to scarify top layers of mulch, add new mulch as needed, and secure coir on the cells in all three Cascades that seemed to be the most plugged with moss and algae. Maintenance was conducted by Whatcom County on the first two bioretention cells of every Cascade. The mulch that was installed during this maintenance round was different from what was originally installed and was noted not to stay in place well.
2025-01-09	Coir mat was installed some time prior to this site visit.
2025-01-14	Coir was installed in top two bioretention cells in each Cascade.

5.1. Bypass Frequency Evaluation

As discussed previously in the Hydrologic Data Collection Procedures and Hydrologic Data sections, bypass frequency and volume was not evaluated or quantified due to the low confidence in the estimated influent flows and because bypass flows were unable to be measured. However, bypass was observed during four of the water quality sampling events, as shown in Table 5. During each observed bypass event, the 90th percentile effluent flow rate did not surpass the design treatment flow rate of 71.6 gpm for Cascade 1, meaning that the observed bypass occurred during event sizes that the system was designed to capture. This could be because the system was either receiving too much flow or was not infiltrating at the design rate.

During November and December 2024, Whatcom County conducted a series of infiltration tests to determine the HPBSM media infiltration rates across various bioretention cells. Infiltration rates were found to be greater than design infiltration rate of 6 in/hr in Cascade 1 and Cascade 3 but below 6 in/hr in two zones of Cascade 2. Results of the infiltration tests are summarized in Appendix I. The results of these infiltration tests support the assumption that Cascade 1 maintained hydraulic performance, indicating that infiltration performance likely did not contribute to the observed instances of bypass.

6. Conclusions

The Austin South bioretention swales were monitored for pollutant reduction in the manner of a typical TAPE project, assessing the system for basic, phosphorus, and metals treatment. Monitoring began in December 2023 and concluded in April 2025. During the monitoring period, composite samples from 19 storm and two base flow events, in addition to grab samples from 15 storm and three base flow events, were sampled to characterize the water quality treatment performance of the Project.

The water quality data were assessed against method quality objectives established for each of the quality assurance indicators defined in the project QAPP (Herrera 2023). Some of the water quality data were qualified as estimates during the assessment of data completeness and comparability; however, no data were rejected, and all individual values were carried forward into the analyses with some additional qualifications (see Appendix E). While some storm events didn't meet all Representativeness criteria, enough benchmarks were achieved for the data to remain scientifically valid. Storm coverage was the most common deviation, but given that the Project's dosing system did not predictably respond to surface runoff, this criterion was less relevant and did not impact the usefulness of the water quality data.

The hydrologic data were also assessed against method quality objectives established for each of the quality assurance indicators defined in the project QAPP (Herrera 2023). The hydrologic data precision and bias assessments were completed as specified in the project QAPP. Despite proper equipment assessment and installation, there were sensor calibration challenges at the inlet flow sensor and inaccurate water level readings at the bypass station. Therefore, cumulative bypass volume could not be quantified, and a complete hydraulic mass balance of the system was not possible, so the Completeness quality assurance indicator was therefore not achieved for the hydrology data. Considering this, treated effluent volume was used to represent a confirmed minimum volume that passed through the Project, with true volume entering the Project likely being greater.

For TSS, total phosphorus, and dissolved copper and zinc, the influent concentrations frequently did not meet the lower limits of the TAPE influent criteria (Table 12). However, because the system is not being evaluated for a GULD, nor is an application planned, removal rates were evaluated for all storm events with composite samples.

The Project met the TAPE criteria for Basic Treatment, achieving effluent concentrations and removal rates within the required benchmarks for TSS. The system also met the TAPE criteria for phosphorus removal, with observed reductions exceeding the minimum thresholds even though many influent concentrations were below the formal evaluation range. This total phosphorus removal rate is very high when compared with other stormwater best management practices, and the median effluent TP concentration was 0.013 mg/L, meeting forested conditions for the Lake Whatcom basin (Matthews et al. 2002).

Table 12. Summary of Austin South Bioretention Swale Performance Compared to TAPE Benchmarks.			
Performance Goal	**TAPE Benchmarks**	**UCL95/LCL95 Results (Events Meeting TAPE Criteria for Influent Concentration) [a]**	**UCL95/LCL95 Results (All Storm Events)**
Basic Treatment (TSS Removal)	Effluent Concentration UCL95 <20 mg/L when Influent TSS between 20 and 100 mg/L	4.8 mg/L (n=7)	3.0 mg/L (n=19)
	Removal Rate LCL95 >80% when TSS >100 mg/L[b]	87.0% (n=7)	79.0% (n=19)
Phosphorus Treatment	Removal Rate LCL95 >50%	86.6% (n=4)	69% (n=18)
Metals Treatment	Dissolved Copper Removal Rate LCL95 >30%	NC (n=1)	0.9% (n=19)
	Dissolved Zinc Removal Rate LCL95 >60%	88.6% (n=2)	70.7% (n=19)

[a] Influent criteria minima are 20 mg/L for TSS, 0.1 mg/L for total phosphorus, 5 ug/L for dissolved copper, and 20 ug/L for dissolved zinc.

[b] Only one sample exceeded 100 mg/L TSS, but all values were used to calculate this removal rate.

Bacteria removal was also very high with observed median fecal coliform and *E. coli* reductions of 97 and 98 percent, respectively. Considering these results alongside the observed total phosphorus reductions, the Austin South bioretention swale is performing as a highly effective best management practice for achieving Lake Whatcom's TMDL objectives.

The system did not meet dissolved copper treatment criteria because the influent concentrations were too low to assess against TAPE standards. While effective for basic and phosphorus treatment, its performance on copper remains unclear under current conditions.

The vegetation health and establishment assessment conducted at the completion of the water quality monitoring period suggested that the surviving conditions of the vegetation in the upland zones of the Project ranged from poor and excellent, while several species located in the bioretention cell bottoms were either in average or excellent surviving condition. The Project was largely free of weeds but also had low (0 to 25 percent) vegetation coverage in general. However, definitive conclusions about the performance of HPBSM as a media to establish and support healthy vegetation cannot be drawn for this Project due to surface scouring of the bioretention cells resulting from the Project's flow conditions.

Routine inspection and maintenance were conducted at the site multiple times throughout the monitoring period. Due to the low confidence in estimated influent flows and lack of reliable bypass flow measurements, it is not possible to reliably draw conclusions about how the maintenance performed at the site impacted the Project's hydrologic performance. However, infiltration testing conducted by the County confirmed that Cascade 1 maintained its hydraulic performance, and reduced infiltration rates likely did not contribute to the observed instances of bypass.

7. References

APHA, AWWA, and WEF. 1992. Standard Methods for the Examination of Water and Wastewater. 18th edition. Edited by A. Greenberg, A.D. Eaton and L. Clesceri. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC.

APHA, AWWA, and WEF. 1998. Standard Methods for the Examination of Water and Wastewater. 20th edition. Edited by A. Greenberg, A.D. Eaton and L. Clesceri. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC.

ASTM. 2007. Book of Standards. Volume 7.02 – Water and Environmental Technology: Water (II). American Society for Testing and Materials, International, West Conshohocken, Pennsylvania.

Ecology. 1997. Analytical Methods for Petroleum Hydrocarbons. Publication No. ECY 97-602. Washington State Department of Ecology, Olympia, Washington. June.

Ecology. 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Publication No. 04-03-030. Washington State Department of Ecology, Olympia, Washington. Revised December 2016.

Ecology. 2018. Technical Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE). Publication No. 18-10-038, Washington State Department of Ecology, Olympia, Washington.

Ecology. 2019. 2019 Stormwater Management Manual for Western Washington: Volume V – Runoff Treatment BMPs. Washington State Department of Ecology, Olympia, Washington.

Ecology. 2021. Guidance on Using New High Performance Bioretention Soil Mixes. Publication 21-10-023. Washington State Department of Ecology, Olympia, Washington.

Efron, B., and R.J. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman & Hall, New York City, New York.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical Methods in Water Resources. Elsevier, Amsterdam.

Herrera. 2021. Comprehensive Bioswale and Filter Vault Evaluation Report: Geneva Neighborhood, Whatcom County, Washington. Prepared for Whatcom County Public Works Department by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2023. Quality Assurance Project Plan, Geneva Bioretention Pilot Project. Prepared for Whatcom County Public Works Department by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2024. Quality Assurance Project Plan Addendum, Geneva Bioretention Pilot Project Contaminants of Emerging Concern, Whatcom County, Washington. Prepared for King County Water and Land Resources Division and Whatcom County Public Works Department by Herrera Environmental Consultants, Inc., Seattle, Washington.

Hua, X.Y., D.M. Dong, L. Liu, M. Gao, and D.P. Liang. 2012. Comparison of Trace Metal Adsorption onto Different Solid Materials and Their Chemical Components in a Natural Aquatic Environment. Applied Geochemistry 27(5):1005–1012.

Matthews, R., M. Hilles, and G. Pelletier. 2002. Determining Trophic State in Lake Whatcom, Washington (USA), a Soft Water Lake Exhibiting Seasonal Nitrogen Limitation. Hydrobiologia 468:107–121.

Porter, P.S., S.T. Rao, J.Y. Ku, R.L. Poirot, and M. Dakins. 1997. Small sample properties of nonparametric bootstrap t confidence intervals. Journal of Air and Waste Management Association 47:1197–1203.

US EPA. 1983. Methods for Chemical Analysis of Water and Wastes. EPA 600/4 79 020, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Washington, DC.

US EPA. 1984. Guidelines Establishing Test Procedures for the Analysis of Pollutants under the Clean Water Act; Final Rule and Interim Final Rule. CFR Part 136, U.S. Environmental Protection Agency, Washington, DC.

US EPA. 1996. Sampling ambient water for trace metals at EPA water quality criteria levels. (Method 1669). U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC.

US EPA. 2002. Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements. EPA-821-B-02-001. U.S. Environmental Protection Agency, Washington, DC.

US EPA. 2007. 40 CFR Part 122, 136, 141, 143, 430, 455, and 456; Guidelines Establishing Test Procedures for the Analysis of Pollutants under the Clean Water Act; National Primary Drinking Water Regulations; and National Secondary Drinking Water Regulations; Analysis and Sampling Procedures; Final Rule. Federal Register. U.S. Environmental Protection Agency, Washington, DC.

Walkowiak, D.K. (Editor). 2006. Isco Open Channel Flow Measurement Handbook. Teledyne Isco, Inc., Lincoln, Nebraska.