TECHNICAL EVALUATION REPORT

StormGarden™ Biofilter System Performance Certification Project

Prepared for
Rotondo Environmental Solutions, LLC

Prepared by
Herrera Environmental Consultants, Inc.

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Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

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Prepared for
Rotondo Environmental Solutions, LLC
4950-C Eisenhower Avenue
Alexandria, Virginia 22304

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

June 10, 2019

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EXECUTIVE SUMMARY

The Rotondo StormGarden™ modular biofiltration system (StormGarden) is a water quality treatment device consisting of a vertical flow media bed with underdrain. The system is housed in a precast concrete vault and can be configured for application in most urban drainage conditions.

From April 20, 2017, through November 22, 2018, Herrera Environmental Consultants, Inc. (Herrera) conducted hydrologic and water quality monitoring of a StormGarden for Rotondo Environmental Solutions, LLC (Rotondo) at a test facility in Seattle, Washington. Herrera conducted the monitoring to obtain performance data to support the issuance of a General Use Level Designation (GULD) for the StormGarden by the Washington State Department of Ecology (Ecology). Monitoring was done in accordance with procedures described in the *Guidance for Evaluating Emerging Stormwater Treatment Technologies; Technology Assessment Protocol – Ecology (TAPE)* (Ecology 2011).

Installation of the monitored StormGarden™ system at the Ship Canal Test Facility in Seattle, Washington.

This technical evaluation report (TER) was prepared by Herrera to demonstrate that the StormGarden meets minimum treatment goals identified in the TAPE to obtain a GULD for basic (total suspended solids) and phosphorus treatment.

This report was prepared after 22 storm events were successfully sampled to characterize the stormwater treatment performance of a StormGarden installed at the Washington State Department of Transportation (WSDOT) Ship Canal Test Facility (SCTF), in Seattle. The sampling yielded 21 paired influent and effluent composite samples and 8 paired grab samples, with one of the grab sample pairs collected during an event where no composite samples were collected.

Sampling Procedures

To evaluate the stormwater treatment performance of the StormGarden based on Ecology's TAPE guidelines, a test system was installed at the SCTF. That test StormGarden is identified herein as the "WB test system." Automated monitoring equipment was installed to continuously measure influent, effluent, and bypass flow volumes for the WB test system. Automated equipment was also installed to collect flow-weighted composite samples of the system's influent and effluent during 22 separate storm events over the monitoring period.

The collected flow-weighted composite samples were analyzed for the following water quality parameters:

- Total suspended solids (TSS)
- Particle size distribution
- Total and dissolved copper
- Total and dissolved zinc
- Total phosphorus (TP)
- Orthophosphorus
- Hardness

In addition, pH was measured in the field during three events, and grab samples were collected during nine storm events and analyzed for total petroleum hydrocarbons. Additional parameters were also analyzed, and the associated results are included in the appendices to this report. However, the main body of this report only presents results for TSS and TP, which are required monitoring parameters pursuant to the TAPE guidelines for assessing basic and phosphorus treatment. The water quality data were subsequently analyzed in the following ways:

- Computation of pollutant removal efficiencies
- Statistical comparisons of influent and effluent concentrations
- Regression analysis to examine the influence of influent flow rate on system performance

The results were then compared to the TAPE goals for basic and phosphorus treatment.

Hydraulic Performance

The WB test system was sized to capture and treat 91 percent of the average annual runoff volume pursuant to minimum requirements for runoff treatment in western Washington. With that sizing and typical pollutant loads in urban stormwater runoff, Rotondo estimates the StormGarden will require maintenance every 6 to 12 months.

The WB test system treated 67 percent of a typical water year during its first year of operation (the remainder of the flow was bypassed), which does not meet the minimum requirement identified above. The StormGarden includes a 3-inch layer of shredded wooden mulch on the surface of the filter media bed (the same mulch as is used in the previously approved Filterra™ system). Due to instances of excessive sediment and oil buildup on top of the mulch layer for the WB test system, the mulch was replaced four times during the first year of operation and five times over the full 19 months of operation. Over the same period, three different systems in adjacent bays at the SCTF (an upward flow media filter, a pleated fabric filter, and another treebox filter) were requiring maintenance at similar intervals. Ecology has subsequently determined that stormwater at the SCTF is atypical for manufactured treatment device applications due to the intermittent occurrence of excessive sediment and oil loading.

It is important to note that the mulch layer was functioning as designed; it was removing sediments that would otherwise clog the engineered filter media. Two days after the final mulch change on November 20, 2018, the system achieved a peak treated flow rate of 38.8 gallons per minute (gpm), which is above the design flow rate of 35 gpm. As with most Manufactured Treatment Devices (MTDs), typical maintenance intervals are based on typical pollutant loading rates, which for the StormGarden is once every 12 months. However, in cases where a site generates excessive amounts of pollutants, such as the SCTF, most MTDs will require additional maintenance visits to maintain the system's design flow rate, as was the case with the StormGarden system tested herein. Therefore, it is reasonable to assume that the StormGarden Biofilter should operate properly under typical maintenance intervals on sites that generate typical pollutant loads.

Water Quality Performance

Basic Treatment

The basic treatment goal in the TAPE guidelines is ≥80 percent removal of TSS for influent concentrations ranging from 100 to 200 milligrams per liter (mg/L). For concentrations less than 100 mg/L, treatment technologies must achieve an effluent goal of ≤20 mg/L.

Out of the 21 sampled storm events, influent samples from 5 events had concentrations below 20 mg/L, and one event was excluded by the BER; consequently, only the samples from the remaining 15 events were used to assess performance. TSS removal rates ranged from 76 to 98 percent and the lower 95th percentile confidence limit (LCL95) around the mean removal was

85.1 percent, exceeding the percent removal goal identified above. Additionally, the upper 95th percentile confidence limit (UCL95) of the mean effluent concentration was 5.4 mg/L, below the effluent goal identified above. A regression analysis of sampled influent flow rate versus TSS removal indicated that the tested StormGarden achieved ≥80 percent removal up to and including the design flow rate of 35 gpm (140 inches per hour, 1.46 gpm/square foot [ft^2] of media).

Phosphorus Treatment

The phosphorus treatment goal in the TAPE guidelines is ≥50 percent removal of TP for influent concentrations ranging from 0.1 to 0.5 mg/L. For this analysis sample pairs with influent below 0.1 mg/L were included in the analysis to generate a conservative estimate of removal while also obtaining enough sample pairs (19) to meet the TAPE minimum of 12. The LCL95 of the mean TP removal for samples collected during these events was 53.4 percent, exceeding the percent removal goal identified above. A regression analysis of sampled flow rate versus TP removal indicated that the system can achieve ≥50 percent removal up to and including the design flow rate of 35 gallons per minute (140 inches per hour, 1.46 gpm/ft^2 of media).

Recommendation

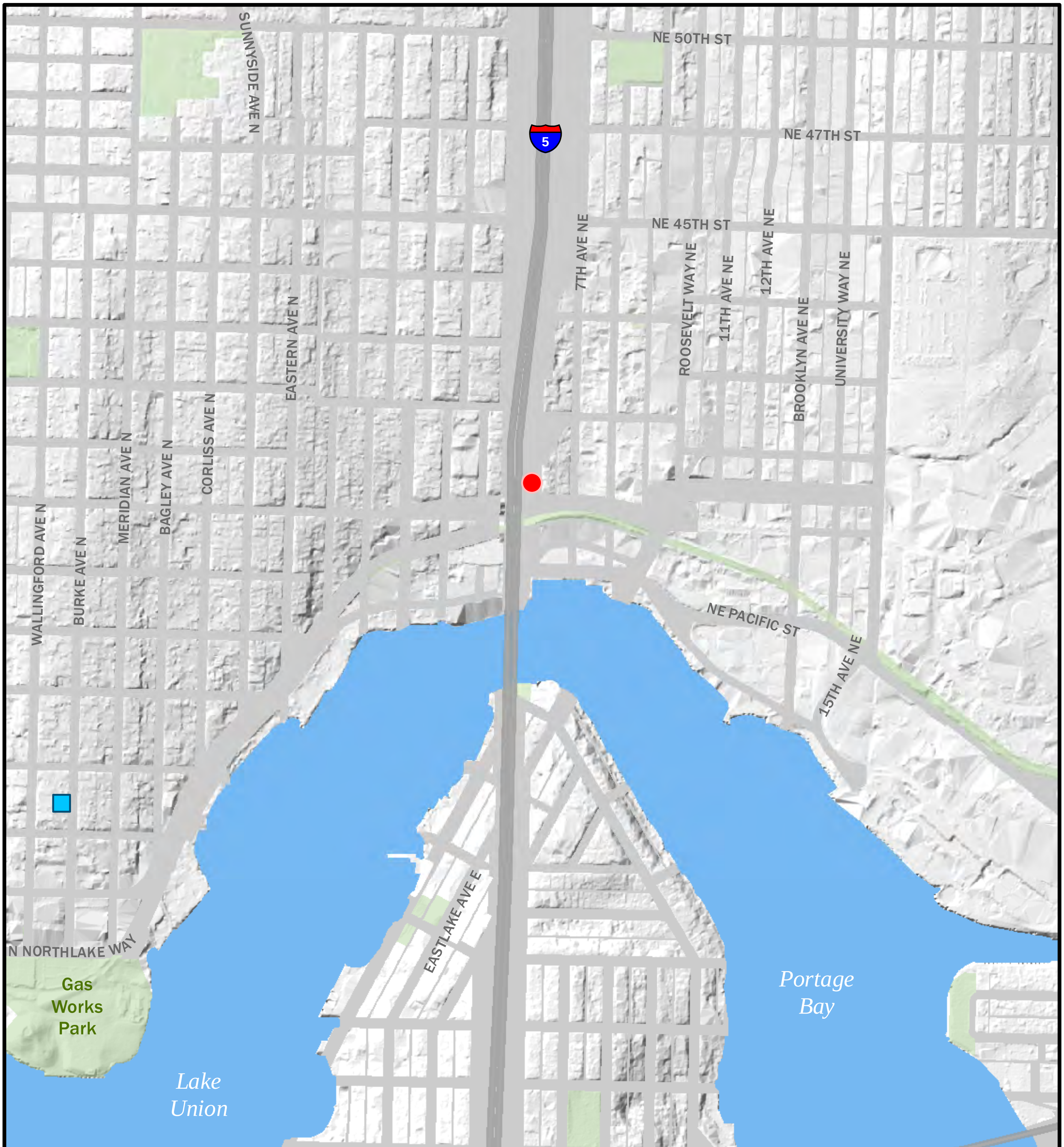
Based on the performance results presented above, it is recommended that the StormGarden system be granted a GULD for basic and phosphorus treatment when sized based on a surface loading rate of 1.46 gpm/ft^2 of media.

INTRODUCTION

The StormGarden™ modular biofiltration system (StormGarden) is a structural stormwater treatment system developed by Rotondo Environmental Solutions, LLC. It is a water quality treatment device consisting of a vertical flow media bed with underdrain. The system is housed in a precast concrete vault and can be configured for application in most urban drainage conditions.

The Washington State Department of Ecology (Ecology) has established specific use level designations for emerging stormwater treatment technologies, like the StormGarden, in accordance with guidelines that are identified by Ecology (2011) in the *Technical Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology* (*TAPE*) (TAPE guidelines). There are three use level designations: pilot, conditional, and general. Pilot and conditional use level designations allow limited application of emerging stormwater treatment technologies in Washington to facilitate field testing. If the testing shows that the treatment technology meets minimum treatment goals identified in the TAPE guidelines, Ecology may issue a general use level designation (GULD) for the treatment technology, permitting its widespread use in Washington. The TAPE guidelines require preparation of a technical evaluation report (TER) for any stormwater treatment system under consideration for a GULD. The TER must demonstrate a treatment technology will achieve Ecology's performance goals for target pollutants, as shown by field testing performed in accordance with the TAPE guidelines.

The StormGarden currently has a conditional use level designation (CULD) (Ecology 2018a) for basic and phosphorus treatment. Herrera Environmental Consultants, Inc. (Herrera) prepared this TER to support the issuance of a GULD for the StormGarden in these same treatment categories. It specifically presents data from monitoring that was performed on a test StormGarden system (WB test system) at the Ship Canal Test Facility (SCTF) in Seattle, Washington (Figure 1). The monitoring involved the collection of water quality and flow data from the WB test system over a 19-month period extending from April 20, 2017, through November 22, 2018. During that period, 22 storm events were sampled yielding 21 paired influent and effluent composite samples and 8 paired grab samples to characterize the treatment performance of the WB test system. This report is organized to present a description of the StormGarden treatment technology, sampling procedures used during the monitoring, detailed summaries of the compiled data, and major conclusions from the monitoring.



Legend

- Project area
- Project rain gauge

**Figure 1.
Site Vicinity Map, WSDOT Ship Canal Facility, Seattle, Washington.**

N

0 500 1,000 2,000 Feet

HERRERA

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TECHNOLOGY DESCRIPTION

The StormGarden is a "living filter" that can support flora and fauna while treating stormwater. It uses a horizontal filter bed that incorporates an advanced media designed to remove gross solids, suspended solids, nutrients, metals, hydrocarbons, and other stormwater pollutants. The system tested is a self-contained, curb inlet style, stormwater treatment system that functions as an offline stormwater treatment device (Figure 2). The major components (media, plants, and drainage infrastructure) are packaged in a prefabricated concrete container. The concrete container is covered with a prefabricated concrete top slab with vegetation that extends through a tree grate cast into the top slab.

Figure 2. The StormGarden Design.

The following subsections provide more detailed information on the StormGarden system's physical components, treatment processes, sizing methods, expected treatment capabilities, expected design life, and maintenance procedures. Alternate configurations of the StormGarden for underground vault type applications are provided in Appendix A. All configurations have the same media composition and depth, sizing, influent flow distribution, and bypass hydraulics.

Physical Components

The test StormGarden includes the following physical components. Each is described below.

- Concrete container
- Inlet
- Surface storage
- Mulch layer
- Engineered filter media
- Vegetation
- Underdrain

Concrete Container

The StormGarden is housed in a concrete container that is available in a variety of precast sizes (ranging from a 4-foot by 6-foot box to a 7-foot by 13-foot box). Each StormGarden vault is designed and constructed to withstand an H-20 non-live load, which is typical for behind-the-curb applications. The container floor and walls are manufactured from 4- to 6-inch-thick reinforced concrete. The top slab of the StormGarden is manufactured with a minimum of 8-inch-thick concrete. The top slab also contains a standard or decorative tree grate rated to withstand pedestrian loading. A schematic of the StormGarden is shown in Figure 2.

The StormGarden Biofilter can also be installed as an underground vault as detailed in Appendix A of this report.

Inlet

The standard StormGarden is designed to be offline. It is typically installed upstream of a standard stormwater catch basin or inlet, and is configured and sized to intercept the treatment flow before it reaches the standard downstream inlet. Stormwater runoff enters the system along the curb line through a 4- to 6-inch curb inlet throat. Fist-sized, rounded rocks are placed along the front of the curb inlet throat just inside of the StormGarden to dissipate the velocity of runoff entering the system. Pretreatment is not required in combination with the StormGarden;

however, pretreatment chambers are available for StormGardens to extend the life of the filter media. (The WB test system installed at the SCTF did not include a pretreatment chamber.)

Surface Storage

The StormGarden is typically designed with approximately 9 inches of freeboard, as measured from the surface of the engineered filter media layer to the gutter elevation at the curb face. That ponding area provides surface storage for a portion of the water quality treatment volume and promotes settling of suspended solids typically present in stormwater.

Mulch Layer

The StormGarden includes a 3-inch layer of shredded wooden mulch on the surface of the filter media. The mulch provides pretreatment and protection of the engineered filter media by filtering out large particles (suspended solids) that would otherwise prematurely clog the filter media below. The mulch layer also helps retain moisture in the system, supporting plant growth.

Engineered Filter Media

The mulch layer is underlain by 21 inches of specially engineered filter media in a standard StormGarden. The engineered filter media consists of a specified gradation of washed aggregate and organic material homogeneously blended under strict quality control conditions. The engineered filter media is tested for hydraulic functionality, fertility, and particle size distribution to ensure uniform performance. Specifically, Rotondo uses the same material sources for each individual ingredient to ensure that the materials are the same from one batch to the next. After the individual materials are blended together, a series of tests are run on each batch to ensure that the blended material meets Rotondo's specifications. Specifically, the particle size distribution of the filter media is tested to ensure that the design flow-through rate and screening capabilities of the media are maintained. In addition, the organic matter content is tested to ensure that the media has enough organics to sustain vegetation.

The engineered filter media contains hydrophilic adsorbents (i.e., aluminosilicates [sand]), hydrophobic adsorbents (i.e., organic matter), and other components. The exact proportion of each component of the media is proprietary.

Vegetation

The StormGarden includes specified vegetation that may include flowers, grasses, a shrub, or a tree. Vegetation is selected based on aesthetics, local climatic conditions, traffic safety (e.g., may limit the height or breadth of the vegetation), and maintenance considerations. A holly shrub was selected for use in the test system installed at the SCTF because of the low light conditions at the test site and the climate zone for the Seattle region. However, the shrub died after its potting soil was removed; and the root system never grew into the media during the course of the study.

Underdrain

The underdrain for the StormGarden is a perforated 4- or 6-inch-diameter, polyvinyl chloride (PVC) pipe. Outflow from the StormGarden is discharged through the underdrain to a nearby stormwater catch basin or inlet, detention pond, biofiltration swale, underground infiltration, or another stormwater detention or infiltration facility. There is a 6-inch layer of bridging gravel around the pipe, communicating directly with the media to avoid geotextile fabrics. For the underdrain to function properly, each StormGarden unit must be sited such that the underdrain is connected to an appropriate outfall that provides free outflow of treated stormwater.

Filter Panel

Each StormGarden contains a floor drain trough and a pervious concrete filter panel inserted at the base of the sidewall (Appendix B, sheet C-3). The 3.5-inch by 3.5-inch by 2-inch-thick filter panel allows treated water to infiltrate into the surrounding soils, which helps recharge groundwater supplies and reduces stormwater runoff volumes. In addition, the floor trough and filter panel work together to completely drain the structure between storm events, preventing anaerobic conditions from developing within the filter media. This is in contrast to many other stormwater treatment systems in which the invert of the underdrain pipe sits at least 2 inches or more above the floor for the pipe elbow, creating anaerobic conditions in the ponded water below the raised underdrain pipe. The StormGarden can easily be configured without a filter panel for locations where infiltration is not feasible or desired.

Pervious concrete typically allows water to infiltrate at approximately 2 to 18 gallons per minute per square foot (gpm/ft^2) (Wanielista et al. 2007). With a 3.5-inch by 3.5-inch filter panel, the most that could exfiltrate from the vault is 1.5 gallons per minute (gpm), or 4.3 percent of the design flow rate. The pervious concrete panel is at the bottom of the back sidewall, opposite the inlet throat. At that location, the filter panel is beneath the engineered media and is surrounded by clean underdrain stone. The water that comes in contact with the filter panel will have passed through the engineered media and, therefore, will be mostly free of any sediment that could potentially clog the panel. Also, the filter panel will be in a vertical position, which will also help prevent clogging.

Bypass

Standard StormGardens are offline systems that bypass high-intensity runoff events externally to a standard catch basin or inlet, detention pond, biofiltration swale, or other stormwater detention or infiltration facility located down gradient. Once the hydraulic capacity of the filter media is exceeded, the system begins to build head over the media. When the head reaches 6 inches above the top of the mulch layer, the remaining runoff volume bypasses the inlet throat of the StormGarden and continues to flow along the curb line to an inlet downstream.

Site Installation Requirements

The following subsections describe the site installation requirements, including necessary soil characteristics, hydraulic grade requirements, depth-to-groundwater limitations, and utility requirements.

Necessary Soil Characteristics

StormGardens require a leveled stone bed with a minimum thickness of 6 inches.

Hydraulic Grade Requirements

The StormGarden is a surface treatment system, so meeting head loss requirements is easier than with piped filters. The elevation between the influent inlet and the invert of the outlet is 2 feet 10 inches. The StormGarden allows for 6 inches of freeboard within the system for sediment, trash, and head accumulation.

Depth-to-Groundwater Limitations

The StormGarden comes in two configurations, one with a filter panel and one with no drain down. The system with no drain down does not have depth-to-groundwater limitations because it is fully enclosed. Each system is manufactured with gasketed PVC couplings precast into a sidewall to ensure an easy, snug, pipe fit from the contractor when installing a StormGarden. The system is generally delivered to a site filled with media; the weighted system does not float.

For the system with the filter panel, the system would be installed with at least 1 foot of separation between the bottom of the facility and the average wet season groundwater elevation.

Utility Requirements

The StormGarden is designed to be a passive system requiring no power. It has a free-draining outfall to an appropriate water conveyance or storage system (i.e., wet pond, storm sewer, underground infiltration.

Treatment Processes

The StormGarden provides water quality treatment of captured flows through physical, chemical, and biological unit processes. Runoff treatment is achieved through sedimentation, filtration, adsorption, absorption, volatilization, evapotranspiration, and biological processes, as described below.

Sedimentation

StormGardens are designed with approximately 6 inches of headspace above the mulch layer (9 inches above the engineered filter media layer). The headspace within the StormGarden matrix and promotes settling of larger particles (gross and suspended solids) and, potentially, metals and other sorbed constituents. Turbulent inflows into the StormGarden unit or bypass flows at the inlet of the system may temporarily interfere with settling and may resuspend sediments, although the hydraulic gradient at the inlet is expected to prevent loss of captured sediment and debris. When StormGardens are sited appropriately, stormwater enters the inlet of the unit with linear flow across the inlet face (as recommended) and export of captured solids should be minimal.

Filtration

Particulates are removed as they percolate through the mulch and engineered soil media. Pollutant removal rates achieved through filtration are a function of the stormwater composition and media properties including depth, porosity, grain size, and hydraulic conductivity. Research indicates that typical bioretention and filtration technologies experience the majority of filtration within approximately the first foot of media (Clark and Pitt 1999).

Adsorption

The engineered filter media contains hydrophilic adsorbents such as aluminosilicates (sand) and hydrophobic adsorbents such as organic matter, which have been included to promote the partitioning of pollutants to the soil particles. The vegetative root system serves as a substrate for bacterial growth, which in turn provides biological processing of organic chemicals, nutrients, and heavy metals.

Volatilization

If captured in the filter media, volatile organic compounds such as gasoline may ultimately volatize.

Biological Processes

Bacterial growth, supported by the root system and organic soil content, also performs a number of treatment processes. Those processes vary as a function of moisture, temperature, pH, salinity, pollutant concentrations (particularly toxins), and available oxygen. The following biological treatment processes take place within the StormGarden and are described below: nutrient assimilation, nitrification/denitrification, biodegradation, bioremediation, and phytoremediation.

Nutrient Assimilation

Biologically available forms of nitrogen, phosphorus, and carbon are actively taken into the cells of vegetation and bacteria and used for metabolic processes (i.e., energy production and growth). Nitrogen and phosphorus are actively taken up as nutrients that are vital for a number of cell functions, growth, and energy production. The metabolic processes remove metabolites from the media during and between storm events, making the media available to capture more nutrients from subsequent storms in a sustainable manner.

Nitrification/Denitrification

Bacteria may transform and cycle various forms of nitrogen, converting nitrogen inputs into organic matter or free nitrogen in gaseous form. Such processes may reduce the total effluent nitrogen, but, depending on the rate of concurrent organic decomposition, they may also contribute nitrogen to the discharge.

Biodegradation

Organisms can break down a wide array of organic compounds into less toxic forms or completely break them down into carbon dioxide and water (Means and Hinchee 1994).

Sizing Methodology

The StormGarden is available in eight standard box sizes that can treat from approximately 1 acre to 3.6 acres of impervious surface (based on an infiltration rate of 140 inches per hour (in/hr) and MGSFlood [version 4.40] modeling). Table 1 provides design flow rates for each box size to remove a target of 80 percent of influent total suspended solids (TSS) with a D50 of 50 microns. The flow rates listed in Table 1 should be used in conjunction with the MGSFlood 4.40 or another continuous hydrologic model approved by Ecology to determine the box size that would result in treatment of 91 percent of the annual runoff volume from the target drainage area. For sizing in eastern Washington, HydroCAD, StormSHED, or another approved single-event model should be used to determine the appropriate box size to treat the 6-month design storm.

Table 1. Specifications of Standard StormGardens.				
Available StormGarden Box Sizes (feet)	**Maximum Contributing Drainage Area (acres)[a]**	**Treatment Flow Rate (cfs)**	**Treatment Flow Rate (gpm)**	**Outlet Pipe Diameter (inches)**
4 x 6	**0.96**	**0.078**	**35**	**4**
4 x 8	1.28	0.104	47	4
4 x 12	1.91	0.156	70	4
6 x 6	1.42	0.117	52	4
6 x 8	1.91	0.156	70	4
6 x 10	2.37	0.194	87	6
6 x 12	2.86	0.233	105	6
7 x 13	3.59	0.295	132	6

[a] Basin area modelled using MGS Flood 4.40, Seattle 38 inch MAP, 100 percent impervious basin, default HSPF values, off-line.

Test system is **bolded**.

Note: Treatment flow rate calculated for a design infiltration rate of 140 inches per hour.

cfs = cubic feet per second

gpm = gallons per minute

Expected Treatment Capabilities

The StormGarden system has been tested in the laboratory, and performance results were presented to Ecology in the application for a pilot use level designation for the system (Herrera 2016a). Based on the laboratory testing, the StormGarden with an infiltration rate of 140 inches per hour is expected to remove 85.3 percent of TSS for influent concentrations at 200 milligrams per liter (mg/L). At the same infiltration rate, the system is also expected to remove 84.1 percent of influent dissolved copper and 62.6 percent of influent dissolved zinc. The system is also expected to reduce influent total phosphorus (TP) concentrations by 50 percent during field testing. Subsequent to obtaining a PULD, Rotondo submitted field data from the SCTF to obtain a CULD (Herrera 2018). The field data indicated that the system could meet both the basic and phosphorus treatment criteria identified in the TAPE. Based on these results the StormGarden was awarded a CULD in December 2018 (Ecology 2018a).

Estimated Design Life

The non-consumable structural components of the StormGarden are designed to last 25 years or more before internal components need to be maintained or replaced. It should be noted that as long as the tree remains healthy and the filter is properly maintained, the life may exceed the estimated 25 years. The concrete structure of the system has a use life of over 50 years. The manufacturer recommends that, on average, the system be maintained every 6 to 12 months. If the system is inadvertently undersized for the basin or sediment loading is unusually high, the mulch may need to be replaced more frequently. Due to the high variability in loading conditions from site to site, it is recommended that two first-year inspections be performed to assess the loading condition of the site on the StormGarden. Based upon that first year of observation, a site-specific maintenance frequency can be established.

INSTALLATION

The StormGarden is a precast concrete structure. The internal components are pre-assembled prior to delivery to the installation site. The system is delivered on a flatbed truck. The installer or contractor will need to provide a crane capable of off-loading the unit and placing it into the ground. Prior to delivery, the appropriate excavation should be completed, and the bottom 6 inches should be backfilled and leveled using the appropriate and manufacturer-recommended material compacted to 95 percent of maximum density.

Prior to installation, all inlets to the structure must be blocked and covered to prevent contamination by construction sediment from the site. Backfilling should be done carefully, bringing the appropriate fill material up in 6-inch lifts on all sides. In all instances, installation of the StormGarden shall conform to ASTM specification C891, *Standard Practice for Installation of Underground Precast Utility Structures*, unless directed otherwise in contract documents.

OPERATION AND MAINTENANCE REQUIREMENTS

Maintenance inspections should be scheduled immediately after a rain event to assess how quickly the StormGarden in draining. If standing water is observed after the storm has ceased, then the system needs to be maintained. Rotondo recommends that long-term maintenance for a standard StormGarden unit be performed on a 6- to 12-month basis.

The StormGarden is designed for easy maintenance. During each maintenance servicing, the recommended servicing activities are:

- Inspection of the unit structure and media
- Removal of trash and silt from the filter surface
- Replacement of the surface mulch layer (Complete replacement of the soil media is generally required only as part of a spill clean-up.)
- Pruning of vegetation (If the vegetation is dead or in poor health, replace it with new vegetation.)
- Appropriate disposal of all refuse items

Additional maintenance documentation is provided in Appendix C.

RELIABILITY

The StormGarden is a robust water quality system designed to withstand a variety of conditions in the field. The system is easy to maintain (no confined space entry or heavy lifting is required) and is designed to last for 25 years if regularly maintained.

Rotondo warranties that the materials used to manufacture its products will be able to withstand and remain durable to environmental conditions for a period of 5 years from the date of purchase.

OTHER BENEFITS AND CHALLENGES

Unlike many precast stormwater treatment devices, the StormGarden has an optional vegetative component. The plants in the StormGarden promote filtering through the engineered filtration media while also adding an aesthetically pleasing element to what may otherwise be an urban hardscape. Though the aesthetic aspects of the technology are in no way assessed herein, they are mentioned here as an element that may be of interest to municipalities.

SAMPLING PROCEDURES

This section describes the sampling procedures that were used to evaluate the performance of the StormGarden. It begins with a general overview of the monitoring design and the specific goals Ecology has established for basic and phosphorus treatment. Separate sections describe in more detail the site location, test system, monitoring schedule, and specific procedures used to obtain the hydrologic and water quality data, respectively. Analytical methods, quality assurance and control measures, data management procedures, and data analysis procedures are also described.

MONITORING DESIGN

To facilitate performance monitoring pursuant to the TAPE guidelines, a 4-foot by 6-foot (internal dimensions) StormGarden was installed for testing purposes at the Ship Canal Test Facility, which is at the corner of Pasadena Place Northeast and Northeast 40th Street in Seattle (Figure 1). The StormGarden system is referred to herein as the “WB test system.”

Automated equipment was installed in conjunction with the WB test system to facilitate continuous monitoring of influent, effluent, and bypass flow volumes over a 19-month period extending from April 20, 2017, through November 22, 2018. In association with the hydrologic monitoring, automated samplers were employed to collect flow-weighted composite samples of the influent and effluent during discrete storm events for subsequent water quality analyses.

Using the monitoring data from the WB test system, Herrera characterized removal efficiencies and effluent concentrations for targeted monitoring parameters and subsequently compared them to goals identified in the TAPE guidelines to support the issuance of a GULD for the StormGarden. The Ecology treatment goals are described below for the two types of treatment that are under consideration for inclusion in the GULD:

1. **Total Suspended Solids (Basic) Treatment:** 80 percent removal of TSS for influent concentrations that are greater than 100 mg/L but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent TSS concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of <20 mg/L.

2. **Phosphorus Treatment:** 50 percent removal of TP for influent concentrations ranging from 0.1 to 0.5 mg/L.

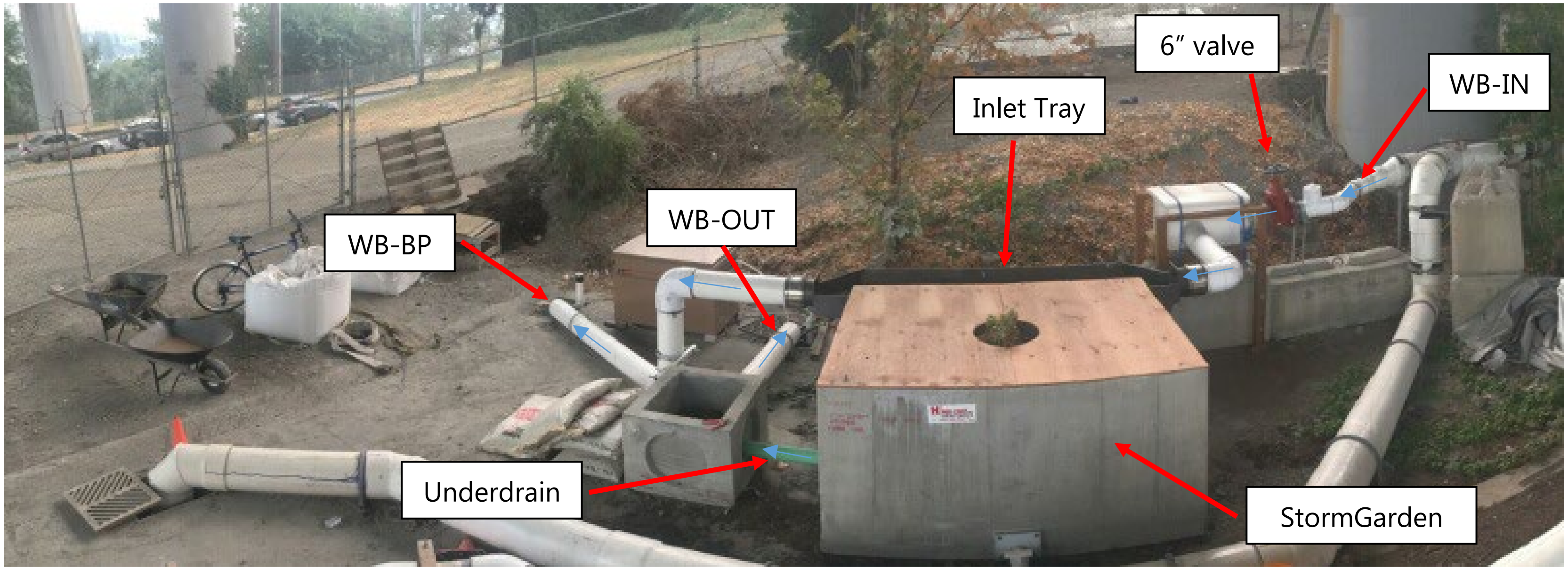
Site Location

The WB test system was installed at the SCTF in Seattle; this facility was constructed by the Washington State Department of Transportation (WSDOT) in the Interstate 5 right-of-way beneath the north side of the Lake Union Ship Canal Bridge (Figure 1). The drainage area contributing to the site is approximately 31.6 acres, with 22.7 acres of pavement and 8.9 acres of roadside landscaping. The WSDOT stormwater collection system is separate from the City of Seattle collection system and includes runoff from the Interstate 5 northbound, southbound, and express lanes, and the on- and off-ramps. All runoff in the drainage basin passes through catch basins prior to entering the stormwater collection system and being consolidated in a 30-inch pipe. The drainage basin contains 15 Type 1 and 53 Type 2 catch basins.

WSDOT constructed the SCTF to allow the simultaneous testing of up to four stormwater treatment technologies, which is accomplished by diverting stormwater flow from the 30-inch pipe to the site using a “drawbridge” half-pipe structure and a series of flow splitters. First, flow from the drawbridge enters an adjustable flow splitter that diverts water toward test bays 1 and 2 on one side and toward test bays 3 and 4 on the other side. On each side, the divided water enters a second flow splitter that further divides the flow such that each of the four test bays can be used independently. Flow to each test bay can be further controlled using a gate valve located at the inflow to each test bay. To fine tune the flow into the test bay even more, a 6-inch bypass valve was installed immediately upstream of the influent pipe to the WB test system (Figure 3) that can divert water around the structure without changing the flow rate into the neighboring test bay. Flow then enters the WB test system via a false curb (Figures 3 and 4), which was designed to mimic the hydraulics of an at-grade curb that would be used for typical installations. A plan view diagram of the entire site is provided in Figure 5.

Ecology approved the use of the site for field testing under the TAPE guidelines and entered into an agreement with WSDOT on February 25, 2016, to allow testing at the facility. Rotondo subsequently entered into a property use agreement with Ecology (Appendix D) for the duration of the WB test system monitoring.

Because influent flow rates can be fine-tuned with the upstream valves and flow splitters, the peak influent flow rate was set to range between 50 and 125 percent of the design flow rate for a 4-foot by 6-foot unit; this equates to between 17.5 and 43.75 gpm (design flow rate = 35 gpm). Storms have a natural hydrograph form except when the valve becomes clogged with gross solids, which results in decreased flows independent of rainfall in the basin. This is discussed further in Appendix E.



Note: Photo was taken from the back side of the unit. Direction of flow is from right to left.

Figure 3. Photo of the Test StormGarden System as Installed at the Ship Canal Test Facility.

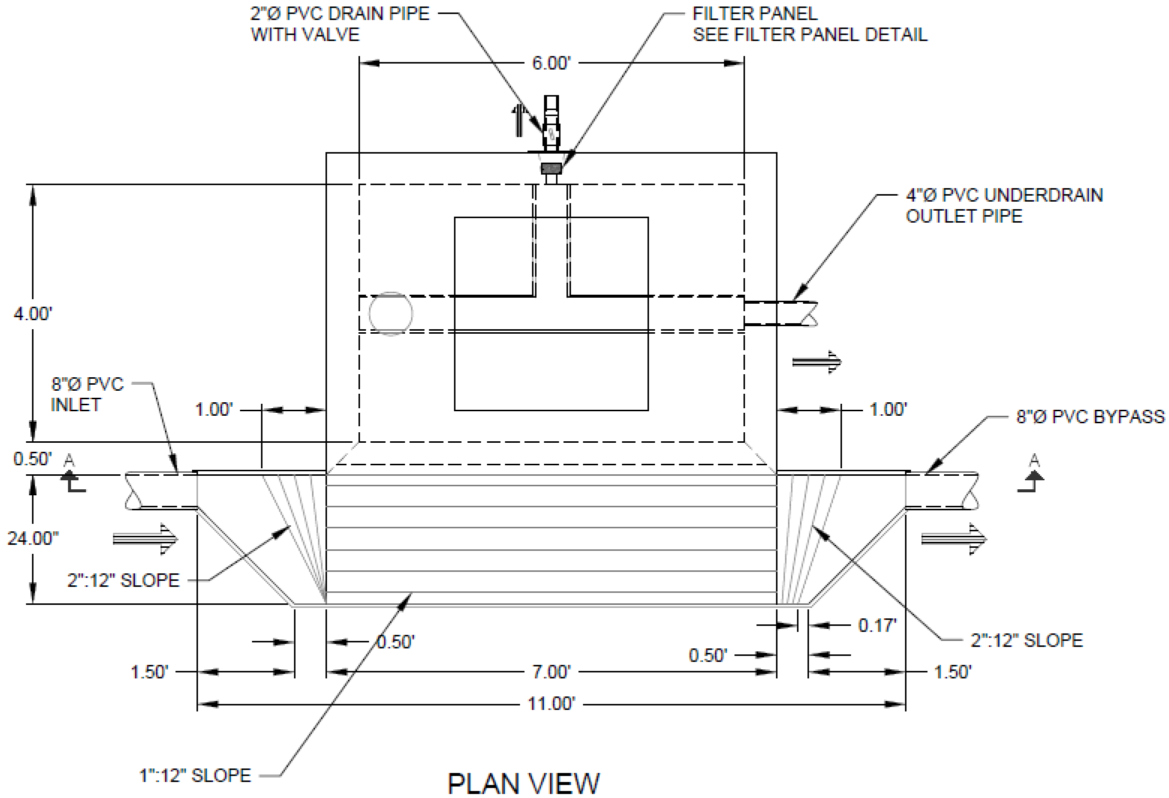


Figure 4. Plan View Schematic of the Test StormGarden System at the Ship Canal Test Facility.

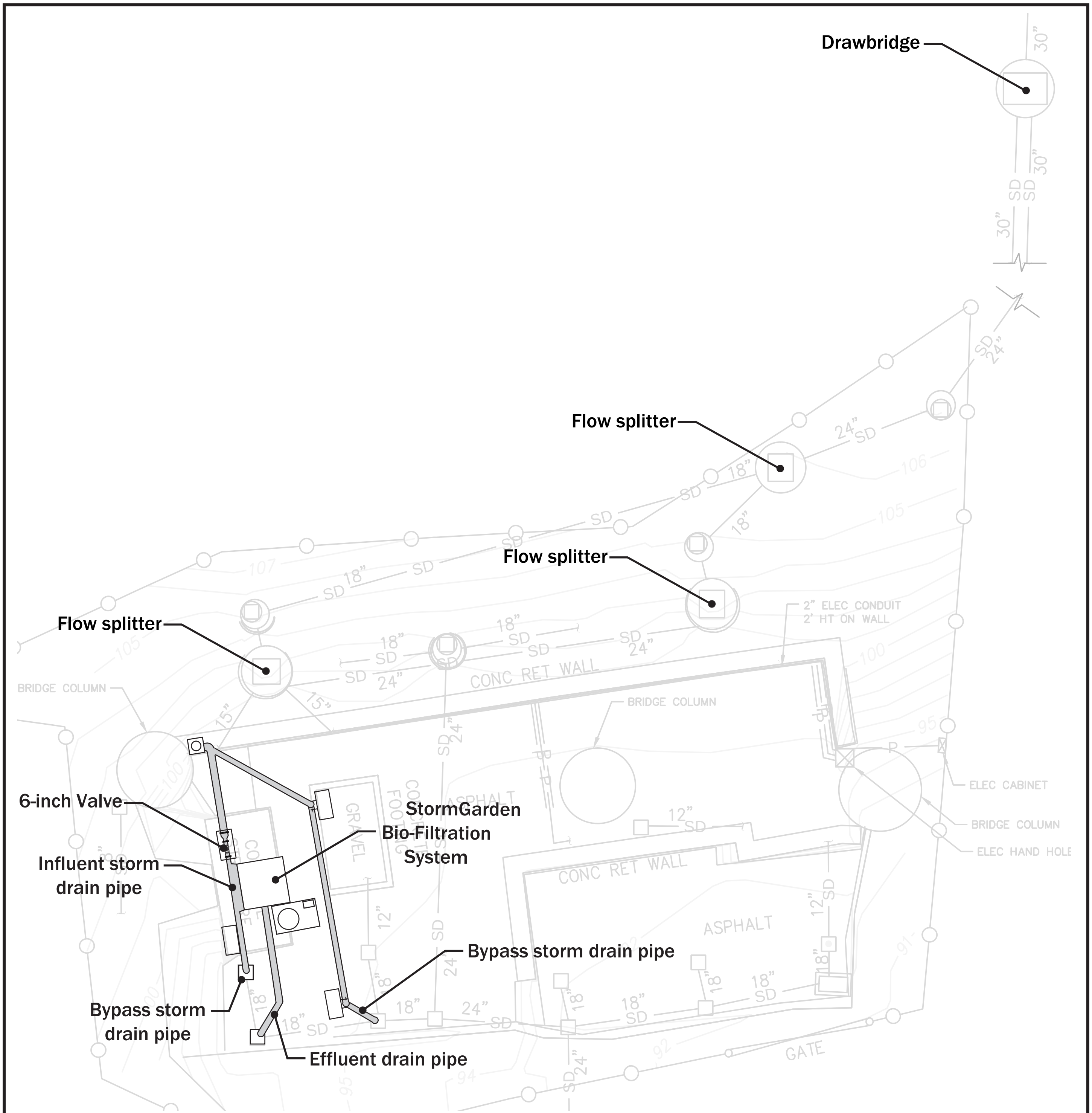


Figure 5.
Site Map of the StormGarden Biofiltration System Performance Evaluation Site at the WSDOT Test Facility.

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Monitoring Schedule

Hydrologic monitoring was conducted at the WB test system over a 19-month period from April 20, 2017, through November 22, 2018. During that time, 21 paired influent and effluent composite samples and 8 paired grab samples were collected for characterizing the stormwater treatment performance of the WB test system.

Test System Description

The WB test system consists of a 4-foot by 6-foot (internal dimensions) vault with a 21-inch layer of engineered media covered by 3 inches of shredded bark mulch (Figure 2). Stormwater enters the system along a false curb line installed adjacent to the vault (Figures 3 and 4) and exits the system from a 4-inch slotted PVC underdrain.

Figure 4 shows a plan view schematic of the WB test system (also see Appendix B). As water enters the StormGarden unit, it is distributed across the media via the false curb line. When the infiltration rate of the media is exceeded, the impounded water builds above the mulch and eventually spills out to the false curb line and continues to the bypass monitoring station.

Test System Sizing

Because the TAPE monitoring was conducted at an Ecology-approved test facility where the flow rate entering the system could be controlled, there was no need to run a model to size the WB test system for the basin. Instead, a 4-foot by 6-foot unit was selected, and the upstream valves and splitters were adjusted so that the system received flows between 50 and 125 percent of the design flow rate (per the TAPE guidelines). Figure 5 provides a site map of the StormGarden evaluation site.

Test System Maintenance Schedule

Typical maintenance of the StormGarden consists of replacing the mulch and raking the top few inches of engineered media. Maintenance is required when sediment and/or oil build up on top of the mulch layer, so the maintenance schedule is driven by pollutant loading from the site.

Due to instances of excessive sediment and oil buildup on top of the mulch layer of the WB test system (presented in the *Data Summaries and Analysis* section later in this report), the mulch was replaced five times over a 19-month period. After each mulch change, flow rates through the media in the StormGarden would again meet design expectations, indicating that the mulch was clogging and not the engineered filter media. During the same 19-month period, three other systems at the SCTF—an upward flow media filter, a pleated fabric filter, and another treebox filter—exhibited similar clogging issues in adjacent bays. Due to the intermittent, excessive sediment and oil loading that contributes to this clogging, Ecology has recognized that the stormwater entering the SCTF may be atypical for manufactured treatment device applications.

Hydrologic Monitoring Procedures

Generalized schematics of the equipment that was installed in association with the WB test system are provided in Figures 6 and 7. The equipment installation was completed in April 2017. Continuous hydrologic monitoring was performed in conjunction with the WB test system at four separate monitoring stations: WB-BP, WB-OUT, WB-IN (Figures 3, 6, and 7), and Wall-RG (Figure 1). WB-BP is a bypass flow monitoring station; WB-OUT is a treated effluent flow monitoring station located at the outlet; combined flows from WB-BP and WB-OUT were used to estimate the flow rate at WB-IN, the influent monitoring station. Wall-RG was a precipitation monitoring station. The four hydrologic monitoring stations are described in separate subsections below, followed by a summary of the maintenance procedures performed on the associated monitoring equipment. The monitoring procedures are described in greater detail in the quality assurance project plan (QAPP) prepared for the study (Herrera 2016b).

Hydrologic monitoring instruments at each monitoring station were all interfaced with a Campbell Scientific CR1000 datalogger, which served to record data, run simple algorithms based on those data, and control the automated sampling equipment. The datalogger was programmed to scan every 10 seconds and to record average readings on a 5-minute time step. The datalogger was interfaced with an Airlink Raven XTV digital cellular modem. The communication system was configured to automatically download data on a 5-minute basis and to send text message alarms to field technicians and project managers when necessary. Power to the system was supplied using onsite 120 V AC power.

The datalogger, digital cell phone link, and automated samplers were housed in a Knaack box model 69 enclosure. Conduit was installed to convey pressure transducer cabling and autosampler suction lines from the base of the enclosure to each station.

Bypass Flow Monitoring (WB-BP)

Bypass flows were monitored at the terminus of an 8-inch PVC pipe that routed flows from the false curb line external bypass point to a downstream storm drain inlet. The photo in Figure 3 shows the pipe configuration, which is also depicted in plan view in Figure 6.

An 8-inch Thel-Mar weir was installed at the end of the bypass pipe, and a hole was drilled through the face of the weir for connecting a section of reinforced 1/2-inch internal diameter polyethylene tubing. The other end of the tubing was connected to a stilling well that was constructed from 3-inch-diameter PVC pipe. A Campbell Scientific CS451 submersible pressure transducer (0 to 2.9 psi) was installed in the stilling well to measure water levels behind the Thel-Mar weir. The pressure transducer was interfaced with the Campbell Scientific CR1000 datalogger described above. When bypass occurred, the datalogger converted water level readings (behind the bypass weir) to estimates of discharge based on standard hydraulic equations (Walkowiak 2006).

Effluent Flow Monitoring Station (WB-OUT)

To facilitate continuous monitoring of treated effluent flow rates, a monitoring station, designated WB-OUT, was established at the end of the 8-inch outlet pipe (Figures 3, 6, and 7). An 8-inch Thel-Mar weir was installed at the end of the outlet pipe, and a hole was drilled through the face of the weir for connecting a section of reinforced 1/2-inch internal diameter polyethylene tubing. The other end of the tubing was connected to a stilling well that was constructed from 3-inch-diameter PVC pipe. A Campbell Scientific CS451 submersible pressure transducer (0 to 2.9 psi) was installed in the stilling well to measure water levels behind the Thel-Mar weir.

The WB-OUT pressure transducer was interfaced with the same Campbell Scientific CR1000 datalogger described above. The datalogger converted water level readings in the stilling well (which were equivalent to water levels behind the Thel-Mar weir) to estimates of discharge based on standard hydraulic equations (Walkowiak 2006).

Influent Flow Monitoring Station (WB-IN)

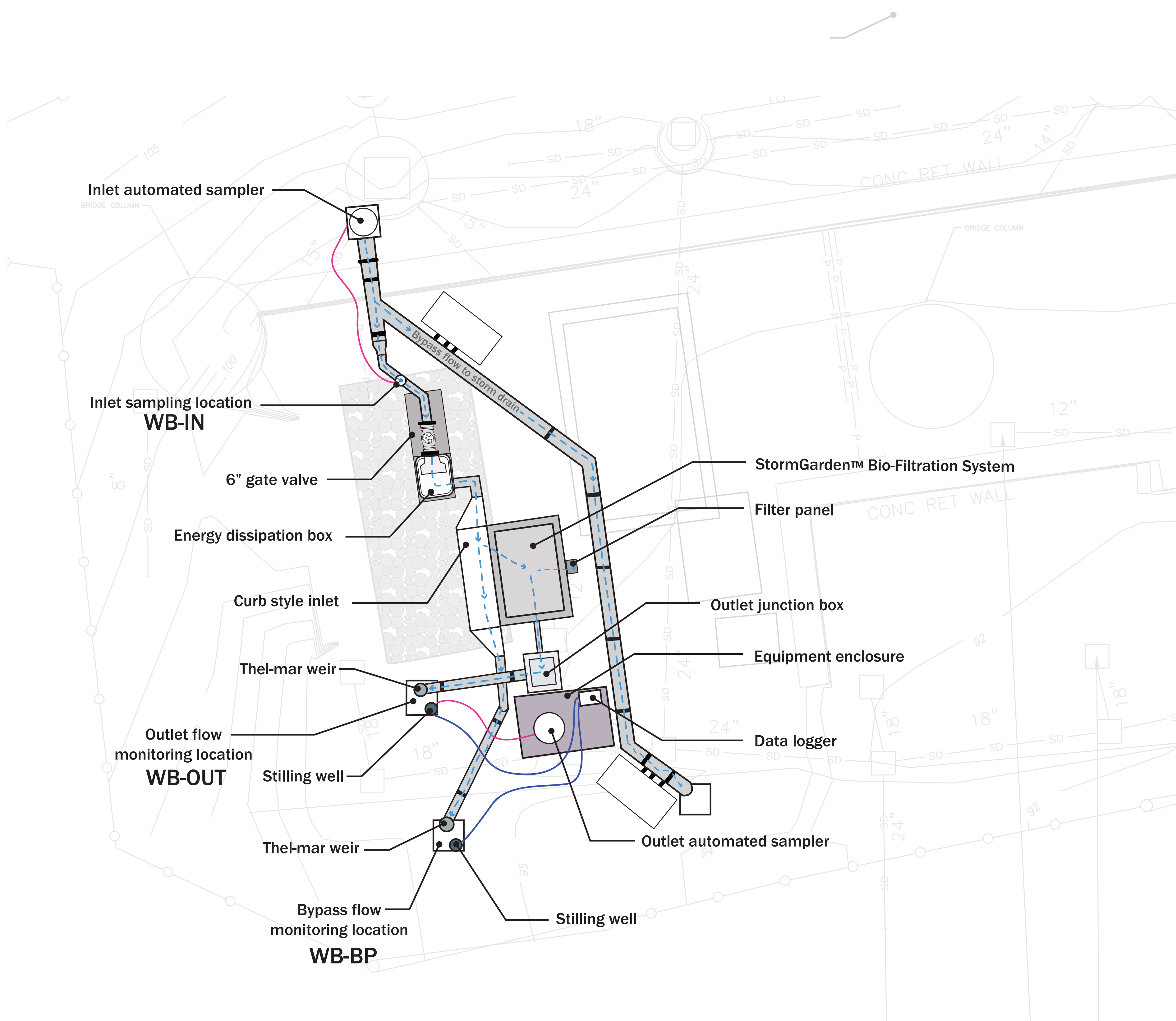
Inflow to the WB test system was estimated by adding the flow rates measured at WB-BP and WB-OUT. Due to the short residence time within the filter of the WB test system, this approach was deemed accurate enough for inlet autosampler pacing.

Precipitation Monitoring Station (Wall-RG)

In addition to the three flow monitoring stations (WB-IN, WB-OUT and WB-BP), a third hydrologic station, designated Wall-RG, was installed approximately 4,000 feet southwest of the equipment enclosure in a residential backyard (Figure 1) to facilitate continuous monitoring of precipitation depths. Precipitation could not be monitored at the test site because it is located under the Interstate 5 bridge.

Precipitation depths were monitored by a Hydrological Services TB4 tipping bucket rain gauge with an 8-inch catch. The rain gauge was installed on a 10-foot steel pole and was interfaced with another Campbell Scientific CR1000 datalogger. The datalogger was equipped with an Airlink Raven XTV digital cell phone link to allow communication with the WB-OUT and WB-BP datalogger via remote access. If the Hydrological Services rain gauge failed, Seattle Public Utilities' rain gauge (RG-03) at the University of Washington Hydraulic Lab, approximately 3,700 feet southeast of the site, was used.

Figure 6.
Plan View of the StormGarden™ Bio-Filtration System Performance Evaluation Site (WB).



Legend
Pressure transducer and cable
Sampling tubing

N
0 .5 1 2
Scale in Feet

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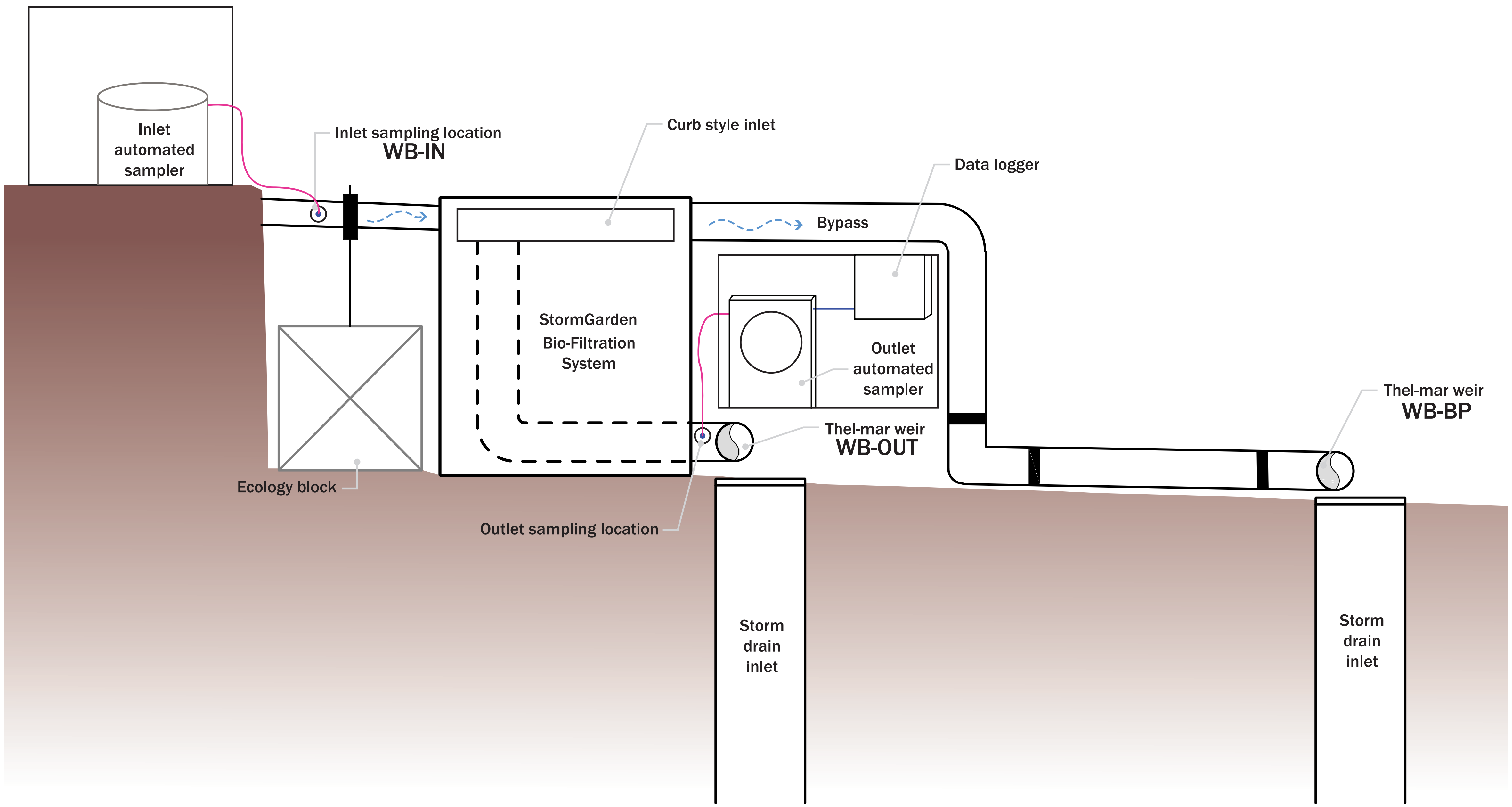
Figure 7.
Cross-Section Diagram of the StormGarden Biofiltration System Performance Evaluation Site.



Legend
Sampling tubing
Direction of flow

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Monitoring Equipment Maintenance and Calibration

The rain gauge and flow monitoring equipment were maintained and calibrated on a routine basis during pre- and post-storm checks. Instrument maintenance and calibration activities were documented on standardized field forms. Rain gauge and level calibration data can be found in the hydrologic data quality assurance memorandum in Appendix E.

In addition, on April 20, 2017, a dynamic flow test of the WB-BP and WB-OUT stations was conducted using known flow rates from a nearby fire hydrant. The hydrant flows were used to calibrate the Thel-Mar weir equations at WB-BP and WB-OUT. Results from the dynamic flow testing are presented in Appendix E. The adjusted rating curves that resulted from the dynamic flow test were applied to the entire dataset prior to final analysis.

WATER QUALITY MONITORING PROCEDURES

To evaluate the stormwater treatment performance of the WB test system, water quality sampling was conducted at the influent (WB-IN) and effluent (WB-OUT) stations (Figures 6 and 7) over a 19-month period from April 20, 2017, through November 22, 2018. During this period, 22 storm events were sampled, yielding 21 paired influent and effluent composite samples and 8 paired grab samples. A general description of the monitoring procedures used is provided herein. A more detailed description can be obtained from the QAPP prepared for this study (Herrera 2016b).

To facilitate water quality sampling for this study, Isco 6712 portable automated samplers were installed in association with the WB-IN and WB-OUT stations. The intake strainer for the automated sampler at the WB-IN station was positioned at the bottom of the inlet pipe above the 6-inch valve, which controlled flow to the WB test system (Figures 3 and 6). The intake strainer for the automated sampler at the WB-OUT station was installed in a sampling tray located below the invert of the outlet pipe (Figures 3 and 6). In both cases, the sampler intakes were positioned to ensure the homogeneity and representativeness of the collected samples. Specifically, sampler intakes were installed to make sure adequate depth was available for sampling and to avoid capture of litter, debris, and other gross solids that might be present. The sampler suction lines consisted of Teflon tubing with a 3/8-inch inner diameter.

The following conditions served as guidelines in defining the acceptability of specific storm events for 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
- **End of storm:** A continuous period of at least 6 hours after the event 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 visited each station to verify that the equipment was operational, to start the sampling program, and to place a clean 20-liter polyethylene carboy and crushed ice in the sampling equipment. The speed and intensity of incoming storm events were tracked using Internet-accessible Doppler radar images. Actual rainfall totals during sampled storm events were quantified based on data from the Wall-RG rain gauge. The datalogger was programmed to enable the sampling routine in response to a predefined increase in water level (stage) at WB-OUT during the storm event sampling. The automated samplers were programmed to collect 220-milliliter 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** are collected for each event.
- Sampling is targeted to capture **at least 75 percent** of the hydrograph.
- Due to sample holding time considerations, the maximum duration of automated sample collection is **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 constituted an acceptable sample was 10. If the sample was determined to be acceptable, the carboy was immediately capped, removed from the automated sampler, and kept below 6 degrees Celsius (°C) using ice during transport to the laboratory. All samples were delivered to the laboratory with appropriate chain-of-custody documentation. At the laboratory, collected flow-weighted composite samples were analyzed for the following parameters:

- Total suspended solids (TSS)
- Particle size distribution
- Total phosphorus (TP)
- Orthophosphorus
- Total and dissolved copper
- Total and dissolved zinc
- pH
- Hardness

In addition to automated sampling, staff measured pH and collected grab samples in the field during nine storm events. The grab samples were analyzed in the laboratory for total petroleum hydrocarbons (TPH). At the initiation of a storm event, field personnel would mobilize to collect grab samples in pre-labeled bottles. At the inlet, each bottle was attached to a sampling pole and lowered into the flow splitter immediately upstream of the unit (Figure 5). At the outlet the sample was collected as the water spilled over the WB-OUT weir. Sample bottles were immediately placed on ice and kept below 6°C until delivery to the laboratory. During the grab sample field visits, field personnel also checked the field equipment and performed any necessary maintenance (without interfering with the functioning of the automated sampling programs). Appendix F provides the Chemistry Data Quality Assurance Memorandum, which assesses the chemistry results in relation to the goals identified in the QAPP.

Additional parameters were also analyzed, and the results are included in Appendix G to this report. However, the main text of the report only addresses those parameters that are pertinent to the basic and phosphorus treatment GULD.

Analytical Methods

Analytical methods for this study are summarized in Table 2. Analytical Resources, Inc., in Tukwila, Washington, was the primary laboratory used in this study. Analyses for particle size distribution were performed by ETS, Inc., in Petaluma, California.

Analytical Resources, Inc., is certified by Ecology, and participates in audits and inter-laboratory studies by Ecology and the US Environmental Protection Agency (US EPA). Such performance and system audits have verified the adequacy of the laboratory’s standard operating procedures, which include preventive maintenance and data reduction procedures.

Quality Assurance and Control Measures

Field and laboratory quality control procedures used for the WB test system evaluation are described in the following sections.

Field Quality Assurance/Quality Control

This section summarizes the quality assurance/quality control (QA/QC) procedures that were implemented by field personnel to evaluate sample contamination and sampling precision.

Field Blanks

Field blanks were collected on April 14, 2017, at the influent and effluent monitoring locations (WB-IN and WB-OUT). A second set of field blanks was collected after five storm events had been sampled. The field blanks were collected by pumping reagent-grade water through the intake tubing into a pre-cleaned 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. The results of the field blanks are presented in the Chemistry Data Quality Assurance Review Memorandum in Appendix F.

To help prevent cross contamination from the tubing during routine sampling, the automated sampler tubing was rinsed with stormwater before the collection of each aliquot using an automated double-rinse cycle. In addition, deionized water was back-flushed through the sample tubing before each monitored event.

Field Duplicate Samples

Field duplicates were collected for approximately 10 percent of the samples. The station where the field duplicates were collected was chosen at random in advance of the storm event. To collect the field duplicates, the collected sample in the 20-liter carboy was split using a 22-liter churn splitter. The resultant data from the duplicate samples were used to assess variation in the results that is attributable to analytical variability. The results of the field duplicates are presented in the data Chemistry Quality Assurance Review Memorandum in Appendix F.

Flow Measurements

The accuracy and precision of the automated flow measurement equipment were tested prior to the first monitoring round and periodically throughout the project. Level calibration data can be found in the Hydrologic Data Quality Assurance Memorandum in Appendix E. In addition, a dynamic flow test was conducted on April 20, 2017, using known flow rates from a nearby hydrant. The results of these QA procedures are presented in Appendix E.

Laboratory Quality Control

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. Analytical Resources, Inc., and ETS, Inc., were responsible for conducting internal QA/QC measures in accordance with their own quality assurance plans.

Water quality results were first reviewed at the laboratories for errors or omissions, and to verify compliance with acceptance criteria. The laboratories also validated the results by examining the completeness of the data package to determine whether method procedures and laboratory QA procedures were followed. The review, verification, and validation by the laboratories were documented in case narratives that accompanied the analytical results.

Herrera also reviewed and validated sampling data within 7 days of receiving the results from the laboratory to ensure that all data were consistent, correct, and complete, and that all required QC information was provided. Specific QC elements for the data were also examined to determine if the method quality objectives (MQOs) for the project were met. Herrera summarized results from the data validation reviews QA worksheets prepared for each sample batch. Values associated with minor QC problems were considered estimates and were assigned *J* qualifiers. Values associated with major QC problems were rejected and were qualified with an *R*. Estimated values were used for evaluation purposes, but rejected values were not used. The results from this chemistry data quality assessment are presented in Appendix F.

Table 2. 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 and hydrometer	ASTM D422		7 days	7 days		Maintain ≤6°C	NA	NA	microns
Total phosphorus	Automated ascorbic acid	SM 4500P-F		NA	28 days		Maintain ≤6°C, H_2SO_4 to pH <2	0.008	0.001	mg/L
Orthophosphorus	Automated ascorbic acid	SM 4500P E		24 hours[d]	48 hours		Maintain ≤6°C	0.004	0.001	mg P/L
Hardness as $CaCO_3$	Titration	SM 2340B		28 days	28 days		Maintain ≤6°C, HNO_3 to pH <2	0.05	1.0	mg/L
Copper, dissolved	ICP-MS	EPA 200.8		24 hours[d]	6 months		Maintain ≤6°C, HNO_3 to pH <2 after filtration[e]	0.0005	0.0001	mg/L
Copper, total				NA			Maintain ≤6°C, HNO_3 to pH <2	0.0005	0.0001	
Zinc, dissolved	ICP-MS	EPA 200.8		24 hours[d]	6 months		Maintain ≤6°C, HNO_3 to pH <2 after filtration[e]	0.004	0.001	mg/L
Zinc, total				NA			Maintain ≤6°C, HNO_3 to pH <2	0.004	0.005	
pH	Field meter (potentiometric)	NA	NA	NA	NA	NA	NA	0.01	0.01	standard units
TPH (diesel)	GC/FID	NWTPH-Dx[g]	Two 500-mL amber glass bottle	7 days	40 days	Maintain ≤6°C	Maintain ≤6°C	0.1	0.05	mg/L
TPH (motor oil)		NWTPH-Gx[g]						0.2	0.1	mg/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 (2003). 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 will be used for the total suspended solids 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 has been adopted for this study, both goals will be reported with the data.

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

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

[g] Washington State Department of Ecology methods (Ecology 2007) includes silica gel extract cleanup step.

°C = degrees Celsius

$CaCO_3$ = calcium carbonate

GC/FID = gas chromatography/flame ionization detection

HDPE = high-density polyethylene

ICP-MS = inductively coupled plasma/mass spectrometry

mg/L = milligrams per liter

mg P/L = milligram phosphorus per liter

NA = not applicable

TPH = total petroleum hydrocarbons

Data Management Procedures

Flow and precipitation data were uploaded remotely after each storm event using telemetry systems (i.e., Raven cell link modem) and were transferred to a database (LoggerNet and Aquarius software) for all subsequent data management tasks.

Analytical Resources, Inc., and ETS, Inc., reported the analytical results within 30 days of receipt of the samples. The laboratories provided sample and QC data in standardized reports suitable for evaluating project data. The reports included all QC results associated with the data, a case narrative summarizing any problems encountered in the analyses, corrective actions taken, any changes to the referenced method, and an explanation of data qualifiers. Laboratory data were subsequently entered into a Microsoft Access database for all subsequent data management and archiving tasks.

Data Management Quality Control

An independent review was performed to ensure that the data were entered into the database without error. Specifically, a random 10 percent of the sample values in the database were crosschecked to confirm they were consistent with the laboratory reports. If an error was found, another random 10 percent were checked. Checks were made until no errors were found.

Data Analysis Procedures

Analysis procedures used for the hydrologic and water quality data are summarized below.

Hydrologic Data Analysis Procedures

The compiled hydrologic data were analyzed to obtain the following information for each sampled and unsampled storm during the monitoring study:

- Precipitation depth
- Average precipitation intensity
- Peak precipitation intensity
- Antecedent dry period
- Precipitation duration
- Bypass flow duration

- Effluent flow duration
- Bypass peak discharge rate
- Effluent peak discharge rate
- Bypass discharge volume
- Effluent discharge volume

A subset of the information was examined in conjunction with sample collection data to determine if individual storm events met the TAPE guidelines for valid storm events. Bypass frequency data was also used to assess when system maintenance was required.

Water Quality Data Analysis Procedures

Data analyses were performed to evaluate the water quality treatment performance of the WB test system. Two specific procedures were used in the analyses:

- Statistical comparison of influent and effluent concentrations
- Calculation of pollutant removal efficiency
- Calculation of pollutant removal efficiency as a function of flow

Each procedure is described in more detail in the following subsections.

Statistical Comparisons of Influent and Effluent Concentrations

Pollutant concentrations were compared for paired influent and effluent across all storm events using a 1-tailed Wilcoxon signed-rank test (Helsel and Hirsch 2002). Using a paired test, differences in the influent and effluent concentrations could be more efficiently assessed because the noise (or variance) associated with monitoring over a range of storm sizes can be factored out of the statistical analyses. A 1-tailed test was used to evaluate the specific hypothesis that effluent pollutant concentrations were significantly lower than those in the influent. In all cases, the statistical significance was evaluated at an alpha level (α) of 0.05.

Calculation of the Pollutant Removal Efficiency using Bootstrap Analysis

The removal (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} = Influent pollutant concentration
C_{eff} = Effluent pollutant concentration

After the percent removal for each qualifying event was calculated, the mean percent removal values and 95 percent confidence interval about the mean were estimated using a bootstrapping approach (Davison and Hinkley 1997). Bootstrapping offers a distribution-free method for estimates of confidence intervals of a measure of central tendency. The generality of bootstrapped confidence intervals means they are well suited to non-normally distributed data or datasets not numerous enough for a powerful test of normality. Results from the bootstrap analysis were used to determine if the mean percent removal was significantly different from percent removal thresholds presented in the TAPE guidelines(e.g., 80 percent TSS removal).

Pollutant Removal as a Function of Flow Rate

For flow-proportional composite sampling, an aliquot-weighted flow rate was calculated based on the time that each aliquot was collected. Specifically, per the 2011 TAPE, the influent flow rate at the time each aliquot was collected was determined for each storm event based on the continuous flow measurements from the effluent monitoring station; the results were then averaged to obtain an aliquot-weighted flow rate for the sampled storm event. After review by the BER and Ecology, it was determined that for this dataset it would be more appropriate to use the 2018 TAPE method (Ecology 2018b) of regressing performance against the 90th percentile of the sampled treated flow rate (instead of the average sampled influent flow rate). A linear regression model was developed for the combined dataset using the 90th percentile sampled treated flow rates as the independent variable and pollutant removal performance data (from the composite samples) as the dependent variable. The model was used to determine whether treatment performance varies as a function of flow. The suitability of the regression equation was evaluated using the diagnostics described in Helsel and Hirsch (2002).

DATA SUMMARIES AND ANALYSIS

This section summarizes data collected during the monitoring period. The presentation of these data is organized under separate subsections for the hydrologic and water quality monitoring results, respectively. A memorandum discussing the quality of the hydrologic data is presented in Appendix E, while Appendix F presents results from the validation review that was performed on the chemistry data.

HYDROLOGIC DATA

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

Historical Rainfall Data Comparison

To provide some context for interpreting the hydrologic performance of the WB test system, an analysis was performed on rainfall data collected at the National Weather Service (NWS) rain gauge at Sand Point, Seattle, Washington, to determine if rainfall totals from the monitoring period (April 2017, through November 2019) were anomalous. The NWS rain gauge is located at Sand Point, approximately 4.25 miles northeast of the Wall-RG rain gauge. The analysis specifically involved a comparison of rainfall totals measured at the Sand Point rain gauge over the monitoring period to averaged totals for the same gauge from the past 29 years. These data are summarized in Table 3 along with data from the rain gauge associated with the SCTF (Wall-RG) and data from the backup rain gauge (City of Seattle RG-03).

Results from this analysis showed the average April 2017 through November 2018 rainfall total at the Sand Point rain gauge from 1981 through 2010 was 60.64 inches. In comparison, the rainfall total at the same rain gauge over the monitoring period was 57.38 inches. This indicates rainfall over the monitoring period was a little drier than is typical, but only 5.5 percent lower than the mean.

Table 3 also indicates that precipitation measured at the City of Seattle RG-03 gauge (located 3,700 feet southeast of the SCTF) was similar to rainfall measurements at Wall-RG during the monitoring period. The difference between these gauges was only 1.33 inches. The discrepancy between the Sand Point and Wall-RG was less (0.64 inches). Taken together, these data indicate that the rainfall measured at Wall-RG was representative of regional rainfall as measured by two other gauges during the study period.

Table 3. Monthly Precipitation Totals at the WB Test Site Compared to Historical Totals at Sand Point.

Month	Monthly Averages from Monitoring Period: April 1, 2017, Through March 31, 2018			Monthly Averages from Historical Data: 1981–2010
	Wall-RG Rain Gauge (inches)	RG-03 Rain Gauge[a] (inches)	Sand Point NWS Station[b] (inches)	Sand Point NWS Station[b] (inches)
April 2017	4.12	3.99	4.12	2.77
May 2017	2.76	2.57	2.25	2.16
June 2017	1.08	1.06	1.63	1.63
July 2017	0.01	0.03	0.00	0.79
August 2017	0.19	0.15	0.02	0.97
September 2017	1.06	1.17	0.59	1.52
October 2017	3.35	3.28	4.80	3.41
November 2017	8.66	8.36	8.62	8.54
December 2017	4.65	4.47	5.38	5.43
January 2018	8.67	8.27	8.12	4.81
February 2018	3.33	3.13	2.04	3.31
March 2018	2.17	2.30	2.53	3.51
April 2018	5.58	5.62	5.75	2.77
May 2018	0.17	0.17	0.30	2.16
June 2018	1.33	1.57	1.76	1.63
July 2018	0.00	0.01	0.02	0.79
August 2018	0.26	0.26	0.28	0.97
September 2018	0.92	0.97	1.41	1.52
October 2018	3.69	3.43	3.43	3.41
November 2018	4.74	4.6	4.33	8.54
Total	56.74	55.41	57.38	60.64

[a] Source: City of Seattle Rain Gauge – RG-03. Located at the University of Washington Hydraulic Lab approximately 3,700 feet southeast of the project site.

[b] Source: NWS Office at Sand Point Seattle (<http://w2.weather.gov/climate/index.php?wfo=sew>). Located 4.25 miles northeast of the project site.

Hydraulic Performance Assessment

To assess the hydraulic performance of the WB test system, the compiled hydrologic data were first assessed for quality using the Aquarius Continuous Data Management System. Based on this assessment, Herrera determined that all the method quality objectives for hydrologic data identified in the project QAPP were met. The data were then exported into a custom data management system for further analyses, which included the development of a water budget for the WB test system to determine influent volume, effluent volume, and bypass frequency and volume. Using that water budget, additional analyses were performed to determine whether treatment goals for the WB test system were met based on the volumes treated and bypassed.

The WB test system was sized to capture and treat 91 percent of the average annual runoff volume pursuant to minimum requirements for runoff treatment in western Washington. The design flow rate for achieving that goal is 35 gpm. Using this design flow rate and assuming a 100 percent impervious basin and Seattle precipitation, the modeled (MGSFlood 4.40) average annual treated volume is 441,965 gallons. The treated volume measured during the study was compared with this annual volume to determine the percent water year treated by the WB test system.

Table 4 presents the hydraulic monitoring results for the WB test system for the 22 sampled events from April 20, 2017, to November 22, 2018. Appendix G presents the results for all the sampled and unsampled events. The data show that the mulch layer in the WB test system needed to be replaced five times during the 19 months of monitoring (121 percent of a water year) due to instances of excessive sediment and oil buildup on the surface of the mulch layer (see Figure 8). This equates to a mulch change approximately every 4 months, which is more frequent than the recommended 6 to 12 months. During the first year of operation, the WB test system treated 67 percent of the annual runoff for a properly sized 6-foot by 4-foot StormGarden system; thus, the system was not able to minimum requirement goal identified above for western Washington.

Three different systems were also being tested at the SCTF during the same time period (an upward flow media filter, a pleated fabric filter, and another treebox filter) and exhibited similar clogging issues. Subsequently, Ecology has recognized that stormwater at the SCTF may be atypical for manufactured treatment device applications because of the intermittent occurrence of excessive sediment and oil loading. It is also important to note that the mulch layer was functioning as designed; it was removing sediments that would otherwise clog the engineered filter media. Table 4 indicates that, after the final mulch change on November 20, 2018, the system achieved a peak treated flow rate of 38.8 gpm on November 22, 2018, which is above the design flow rate of 35 gpm.

Table 4. Hydraulic Performance of the Sampled Events at the WB Test System.						
Date	**90th Percentile Sampled Outflow (gpm)**	**Peak Inflow (gpm)**	**Peak Outflow (treated) (gpm)**	**Peak Bypass Flow (gpm)**	**Averaged Outflow Flow During Bypass (gpm)**	**Cumulative Percent of a Water Year Treated**
5/11/2017	39.3	44.6	44.6	–	–	4
Maintenance – Mulch Changed, Shrub Replaced with Bare Root 5/14/2017						
5/15/2017	23.2	29.5	29.5	–	–	6
6/8/2017	40.2	43.6	43.6	6.1	24	9
6/15/2017	1.0	1.1	1.1	–	–	9
11/2/2017	11.6	16.1	16.1	–	–	11
11/4/2017	3.2	3.4	3.4	–	–	12
11/8/2017	11.5	21.6	21.6	3.3	2.5	13
Maintenance – Mulch Changed. Dead Bare Root Shrub Removed 11/10/2017						
11/12/2017	18.4	18.4	18.4	–	–	18
11/19/2017	3.2	34.0	3.9	31.3	3	19
Maintenance – Mulch Changed 11/20/2017						
11/21/2017	12.0	15.2	15.2	–	–	21
11/30/2017	23.9	24.3	24.3	–	–	25
12/2/2017	2.7	3.7	3.7	–	–	26
12/28/2017	34.0	59.9	35.4	24.5	33	26
1/4/2018	27.9	36.7	28.1	9.0	25	27
1/8/2018	14.8	21.0	14.9	6.3	14.7	33
1/17/2018	10.8	21.7	11.7	10.0	10.3	35
1/23/2018	16.7	17.1	17.1	–	–	36
1/26/2018	11.4	11.9	11.9	–	–	38
2/1/2018	12.1	12.3	12.3	–	–	39
2/3/2018	6.2	7.0	7.0	–	–	40
2/13/2018	11.6	11.9	11.9	–	–	40
Maintenance – Mulch Changed 2/20/2018						
Maintenance – Mulch Changed 11/20/2018						
11/22/2018	32.5	136.8	38.8	101.8	23	121
Mean	**16.7**	**26.9**	**18.8**	**24.0**	**16.9**	**–**

Sediment buildup on mulch after first event.

Sediment buildup on mulch after first event.

Figure 8. Photos of Sediment Loading at the StormGarden Biofiltration System Performance Evaluation Site.

Water Quality Data

This section summarizes water quality data collected at the WB test system over the monitoring period extending from April 20, 2017, through November 22, 2018. It begins with a comparison of the collected data to criteria identified in the TAPE guidelines for determining sample acceptability. Water quality data are then compared to treatment goals identified in the TAPE guidelines. A complete database of all the analyzed parameters is provided in Appendix G. Field forms completed by staff during each sampling visit are presented in Appendix H. Individual storm reports showing sample collection times in relation to influent and effluent hydrographs are presented in Appendix I for all sampled storm events. Finally, laboratory reports for each sampled event are presented in Appendix J.

Comparison of Data to TAPE Criteria

The TAPE guidelines identify criteria for determining data acceptability based on the characteristics of sampled storm events and the collected samples. Data collected through this monitoring effort are evaluated relative to those criteria below.

Storm Event Guidelines

During the April 20, 2017, through November 22, 2018, monitoring period, 22 storm events were sampled to characterize the water quality treatment performance of the WB test system. Precipitation data from these sampled storm events were compared to the following criteria from the TAPE guidelines for determining their acceptability:

- **Minimum precipitation depth**: 0.15 inch
- **Minimum antecedent dry period**: 6 hours with less than 0.04 inch of rain
- **Minimum storm duration**: 1 hour
- **Minimum average storm intensity**: 0.03 inch per hour for at least half the sampled storms

Summary data related to these criteria are presented in Table 5. As shown, the criterion for minimum precipitation depth (0.15 inch) was met during all storm events. The minimum, median, and maximum precipitation depths across all sampled storm events were 0.23, 0.63, and 1.92 inches, respectively. The criterion for minimum antecedent dry period (6 hours) and storm duration criterion (1 hour) were also met for all storm events. Antecedent dry periods during the sampled storm events ranged from 11.5 to 277 hours, with a median value of 40.5 hours. Storm durations ranged from 3 to 35 hours, with a median value of 16 hours (Table 5).

Table 5. Comparison of Precipitation Data from Sampled Storm Events at the WB Test System to Storm Event Guidelines in the TAPE.				
Storm Start Date and Time	**Storm Precipitation Depth (inches)**	**Storm Antecedent Dry Period (hours)**	**Storm Precipitation Duration (hours)**	**Average Storm Intensity (inches/hour)**
5/11/2017 3:30	0.25	122	16	0.02
5/15/2017 14:00	0.73	41	21	0.04
6/8/2017 1:05	0.32	171	10	0.03
6/15/2017 6:30	0.69	166	15	0.05
11/2/2017 11:40	0.67	277	27	0.03
11/4/2017 13:55	0.97	24	24	0.04
11/8/2017 16:30	0.46	76	28	0.02
11/12/2017 3:45	0.25	16	5	0.05
11/19/2017 15:55	0.76	77	18	0.04
11/21/2017 5:15	1.92	14	35	0.06
11/30/2017 6:25	0.31	40	5	0.06
12/2/2017 9:00	0.79	15	19	0.04
12/28/2017 19:45	1.31	55	25	0.05
1/4/2018 22:20	0.37	150	13	0.03
1/8/2018 22:20	0.23	24	9	0.02
1/17/2018 12:50	1.17	32	16	0.07
1/23/2018 8:10	1.02	27	21	0.05
1/26/2018 18:30	0.78	30	18	0.04
2/1/2018 11:30	0.58	67	11	0.05
2/3/2018 10:55	0.35	30	11	0.03
2/13/2018 21:05	0.27	97	3	0.08
11/22/2018 13:40	0.39	11.5	3	0.12
Minimum	0.23	11.5	3	0.02
Median	0.63	40.5	16	0.04
Maximum	1.92	277	35	0.12
Criteria	≥0.15	≥6	≥1	Range[a]

[a] Majority of events exceeded the rainfall intensity criterion of 0.03 inch per hour.

Values in **bold** do not meet storm event guidelines recommended in the TAPE (Ecology 2011).

The criterion for minimum average storm intensity (0.03 inch per hour) was met for 77 percent of the sampled storm events (Table 5). The TAPE guidelines recommend this threshold be met for at least half of the sampled storms; consequently, this goal was also met.

Sample Collection Guidelines

As described in the *Water Quality Monitoring Procedures* section, automated samplers were programmed with the goal of meeting the following criteria, identified in the TAPE guidelines, for acceptable composite samples:

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

It should be noted that 1 of the 22 sampled events involved the collection of discrete samples during peak flows. The TAPE guidelines indicate that sampling must capture a wide range of treated flows including the system's design flow rate; to obtain representative samples at this threshold, discrete sampling at the peak flow was required. The discrete samples were collected on December 28, 2017, by opening the upstream valve conveying stormwater to the WB test system until the treated flow rate was equivalent to the design flow rate; at this point the automated samplers at WB-IN and WB-OUT were manually activated until an adequate volume of stormwater was collected for sample analysis at both stations. This method was used to collect water quality data near the design flow rate, which was not possible by collecting flow-weighted composite samples alone (due to the collection of sample aliquots for compositing across the rising, peak, and falling limbs of the hydrograph). On review by the BER, it was determined that this event should be disqualified because the influent and effluent samples did not account for residence time in the filter and thus should not be paired. Consequently, the chemistry data from this event are excluded in the analyses below.

The criterion for minimum number of sample aliquots (10) in composite samples was met for all of the sampled events (see Table 6). A grab sample was collected during the June 15, 2017, event; and multiple samples targeting the system's design flow rate were collected during the December 28, 2017 event; consequently, the sampling criteria are not applicable to those events. Table 6 also indicates that the criterion for minimum hydrograph capture (75 percent) was met for all sampled events, and the sample collection duration never exceeded 36 hours.

Table 6. Comparison of Sampling Data from Storm Events at the WB Test System to TAPE Guidelines for Sample Events.

Storm Start Date and Time	Sample Aliquots (number)		Storm Coverage (percent)		Sampling Duration (hours)	
	WB-IN	WB-OUT	WB-IN	WB-OUT	WB-IN	WB-OUT
5/11/2017 3:30	47	51	94.4	96.8	15.1	15.2
5/15/2017 14:00	44	49	83.2	84.3	18.3	18.8
6/8/2017 1:05	46	47	92.2	96.0	7.5	8.0
6/15/2017 6:30[a]	**1**	**1**	NA	NA	NA	NA
11/2/2017 11:40	65	79	80.5	80.5	23.7	23.7
11/4/2017 13:55	84	83	77.7	77.1	21.5	21.3
11/8/2017 16:30	78	86	85.9	83.4	32.3	31.7
11/12/2017 3:45	15	16	85.6	91.3	3.7	4.5
11/19/2017 15:55	32	12	84.3	75.3	4.0	6.2
11/21/2017 5:15	24	23	93.8	90.5	26.8	26.6
11/30/2017 6:25	88	87	75.7	75.2	7.5	7.5
12/2/2017 9:00	39	39	95.5	93.9	14.5	14.7
12/28/2017 19:45[a]	13	12	NA	NA	NA	NA
1/4/2018 22:20	100	100	86.8	92.9	6.2	8.2
1/8/2018 22:20	31	27	89.0	95.5	2.7	5.7
1/17/2018 12:50	93	87	95.2	93.5	19.4	19.3
1/23/2018 8:10	31	31	97.6	97.6	15.7	15.7
1/26/2018 18:30	18	19	92.0	92.5	8.0	8.6
2/1/2018 11:30	27	26	95.6	92.4	5.7	5.6
2/3/2018 10:55	17	16	95.5	89.0	7.7	7.2
2/13/2018 21:05	23	22	94.1	91.5	3.7	3.7
11/22/2018 13:40	54	36	85.8	85.8	6.9	7.4
Minimum	1	1	75.7	75.2	2.7	3.7
Median	36	34	91	91	8	8
Maximum	100	100	97.6	97.6	32.3	31.7
Criteria	≥10		≥75		≤36	

[a] All sampled events were flow-weighted composites except: the June 15, 2017, event was a grab sample for total petroleum hydrocarbons, and the December 28, 2017, event was a peak flow composite sample event. TAPE sampling criteria are not applicable to these events.

Values in **bold** do not meet storm event guidelines recommended in the TAPE (Ecology 2011).

NA = not applicable

Water Quality Treatment Performance Evaluation

This section evaluates water quality data based on treatment goals identified in the TAPE guidelines. Particle size distribution data are presented first to assess the representativeness of influent stormwater; results from monitoring performed to evaluate the performance of the WB test system relative to the goals for basic and phosphorus treatment are then presented.

Particle Size Distribution

The TAPE guidelines indicate that stormwater in the Pacific Northwest typically contains mostly silt-sized particles; therefore, results for particle size distribution should be provided to indicate whether the stormwater runoff analyzed conforms to this assumption and is thus representative of regional conditions. In Figure 9, it is apparent that the suspended solids in the stormwater delivered to the WB test system were composed mostly of silt sized particles. The average D_{50} of the influent water at the Ship Canal Test Facility was 33 microns.

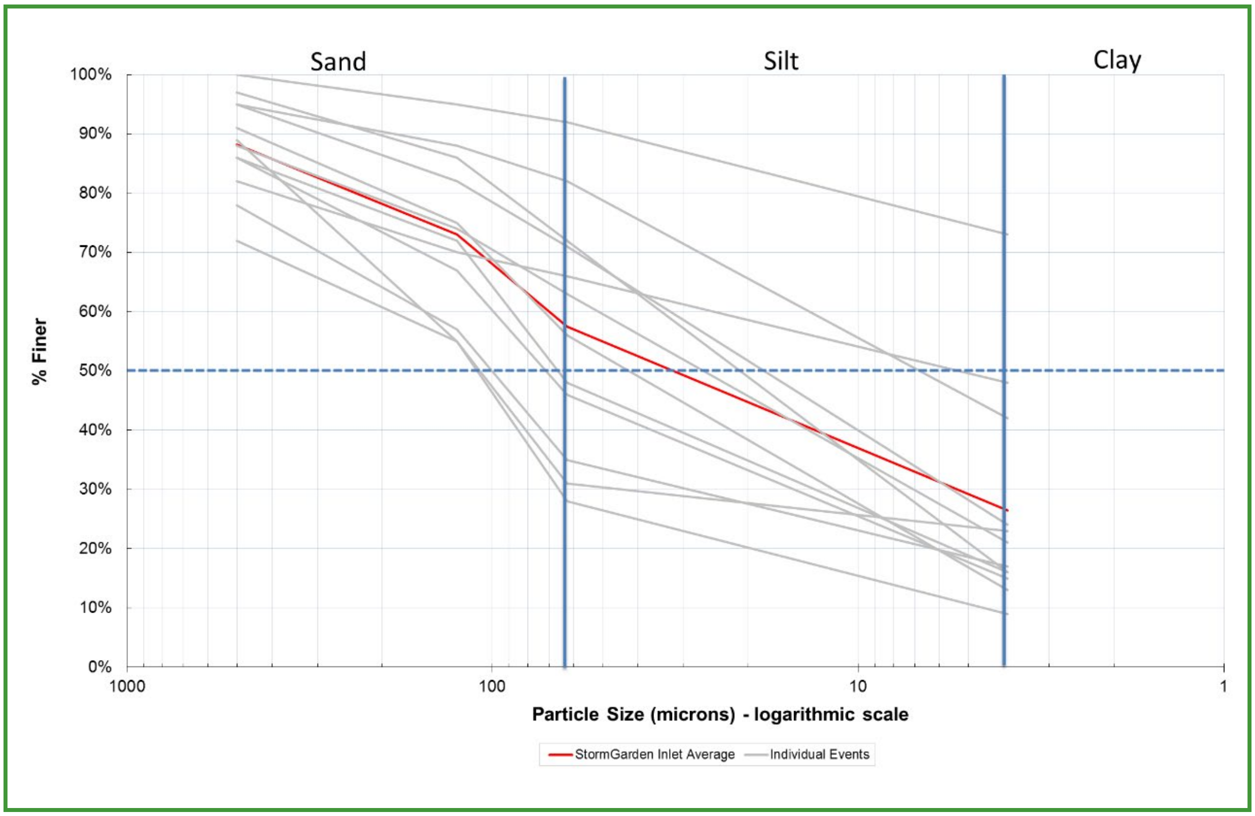

Figure 9. Influent Particle Size Distribution Results.

Basic Treatment

The basic treatment goal from the TAPE guidelines indicates the bootstrapped 95 percent lower confidence interval (LCL95) of the mean TSS removal must be greater than or equal to 80 percent for influent concentrations ranging from 100 to 200 mg/L. For influent TSS concentrations less than or equal to 100 mg/L but greater than 20 mg/L, the upper 95 percent confidence interval (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 that exceed 200 mg/L, the treatment goal is an LCL95 of at least an 80 percent reduction. Additionally, a statistically significant difference between influent and effluent concentrations must be demonstrated. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of flow rates up to and including the design flow rate.

Influent composite samples from 16 of the 21 sampled storm events had TSS concentrations above 20 mg/L. Samples with influent concentrations below this threshold could not be used in the analysis per the TAPE guidelines. After excluding the December 28, 2017, event per BER recommendation, a one-tailed Wilcoxon signed-rank test performed on the available TSS data ($n = 15$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent TSS concentrations compared to influent TSS concentrations. Consequently, this goal for basic treatment was met.

All the influent composite samples described above had concentrations between 20 and 100 mg/L except for the sample from the November 22, 2018, event, which had a concentration of 289 mg/L (Table 7). To provide a conservative estimate of performance, data from this sample were included in the calculation of the UCL95 of the mean effluent concentration for comparison to the effluent concentration goal identified above. Table 7 indicates the calculated UCL95 was 5.4 mg/L, well below the goal. Consequently, this basic treatment goal was also met.

A secondary assessment of performance was conducted by comparing the data to the percent reduction goal identified above. Again, this is a conservative estimate because the majority of the data had influent concentrations below 100 mg/L. Regardless, Table 7 indicates the calculated LCL95 for the mean percent reduction was 85.1 percent; hence, the percent reduction goal was also met.

To evaluate how TSS treatment efficiency may vary as a function of flow rate, analyses were performed to determine the flow rate at the time each aliquot for a flow-weighted composite sample was collected. Based on TAPE (2018b) guidelines the 90th percentile of those flow rates was calculated to represent the flow for that event. This was repeated for each event. Figure 10 displays percent removal versus the 90th percentile effluent flow rate for all 15 qualifying events. The TAPE guidelines state that a regression analysis should be conducted to evaluate whether treatment efficiency for TSS varies as a function of influent flow rate. Results from this analysis indicated no significant relationship between treatment efficiency and influent flow rate ($p = 0.565$). As is apparent from Figure 10, the WB test system removed greater than 80 percent of the influent TSS up to and including the design flow rate of 35 gpm.

Taken together, the analyses of the monitoring data indicate that the basic treatment goals from the TAPE guidelines were met by the WB test system.

Table 7. Water Quality Results and Comparison to TAPE Criteria.											
	Total Suspended Solids (mg/L)			Total Phosphorus (mg/L)			Orthophosphorus (mg/L)			Average Influent Sampled Flow (gpm)	Peak Treated Flow Rate (gpm)
Date	IN	OUT	Percent Reduction	IN	OUT	Percent Reduction	IN	OUT	Percent Reduction		
5/11/2017	90.0	9.0	90	0.208[a]	0.142[a]	32[a]	0.017[a]	0.090[a]	-429[a]	25.8	44.6
5/15/2017	28.0	3.0	89	0.076	0.030	61	0.004	0.006	-50	12.9	29.5
6/8/2017	48.0	1.0	98	0.252	0.104	59	0.018	0.012	33	30.7	43.6
6/15/2017[b]										0.5	1.1
11/2/2017	12.0[c]	3.0[c]	75[c]	0.136	0.070	49	0.031	0.017	45	7.2	16.1
11/4/2017	7.0[c]	1.0[c]	86[c]	0.054	0.020	63	0.028	0.015	46	2.8	3.4
11/8/2017	15.0[c]	4.0[c]	73[c]	0.064	0.026	59	0.009	0.004	56	5.2	21.6
11/12/2017	29.0	5.0	83	0.076	0.030	61	0.009	0.007	22	16.3	18.4
11/19/2017	45.8	1.4	97	0.090	0.024	73	0.004	0.005	-25	25.8	3.9
11/21/2017	32.0	7.0	78	0.088	0.036	59	0.009	0.012	-33	4.2	15.2
11/30/2017	14.0[c]	5.0[c]	64[c]	0.066	0.038	42	0.010	0.011	-10	20.2	24.3
12/2/2017	20.0	2.0	90	0.080	0.016	80	0.008	0.007	13	2.2	3.7
12/28/2017[d]	~~98.0~~	~~6.0~~	~~94~~	~~0.152~~	~~0.082~~	~~46~~	~~0.008~~	~~0.016~~	~~-100~~	52.7	35.4
1/4/2017	21.5	4.5	79	0.108	0.054	50	0.017	0.015	12	23.9	28.1
1/8/2018	19.0[c]	2.0[c]	89[c]	0.030	0.020	33	0.006	0.006	0	18.1	14.9
1/17/2018	21.0	5.0	76	0.060	0.026	57	0.008	0.007	13	10.8	11.7
1/23/2018	43.0	8.0	81	0.062	0.038	39	0.010	0.012	-20	11.6	17.1
1/26/2018	41.0	7.0	83	0.078	0.022	72	0.004	0.004	0	7.5	11.9
2/1/2018	52.0	3.0	94	0.068	0.034	50	0.012	0.009	24	8.4	12.3
2/3/2018	34.0	2.0	94	0.056	0.020	64	0.009	0.006	33	4.9	7.0
2/13/2018	27.0	2.0	93	0.092	0.042	54	0.017	0.016	6	5.8	11.9
11/22/2018	289	5.0	98[e]	0.346	0.068	80	0.014	0.041	-193	76.5	38.8

Table 7 (continued). Water Quality Results and Comparison to TAPE Criteria.											
	Total Suspended Solids (mg/L)			**Total Phosphorus (mg/L)**			**Orthophosphorus (mg/L)**			**Average Influent Sampled Flow (gpm)**	**Peak Treated Flow Rate (gpm)**
Date	**IN**	**OUT**	**Percent Reduction**	**IN**	**OUT**	**Percent Reduction**	**IN**	**OUT**	**Percent Reduction**		
Criteria		<20	≥80			≥50			NA		
n-value[f]	15	15	15	19	19	19	19	19	19	22	22
UCL95 Mean	87.3	**5.4**	91.2	0.129	0.046	62.8	0.015	0.014	15.8	23.7	23.5
LCL95 Mean	33.1	3.3	**85.1**	0.075	0.030	**53.4**	0.009	0.008	-23.2	11.3	14.5

[a] Data point was excluded from the analysis because the WB test system was leaching phosphate from the holly shrub in the system during this event. The shrub and potting soil were removed on May 14, 2017, and the same shrub was replanted with bare roots. See text under Phosphorus Treatment in the *Performance Evaluation* section.

[b] Only grab samples for total petroleum hydrocarbons were collected for this event. Sample data are presented in Appendix G and Appendix J.

[c] Value excluded from calculated summary statistics because the influent concentrations were less than 20 mg/L, which is below the TAPE acceptable range.

[d] Values excluded on BER recommendation.

[e] Per the TAPE, the influent value was reduced to 200 mg/L prior to calculation of percent reduction.

[f] The n-value indicates the number of samples used to calculate summary statistics for each parameter after excluding samples based on influent and special case screening. Descriptions of screening are provided in the other footnotes to this table and in the *Performance Evaluation* section.

Note: Design flow rate = 35 gallons per minute, or 140 inches per hour.

Bold values meet the performance target from the TAPE guidelines for the associated parameter.

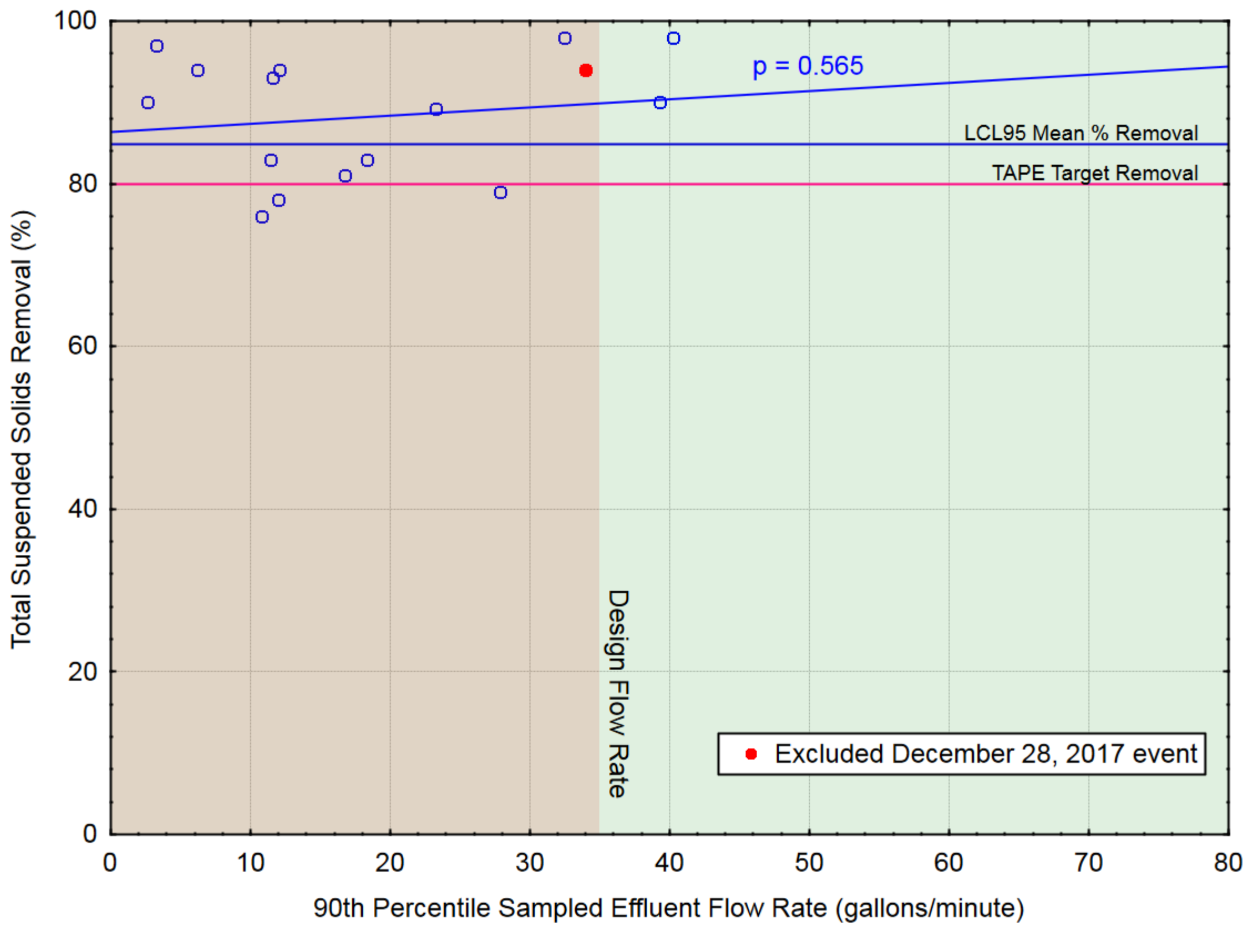

Figure 10. TSS Removal (percent) as a Function of Sampled Effluent Flow Rate.

Phosphorus Treatment

The phosphorus treatment goal from the TAPE guidelines indicates that the LCL95 of the mean removal must be greater than or equal to 50 percent for influent TP concentrations ranging from 0.1 to 0.5 mg/L. In addition, a statistically significant difference between influent and effluent concentrations must be demonstrated. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of treated flow rates up to and including the design flow rate.

As shown in Table 7, influent composite samples from 6 of the 21 sampled storm events had TP concentrations between 0.1 and 0.5 mg/L; while the remaining 15 samples had concentrations less than 0.1 mg/L. Per the TAPE guidelines, the latter sample pairs should be omitted from subsequent analyses of treatment performance because influent concentrations below the 0.1 mg/L threshold are deemed too difficult to treat relative to the percent reduction goal identified above. However, observations made over the course of monitoring indicated that the WB test system was able to meet the 50 percent reduction goal even when the low influent samples were included in the final dataset. Consequently, influent screening was not conducted, resulting in a more conservative assessment of performance while still providing a large enough dataset (n = 20) to conduct the analysis.

Data from the influent and effluent sample pair collected during the May 11, 2017, event were excluded from the analysis because the results were anomalous. This was the first sampled event and was characterized by elevated TP (Table 7) and orthophosphorus concentrations (Table 8) in the effluent sample. The source of the phosphorus was traced to the potting soil associated with the holly shrub that was planted in the WB test system. A synthetic precipitation leaching protocol test conducted on the engineered filter media and the potting soil indicated that the media leached only 0.056 mg/L of TP while the potting soil leached 0.308 mg/L (Appendix J)—more than 5 times that of the main filter media. The shrub and potting soil were removed on May 14, 2017, and the same shrub was replaced with bare roots. Subsequently, the WP test system's performance for TP removal improved considerably (Table 7). The shrub with bare roots began to senesce after replanting and died within a month. The dead shrub was removed on November 10, 2017, and the roots had not appeared to grow into the media after replanting. Due to this, we interpret this dataset as representative of a non-planted filter. In typical planted StormGarden installations Rotondo removes the potting soil prior to planting the shrub.

Table 8. Results of Other Screening Parameters.														
Date	Hardness (as $CaCO_3$ in mg/L)		pH (standard units)		Total Copper (µg/L)		Dissolved Copper (µg/L)		Total Zinc (µg/L)		Dissolved Zinc (µg/L)		Average Influent Sampled Flow (gpm)	Peak Treated Flow Rate (gpm)
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT		
5/11/2017	49.8	53.5	7.48	7.48	57.8	18.5	19.6	13.2	180	26.2	41	14.8	25.8	44.6
5/15/2017	39.9	43.7	7.69	7.54	33.8	12.9	14.1	9.2	82.7	20.2	33.2	11.6	12.9	29.5
6/8/2017	57.4	55.3	6.58	6.93	40.1	26.8	26.9	19.7	97.7	32.3	55.2	23.3	30.7	43.6
6/15/2017[a]													0.5	1.1
11/2/2017	66.3	68.8			24.9	13.7	13.8	10.7	91.4	20	41.2	13.2	7.2	16.1
11/4/2017	53.7	53.8			12.7	8.6	8.32	6.8	44.2	10.8	28.1	7.6	2.8	3.4
11/8/2017	96	106			27.2	10.0	14.1	7.6	79.8	16	43.6	11.9	5.2	21.6
11/12/2017	59.4	51.1			20.7	11.5	9.01	8.7	66.3	23.4	29.9	17.5	16.3	18.4
11/19/2017	35.6	38.9			36.4	7.0	10.5	5.4	112	12.6	39.6	8.9	25.8	3.9
11/21/2017	48.4	38.6			31.1	10.1	12	8.1	99.6	20.1	37.9	12.7	4.2	15.2
11/30/2017	48.6	49.3			24.1	16.5	12.3	12.9	73.6	25.8	33	14.9	20.2	24.3
12/2/2017	35.5	35.2			21.6	9.1	9.9	5.6	64.1	22.3	30	11.3	2.2	3.7
12/28/2017	29	32.1			56.7	19.6	9.4	7.7	180	46.4	43.4	14.8	52.7	35.4
1/4/2017	61.5	66.3			28.6	14.1	13	9.5	91	30.8	38	18.3	23.9	28.1
1/8/2018	46.1	49			16.8	7.8	8.2	6.1	54.9	17.5	28.2	13.6	18.1	14.9
1/17/2018	48.1	51.3			24	10.5	12.2	8.3	76	26.8	34.1	19.8	10.8	11.7
1/23/2018	31.2	30.2			31.3	13.1	11.3	8.6	102	33.8	35.1	20.2	11.6	17.1
1/26/2018	28.3	24.4			22	8.7	9.3	1.8	67.3	23.2	28	38.7	7.5	11.9
2/1/2018	33.6	31.9			30.1	11.9	10.7	8.1	83.5	32.2	33.7	20.6	8.4	12.3
2/3/2018	40.6	39.7			24.3	9.5	10.2	7.4	60.9	26.2	28.4	34.7	4.9	7.0
2/13/2018	43.4	46.5			31.1	12.6	10.8	8.7	88.2	31.7	29.9	24.5	5.8	11.9
11/22/2018	42.7	35.6			70.1	15.9	10.5	11.6	217	29.8	23.4	21	76.5	38.8
Mean	**47.4**	**47.7**	**7.3**	**7.3**	**31.7**	**12.8**	**12.2**	**8.8**	**95.8**	**25.1**	**35.0**	**17.8**	**17.0**	**18.8**

[a] Only grab samples for total petroleum hydrocarbons were collected for this event. Sample data are presented in Appendix G and Appendix J.

$CaCO_3$ = calcium carbonate

µg/L = micrograms per liter

mg/L = milligrams per liter

Next, based on BER recommendation, the December 28, 2017, event was excluded from the analysis because of concerns about the influent and effluent data not being properly paired at the peak flows.

A one-tailed Wilcoxon signed-rank test applied to the final dataset ($n = 19$) indicated there was a statistically significant ($p < 0.001$) decrease in effluent TP concentrations compared to influent concentrations. Consequently, this component of the phosphorus treatment goal from the TAPE guidelines was met.

Table 7 indicates that the calculated LCL95 of the mean TP reduction for this dataset was 53.4 percent, which exceeds the percent removal goal identified above. Consequently, this component of the phosphorus treatment goal from the TAPE guidelines was also met.

Analyses were performed to evaluate TP treatment efficiency as a function of 90th percentile of the sampled effluent flow rate, as described above for basic treatment. Figure 11 displays percent removal versus the flow rate for all 19 qualifying events. Results from the regression analysis performed on these data indicated there was no significant relationship between treatment efficiency and treated flow rate ($p = 0.498$). As is apparent from Figure 11, the WB test system removed greater than 50 percent of the influent TP up to and including the design flow rate of 35 gpm.

Taken together, analyses of the monitoring data indicate the WB test system was able to meet the phosphorus treatment goals from the TAPE guidelines at flow rates up to and including the design flow rate of 35 gpm.

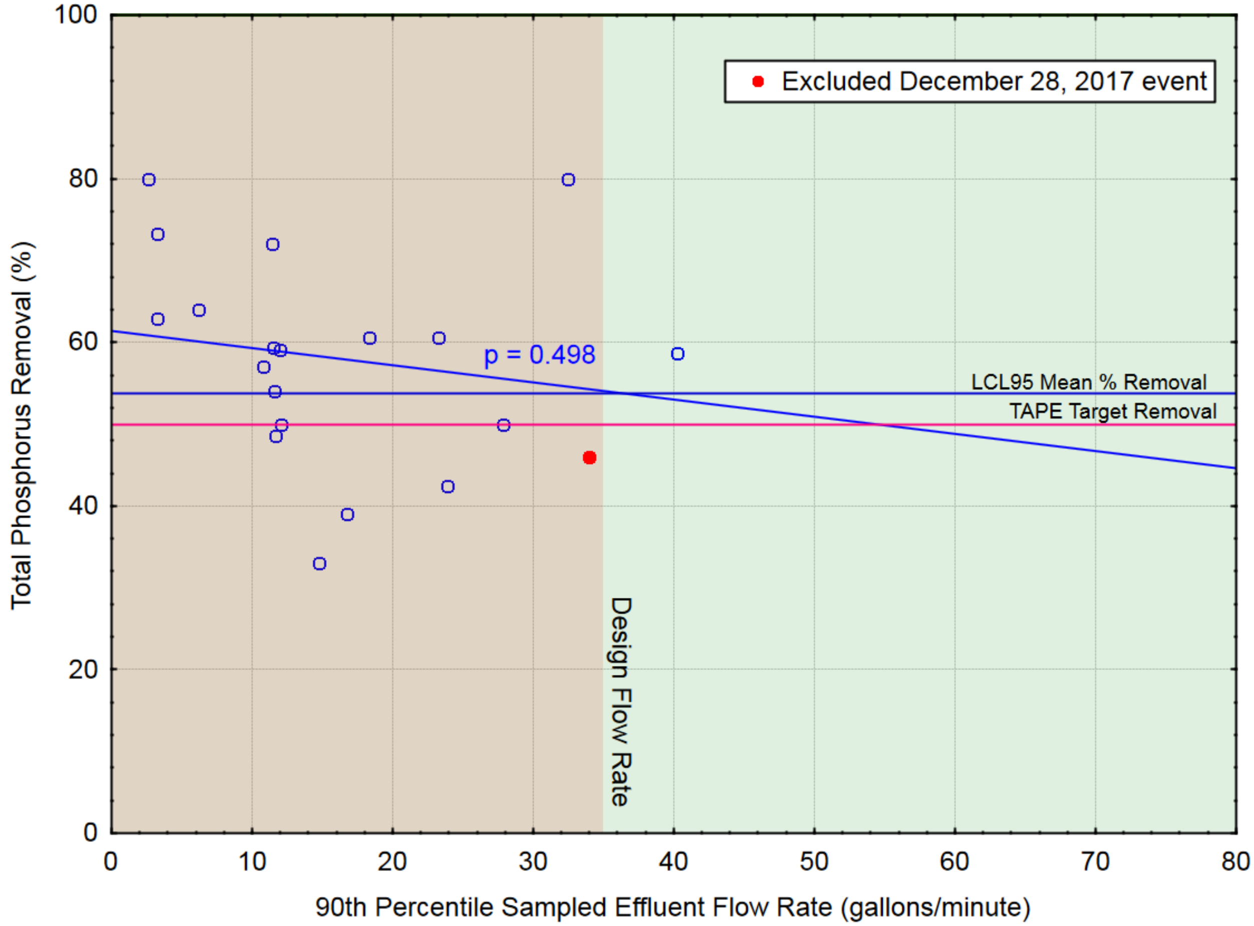

Figure 11. TP Removal (percent) as a Function of Sampled Effluent Flow Rate.

Other Factors

In addition to the required parameters addressed above, the TAPE guidelines indicate screening parameters consisting of hardness, pH, total and dissolved copper, and total and dissolved zinc should also be analyzed. Results for those parameters are presented in Table 8. The mean hardness concentrations were 49.0 and 47.5 mg/L of calcium carbonate ($CaCO_3$) from influent and effluent samples, respectively. The mean pH levels were 7.25 and 7.32 from influent and effluent samples, respectively. The TAPE guidelines indicate that the test system should not increase or decrease pH by more than one unit for any given event and should not discharge effluent with pH levels less than 4 or greater than 9. The pH data presented in Table 8 indicate that those conditions were met for each sampled event.

Table 8 also indicates reductions were achieved for both total and dissolved copper and zinc. These reductions were not great enough to meet enhanced treatment criteria from the TAPE guidelines; hence, they are only included as screening parameters. In addition to collecting data for the screening parameters, Herrera collected samples for TPH during eight storm events. Laboratory results for TPH are included in Appendices G and J for reference only.

Finally, an analysis of the Filter Panel's effect on system infiltration and water quality performance was conducted. The results indicate that the Filter Panel likely increases the hydraulic and water quality performance of the StormGarden (Appendix K). The Filter Panel was sealed during the TAPE testing; if unsealed, it is anticipated that StormGarden performance would improve above what was quantified in this study primarily because a portion of the pollutant load would be infiltrated instead of leaving the system and entering the MS4.

CONCLUSIONS

To obtain performance data to support the issuance of a GULD for the StormGarden™, Herrera conducted hydrologic and water quality monitoring at a test system located at the WSDOT SCTF in Seattle, Washington, from April 20, 2017, to November 22, 2018. During the monitoring period, 22 separate storm events were sampled. The sampling yielded 21 paired influent and effluent composite samples and 8 paired grab samples for characterizing the performance of the WB test system.

Of the 21 paired composite samples collected, 15 were suitable for use in evaluating the WB test system's performance against the basic treatment goal from the TAPE guidelines. The UCL95 of mean effluent TSS concentration from the 15 samples was 5.4 mg/L, and the goal for basic treatment from the TAPE program is ≤20 mg/L; therefore, the WB system met this goal for basic treatment. The LCL95 of the mean percent removal was 85.1 percent, which also meets the basic treatment goal of ≥80 percent removal. The StormGarden test system also meets the goal of at least 80 percent TSS removal up to and including the design flow rate of 35 gpm (140 in/hr).

After excluding the first sample collected during the monitoring period identified above (due to nutrient contamination from potting soil used in the test system) and omitting low concentration influent screening (because of the persistently low influent TP concentrations), the LCL95 mean percent TP removal for the remaining 19 composite samples was 53.4 percent, which meets the TAPE goal of ≥50 percent removal. A regression analysis of TP versus sampled treated flow rate indicated that the WB system was able to remove ≥50 percent of influent TP up to and including the design flow rate of 35 gpm (140 in/hr).

Taken together, the sampling results present strong evidence that the Rotondo StormGarden biofilter system should receive a GULD for basic and phosphorus treatment.

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APPENDIX A

StormGarden Vault Configurations

StormGarden Vault Filter

Technology Description

The StormGarden Vault Filter (SGVF) is an underground vault version of the StormGarden tree-box filter with the addition of a pre-treatment chamber upstream of the filter chamber. The filter consists of three chambers, an inlet chamber, a treatment chamber with a filter bed, and an outlet chamber with a bypass weir, housed in an underground concrete vault. While the StormGarden tree-box filter is typically located along the curb of a roadway or parking lot accepting runoff through a throat inlet, the concrete vault can either be installed flush with finish grade to allow water to enter through a grated inlet or can be buried underground to accept runoff from a pipe fed by curb inlets located upstream of the filter. Stormwater runoff enters the pre-treatment chamber through an inlet pipe or a grated inlet allowing gross solids to settle out and trapping floating trash and debris preventing them from reaching the filter chamber. Pre-treated flow is then directed to the treatment chamber through a submerged opening in the baffle wall between the inlet chamber and the filter chamber.

The treatment chamber contains a filter media bed that is identical to the standard StormGarden filter media used in the TAPE test unit. The standard StormGarden media consists of a 3" top layer of shredded wooden mulch, a 21" middle layer of the standard StormGarden engineered media, and a bottom 6" layer of clean underdrain stone housing a 4" or 6" perforated underdrain pipe that discharges directly to the outlet chamber.

The outlet chamber is opened at the top providing an overflow weir that allows flows exceeding the treatment flow to bypass the system internally, thus allowing the filter to be installed on-line or off-line.

Pre-Treatment Chamber (Inlet Chamber)

Although the StormGarden Vault Filter (SGVF) is basically identical to the StormGarden tree-box filter, one big difference is the addition of the pre-treatment chamber. Because the runoff is entering the filter via a pipe, in order to prevent scour of the filter media, a pre-treatment chamber with a permanent pool of water was added. The chamber has a dual function, first the permanent pool of water in the chamber provides energy dissipation of the influent flow thus eliminating the possibility of scouring of the media. Second, the chamber pre-treats the influent prior to entering the filter chamber by allowing gross solids to settle to the bottom of the chamber and trapping floating trash and debris inside the chamber. By pre-treating the influent, we are extending the life of the media and reducing the annual maintenance costs. The chamber also allows the filter media to maintain its design hydraulic flow rate over a longer period of time by preventing sediment from building up on top of the media and clogging it.

The addition of the pre-treatment chamber will improve the performance of the StormGarden filter above and beyond what was demonstrated in the TAPE test as shown in this report.

StormGarden Filter Media

The SGVF filter chamber contains the same StormGarden standard filter media used in the TAPE test unit as detailed in the attached report. The overall media consists of a 3" top layer of shredded hardwood mulch, a 21" middle layer of the StormGarden engineered media, and a 6" thick bottom layer of clean underdrain stone. Within the stone layer is a 4" or 6" diameter perforated underdrain pipe that collects the water after filtering down through the media allowing the treated water to drain directly to the outlet chamber.

Bypass Weir/Outlet Chamber

The outlet chamber is a separate chamber inside the filter structure that is opened on top with the top perimeter acting as a bypass weir. The top of the wall, which acts as the weir, is set at an elevation 6 inches above the top of the filter media. This provides 6 inches of ponding over the top of the media allowing storage of the treatment flow as it filters down through the media. As the flow rate exceeds the design treatment flow rate, the water begins to rise above the weir bypassing the filtering process.

Concrete Structure

The SGVF container structure consists of a reinforced precast concrete shell that is designed to support AASHTO HS-20 wheel loading as well as varying depths of earth fill over the top of it. Access to the inside of the filter structure is through manhole covers above each chamber.

Site Installation Requirements

The following subsections describe the site installation requirements including necessary soil characteristics, hydraulic grade requirements depth to groundwater limitations, utility requirements, and other limitations.

Necessary Soil Characteristics

The SGVF requires a level stone bed with a minimum thickness of 6 inches.

Hydraulic Grade Requirements

The elevation between the invert of the influent pipe and the invert of the outlet pipe is 2'-10". The SGVF allows for 6 inches of freeboard within the system for head accumulation. If the drop across the system, as measured from the invert of the influent pipe to the invert of the outlet pipe, is greater than or equal to 2'-10", the SGVF will not induce significant backwater in the collection system upstream. If the drop across the system is less than 2'-10", backwater may occur. Given the physical constraints of the system, the drop across the system cannot be less than 2'-4".

Depth to Groundwater Limitations

The SGVF does not have depth-to-groundwater limitations since it is a fully enclosed watertight system. With regards to buoyancy, if the groundwater elevation is such that the structure becomes buoyant, an exterior concrete anti-flotation collar can be added to the base of the structure to increase the structure weight to prevent it from floating.

Utility Requirements

The SGVF is designed to be a passive system requiring no power and has a free-draining outfall to an appropriate water conveyance or storage system (i.e. wet pond, storm sewer, underground filtration).

Treatment Process

Because the StormGarden Vault Filter uses the same filter media as the StormGarden tree-box filter, the treatment process is as described in the StormGarden report.

Sizing Methodology

Because the SGVF has the same basic function and media as the StormGarden tree-box filter, and comes in similar sizes, the sizing methodology is the same as the standard StormGarden tree-box filter as detailed in the attached report.

Below is a chart showing the available sizes of the StormGarden Vault Filter (SGVF). The smaller filter sizes are housed in a singular reinforced concrete vault ranging in size from 4' x 6' up to 8' x 18'. The larger filters, "StormGarden/Magna-Pod Vault Filter" (SGMPVF), consists of modular concrete components adjoined together to create larger filters.

Filter	Vault Width	Vault Length	Media Length	Filter Area (sf)
SGVF-46	4’-0”	6’-0”	3’-9”	15
SGVF-48	4’-0”	8’-0”	5’-9”	23
SGVF-410	4’-0”	10’-0”	7’-9”	31
SGVF-412	4’-0”	12’-0”	9’-9”	39
SGVF-66	6’-0”	6’-0”	3’-9”	22.5
SGVF-68	6’-0”	8’-0”	5’-9”	34.5
SGVF-610	6’-0”	10’-0”	7’-9”	46.5
SGVF-612	6’-0”	12’-0”	9’-9”	58.5
SGVF-614	6’-0”	14’-0”	11’-9”	70.5
SGVF-616	6’-0”	16’-0”	6’-6”	78
SGVF-618	6’-0”	18’-0”	7’-6”	90
SGVF-88	8’-0”	8’-0”	5’-9”	46
SGVF-810	8’-0”	10’-0”	7’-9”	62
SGVF-812	8’-0”	12’-0”	9’-9”	78
SGVF-814	8’-0”	14’-0”	11’-9”	94
SGVF-816	8’-0”	16’-0”	6’-6”	104
SGVF-818	8’-0”	18’-0”	7’-6”	120
SGMPVF-2	14’-0”	16’-0”	8’-0”	147
SGMPVF-3	22’-0”	16’-0”	8’-0”	253
SGMPVF-6	22’-0”	32’-0”	8’-0”	464

Operation & Maintenance Requirements

Inspection

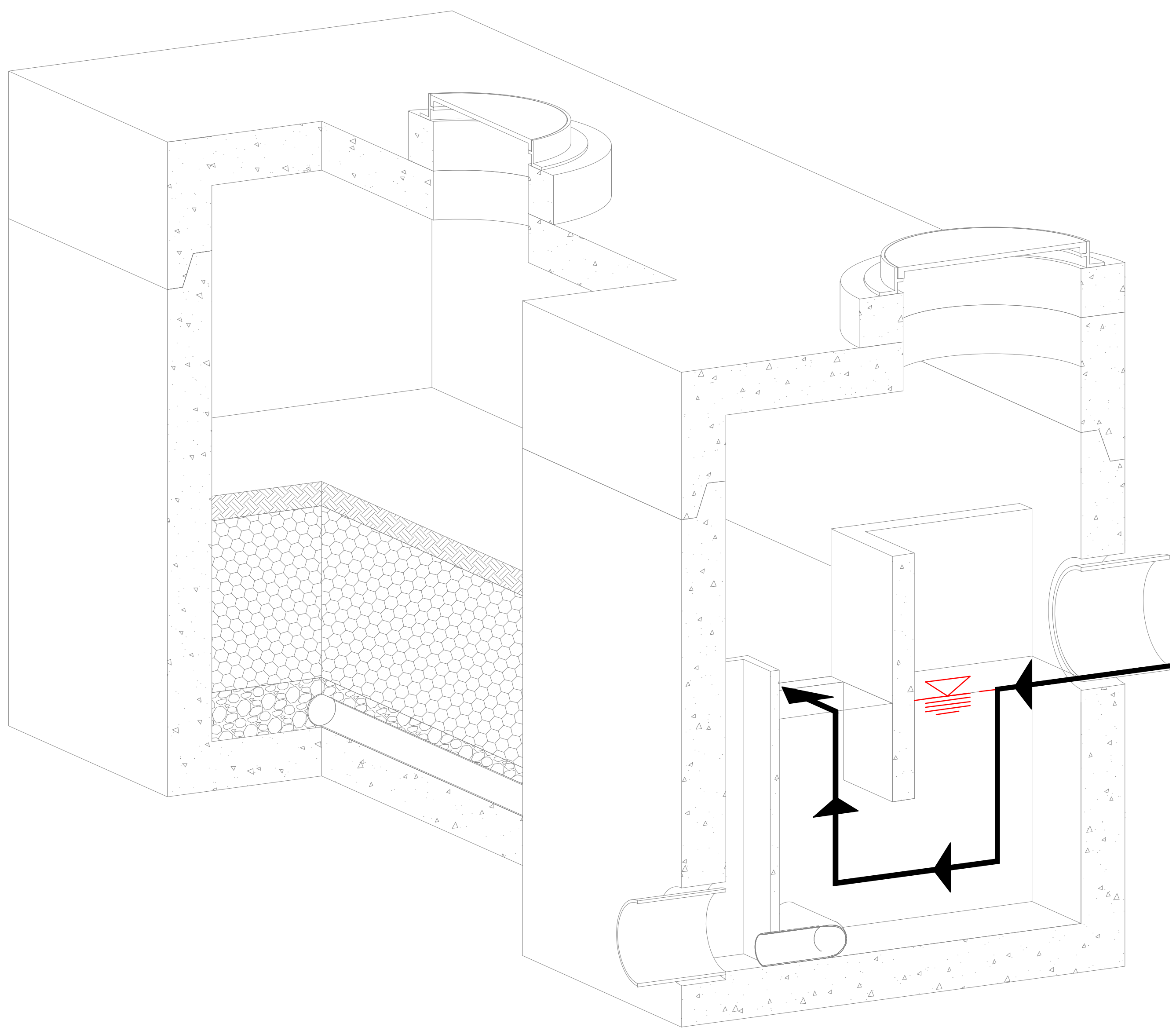
The SGVF inspections are visual and may be conducted from the ground surface without entering the unit. To complete an inspection, safety measures including traffic control should be deployed before the access covers are removed. Once the covers have been removed, the following items should be checked and recorded to determine whether maintenance is required.

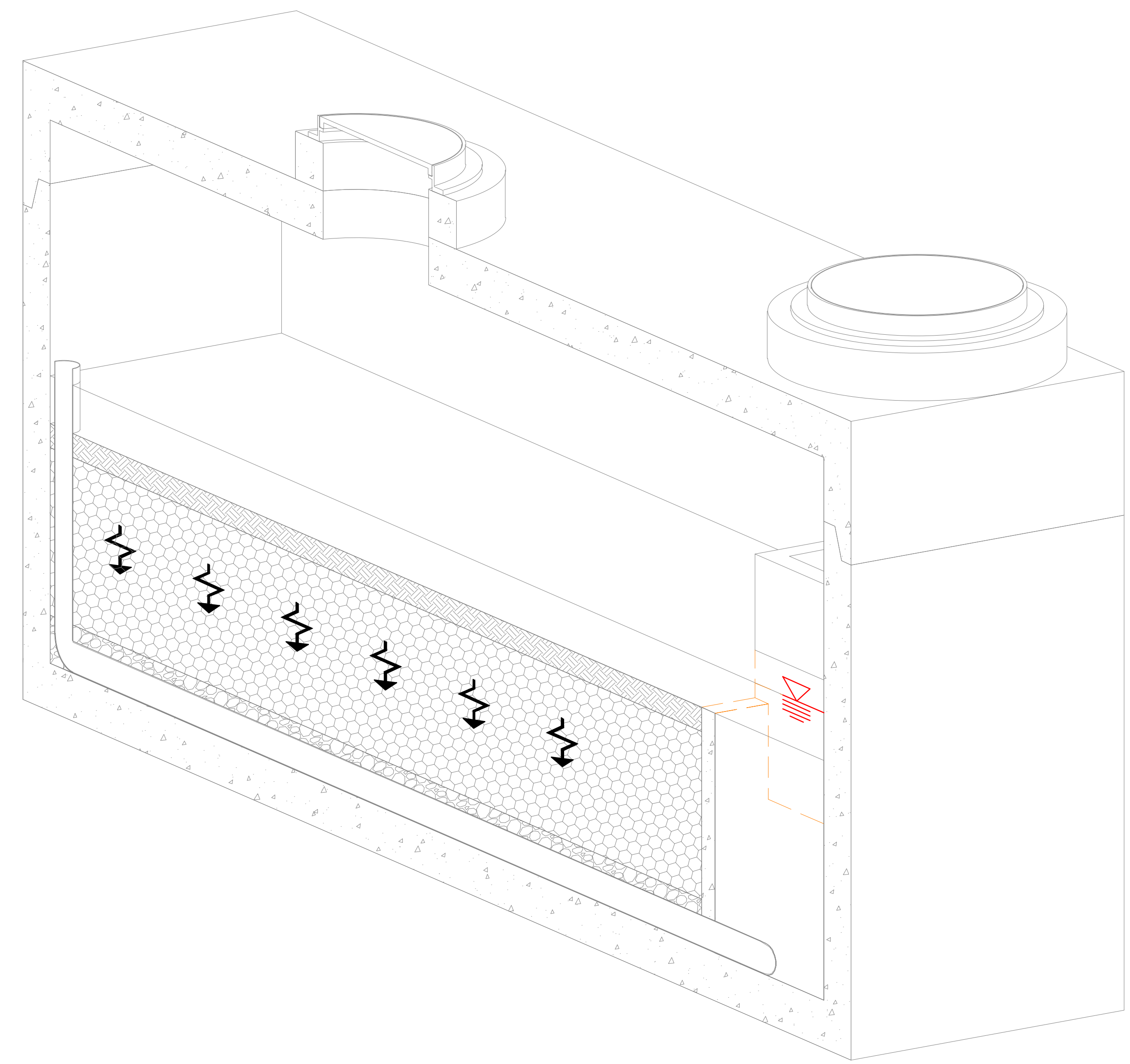
- Observe whether the inlet pipe or bypass weir is blocked or obstructed. The outlet pipe is covered by the outlet chamber wall and cannot be observed without entering the unit.
- Observe and record the amount of floating trash and debris in the inlet chamber. The significance of accumulated floating trash and debris is a matter of judgement. A long-handled net may be used to retrieve the bulk of trash and debris at the time of inspection if full maintenance due to the accumulation of floating oils or settled sediment is not yet warranted.
- Observe and record the amount of accumulated oils in the inlet chamber. The significance of accumulated floating oils is a matter of judgement. However, if there is evidence of an oil or fuel spill, immediate maintenance by appropriate certified personnel is warranted.
- Observe and record the average accumulation of sediment in the inlet chamber. A calibrated dip-stick or tape measure may be used to determine the amount of accumulated sediment. The depth of sediment may be determined by calculating the difference between the measurement from the surface of the permanent pool to the top of the accumulated sediment and the measurement from the surface of the permanently pool to the bottom of the inlet chamber.
- Observe and record the amount of sediment, trach and debris resting on top of the filter bed.

Maintenance Procedures

Maintenance should be conducted during dry weather when no flow is entering the system. Confined space entry is necessary to maintain the StormGarden Vault Filter. Only personnel that are OSHA Confined Space Entry trained and certified may enter underground structures. Once safety measures such as traffic control are deployed, the access covers may be removed, and the following activities may be conducted to complete maintenance.

- Remove floating trash, debris and oils from the water surface in the inlet chamber using the extension nozzle on the end of the boom hose of the vacuum truck. Continue using the vacuum truck to completely dewater the inlet chamber and evacuate all accumulated sediment from the inlet chamber. Some jetting may be required to fully remove sediment. The inlet chamber does not need to be refilled with water after maintenance is complete. The system will fill with water when the next storm event occurs.
- Remove built-up sediment, trash and debris on top of the filter media by removing the top 3-inch layer of mulch. After removing the mulch, inspect the filter media to determine if sediment build-up has occurred. If sediment is detected, scrape off the top few inches of media until clean media is reached and replace with clean media. Replace the top layer of mulch with new mulch.
- Securely replace access covers, as appropriate.
- The handling and disposal of sediment and waste must comply with all local, county, state and federal regulations.





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PATENT PENDING

DRAWN BY: FRJ	PROJECT: STORMGARDEN VAULT FILTERS
CHECKED BY: .	
DATE: 12–20–2018	
SCALE: NTS	CUSTOMER: .
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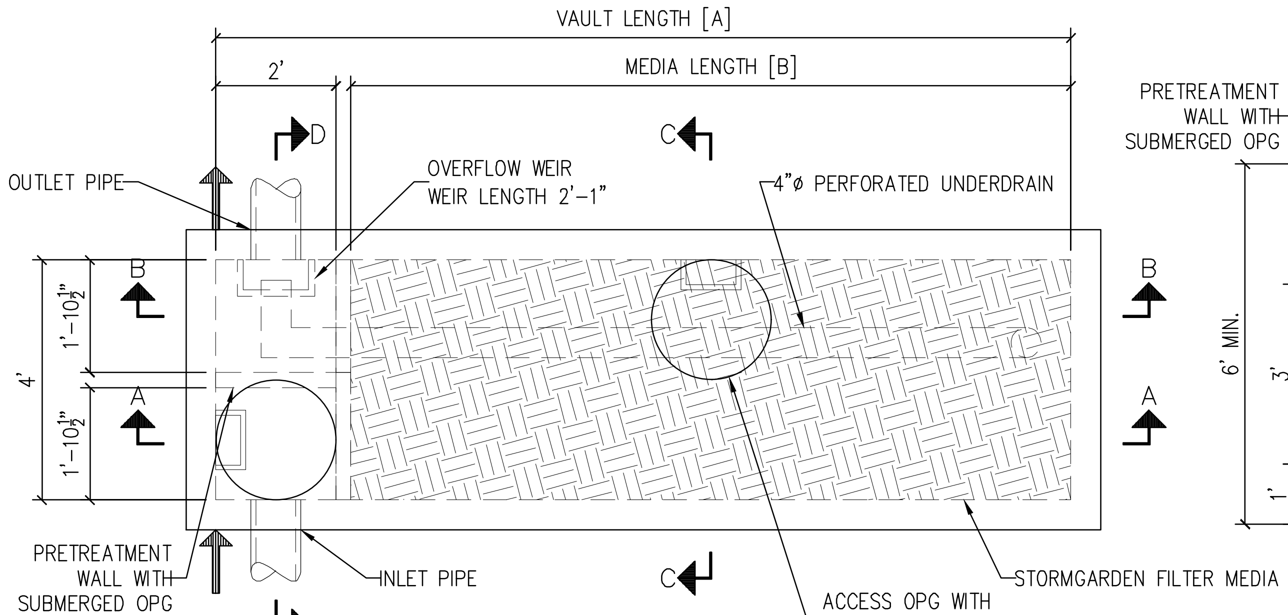
	SHT.:



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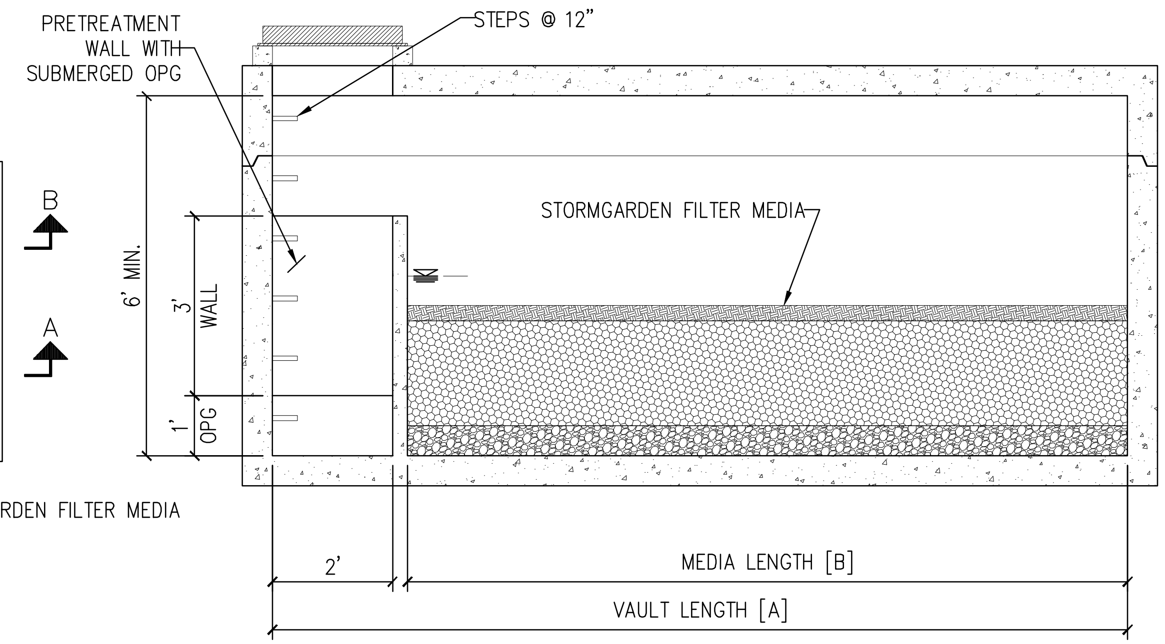

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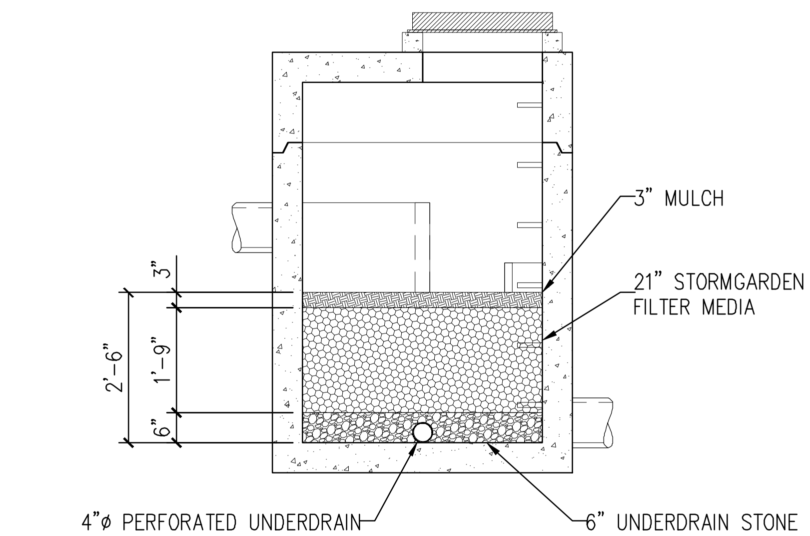

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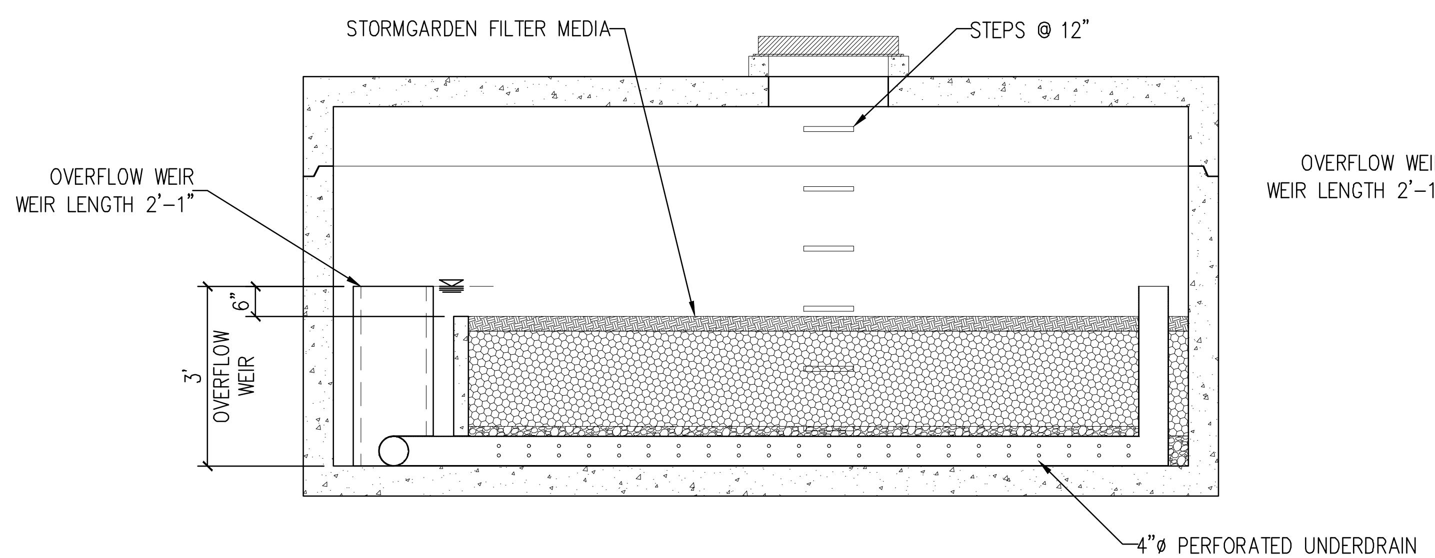

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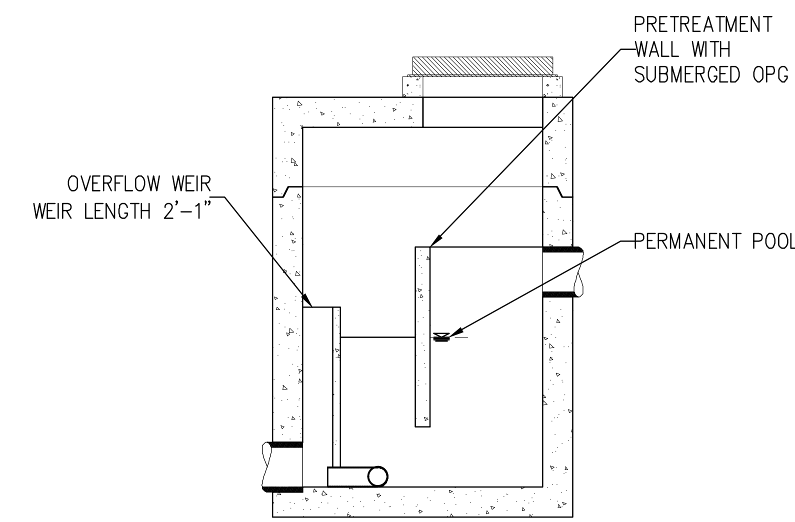

SECTION D-D

SGVF-4X STORMGARDEN FILTERS				
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SGVF-46	6'-0"	3'-9"	2'-1"	2.48
SGVF-48	8'-0"	5'-9"	2'-1"	2.48
SGVF-410	10"-0"	7'-9"	2'-1"	2.48
SGVF-412	12'-0"	9'-9"	2'-1"	2.48

** BYPASS FLOW RATE IS BASED ON A HEAD OF 0.50' ABOVE THE WEIR.

DESIGN NOTES:

- CONCRETE MINIMUM (28-DAY) COMPRESSIVE STRENGTH: 5,000 PSI
- REINFORCING BARS CONFORMING TO ASTM A615 (FY = 60 KSI)
- DESIGN LIVE LOAD: HS-20

SGVF-4X STORMGARDEN FILTERS

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CHECKED BY: .
DATE: 12-20-2018
SCALE: NTS
JOB NO.:
PROJECT: STORMGARDEN VAULT FILTERS
CUSTOMER: .
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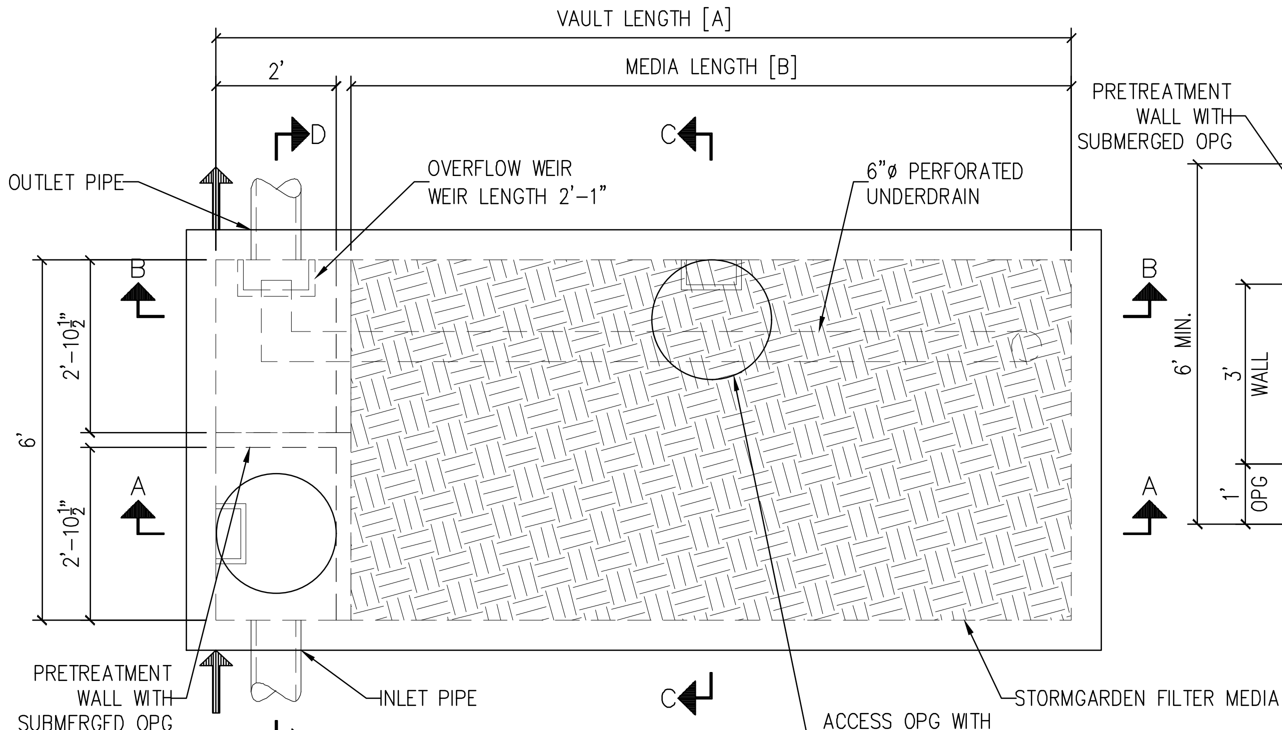

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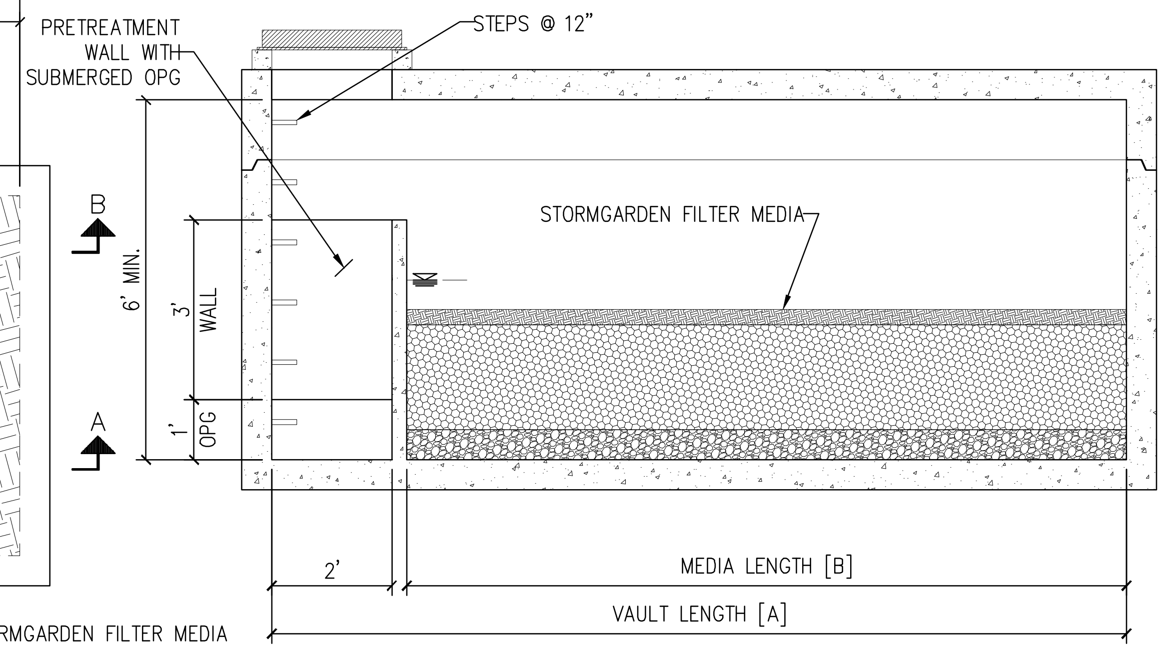

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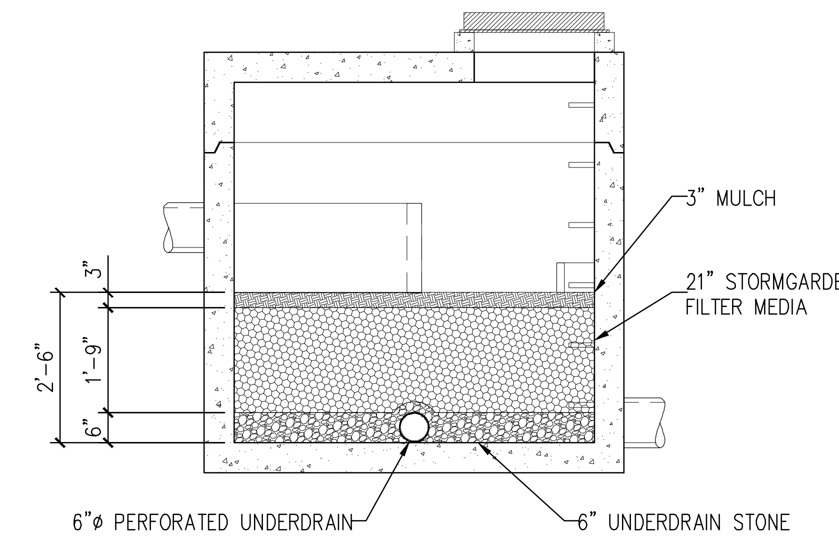

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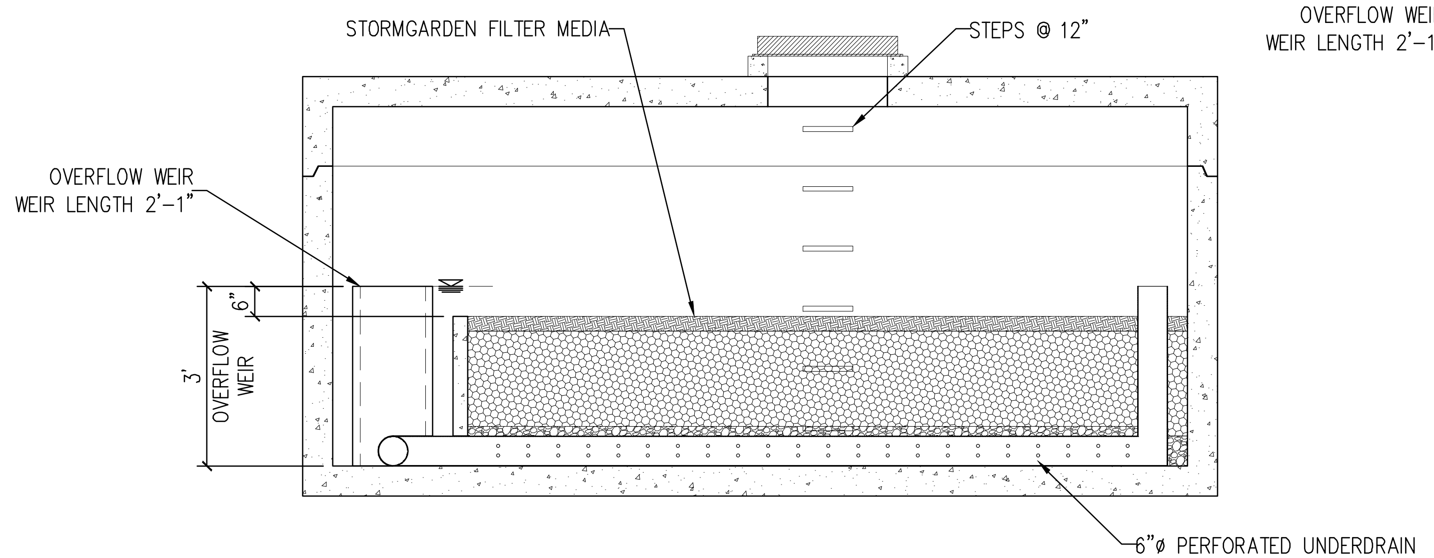

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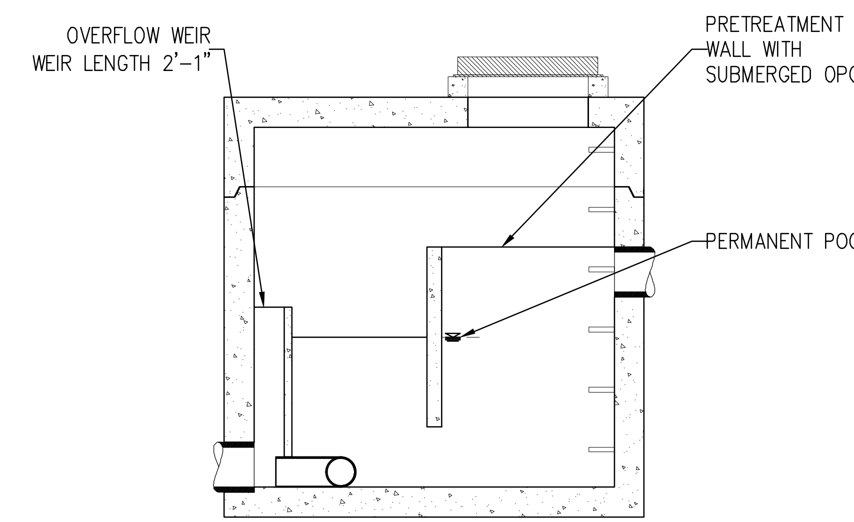

SECTION D-D

SGVF-6X STORMGARDEN FILTERS				
DESIGNATION:	[A] VAULT LENGTH:	[B] MEDIA LENGTH:	WEIR LENGTH:	**BYPASS FLOW (CFS):
SGVF-66	6'-0"	3'-9"	2'-1"	2.48
SGVF-68	8'-0"	5'-9"	2'-1"	2.48
SGVF-610	10"-0"	7'-9"	2'-1"	2.48
SGVF-612	12'-0"	9'-9"	2'-1"	2.48
SGVF-614	14'-0"	11'-9"	2'-1"	2.48

** BYPASS FLOW RATE IS BASED ON A HEAD OF 0.50' ABOVE THE WEIR.

DESIGN NOTES:
- CONCRETE MINIMUM (28-DAY) COMPRESSIVE STRENGTH: 5,000 PSI
- REINFORCING BARS CONFORMING TO ASTM A615 (FY = 60 KSI)
- DESIGN LIVE LOAD: HS-20

SGVF-6X STORMGARDEN FILTERS

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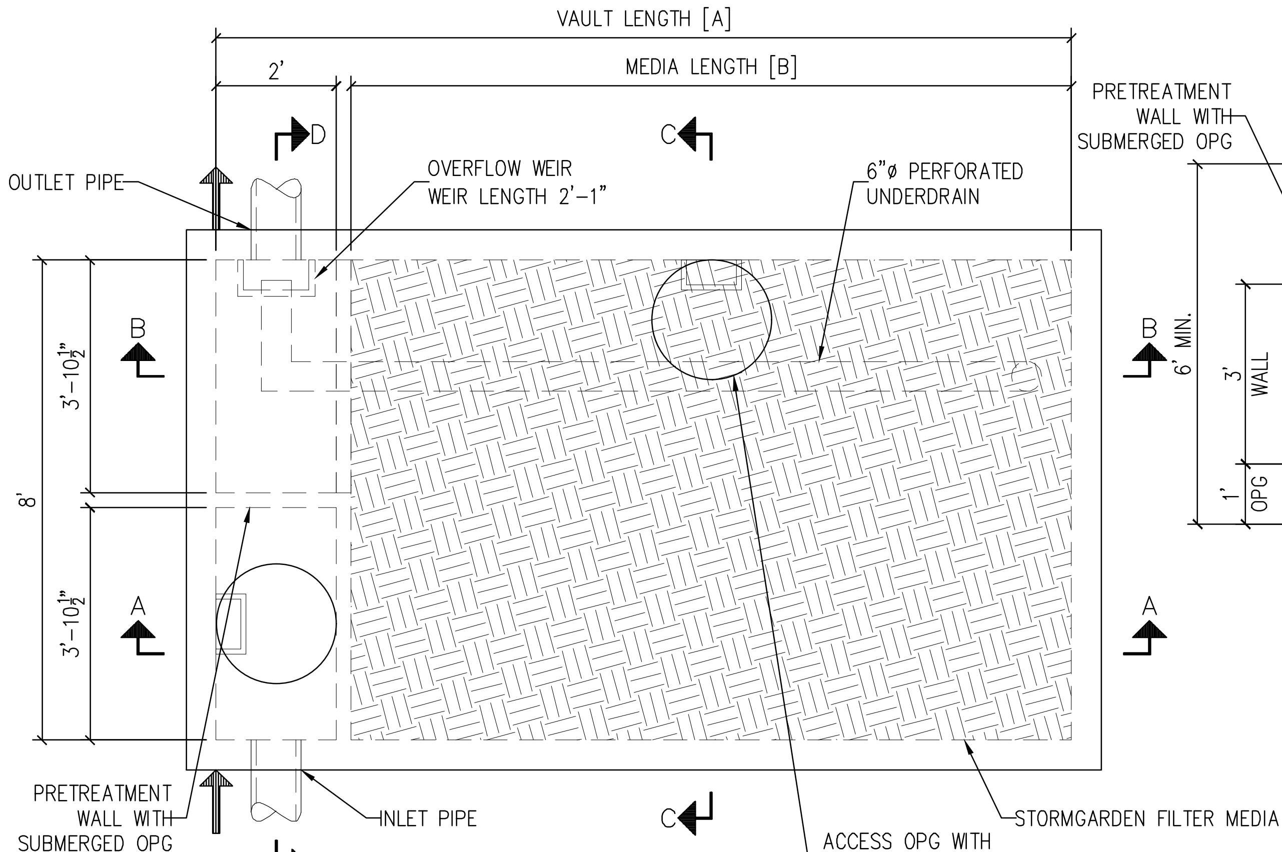
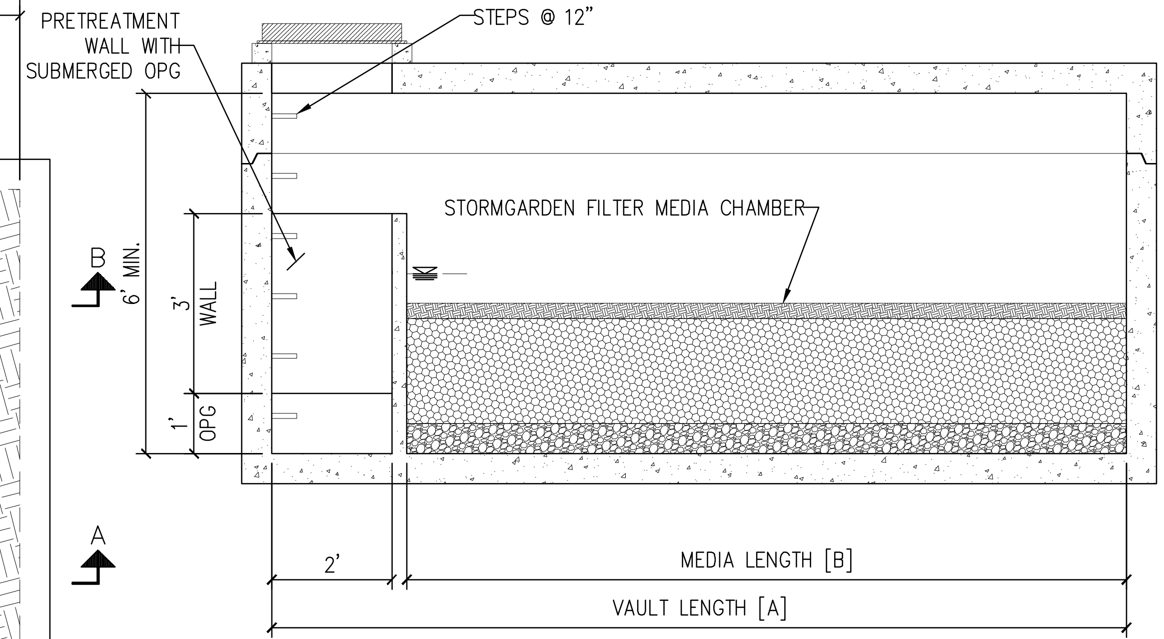
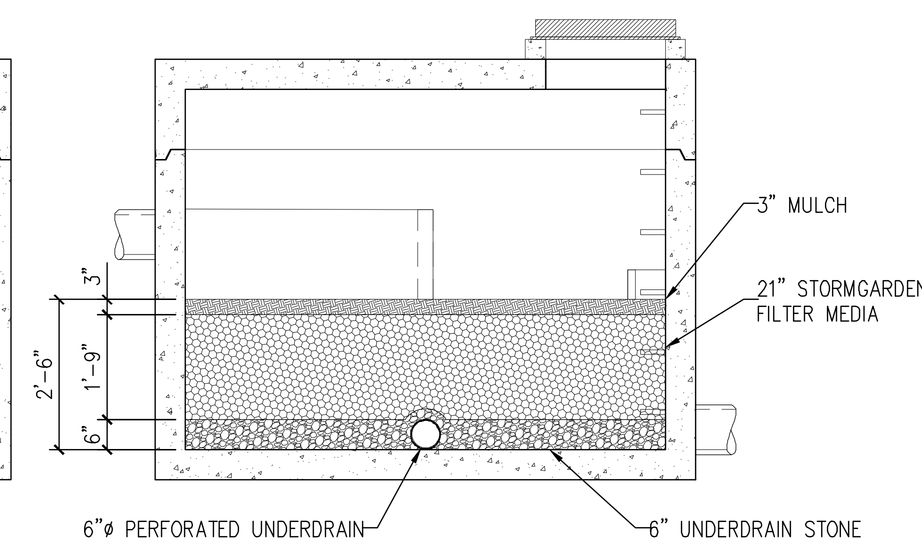


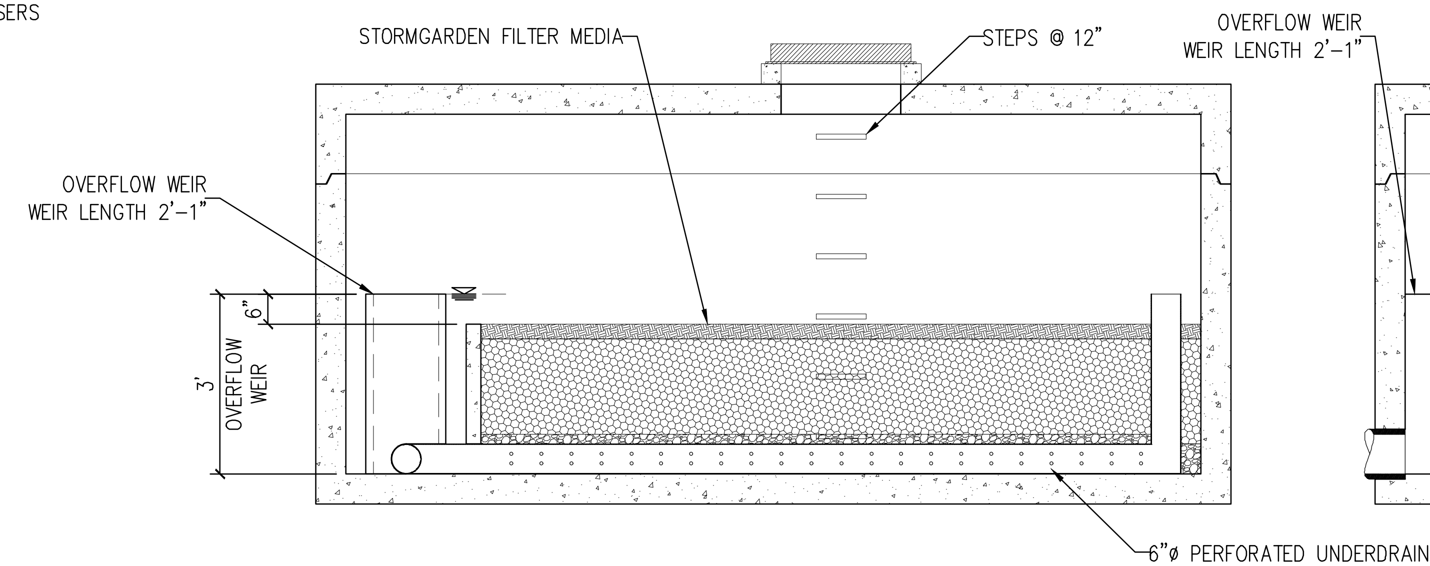
PLAN VIEW



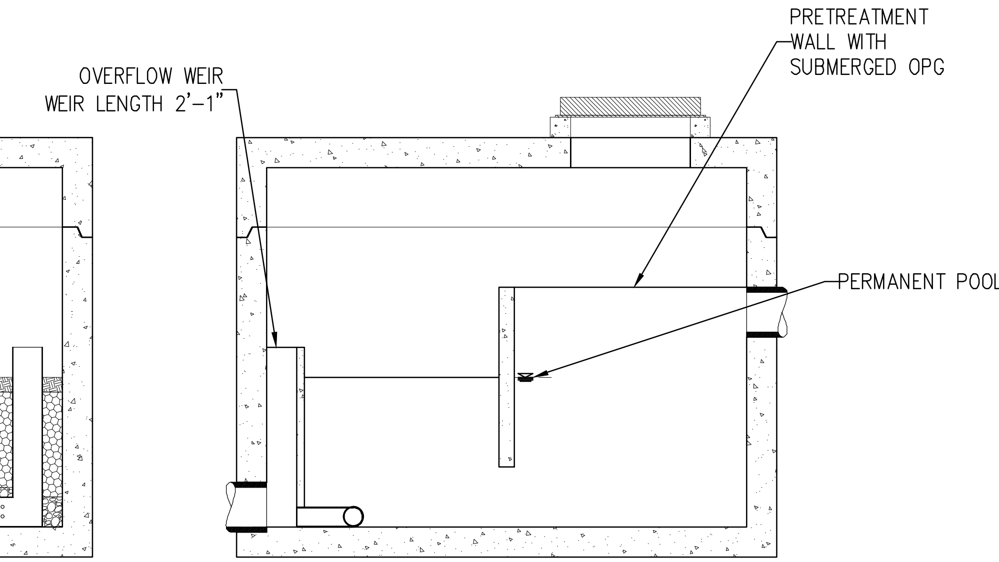
SECTION A-A



SECTION C-C



SECTION B-B



SECTION D-D

SGVF-8X STORMGARDEN FILTERS				
DESIGNATION:	[A] VAULT LENGTH:	[B] MEDIA LENGTH:	WEIR LENGTH:	**BYPASS FLOW (CFS):
SGVF-88	8'-0"	5'-9"	2'-1"	2.48
SGVF-810	10"-0"	7'-9"	2'-1"	2.48
SGVF-812	12'-0"	9'-9"	2'-1"	2.48
SGVF-814	14'-0"	11'-9"	2'-1"	2.48

** BYPASS FLOW RATE IS BASED ON A HEAD OF 0.50' ABOVE THE WEIR.

DESIGN NOTES:
- CONCRETE MINIMUM (28-DAY) COMPRESSIVE STRENGTH: 5,000 PSI
- REINFORCING BARS CONFORMING TO ASTM A615 (FY = 60 KSI)
- DESIGN LIVE LOAD: HS-20

SGVF-8X STORMGARDEN FILTERS

REVISIONS	
NO	DATE
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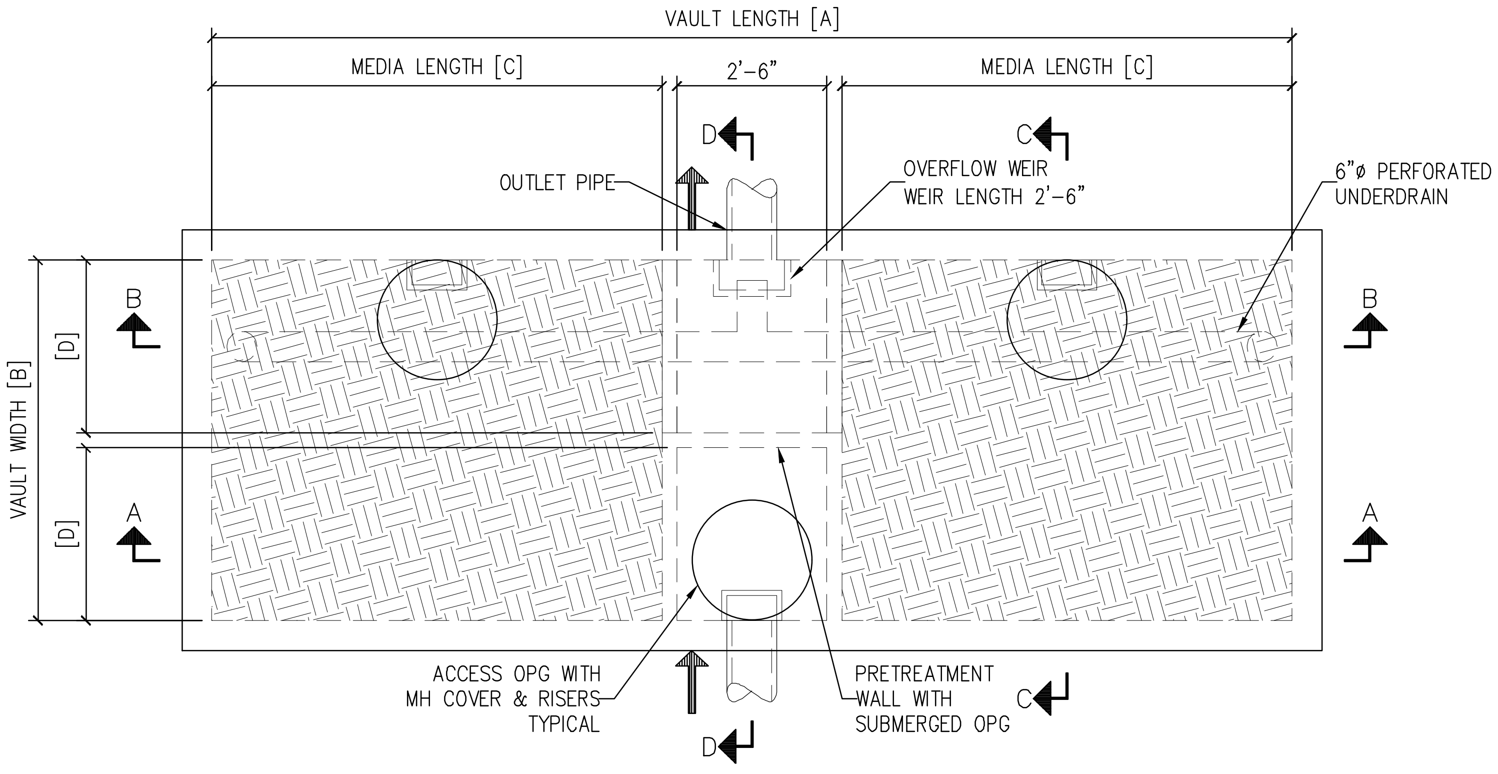
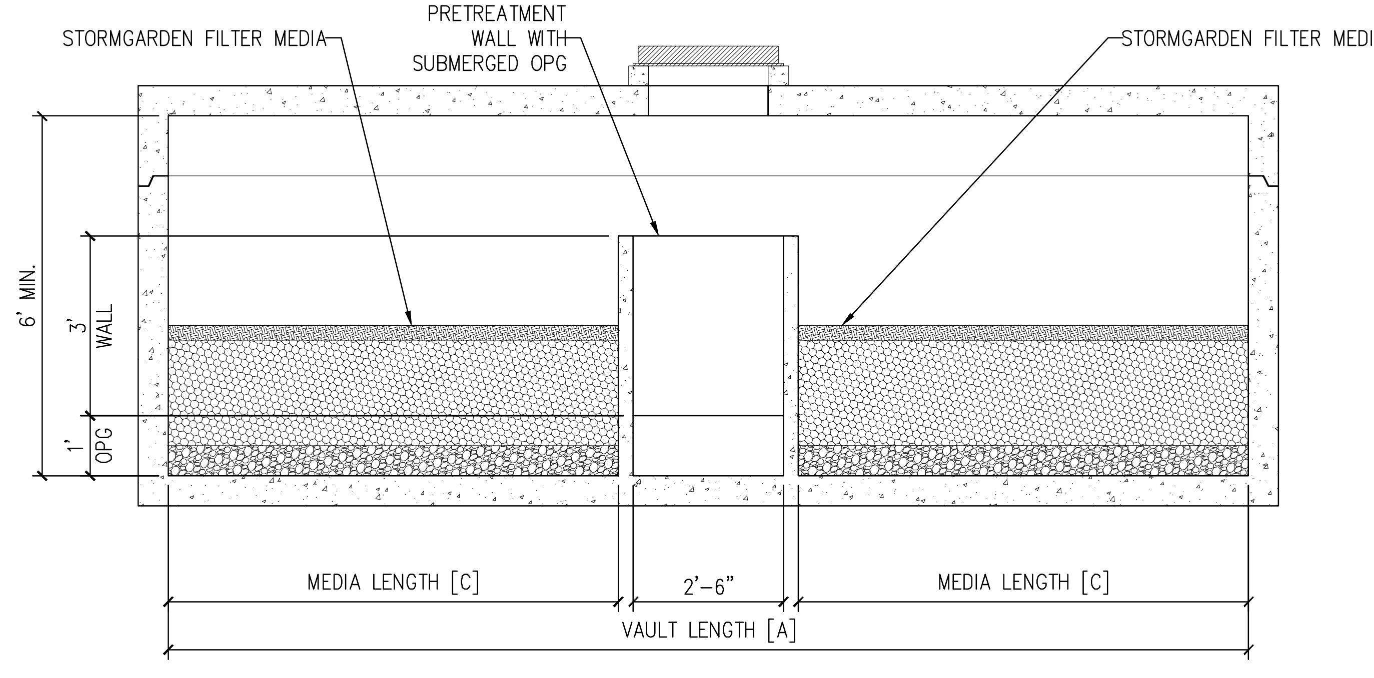
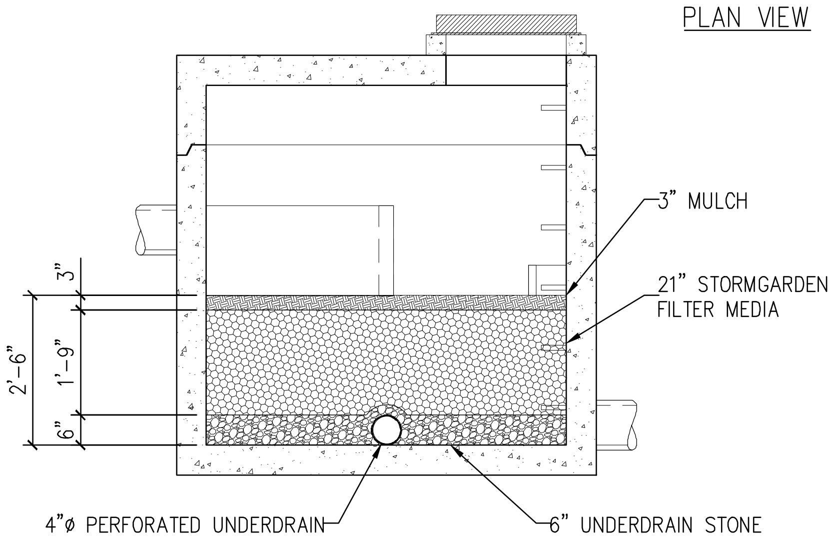
DRAWN BY: FRJ	PROJECT: STORMGARDEN VAULT FILTERS		
CHECKED BY: .			
DATE: 12-20-2018			
SCALE: NTS	CUSTOMER: .		DWG. NO.
JOB NO.:			SHT.



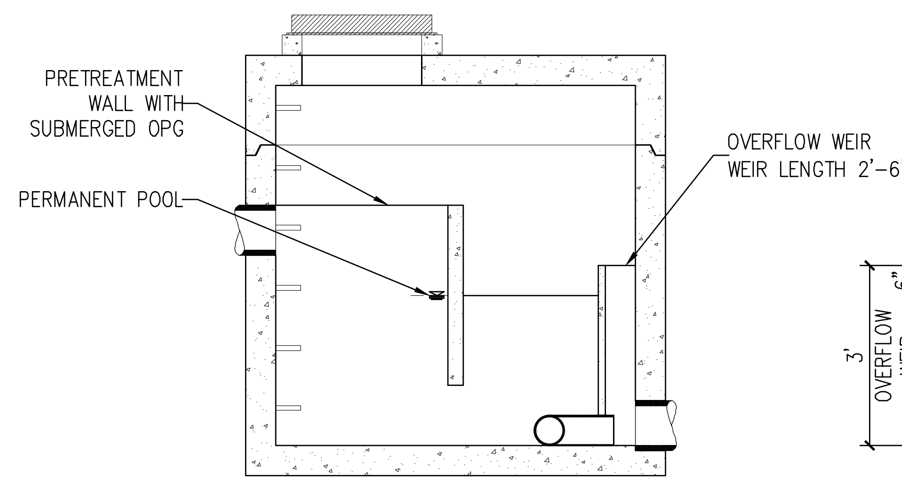
PLAN VIEW



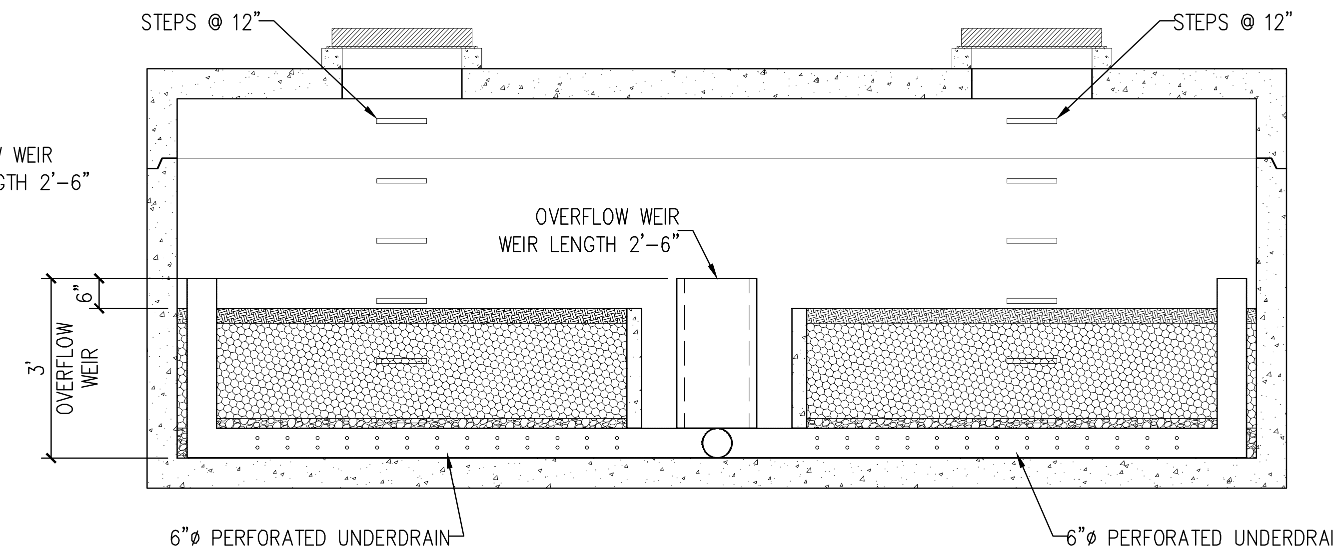
SECTION A-A



SECTION C-C



SECTION D-D



SECTION B-B

SGVF STORMGARDEN FILTERS						
DESIGNATION:	[A] VAULT LENGTH:	[B] VAULT WIDTH:	[C] MEDIA LENGTH:	[D] CHAMBER WIDTH:	WEIR LENGTH:	**BYPASS FLOW (CFS):
SGVF-616	16'-0"	6'-0"	6'-6"	2'-10½"	2'-6"	2.98
SGVF-618	18'-0"	6'-0"	7'-6"	2'-10½"	2'-6"	2.98
SGVF-816	16'-0"	8'-0"	6'-6"	3'-10½"	2'-6"	2.98
SGVF-818	18'-0"	8'-0"	7'-6"	3'-10½"	2'-6"	2.98
** BYPASS FLOW RATE IS BASED ON A HEAD OF 0.50' ABOVE THE WEIR.						

DESIGN NOTES:

- CONCRETE MINIMUM (28-DAY) COMPRESSIVE STRENGTH: 5,000 PSI
- REINFORCING BARS CONFORMING TO ASTM A615 (FY = 60 KSI)
- DESIGN LIVE LOAD: HS-20

SGVF STORMGARDEN FILTERS

REVISIONS	
NO	DATE
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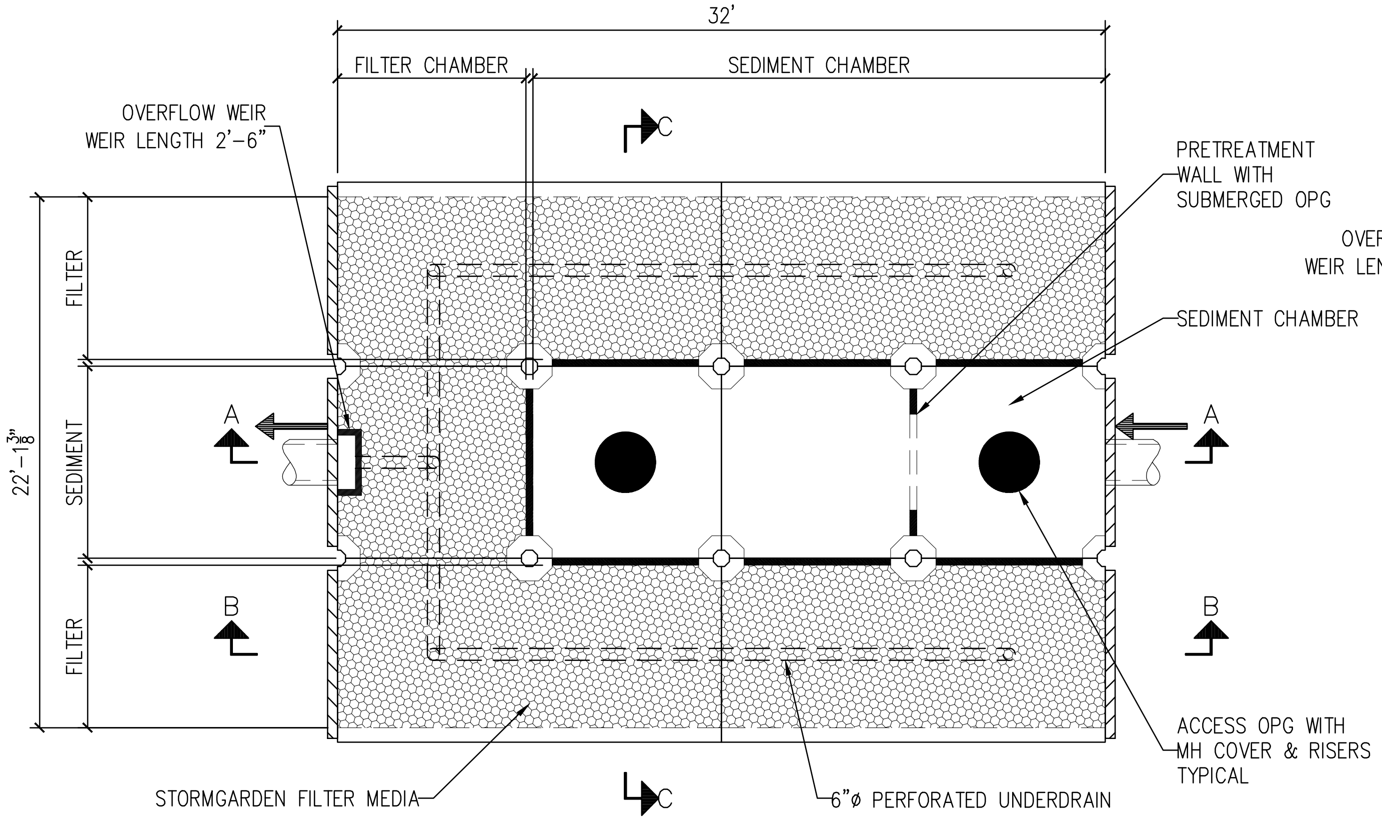
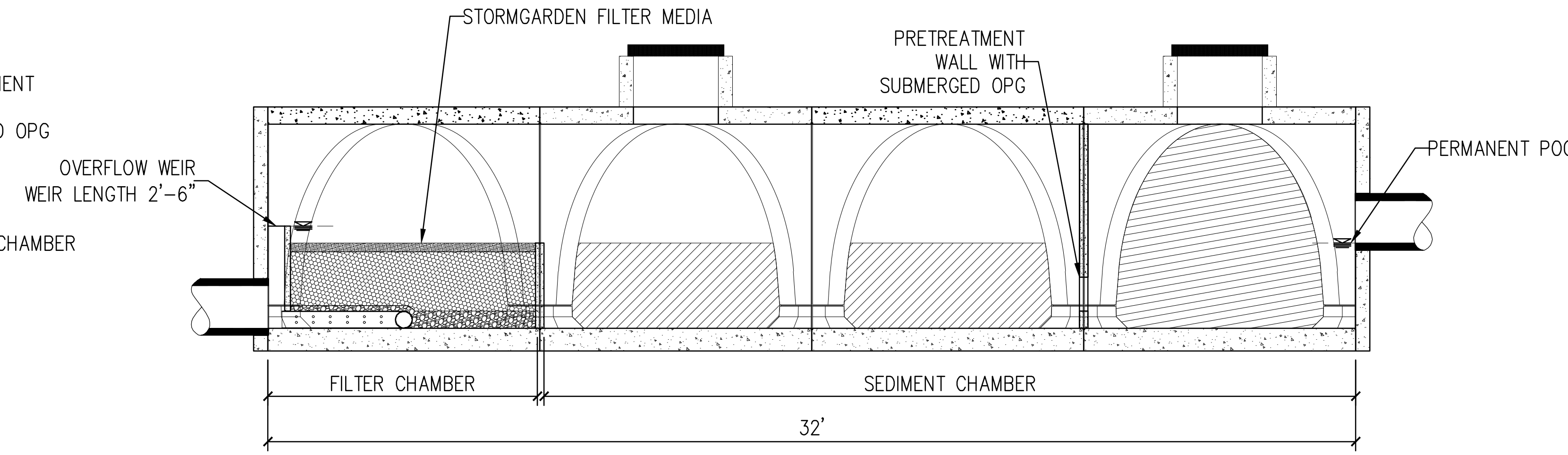
SCALE: NTS
JOB NO.:

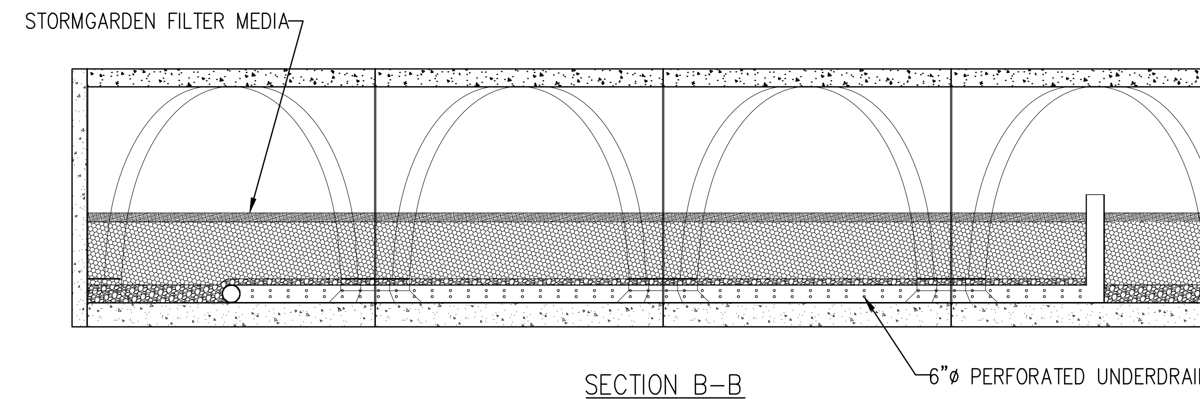
PROJECT: STORMGARDEN VAULT FILTERS
CUSTOMER: .
DWG. NO.
SHT.



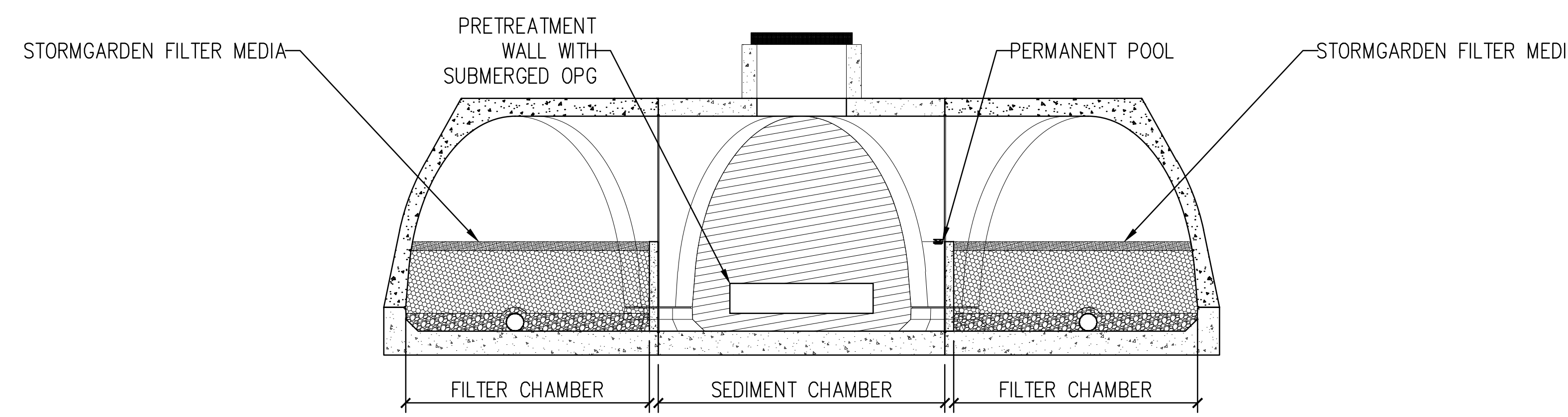
PLAN VIEW



SECTION A-A



SECTION B-B



SECTION C-C

SGMPVF STORMGARDEN/MAGNA-POD FILTERS					
DESIGNATION:	VAULT LENGTH:	VAULT WIDTH:	MEDIA AREA (SF):	WEIR LENGTH:	**BYPASS FLOW (CFS):
SGMPVF-2	16'-0"	14'-1 3/8"	147	2'-6"	2.98
SGMPVF-3	16'-0"	22'-1 3/8"	253	2'-6"	2.98
SGMPVF-6	32'-0"	22'-1 3/8"	464	2'-6"	2.98
** BYPASS FLOW RATE IS BASED ON A HEAD OF 0.50' ABOVE THE WEIR.					

DESIGN NOTES:

- CONCRETE MINIMUM (28-DAY) COMPRESSIVE STRENGTH: 6,000 PSI
- REINFORCING BARS CONFORMING TO ASTM A615 (FY=60 KSI)
- STRUCTURAL REINFORCING FIBERS CONFORMING TO ASTM C1116
- DESIGN LIVE LOAD: AASHTO HL 93

STORMGARDEN/MAGNA-POD
VAULT FILTERS

REVISIONS	
NO	DATE
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CHECKED BY: .	
DATE: 12-20-2018	
SCALE: NTS	CUSTOMER: .
JOB NO.:	DWG. NO. / SHT.