TECHNICAL EVALUATION REPORT

FILTERRA SYSTEM PHOSPHORUS TREATMENT AND SUPPLEMENTAL BASIC TREATMENT PERFORMANCE MONITORING

Prepared for
Americast, Inc.

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA

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

TECHNICAL EVALUATION REPORT

FILTERRA SYSTEM PHOSPHORUS TREATMENT AND SUPPLEMENTAL BASIC TREATMENT PERFORMANCE MONITORING

Prepared for
Americast, Inc.
11352 Virginia Precast Road
Ashland, Virginia 23005
Telephone: 866/349-3458

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

February 12, 2014

CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

Herrera Environmental Consultants (Herrera) conducted hydrologic and water quality monitoring for Americast, Inc. at a Filterra® Stormwater Bioretention Filtration System (Filterra system) that is currently installed in the City of Bellingham, Washington. Herrera conducted this monitoring to obtain data for assessing the performance of the Filterra system relative to Washington State Department of Ecology (Ecology) goals for Phosphorus Treatment. These data were also used to evaluate the performance of the Filterra system at a higher infiltration rate relative to the rate specified in the Filterra system's existing use level designations from Ecology for Basic Treatment and Phosphorus Treatment. All monitoring was performed in accordance with procedures described in Guidance for Evaluating Emerging Stormwater Treatment Technologies; Technology Assessment Protocol – Ecology (TAPE) (Ecology 2011).

This document is the technical evaluation report (TER) for the Filterra system and was prepared by Herrera to demonstrate satisfactory performance of the Filterra system for issuance of a General Use Level Designation (GULD) in relation to the following treatment goals:

- Phosphorus Treatment at a higher infiltration rate than specified in the existing use level designation
- Basic Treatment at a higher infiltration rate than specified in the existing use level designation

Technology Description

The Filterra system tested is an offline water quality treatment system that 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. Online configurations with internal bypass are also available. The system is housed in a precast concrete curb inlet structure with a tree frame and grate cast in the top slab, and includes the following components:

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

- Underdrain
- Bypass

The Filterra system provides water quality treatment of captured flows through the following physical, chemical, and biological unit processes:

- Sedimentation
- Filtration
- Adsorption
- Absorption
- Volatilization
- Evapotranspiration
- Biological processes

Sampling Procedures

The Filterra system used for this monitoring study was installed in 2007 and is located on the northwest end of Lake Whatcom near the intersection of Hayward Drive and Northshore Drive in Bellingham, Washington. The land use in the drainage basin (located in the Silver Beach neighborhood) is primarily medium density single-family residential.

Automated monitoring equipment was installed with this test system to characterize influent, effluent, and bypass flow volumes over a 8-month period, from January 2013 through July 2013. During this monitoring period, a total of 22 separate storm events were sampled, resulting in a total of 17 composite samples and 5 discrete samples. The collected samples were subsequently analyzed for the following parameters:

- Total suspended solids (TSS)
- Total phosphorus (TP)
- Orthophosphorus
- Particle size distribution (PSD)
- pH

These data were subsequently evaluated in the following ways:

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

Hydrologic Performance

The water quality treatment goal for the test system was to capture and treat 91 percent of the average annual runoff volume. Precipitation and flow data measured during storms that produced bypass flow indicate that the Filterra test system bypassed during only 4 out of 59 qualifying storm events that occurred from January 1, 2013, through July 23, 2013. The system was able to treat 98.9 percent of the total 8-month volume. Consequently, the goal of treating 91 percent of the volume from the site was achieved.

In order to investigate system performance over the course of the study period, peak treated flow rate during bypass was assessed as a function of time. During bypass, the maximum driving head above the media is reached, so the peak treated flow rate during bypass should be at or above the water quality design flow rate. If this flow rate falls below the design flow rate, then that would indicate that the media is clogging. Based on the data collected for this monitoring study, there was no trend in peak treated flow rate during bypass; in fact, the maximum treated flow rate among the four bypass events occurred near the end of the sampling period on May 11, 2013. These data indicate that the manufacturer recommended 6-month maintenance cycle is sufficient to prevent clogging of the media.

Water Quality Performance

To obtain performance data to support the issuance of a GULD for the Filterra system, Herrera conducted hydrologic and water quality monitoring at a test system in Bellingham, Washington from January 1, 2013, through July 23, 2013. During this monitoring period, 22 separate storm events were sampled. Conclusions derived from the monitoring data are summarized below for each treatment goal addressed in this TER.

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 influent TSS concentrations less than 100 mg/L, facilities should achieve an effluent goal of 20 mg/L. There is no specified criterion for influent TSS concentrations less than 20 mg/L.

Of the 22 sampled events, 18 qualified for TSS analysis. The data were segregated into sample pairs with influent concentration greater than and less than 100 mg/L. The UCL95 mean effluent concentration for the data with influent less than 100 mg/L was 5.2 mg/L, below the 20 mg/L threshold. Although the TAPE guidelines do not require an evaluation of TSS removal efficiency for influent concentrations below 100 mg/L, the mean TSS removal for these samples was 90.1 percent. In addition, the system consistently exhibited TSS removal greater than 80 percent at flow rates at the design flow rate of 27.6 gallons per minute [gpm] (100 inches per hour [in/hr]) and was also observed at 150 in/hr.

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. Ten of the 22 sampled events qualified for TP analysis. The dataset was augmented using two sample pairs from previous monitoring at the site. The mean TP removal for these samples was 72.6 percent. The LCL95 mean percent removal was 66.0, well above the TAPE goal of 50 percent. Treatment above 50 percent was evident at the design flow rate of 27.6 gpm (100 in/hr) and as high as 150 in/hr. Consequently, the Filterra test system met the TAPE Phosphorus Treatment goal at the target design flow rate of 27.6 gpm (100 in/hr).

INTRODUCTION

Herrera Environmental Consultants (Herrera) conducted hydrologic and water quality monitoring for Americast, Inc. at a Filterra® Stormwater Bioretention Filtration System (Filterra system) that is currently installed in the City of Bellingham, Washington. Herrera conducted this monitoring to obtain data for assessing the performance of the Filterra system relative to Washington State Department of Ecology (Ecology) goals for Phosphorus Treatment. These data were also used to evaluate the performance of the Filterra system at a higher infiltration rate relative to the rate specified in the Filterra system's existing use level designations from Ecology for Basic Treatment and Phosphorus Treatment. In December 2009, the Filterra system received a General Use Level Designation (GULD) for Basic and Oil Treatment at an infiltration rate of 50 inches per hour, a GULD for Enhanced Treatment at an infiltration rate of 35 inches per hour for Enhanced Treatment, and a Conditional Use Level Designation (CULD) for Phosphorus Treatment (Ecology 2013). The results presented herein are intended to show that the Filterra system achieves the treatment goals for Basic and Phosphorus Treatment at an infiltration rate of 100 inches per hour.

All monitoring was performed in accordance with procedures described in Guidance for Evaluating Emerging Stormwater Treatment Technologies; Technology Assessment Protocol – Ecology (TAPE) (Ecology 2011). TAPE guidelines indicate that a technical evaluation report (TER) must be completed for any stormwater treatment system under consideration for a GULD. Specifically, the TER should document treatment performance of a technology to show that it will achieve Ecology's performance goals for target pollutants, as demonstrated by field testing performed in accordance with the TAPE.

This document is the TER for the Filterra system and was prepared by Herrera to demonstrate satisfactory performance of the Filterra system for issuance of a GULD in relation to the following treatment goals:

- Phosphorus Treatment at a higher infiltration rate than specified in the existing use level designation
- Basic Treatment at a higher infiltration rate than specified in the existing use level designation

Pursuant to the guidelines in Ecology (2011), the data and analyses used to determine performance results are presented under the following major headings:

- Technology Description
- Sampling Procedures
- Data Summaries
- Evaluation of Performance Goals
- Conclusions

TECHNOLOGY DESCRIPTION

This section provides a detailed description of the Filterra system including treatment processes, sizing methods, expected treatment capabilities, expected design life, and maintenance procedures.

Physical Description

The Filterra system is a self-contained stormwater treatment system manufactured by Americast, Inc. The technology packages soil media, plants and drainage infrastructure found in typical bioretention best management practices (BMPs) into a prefabricated concrete housing. The Filterra system is a flow-through stormwater treatment device intended to remove suspended sediments, nutrients, heavy metals, and oil and grease from stormwater flows within small-scale catchments like parking lots and streetscapes (Figure 1).

Figure 1. Typical Filterra System Application.

Concrete Container

The Filterra system is housed in a concrete container that is available in a variety of precast sizes (i.e., ranging from a 4-foot by 4-foot box to a 6-foot by 12-foot box). Each Filterra system (i.e., container and top slab) is designed and constructed to withstand an H_20 non-live load, 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 Filterra system 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 Filterra system is provided in Figure 2. Schematics of various Filterra system outfall configurations can be found in Appendix A.

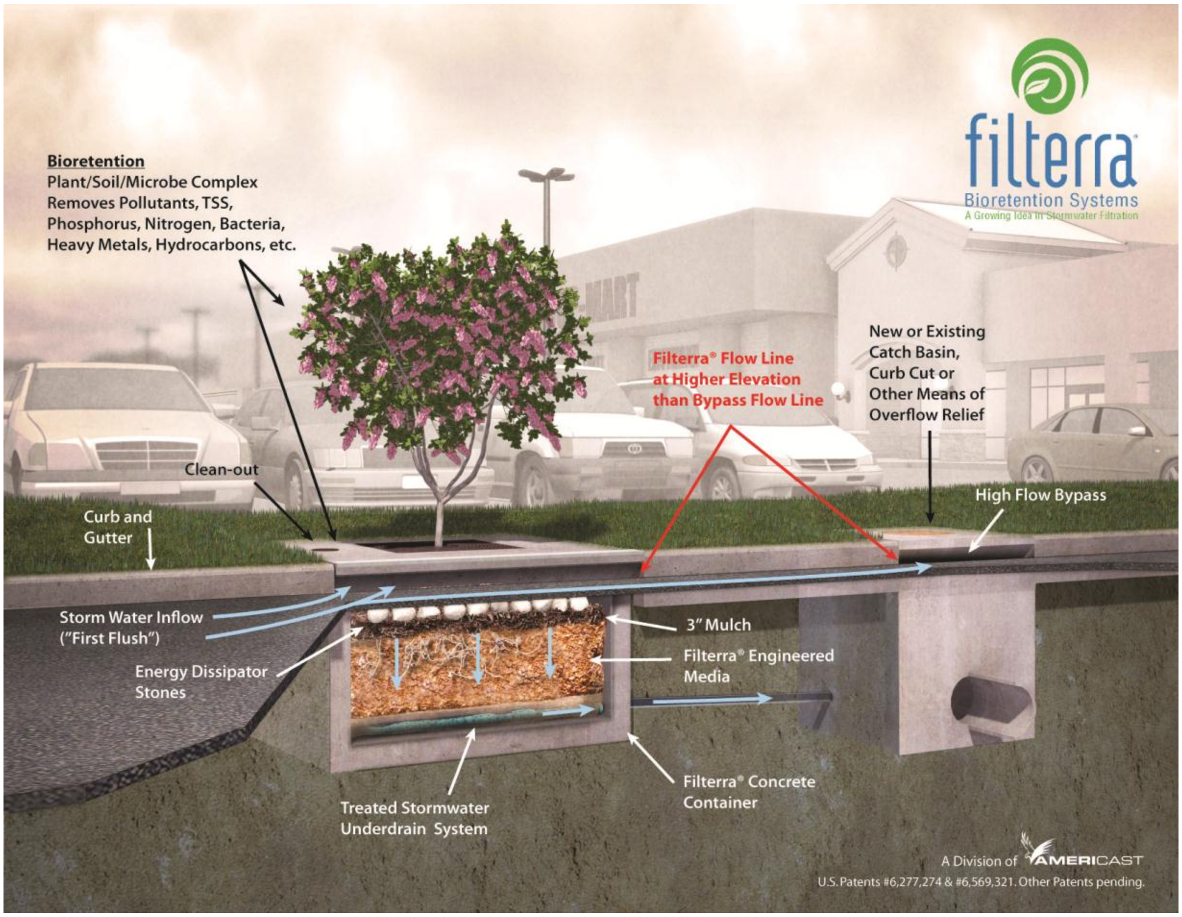

Figure 2. Typical Filterra System Design.

Inlet

The standard Filterra system 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. If flow monitoring equipment is installed with the Filterra system, the water is routed through a flume before entering the curb inlet throat. Fist-sized quarry spalls are placed along the front of the curb inlet throat just inside of the Filterra system, to dissipate the velocity of runoff entering the system. Pretreatment is not required in combination with the Filterra system.

Approved alternate inlet configurations that are designed as online systems include the Filterra Internal Bypass – Pipe (FTIB-P) and the Filterra Internal Bypass – Curb (FTIB-C). The FTIB-P allows for piped-in flow from area drains, grated inlets, trench drains, and/or roof drains. Stormwater runoff enters the system through an internal slotted pipe that drops through to a series of splash plates that disperse the flows over the top surface of the Filterra mulch layer. The FTIB-C incorporates a curb inlet and internal high flow bypass for use in a sag or sump condition. Stormwater runoff enters the system from both directions along the gutter line. An internal flume tray weir directs flows into the structure.

Surface Storage

To promote settling, the Filterra system is typically designed with approximately 9 inches of freeboard, as measured from the surface of the engineered filter media to the gutter elevation at the curb face.

Mulch Layer

The Filterra system includes a 3-inch layer of shredded wooden mulch. The mulch provides both pollutant removal treatment and pretreatment/protection of the engineered filter media.

Engineered Filter Media

The mulch layer is underlain by approximately 22 inches of engineered filter media in the standard Filterra system, consisting 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. Appendix B provides the manufacturer specifications for the engineered filter media.

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

In the Filterra Bioretention Shallow system, an approved alternate configuration, the media depth is 6 inches less than the standard Filterra system. This design provides additional flexibility for situations where there is limited depth and various elevation constraints. Since the media depth is shallower, the surface area of the system is increased to provide a contact time equivalent to the standard Filterra system.

Vegetation

The Filterra system also includes specified vegetation that may include flowers, grasses, a shrub, or a tree. Vegetation is selected based on aesthetics, local climatic conditions, traffic safety (i.e., may limit the height or breadth of the vegetation), and maintenance considerations (i.e., may restrict deciduous vegetation). A list of appropriate plants for use with the Filterra system in the Pacific Northwest is provided in Appendix C.

Underdrain

The underdrain for the Filterra system is a perforated 4- to 6-inch diameter plastic pipe wrapped in a fiberglass mesh. Outflow from the Filterra system 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.

Bypass

When the hydraulic capacity of the Filterra system is reached in the offline configuration (standard Filterra system or Filterra Bioretention Shallow system), surcharge forces the bypass flow past the Filterra system and into a standard catch basin or inlet, detention pond, biofiltration swale, or another stormwater detention or infiltration facility located down-gradient. Bypass flow in excess of the design flow does not enter the Filterra system's treatment chamber.

In the FTIB-P online configuration, flows greater than the design flow bypass the slotted pipe and are conveyed out the system. In the FTIB-C online configuration, flows greater than the design flow bypass the system by rising above the internal flume tray weir and discharging through a standpipe orifice.

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

Specific underlying soil characteristics are not required for the Filterra system since it is a self-contained, water-tight system and is fully enclosed.

Hydraulic Grade Requirements

The Filterra system is a surface treatment system requiring no head to achieve treatment. The elevation between the influent in and the invert out is 3 feet. The Filterra system does allow 9 inches of freeboard within the system for sediment, trash, and head accumulation.

Depth to Groundwater Limitations

The Filterra system does not have depth to groundwater limitations since it is fully enclosed. Each system is manufactured with gasketed polyvinyl chloride (PVC) couplings precast into the 6-inch thick wall to ensure an easy, snug pipe fit from the contractor when installing a Filterra system. The system is generally delivered to site filled with media and accordingly, the weighted system does not float. The Filterra system also comes with an underdrain, thus any groundwater entering the system will drain away and will not affect the media or performance of the Filterra system.

Utility Requirements

The Filterra system 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 infiltration). Various outfall configurations used with the Filterra system are depicted in the schematics in Appendix A.

Treatment Processes

The Filterra system 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, described below. The treatment processes are described in more detail in Appendix D of the 2009 Filterra TER (Herrera 2009).

Sedimentation

The Filterra system is designed to have approximately 9 inches of headspace above the engineered filter media layer. Dynamic settling of larger particles (gross and suspended solids) contained in stormwater occurs while stormwater is ponded at the surface of the mulch/filter media/plant matrix during storm events. The amount of sedimentation is a function of particle density, size, and water density.

Filtration

Particulates are removed as they filter 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.

Adsorption

The engineered filter media contains hydrophilic adsorbents such as aluminosilicates (sand) and hydrophobic adsorbents such as carbonaceous/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 produces a "sticky" surface that binds particulate-borne organic matter and heavy metals.

Absorption

The engineered filter media is designed with a high percentage of organic material for uptake of nutrients and other pollutants. Organic material is added for initial organic complexing (i.e., cation exchange) with pollutants and to help promote biological growth. The mulch, rhizosphere degradation, and runoff continuously add organics to the media to replace the amount lost to microbiological processes.

Volatilization

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

Evapotranspiration

The Filterra system may act to dry soils between runoff events through uptake and transpiration of moisture as water vapor. This, in turn, helps restore soil permeability.

Biological Processes

Bacterial growth, supported by the root system and organic soil content, also perform a number of treatment processes. These 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 Filterra system 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. These 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. These processes may reduce the total effluent nitrogen, but may also contribute nitrogen to the discharge, depending on the rate of concurrent organic decomposition.

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).

Bioremediation

Bacteria can cause metals to precipitate out as salts, bind them within organic material, and accumulate metals in nodules within the cells.

Phytoremediation

The plant material may metabolize many pollutants, fixing them and/or rendering them less toxic (Reeves and Baker 2000). As the biomass (i.e., plant and microbes) of the system grows in mass, it is assumed that the system's capacity to capture and process more pollutants increases (Ruby and Appleton 2009).

Sizing Methods

The following subsections below describe the sizing methods for western and eastern Washington based on 100 inches per hour.

Western Washington

Filterra systems designed for use in western Washington are sized using the Western Washington Hydrology Model, Version 2012 (WWHM2012), or another continuous hydrologic model approved by Ecology, to filter 91 percent of the annual stormwater volume. Using WWHM2012, the Filterra system is modeled as a sand filter, based on guidance provided in the Filterra system use level designation (Ecology 2013). The hydraulic conductivity of 70.9 inches per hour was calculated based on an infiltration rate of 100 inches per hour and a hydraulic gradient of 1.41 inch/inch.

The following sand filter parameters were used to model the standard Filterra system:

- Filter media depth: 1.8 feet (22 inches)
- Effective ponding depth: 0.75 feet
- Side slopes: 0
- Riser height: 0.7 feet
- Riser diameter: 100 inches
- Filter hydraulic conductivity: 70.9 inches per hour

For preliminary sizing purposes, a sizing table was developed that provides maximum contributing areas for each of the standard sizes of Filterra systems (Table 1). The sizing table was generated based on a developed ("mitigated") basin that consists of a flat parking area located in a region represented by the SeaTac rain gauge with a precipitation scaling factor of 1.0. The sizing table is to be used for planning level use only. The design engineer must use a continuous model with the site-specific drainage area and precipitation to confirm that the system will treat the required volume.

Table 1. Filterra Sizing Table for Western Washington.

Available Filterra Box Sizes (feet)	Percent Filtered	Maximum Contributing Drainage Area (acres)	15-minute Offline Water Quality Flow Rate (cfs)
4 x 4	91.19%	0.38	0.0348
4 x 6 or 6 x 4	91.28%	0.57	0.0523
4 x 8 or 8 x 4	91.08%	0.77	0.0706
6 x 6	91.04%	0.87	0.0798
6 x 8 or 8 x 6	91.09%	1.16	0.1064
6 x 10 or 10 x 6	91.12%	1.45	0.1331
6 x 12 or 12 x 6	91.01%	1.75	0.1606

Notes:

1. Sizing table intended for planning level use. The design engineer must use WWHM2012 and the site location mapping to calculate the appropriate sized facility.
2. Sizing table meets the 91 percent annual stormwater volume filtered and offline 15-minute water quality flow rate specified in the Stormwater Management Manual for Western Washington (Ecology 2012)
3. Sizing table based on WWHM2012 parking/flat basin (100 percent impervious) and SeaTac rain gauge with precipitation factor of 1.0.
4. All boxes are a standard 3.5-foot depth (INV to TC).
5. A standard SDR-35 PVC pipe coupling is cast into the wall for easy connection to discharge drain.
6. Dimensions shown are internal. Please add 1' to each external dimension (using 6-inch walls).

Eastern Washington

Filterra systems designed for use in eastern Washington are sized based on design guidance provided for Sand Filter Treatment Facilities – Large Sand Filter in the Stormwater Management Manual for Eastern Washington (Ecology 2004). The sizing methodology is based on Darcy's Law. An offline system, such as the Filterra system, is sized to treat 95 percent of the annual runoff volume. For preliminary sizing purposes, a sizing table was developed that provides maximum contributing areas for each of the standard sizes of Filterra systems in Region 3 - Spokane (Table 2). The sizing table is to be used for planning level use only. The design engineer must use an approved single event model with the site-specific drainage area and precipitation to confirm that the system will treat the required volume.

Table 2. Filterra Sizing Table for Eastern Washington.

Available Filterra Box Sizes (feet)	Maximum Contributing Drainage Area (acres)
4 x 4	0.52
4 x 6 or 6 x 4	0.79
4 x 8 or 8 x 4	1.05
6 x 6	1.18
6 x 8 or 8 x 6	1.57
6 x 10 or 10 x 6	1.97
6 x 12 or 12 x 6	2.36

Notes:

1. Sizing table intended for planning level use. The design engineer must use the equations in the Sand Filter Treatment Facilities – Large Sand Filter section of the Stormwater Management Manual for Eastern Washington (Ecology 2004) and the site location mapping to calculate the appropriate sized facility.
2. Sizing table treats 95 percent of the annual stormwater volume specified in the Stormwater Management Manual for Eastern Washington (Ecology 2004).
3. Sizing table based on a 100 percent impervious basin (CN = 98) and Region 3 – Spokane precipitation.
4. All boxes are a standard 3.5-foot depth (INV to TC).
5. A standard SDR-35 PVC pipe coupling is cast into the wall for easy connection to discharge drain.
6. Dimensions shown are internal. Please add 1' to each external dimension (using 6-inch walls).

The following sand filter parameters were used to size the standard Filterra system:

- Filter media depth: 1.8 feet (22 inches)
- Effective ponding depth: 0.75 feet
- Drawdown time: 1 day
- Routing adjustment factor: 0.95 (e.g., 95 percent of the annual runoff volume)
- Filter hydraulic conductivity: 142 feet per day (70.9 inches per hour)

Expected Treatment Capabilities

The Filterra system is designed to remove TSS, heavy metals, oil and grease, phosphorus, and nitrogen. The studies included in the 2009 Filterra TER (Herrera 2009) indicate that the

Filterra system provides significant removal of several stormwater pollutants of concern, including TSS, TP, select heavy metals, and oil and grease. The following are selected Findings of Fact as reported in the use level designation for the Filterra system (Ecology 2013):

- The field data showed a removal rate greater than 80 percent for TSS with an influent concentration greater than 20 milligrams per liter (mg/L) at an average instantaneous hydraulic loading rate up to 53 inches per hour (in/hr) (average influent concentration of 28.8 mg/L, average effluent concentration of 4.3 mg/L).
- The field data showed low percentage removals of TP at all storm flows at an average influent concentration of 0.189 mg/L (average effluent concentration of 0.171 mg/L). We may relate the relatively poor treatment performance of the Filterra system at this location to influent characteristics for TP that are unique to the Port of Tacoma site. It appears that the Filterra system will not meet the 50 percent removal performance goal when you expect the majority of phosphorus in the runoff to be in the dissolved form.
- Lab scale testing using Sil-Co-Sil 106 showed percent removals ranging from 70.1 to 95.5 percent with a median percent removal of 90.7 percent, for influent concentrations ranging from 8.3 to 260 mg/L. Americast, Inc. ran these laboratory tests at an infiltration rate of 50 in/hr.
- Supplemental lab testing conducted in September 2009 using Sil-Co-Sil 106 showed an average percent removal of 90.6 percent. These laboratory tests were run at infiltration rates ranging from 25 to 150 in/hr for influent concentrations ranging from 41.6 to 252.5 mg/L. Regression analysis results indicate that the Filterra system's TSS removal performance is independent of influent concentration in the concentration range evaluated at hydraulic loading rates of up to 150 in/hr.

Expected Design Life

Americast conservatively estimates that the Filterra system will last for 20 years or longer and is based on the expected life span of the plant. There are examples of bioretention systems operating at or above design parameters since 1992 (Davis et al. 2006; Davis 2007, 2008). Several studies have estimated the pollutant removal capabilities for bioretention systems at up to 20 years; however, since bioretention is a relatively new BMP, the effective life of a system has not yet been fully tested (FHWA 2002). Under normal conditions, bioretention will last for decades without media replacement. Filterra systems have been in operation for 12 years without replacing the media. The concrete components are expected to last in excess of 50 years.

Unlike conventional filtering systems that may occlude and slow over time, properly-maintained Filterra systems have demonstrated an increased flow rate as the physical and biological components of the system mature (Appendix D of Herrera 2009). The increase in biomass (i.e., plant growth) over time provides an increase in the surface area available for phytoremediation. This increase in biomass not only increases infiltration rates, but also increases the surface area of the roots allowing for increased pollutant adsorption. Plant roots contract and expand depending on water availability which helps to develop preferential flow pathways. Plant roots also increase aeration and void space by breaking up the media for water and oxygen to permeate. A field study performed by the Facility for Advancing Water Biofiltration (2008) in Australia found that infiltration rates of bioretention systems increased over time most likely due to plant root growth creating macropores in the media.

Fungi also play a critical role in maintaining aggregate stability within the Filterra media. For example, fungi contain individual fungal filaments known as hyphae, which together form mycelia and aid in soil structure stabilization.

Finally, worms have also been observed in many Filterra systems and aid in the development of natural soil structure overtime, which can increase infiltration rates. Worms create cavities, but worm castings also help in soil aggregation as well as pollutant removal. Other macroinvertebrates also help to aerate the media.

These physical alterations of the media over time help to maintain or increase flow rate capacity through the system. For example, maximum capacity flow rate tests were performed on ten different Filterra systems of varying age (recently activated to 3 years) and varying maintenance periods (recently maintained to 2 years without maintenance). The results of the flow rate tests demonstrated the flow rate longevity of the systems with lower and upper confidence intervals ranging from 140 and 186 inches per hour (excluding two sediment-laden systems).

Different wetting periods were also tested in these flow rate studies, looking at both constant wetting and periodic wetting (Appendix D of Herrera 2009). These studies showed that a typical periodic introduction of runoff into the system achieved the highest flow rate. In general, the media is dry under normal operating conditions. The wetting and drying of the media during and after storm events expand and contract organics in the system, which help in the creation of preferential flow pathways. Finally, the concrete top slab on the Filterra system also protects the media from vehicles or foot traffic which, in turn, preserves void spaces within the media.

Core samples were also collected from Filterra systems of different ages (6 to 18 months) to observe if the particle size distribution of the media and the amount of silts and clays were altered over time (Appendix D of Herrera 2009). Results from 11 different systems showed that there was not a significant change in the particle size distribution of the media. The older systems still contained the percentage of fines that matched the Filterra media specification.

The major issue in terms of longevity of the Filterra system is the build-up of sediment on the surface of the Filterra system which could restrict free flow of runoff, trash and debris into the system. As long as routine maintenance is performed, the Filterra system will theoretically last indefinitely since it essentially sequesters and recycles nutrients, metals, and organics in the biomass (i.e., plant and microbes). The only major maintenance required would be replacement of the plant if it should die. As long as the plant is thriving, the Filterra system will function as designed.

Maintenance Procedures

Routine, semi-annual maintenance for the Filterra system is recommended. Maintenance should follow procedures given in the most recent version of the Filterra Installation, Operation, and Maintenance Manual (Appendix D).

The only tools required to perform maintenance activities are typical landscaping tools, including a rake, shovel, and pruning tools. One person can typically perform required maintenance in 30 to 45 minutes.

The following are specific maintenance procedures to be completed:

1. Open tree grate and inspect. The tree or shrub may need to be trimmed back to allow for easy access through the tree grate opening.
2. Remove accumulated trash and degraded 3-inch mulch layer using a rake and shovel.
3. Add fresh 3-inch mulch layer, consisting of shredded wooden mulch purchased from local gardening and home improvement stores.
4. Replace tree grate, sweep, and record maintenance details.

Americast Maintenance Support

A complete Installation, Operation and Maintenance Manual and one-year maintenance plan is provided by Americast to Filterra customers. Americast also offers an extended maintenance service contract and maintenance training based on the Installation, Operation & Maintenance Manual (Appendix D) for those who wish to perform their own maintenance.

Vegetation

Each Filterra system must receive adequate irrigation to ensure survival of the living system during periods of drier weather. This may be achieved through a piped system, gutter flow, or through the tree grate. In general, irrigation needs should be the same as that of the surrounding landscaping (i.e., if the landscaping is being watered, the Filterra system should also be watered).

Sampling Procedures

This section begins with a general overview of the monitoring design and describes the specific goals Ecology has established for the types of treatment that are being sought under the GULD. Separate sections then describe in more detail the site location, test system, monitoring schedule, and the 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 discussed.

Monitoring Design

To facilitate the performance monitoring pursuant to the TAPE procedures, a standard Filterra system installation located on Hayward Drive in Bellingham, Washington was selected for testing. Using the data obtained from this monitoring site, removal efficiency estimates were computed for targeted monitoring parameters. These removal efficiency estimates were subsequently compared to the following goals identified in the TAPE:

- **Phosphorus Treatment** – 50 percent removal of TP for influent concentrations ranging from 0.1 to 0.5 mg/L.
- **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 concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L TSS.

The Filterra system has already been issued a GULD for Basic, Enhanced, and Oil Treatment (Ecology 2013) and a CULD for Phosphorus Treatment. The monitoring described here provides Phosphorus Treatment performance data and supplemental data to evaluate Basic Treatment performance at higher flow rates than were observed during a previous monitoring study (Herrera 2009) for the existing Ecology use level designations (Table 3).

Table 3. Approved Hydraulic Conductivity and Infiltration Rates for Approved Filterra System Installations.

Treatment Category	Hydraulic Conductivity (inches/hour)	Infiltration Rate (inches/hour)
Current GULD approval for Basic and Oil Treatment	35.46	50
Current GULD approval for Enhanced Treatment	24.82	35
Monitoring Goals for Basic and Phosphorus Treatment	70.9	100

Site Location

The Filterra system is located on the northwest end of Lake Whatcom near the intersection of Hayward Drive and Northshore Drive in Bellingham, Washington (latitude = 48°46’6.70” N, longitude = 122°24’16.16” W). Figure 3 shows a photograph of the 4-foot by 6.5-foot Filterra system that was installed at this location in 2007. The drainage plan and details for the Hayward Drive installation are included in Appendix E. The drainage basin contributing to the Filterra system includes stormwater runoff from Hayward Drive and Hayward Court. The land use in the drainage basin (located in the Silver Beach neighborhood) is primarily medium density single-family residential. This site was selected for monitoring for this study because previous monitoring conducted at the site indicated the majority of the influent TP concentrations fell within the range specified in the TAPE guidelines. Lake Whatcom is also on Ecology’s 303(d) list for phosphorus and development of a total maximum daily load (TMDL) for phosphorus is underway. Approval of treatment technologies for phosphorus treatment would be beneficial for future drainage basin retrofits.

Figure 3. Photograph of the Filterra System on Hayward Drive.

The City of Bellingham provided the drainage basin delineation used for sizing the Filterra system which includes 0.4 acres of impervious area (streets and driveways) with minimal contribution from lawns and landscaping and no contribution from rooftops.

Slopes in the drainage basin are moderate (5 to 15 percent). The soils in the drainage basin are classified as Squalicum-gravely loam (hydrologic soil group B). Treated runoff from the

Filterra system is routed into the existing stormwater drainage system and discharges to Lake Whatcom west of Hayward Drive.

Potential pollutant sources in the drainage basin consist of residential sources: vehicle use (resulting in TSS, dissolved metals, and oil), fertilizer use and yard waste (resulting in phosphorus runoff), pet waste and leaky septic systems (resulting in fecal coliform bacteria loading), and car washing (resulting in phosphorus runoff).

Monitoring Schedule

Collection of hydrologic and water quality monitoring data in association with the Filterra test system was conducted for approximately 7 months from January 1, 2013, to July 23, 2013. On June 5, 2013, Ecology indicated that the 8-month monitoring duration was sufficient for the TER analysis.

Test System Description

The physical configuration and basis of design of the Filterra system is provided below, followed by a brief summary of bypass conditions and maintenance schedule for the test system.

In accordance with Ecology requirements (Ecology 2011), the Filterra test system was sized to provide treatment for 91 percent of the annual runoff volume. To confirm that the test system sizing was correct, modeling was performed using the Western Washington Hydrology Model 2012 (WWHM 2012) to determine the actual percentage of the annual runoff volume that would be treated given the system size and local precipitation patterns. WWHM3 is a continuous hydrologic model that simulates rainfall runoff based on topography, soils, and vegetation. For this evaluation, the sand filter module in WWHM 2012 was run at a 15-minute timestep for a 51-year simulation period (October 1948 to September 1999) using the Whatcom County precipitation series from the Blaine rain gauge.

Model parameters were selected based on the Western Washington Engineering Design Assistance Kit (Appendix A) produced in 2010 and may be slightly different from the model parameters recommended when the Filterra system was installed in 2007. The following parameters were specifically used as inputs to the sand filter module:

- Bottom length: 6 feet
- Bottom width: 4 feet
- Filter material depth: 1.8 feet
- Effective ponding depth: 0.75 feet
- Slope on the filter box: 0
- Infiltration: yes
- Filter hydraulic conductivity: 35.46 inches/hour
- Riser height: 0.7 feet

- Riser diameter: 100 inches
- Riser type: flat

Results from the model indicated the Filterra test system would treat approximately 85.3 percent of the annual runoff volume from a 0.40-acre drainage basin with the 4-foot by 6-foot box (Table 4). Based on these results, the Filterra test system was slightly undersized.

Table 4. Flow Rates Obtained from WWHM 2012 for Predeveloped Conditions and the Developed, Mitigated Condition for the Hayward Drive Filterra Installation.

Flow (cubic feet per second)	Predeveloped	Developed, Mitigated
Water quality design flow	NA	0.0360
2-year peak flow	0.0003	0.1405
10-year peak flow	0.0006	0.2441
100-year peak flow	0.0010	0.3829

NA = not applicable

Note: These results were modeled at a 15-minute timestep for a 0.4-acre, 100% impervious drainage basin.

Using the 100 in/hr infiltration rate (hydraulic conductivity of 70.9 in/hr), the modeling results indicate that the Filterra test system will treat approximately 95.8 percent of the annual runoff volume. Based on these results, the Filterra test system is slightly oversized.

Bypass Conditions

Bypass flow exceeding the infiltration capacity of the filter media enters the catch basin located directly south of the Filterra system and also discharges to Lake Whatcom.

Maintenance Schedule

Maintenance of the Filterra system was not performed during monitoring. However, on December 11, 2012, immediately prior to monitoring, new media was installed in the system. In addition, on August 31, 2013, approximately 1 month after the end of monitoring, routine maintenance was conducted. The August 2013 maintenance records (Appendix F) indicate that there was no silt buildup on the media and that the mulch was “clean and in good shape”.

Hydrologic Monitoring Procedures

Effluent and bypassed flows from the Filterra test system were monitored continuously over an 8-month period beginning in January 2013. In addition, precipitation depths at the monitoring site were monitored continuously over this same period. Due to the residential setting of the Hayward Drive Filterra installation, limited site modifications were recommended by the City of Bellingham Public Works Department due to public safety issues in the existing right-of-way. Consequently, continuous influent flow measurement was not feasible at this monitoring location and effluent flow monitoring data was used to represent both influent and effluent flow for the purposes of pacing the automated samplers. In previous monitoring of Filterra systems of similar design, it has been shown that influent and effluent flows track very closely with each other when bypass is not occurring (Herrera 2009). Consequently, pacing the influent sampler based on effluent flow rates should not introduce measurable error.

All monitoring equipment is described in more detail in the Quality Assurance Project Plan (QAPP) for this project included in Appendix M (Herrera 2012).

Effluent Monitoring

To facilitate continuous monitoring of effluent flow rates, a monitoring station, designated FB-OUT, was established in the 6-inch underdrain at the downstream end of the Filterra system. The underdrain was accessed through a 12-inch monitoring port that narrows to 6 inches as it interfaces with the 6-inch underdrain pipe at the south end of the system (Figure 4). Downstream of the monitoring port, the underdrain pipe intersects with a pipe that drains the hillside to the east of the system. Water from the hillside produces a “base flow” that backs water up into the underdrain pipe (approximately 0.5 inches of standing water in the pipe at the monitoring well between storm events). Due to these backwater conditions, an area-velocity meter (Marsh McBirney Flo-Tote 3) was used for measuring flow in the underdrain. The velocity sensor was placed directly in the bottom of the monitoring well access so that depth calibration measurements could be collected from the surface. The velocity meter was interfaced with a FL900 logger housed in the equipment enclosure. The FL900 interfaced via a Modbus RS-232 connection to a Campbell Scientific CR800 datalogger. The datalogger was programmed to continuously record hydrological measurements (effluent and bypass discharge and precipitation depth).

The datalogger was connected to a Raven XTV digital cellular modem. This communication system was configured to automatically download data on an hourly basis and sent text message alarms to field technicians based on programmable sampling criteria. All flow data were stored on a SQL server.

Power to the data logger was supplied using a 12-volt deep cycle marine battery that was charged using a 60-watt solar panel installed at the site. The data logger, battery, and digital cell phone links were housed in a Knaack box model 69 enclosure. Conduit was installed to convey cabling for the FL900 logger from the base of the enclosure to the area-velocity meter.

Bypass Flow Monitoring

Monitoring the bypass flow required installation of an H-flume along the curb between the Filterra system and the bypass inlet located south (downslope) of the Filterra system (Figure 4). This flow monitoring station was designated FB-BP. The flume was installed flush with the asphalt of the street and a temporary asphalt curb was poured to direct flow into the flume and prevent damage from passing automobiles. An OTT CBS bubble level gauge was installed in conjunction with the flume to measure the water level. The OTT bubbler interfaced with the datalogger described above using SDI-12 communication protocol. Water level measurements were recorded on a 5-minute logging interval. When bypass occurred, the data logger converted water level readings to estimates of discharge based on standard hydraulic equations (Walkowiak 2006).

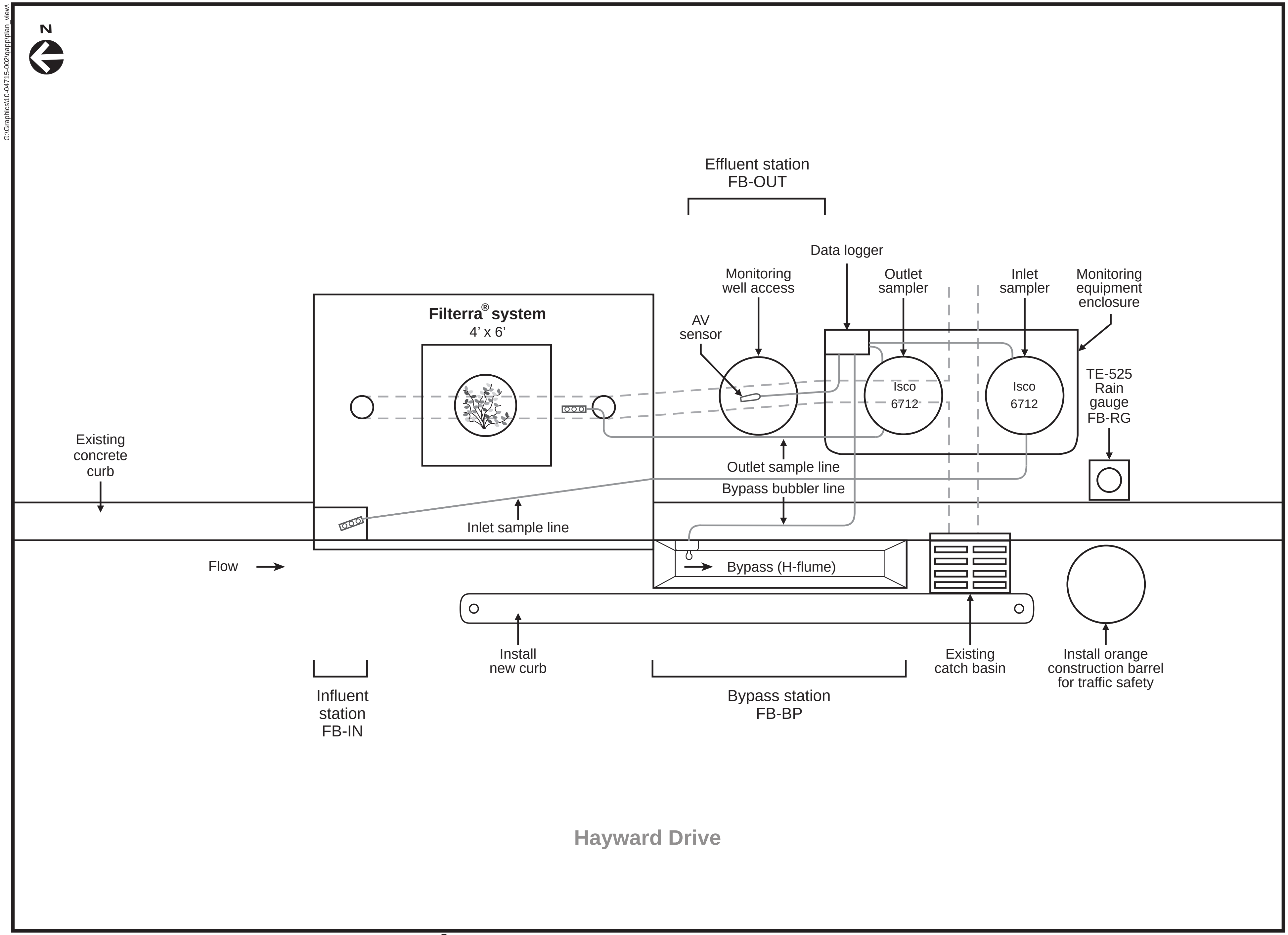

Figure 4. Site schematic (plan view) for Filterra® system performance monitoring at Hayward Drive, Bellingham, Washington.

Precipitation Monitoring

In addition to the two flow monitoring stations, a third station, designated FB-RG, was installed in order to monitor precipitation. A Texas Electronics (TR-525) rain gauge was installed on an 8-foot pole adjacent to the equipment enclosure (Figures 4 and 5). The rain gauge measured rainfall to the nearest 0.01 inch. The gauge was interfaced with the datalogger mentioned above and set to record rainfall in 5-minute intervals. All precipitation data was downloaded via cellular telemetry on an hourly basis and stored locally on a SQL server. The rainfall data was used to determine whether sufficient rainfall (> 0.15 inches) occurred for the storm to qualify as a viable sampling event. Rainfall data was also used to verify the measured treated and bypassed flow volumes.

Monitoring Equipment Maintenance

Maintenance of automated samplers, rain gauges, and flow monitoring equipment was conducted on a routine basis during pre-storm checks and during sample collection. Maintenance procedures and frequencies are summarized in Table 5. Rain gauge and level calibration data can be found in the hydrologic data quality assurance memorandum in Appendix G.

Table 5. Equipment Maintenance Schedule.

Equipment	Item	Procedure	Minimum Frequency
Rain Gauge	Funnel and screen	Check for debris	Monthly
	Level check	Verify level with bubble indicator	Monthly
	Calibration	Calibrate in accordance with manufacturer's instructions	At installation and once annually
Flow Monitoring	Desiccant	Check color – when pink, exchange for new desiccant	Every visit
	Vent tubing	Check for obstructions	Every visit
	Calibration	Calibrate in accordance with manufacturer's instructions	At installation and monthly
Automated Sampler	Pump tubing	Check integrity	Every visit
	Sample tubing and intake	Check integrity; verify no obstructions at intake	Every visit
	Humidity indicator	Check surface indicator	Every visit
pH field meter	Calibration	Calibrate in accordance with manufacturer's instructions	Before and after each use

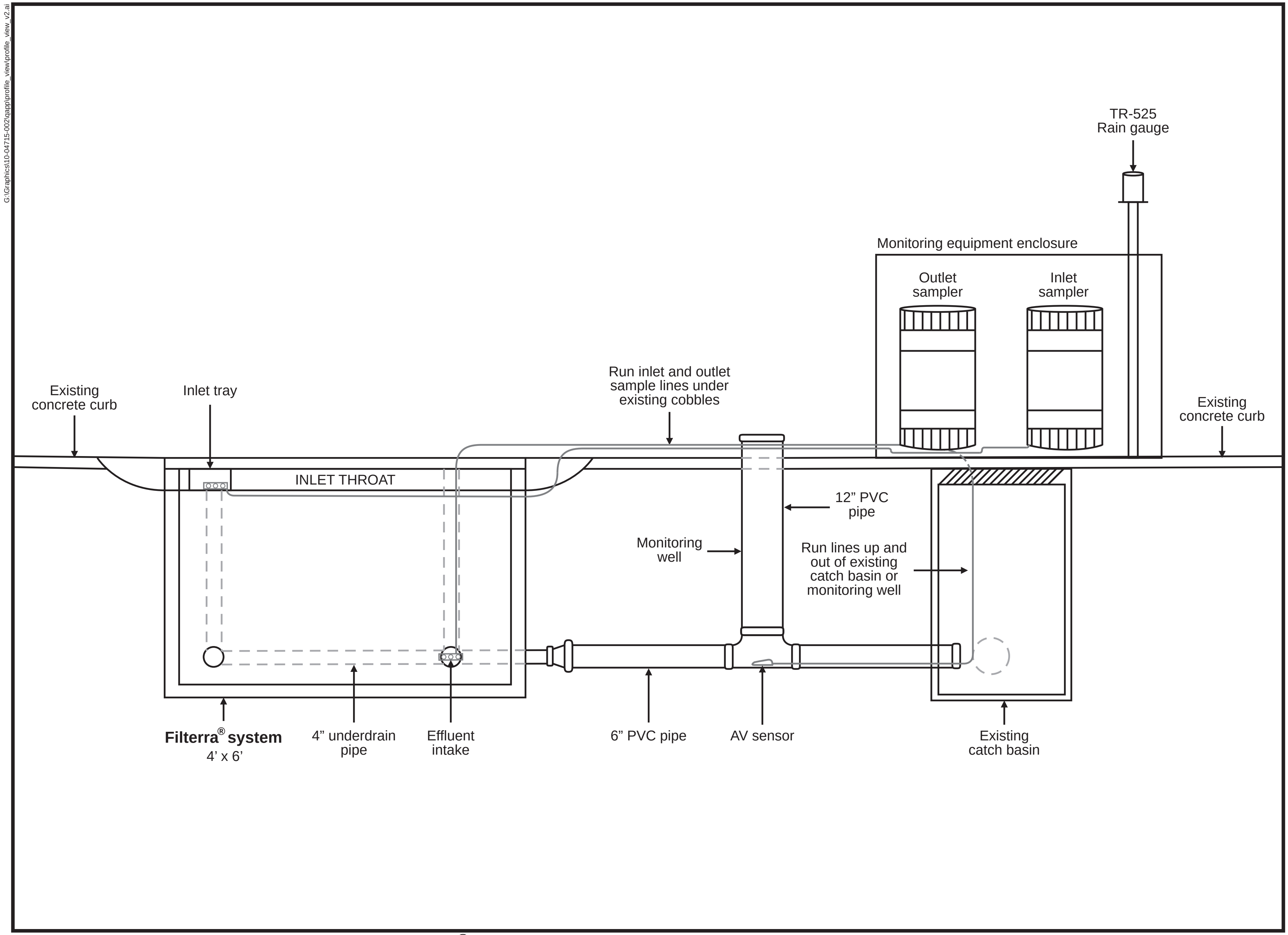

Figure 5. Site schematic (profile view) for Filterra® system performance monitoring at Hayward Drive, Bellingham, Washington.

Water Quality Monitoring Procedures

To evaluate the water quality treatment performance of the Filterra system, sampling was conducted at the associated influent and effluent stations. To facilitate sampling, each station was equipped with automated sampling equipment interfaced with the flow monitoring equipment (described in the Hydrologic Monitoring Procedures section). These monitoring procedures are described in greater detail in the QAPP that was prepared for this study (Appendix M). During the monitoring period, a total of 22 separate storm events were sampled including 17 composite samples and 5 discrete samples.

Influent samples were collected at a tray in the upstream edge of the Filterra system on top of the mulch layer. The influent sample intake tubing was installed with a constant linear grade so that water completely drained through the sample tube during rinse, purge, and sampling cycles. The sampler intakes were positioned at an adequate depth to be available for sampling and to avoid the capture of litter, debris, and bed load that may be present. Effluent samples were collected downstream of the two Filterra cleanout access points. The effluent sample intake was placed in the outlet pipe next to the underdrain to reduce the likelihood that backed up water from the hillside flow would be collected.

The following conditions served as guidelines in defining the acceptability of specific storm events for sampling:

- **Target storm depth**: A minimum of 0.15 inches of precipitation over a 24-hour period
- **Antecedent conditions**: A period of at least 6 hours preceding the event with less than 0.04 inches of precipitation
- **End of storm**: A continuous period of at least 6 hours after the event with less than 0.04 inches 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 the site to verify that the equipment was operational and to set up the automated samplers at both the FB-IN and FB-OUT monitoring stations. During these pre-storm site visits, field staff performed the following activities:

- Removed any blockages in the rain gauge and flow monitoring stations
- Checked calibration of the flow measurement devices
- Back-flushed the sample lines with deionized water
- Checked the state of the desiccant associated with the equipment
- Placed clean samples bottle in the samplers
- Packed ice around the sample bottles within each sampler (Ice is estimated to keep the interior of the samplers cool for 48 hours; therefore, ice was added to the samplers not more than 24 hours before a targeted storm event.)

For composite sampling, the automated samplers were programmed to collect a minimum of 10 aliquots of equal volume at equal increments of flow. For discrete sampling, the automated samplers were programmed to collect one 4-liter composite at a pre-determined peak flow threshold. Volumetric sample pacing for the automated samplers was determined based on rainfall versus runoff relationships that were developed using linear regressions of data that were collected during previous storm events. These regressions were continually updated throughout the year to reflect changing hydrologic conditions. The rainfall versus runoff regressions were used to convert forecast rainfall totals into runoff volumes. The resultant runoff volume (cubic feet) was then divided by 44 (the median number of 220 mL aliquots that a 20-liter bottle holds) to determine the sample pacing (cubic feet) volume necessary to collect an adequate number (greater than 10) of aliquots across at least 75 percent of the storm. A minimum of 2.65 liters (approximately 12 aliquots) was required to analyze all of the targeted water quality parameters.

Flow-weighted composite sampling criteria were assessed before post-storm sample retrieval by accessing sampling data with a remote cellular link (Raven 100 XTV). When sampling criteria were not met, the samples were retrieved and dumped before the next storm event. When sampling criteria were met, field personnel returned to the site, made visual and operational checks of the system, and collected detailed field notes using standardized field forms. Field personnel then removed the 20-liter HDPE bottle from each automated sampler and transported them on ice to the laboratory within the allowable limits for sample holding times (see Table 6). Additional samples were also collected through the course of the performance verification for quality assurance purposes (see Table 7).

In the laboratory, water from the 20-liter HDPE bottles were split using a 22-liter churn splitter and divided into decontaminated, preserved (where appropriate) sample bottles for the required analyses. The samples were analyzed for the following parameters:

- TSS
- TP
- Orthophosphorus
- Particle size distribution (PSD)
- pH

Additional parameters were analyzed and are included in Appendix J. However, only the parameters in the list above are presented in the results section as they are required for Basic and Phosphorus GULD certification.

Analytical Methods

Analytical methods for this project are summarized in Table 6. Aquatic Research, Inc. in Seattle, Washington was the laboratory used for this project. This laboratory is certified by Ecology and participates in audits and inter-laboratory studies by Ecology and EPA. These performance and system audits have verified the adequacy of the laboratory's standard

Table 6. Methods and Detection Limits for Water Quality Analyses.

Analyte	Analytical Method	Method Number[a]	Holding Time[b]	Sample Container	Preservation	Reporting Limit/ Resolution	Units
Total suspended solids	Gravimetric, 103°C	SM 2540D	7 days	P, FP, G	Cool, ≤6°C	0.50	mg/L
Total phosphorus	Automated ascorbic acid	EPA 365.3 or 365.4	28 days	P, FP, G	Cool, ≤6°C; H_2SO_4 to pH < 2	0.01	mg/L
Orthophosphorus	Automated ascorbic acid	EPA 365.1		P, FP, G	Cool, ≤6°C; filtration, 0.45 µm	0.01	mg/L
Hardness	Persulfate	SM 2340B or C		P, FP, G	HNO_3 or H_2SO_4 to pH < 2	0.1	mg/L
Copper, dissolved	GFAA	EPA 200.8	Filter – 12 hours Analyze – 6 months	P, FP, G	Cool, ≤6°C; filtration, 0.45 µm; HNO_3 to pH < 2	0.1	µg/L
Copper, total			6 months	P, FP, G	Cool, ≤6°C; HNO_3 to pH < 2		
Zinc, dissolved	ICP	EPA 200.8	Filter – 12 hours Analyze – 6 months	P, FP, G	Cool, ≤6°C; filtration, 0.45 µm; HNO3 to pH < 2	1.0	µg/L
Zinc, total			6 months	P, FP, G	Cool, ≤6°C; HNO3 to pH < 2	5.0	µg/L
pH	Field meter	NA	NA	NA	NA	0.01	std. units
Particle size distribution	TAPE method[c]	ASTM 3977 (modified)	7 days	P	Cool, ≤6°C	1	micron

[a] SM method numbers are from APHA et al. 1998; EPA method numbers are from U.S. EPA 1983, 1984. 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 (CFR). However, the 20th edition provides additional guidance on certain key items. For this reason, the 20th edition is referenced in this table as the best available guidance. An equivalent standard method can be substituted.

[b] Holding time specified in EPA guidance or referenced in Standard Methods for equivalent method.

[c] Follows laboratory procedure specified in the TAPE guidelines (Ecology 2011).

GFAA = graphite furnace atomic absorption.
ICP = inductively coupled plasma
NA = not applicable
mg/L = milligrams per liter
std. units = standard units
µg/L = micrograms per liter
µm = micron
C = Celsius
FP = fluoropolymer (polytetrafluoroethylene [PTFE, Teflon]
G = glass
P = polyethylene or other fluoropolymer)

Table 7. Quality Assurance Samples and Requirements.										
Parameter	**Sample Type**	**Storm Events**	**Number of Monitoring Locations**	**Total Number of Samples**	**Field Blanks**	**Method Blanks**	**Control Standard**	**Matrix Spike**	**Lab Duplicates**	**Field Duplicates**
Total suspended solids	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	NA	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	NA	1/storm event	5% of samples
Total phosphorus	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Orthophosphorus	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Hardness	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Copper, dissolved	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Copper, total	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Zinc, dissolved	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
Zinc, total	Flow-weighted composite	16	2	32	3	1/storm event	1/storm event	1/storm event	1/storm event	10% of samples
	Discrete	8	2	16	NA	1/storm event	1/storm event	1/storm event	1/storm event	5% of samples
pH	In situ	3	2	6	NA	NA	NA	NA	NA	10% of samples
Particle size distribution	Flow-weighted composite	3	2	6	NA	NA	NA	NA	NA	10% of samples

NA = not applicable

operating procedures, which include preventive maintenance and data reduction procedures. Analytical Resources, Inc. in Tukwila, Washington was used for PSD analysis. Both laboratories provided sample and quality control data in standardized reports suitable for evaluating project data. The laboratory reports also included a case narrative summarizing any problems encountered in the analyses.

Quality Assurance and Control Measures

Field and laboratory quality control procedures used for the Filterra monitoring program are discussed in the following sections. Quality assurance memorandums discussing hydrologic and water quality data can be found in Appendices G and I, respectively.

Field Quality Assurance and 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.

Rinsate Blanks

Rinsate blanks were collected at the beginning of the monitoring program after decontaminating the equipment, and at the end of the monitoring program. The rinsate blank was 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 rinsate blank was similar to the volume of water collected during a storm event.

Field Duplicate Samples

Field duplicates were collected by placing a 4-bottle rack in the automated sampler and compositing two sub-samples at the end of the sampled storm event. The number of field duplicates collected is listed in Table 7. The station where field duplicates were collected was chosen at random in advance of the storm events. All duplicate samples were submitted to the laboratory and labeled as separate (blind) samples. The resultant data from these samples were then used to assess variation in the analytical results that is attributable to environmental (natural), sub-sampling, and analytical variability.

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 G.

Laboratory Quality Control

This section summarizes the quality control procedures that the laboratories performed and reported with the analytical results. Accuracy of the laboratory analyses was verified through the use of blank analyses, duplicate analyses, laboratory control spikes, and matrix spikes in accordance with the EPA methods employed. Aquatic Research, Inc. and Analytical Resources, Inc. were responsible for conducting internal quality control and quality assurance measures in accordance with their own quality assurance plans. The frequency of quality control procedures and evaluation criteria are summarized in Table 7.

Water quality results were first reviewed at the laboratory 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 quality assurance procedures were followed. The review, verification, and validation by the laboratory were documented in a case narrative that accompanied the analytical results.

Data were reviewed and validated within seven days of receiving the results from the laboratory. This review was performed to ensure that all data were consistent, correct, and complete, and that all required quality control information was provided. Specific quality control elements for the data were also examined to determine if the MQOs for the project were met.

Results from these data validation reviews were summarized in quality assurance worksheets that were prepared for each sample batch. Values associated with minor quality control problems were considered estimates and assigned J qualifiers. Values associated with major quality control problems were rejected and qualified with an R. Estimated values were used for evaluation purposes, while rejected values were not used.

Data Management Procedures

All hydrologic data (discharge and precipitation depth) were downloaded via cellular telemetry on an hourly basis and imported directly into the Aquarius data management software for subsequent data management tasks.

Aquatic Research, Inc. and Analytical Resources, Inc. reported the analytical results within 30 days of receipt of the samples. The laboratories provided sample and quality control data in standardized reports suitable for evaluating project data. These reports included all quality control results associated with the data, a case narrative summarizing any problems encountered in the analyses, corrective actions taken, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers.

Laboratory data was then entered into a database for all subsequent data management and archiving tasks. Herrera's quality assurance lead for water quality data performed an independent review to ensure that the data were entered without error. Specifically, 10 percent of the sample values were randomly selected for rechecking and crosschecking with laboratory reports.

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 this 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 maintenance of the Filterra system was needed.

Water Quality Data Analysis Procedures

Data analyses were performed to evaluate the water quality treatment performance of the test system. The specific procedures that were used in these analyses are as follows:

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

Each of these procedures 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 one-tailed test was used to evaluate the specific hypothesis that effluent pollutant concentrations were significantly lower than those in the influent were. 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} = Flow-weighted influent pollutant concentration

C_{eff} = Flow-weighted 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 (Davidson 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.

To perform the bootstrapping analysis, the percent removal values for each valid event were sampled randomly with replacement until a new synthetic percent removal dataset of equivalent size was generated. The median percent removal was then calculated on the synthetic dataset and the process was repeated. Repetition generates a distribution of possible values for the mean. Quantiles of this distribution are confidence intervals of the statistic. For example, in the analysis the mean was replicated 10,001 times; after sorting the replications, the 250th and 9,750th elements constituted the 95 percent confidence interval of the median, while the reported mean was the 5,000th ranked value.

The results from this test were used to determine if the mean percent removal was significantly different from percent removal thresholds presented in TAPE (e.g., 80 percent total suspended solids removal).

Calculation of Pollutant Removal Efficiency as a Function of Flow

To determine pollutant removal performance as a function of flow rate the sampled flow rate must first be calculated. Specifically, for composite samples the instantaneous flow rates associated with each aliquot were averaged over the sampled event to generate an average sampled flow rate. This value was then compared with the percent pollutant removal for the event. This process was repeated for each sampled event, the results were plotted on a percent removal versus sampled flow rate graph, and a regression analysis conducted.

DATA SUMMARIES

This section summarizes data collected during the 2013 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 G, while a quality assessment of the water quality data is presented in Appendix I.

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. Appendix G summarizes results from the quality assurance review that was performed on hydrologic data prior to their analysis herein.

Historical Rainfall Data Comparison

To provide some context for interpreting the hydrologic performance of the Filterra system, an analysis was performed on rainfall data collected at the rain gauge at the Bellingham Airport to determine if rainfall totals from the monitoring period (i.e., January 1, 2013, through July 23, 2013) were anomalous. The rain gauge is located at the Bellingham International Airport, approximately 5.9 miles northwest of the FB-RG rain gauge. The analysis specifically involved a comparison of rainfall totals measured at the Bellingham Airport rain gauge over the monitoring period to averaged totals for the same gauge from the past 64 years. These data are summarized in Table 8 along with data from FB-RG.

Table 8. Monthly Precipitation Totals (in Inches) for 2013 at the Filterra Monitoring Site, Compared to Historical Totals at Bellingham Airport.

Month	FB-RG Monitoring Site Rainfall Data (2013) [a]	Bellingham Airport Rainfall Data (2013) [b]	Bellingham Airport Rainfall Data (1949-2013) [c]
January	4.23	4.1	4.60
February	2.32	2.27	3.36
March	3.62	3.16	3.05
April	5.00	4.19	2.62
May	3.49	2.57	2.2
June	2.57	1.62	1.77
July	0.00	0.05	1.2
Total	**21.23**	**17.96**	**18.8**

[a] Source: Filterra Bellingham monitoring site rain gauge (FB-RG)

[b] Source: Bellingham Airport rain gauge (www.nws.noaa.gov/climate/xmacis.php?wfo=sew)

[c] Source: Bellingham Airport rain gauge (www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa0574). Based on average monthly precipitation totals measured over the period from 1949 to 2013.

Results from this analysis showed the average rainfall total for the monitoring period at the Bellingham Airport rain gauge from 1939 through 2013 was 18.80 inches. In comparison, the rainfall total at the same rain gauge over the monitoring period was 17.96 inches. The relative percent difference of these values is 4.6 percent, thus the rainfall total during the monitoring period is generally representative of rainfall during an average year.

Table 8 also indicates that precipitation measured at FB-RG was greater than rainfall measurements at the Bellingham Airport during the monitoring period. The relative percent difference was 16.7 percent. Quality assurance measures indicated that FB-RG performed within specification during the monitoring period, so this variation is likely the result of variable rainfall in the region.

Water Budget

The water budget for the Filterra test system was analyzed to determine bypass frequency and volume (Table 9). WWHM modeling indicated that with the estimated basin area of 0.4 acres, the water quality design flow rate is 0.0615 cubic feet per second (cfs) or 27.6 gallons per minute (gpm) (equivalent to 100 in/hr infiltration rate).

Table 9. Summary Statistics for Storms That Produced Bypass Flow at the Filterra Test System from January 1, 2013, through July 23, 2013.

Storm Start Date & Time	Storm Depth (inches)	Peak Storm Intensity (in/hr)	Total Volume (gpm)	Bypass Volume (gallons)	% of Total Volume Bypassed	Peak Treated Flow Rate during Bypass (gpm)	Peak Infiltration Rate during Bypass (in/hr)
New media installed on 12/11/2012							
1/8/2013 7:35	1.42	0.48	14,076	368	2.6	60	222
3/19/2013 17:00	0.5	0.48	3,300	144	4.4	42	155
4/6/2013 17:25	1.38	0.48	14,491	618	4.3	52	192
5/11/2013 22:20	0.7	0.72	5,890	52	0.9	151	559
Mulch replaced and routine maintenance on 8/31/2013							

gpm: gallons per minute

in/hr = inches per hour. Peak storm intensity based on 5-minute precipitation data.

Separate analyses of hydrologic data were performed to meet the following objectives:

- Determine whether treatment goals for the test system were met based on the volume treated and bypassed
- Determine whether bypass frequency and volume varied as a function of storm rainfall depth, storm rainfall intensity, influent flow volume, and sampling date
- Determine site specific maintenance frequency by examining bypass over the course of the study

The data used in these analyses are presented in their entirety in Appendix H.

Performance in Relation to Design Treatment Goal

The water quality treatment goal for the Filterra test system was to capture and treat 91 percent of the average annual runoff volume. Precipitation and flow data measured during storms that produced bypass flow are presented in Table 9. These data indicate that the Filterra test system bypassed during only 4 out of 59 qualifying storm events that occurred from January 1, 2013, through July 23, 2013. The system was able to treat 98.9 percent of the total 8-month volume. Consequently, the goal of treating 91 percent of the volume from the site was achieved.

Treated Flow Rate during Bypass

In order to investigate system performance over the course of the study period, peak treated flow rate during bypass was assessed as a function of time. During bypass, the maximum driving head above the media is reached, so the peak treated flow rate during bypass should be at or above the water quality design flow rate. If this flow rate falls below the design flow rate, then that would indicate that the media is clogging. As is apparent from Table 9, there is no trend in peak treated flow rate during bypass, and in fact, the maximum treated flow rate among the four bypass events occurred near the end of the sampling period on May 11, 2013. These data indicate that the manufacturer recommended 6-month maintenance cycle is sufficient to prevent clogging of the media.

Water Quality Data

This section summarizes water quality data collected during the monitoring period at the Filterra test system, including a comparison of data compiled over this period with guidelines identified by Ecology (2011) for assessing data acceptability. Monitoring results for each parameter are summarized and discussed in separate sections. Field forms completed by staff during each sampling visit are presented in Appendix J. Individual Storm Reports showing sample collection times in relation to influent and effluent hydrographs are presented in Appendix K for all sampled storm events. In addition, laboratory reports and chain of custody forms for each sampled event are presented in Appendix L.

Comparison of Data to TAPE Guidelines

Ecology (2011)provides guidelines for determining data acceptability based on the characteristics of sampled storm events and the collected samples. The data collected through this monitoring effort are evaluated relative to these guidelines in the following subsections. In this section, only the data that are being submitted as valid for TAPE certification are presented. Sampled events that did not meet the TAPE criteria and hydrologic data from unsampled events are presented in Appendix H.

Comparison to Hydrologic Guidelines

During the January 1, 2013, through July 23, 2013, monitoring period, 22 storm events were sampled to characterize the water quality treatment performance of the Filterra test system. Precipitation data from the sampled storm events were compared to the following TAPE storm event guidelines:

- Minimum precipitation depth: 0.15 inches
- Minimum antecedent dry period: 6 hours with less than 0.04 inches of rain

- Minimum storm duration: 1 hour
- Minimum average storm intensity: 0.03 inches per hour for at least half the sampled storms

Summary data related to these guidelines are presented in Table 10 for each of the 22 sampled storm events. These data show the guideline for minimum precipitation depth (0.15 inch) was met during all storm events. The minimum, median, and maximum precipitation depths across all 22 sampled storm events were 0.18, 0.45, and 1.51 inches, respectively. The guideline for minimum antecedent dry period (6 hours) was met for all 22 of the events. The minimum storm duration criteria (1 hour) was also met for all 22 storm events. Antecedent dry periods during the sampled storm events ranged from 6.9 to 313 hours, with a median value of 27.4 hours. Storm durations ranged from 3.5 to 27.5 hours, with a median value of 11.8 hours. Average storm intensities ranged from 0.014 to 0.081 inches per hour, with a median value of 0.032 inches per hour.

Comparison to Sample Collection Guidelines

As described in the methods section, automated samplers were programmed with the goal of meeting the following criteria for acceptable composite samples that are identified by Ecology (Ecology 2011):

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

The guideline for minimum number of sample aliquots (10) was met for all of the sampled storm events (Table 11). The criterion for minimum portion of storm volume covered by sampling (75 percent) was met for all but one of the sampled storm events. The January 8, 2013, event had 72.6 percent sampling coverage (Table 11). This was deemed close enough to 75 percent and the sample was included for analysis.

Table 10. Comparison of Precipitation Data from Sampled Storm Events at the Filterra Test System to TAPE Storm Event Guidelines.

Storm Start Date & Time	Storm Precipitation Depth (inches)	Storm Antecedent Dry Period (hours)	Storm Precipitation Duration (hours)	Average Storm Intensity (inches/hour)
1/8/2013 7:35	1.42	24.3	18.6	0.076
1/23/2013 9:30	0.62	313	11.7	0.053
1/24/2013 16:50	0.20	23.2	9.4	0.021
1/26/2013 5:20	0.45	31.7	14.4	0.031
1/28/2013 8:55	0.18	12.2	7.8	0.023
1/29/2013 15:15	0.21	24.2	10.5	0.020
2/22/2013 1:45	0.44	17.9	13.7	0.032
2/24/2013 23:20	0.52	57.1	11.8	0.044
2/28/2013 8:20	0.55	31.3	27.5	0.020
3/6/2013 10:45	0.44	87.3	23.4	0.019
3/12/2013 6:45	0.56	6.9	22.8	0.025
3/14/2013 9:15	0.20	14.6	14.7	0.014
3/16/2013 11:30	0.28	10.2	8.8	0.032
3/19/2013 17:00	0.50	37.5	20.3	0.025
4/5/2013 3:20	0.47	9.2	8.2	0.057
4/5/2013 18:25	0.30	11.3	10.5	0.029
4/10/2013 5:20	0.40	65.8	5.9	0.068
5/11/2013 22:20 [a]	0.70	310	10.5	0.067
5/21/2013 [a]	0.85	66.9	13.9	0.061
5/22/2013 18:55 [a]	0.26	30.4	3.5	0.074
6/12/2013 12:35 [a]	0.24	7.3	3.9	0.061
6/19/2013 23:50 [a]	1.51	77.9	18.8	0.081
Minimum	0.18	6.9	3.5	0.014
Median	0.45	27.4	11.8	0.032
Maximum	1.51	313	27.5	0.081

[a] All sampled events were flow-weighted composite sampled except for the last five sampled events, which consisted of samples collected above a high flow rate threshold.

Table 11. Comparison of Flow-weighted Composite Data from Sampled Storm Events at the Filterra Test System to TAPE Criteria.			
Storm Start Date & Time	Influent and Effluent Sample Aliquots (#)	Influent and Effluent Storm Coverage (%)	Influent and Effluent Sampling Duration (hours)
1/8/2013 7:35	91	**72.6**	13.7
1/23/2013 9:30	91	95.8	7.1
1/24/2013 16:50	35	85.1	4.3
1/26/2013 5:20	64	89.3	5.0
1/28/2013 8:55	21	95.3	7.0
1/29/2013 15:15	23	98.6	8.8
2/22/2013 1:45	30	96.4	6.5
2/24/2013 23:20	55	100	11.7
2/28/2013 8:20	17	92.7	20.1
3/6/2013 10:45	22	93.9	8.5
3/12/2013 6:45	18	91.6	14.4
3/14/2013 9:15	12	89.9	1.7
3/16/2013 11:30	44	90.8	2.7
3/19/2013 17:00	28	96.9	10.9
4/5/2013 3:20	27	98.4	3.2
4/5/2013 18:25	16	90.5	4.4
4/10/2013 5:20	30	97.4	4.7
5/11/2013 22:20 [a]	1	NA	NA
5/21/2013 [a]	1	NA	NA
5/22/2013 18:55 [a]	1	NA	NA
6/12/2013 12:35 [a]	1	NA	NA
6/19/2013 23:50 [a]	1	NA	NA
Minimum	1	72.6	1.7
Median	22.5	93.9	7.0
Maximum	91	100	20.1

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

NA = not applicable

[a] All sampled events were flow-weighted composite sampled except for the last five sampled events, which consisted of samples collected above a high flow rate threshold.

EVALUATION OF PERFORMANCE GOALS

This section evaluates water quality data based on treatment goals addressed in this TER.

Particle Size Distribution

The TAPE guidelines state that Pacific Northwest stormwater typically contains mostly silt-sized particles; thus, PSD results should be provided to indicate whether the stormwater runoff analyzed is consistent with particle sizes typically found in urban runoff in this region.

In Figure 6, it is apparent that the suspended solids in the stormwater are on average composed of majority silt and finer particles. Consequently, it can be assumed that the runoff from the drainage basin is typical of runoff in the Pacific Northwest.

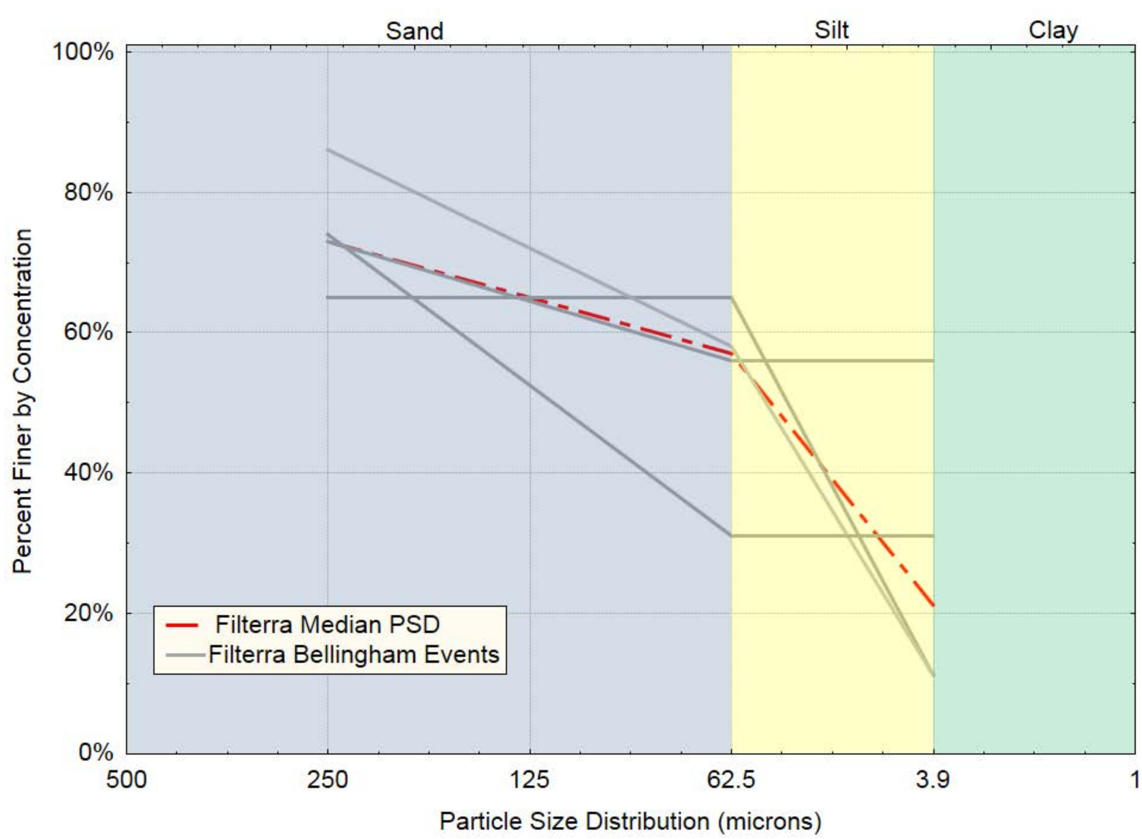

Figure 6. Influent PSD results from the Filterra test site in Bellingham, Washington.

Basic Treatment

The Basic Treatment goal listed in the TAPE guidelines indicate that 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 criterion for influent TSS concentrations less than 20 mg/L; consequently, those sample pairs (influent and effluent) cannot be used for assessment of TSS removal performance. For influent concentrations that exceed 200 mg/L, the treatment goal is an LCL95 of greater than an 80 percent reduction. Additionally, it must be shown that a statistically significant difference between influent and effluent concentrations exists. 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. This section describes the TSS data in relation to these criteria.

A one-tailed Wilcoxon signed-rank test performed on the TSS data with influent concentrations ≥ 20 mg/L (n=18) indicated there was a statistically significant ($p < 0.001$) decrease in effluent total suspended solids concentrations compared to influent total suspended solids concentrations. Consequently, this aspect of the TAPE Basic Treatment criteria is met.

The majority of the samples collected at the Filterra test site had influent concentrations below 100 mg/L (Table 12). Of the 22 sampled events, 15 had influent concentrations between 20 and 100 mg/L. The UCL95 mean concentration for these 15 samples was 5.2 mg/L (Table 12), which is below the 20 mg/L threshold, and consequently these samples achieve the TSS removal goal. Although the TAPE guidelines do not require an evaluation of TSS removal efficiency for influent concentrations below 100 mg/L, the mean TSS removal for these samples was 90.1 percent.

Three of the sampled events were characterized by influent concentrations greater than 100 mg/L (Table 12). The mean TSS removal for these events was 85.2 percent (above the 80 percent reduction criteria). An LCL95 mean removal was not calculable since at least 10 samples are required for a bootstrap analysis. However, these samples were used in the assessment of removal efficiency at various treatment flow rates.

To determine with what flow rates the TSS removals were associated, the flow rate at the point when each aliquot was collected was calculated. These flow rates were then averaged for each sampled event. As shown in Table 12, these results indicate the mean sampled treated flow rate was 19.0 gpm (equivalent to 70.8 in/hr). As described in the *Test System Sizing* section above, the design flow rate for the system is 27.6 gpm.

Figure 7 displays percent removal versus average treated infiltration rate for the 18 qualifying TSS sample pairs with influent concentrations greater than 20 mg/L. In TAPE analyses involving percent removal, the prescribed approach is to only use data with influent concentrations greater than 100 mg/L; however, in this dataset there were only three sample pairs that met this criterion. In order to increase the n-value and because TSS percent removal was very high independent of influent concentrations, the 18 qualifying TSS sample pairs with influent concentrations greater than 20 mg/L were used in the analysis presented in Figure 7.

Table 12. Total Suspended Solids Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the Filterra Test System.

Storm Start Date & Time	Influent Concentration (mg/L)	QA	Effluent Concentration (mg/L)	QA	Percent Removal [b]	Sampled Flow Rate (gpm) [c]	Sampled Infiltration Rate (in/hr) [c]
1/8/2013 7:35	**30**		**7.0**			23.1	85.7
1/23/2013 9:30	14		4.7			6.1	22.7
1/24/2013 16:50	12		3.0			6.9	25.4
1/26/2013 5:20	9.5		2.7			11.0	41.1
1/28/2013 8:55	**107**		**5.0**		**95.3**	4.4	16.8
1/29/2013 15:15	**86**		**3.0**			10.6	40.9
2/22/2013 1:45	**26**		**2.5**			6.6	24.8
2/24/2013 23:20	**55**		**5.0**			22.8	85.9
2/28/2013 8:20	**56**	J	**3.0**			5.6	21.0
3/6/2013 10:45	7.5	J	1.8			4.4	16.7
3/12/2013 6:45	**60**		**3.7**			13.6	52.6
3/14/2013 9:15	**73**		**2.3**			8.1	31.4
3/16/2013 11:30	**30**		**1.8**			20.4	76.3
3/19/2013 17:00	**49**		**5.3**			22.4	85.9
4/5/2013 3:20	**80**		**5.0**			17.2	63.8
4/5/2013 18:25	**70**		**9.5**			33.7	125
4/10/2013 5:20	**38**		**4.8**			15.7	58.1
5/11/2013 22:20 [a]	**138**		**47**		**65.9**	27.2	100
5/21/2013 [a]	**30**		**5.3**			35.9	133
5/22/2013 18:55 [a]	**122**		**6.8**		**94.4**	40.5	150
6/12/2013 12:35 [a]	**30**		**2.8**			40.5	150
6/19/2013 23:50 [a]	**25**		**3.0**			40.5	150
Minimum	7.5		1.8		65.9	4.4	16.7
Mean	52.2		6.1		85.2	19.0	70.8
UCL95 Mean [d]			5.2		NC		
Maximum	138		47		95.3	40.5	150

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold

[b] Percent removal is only calculated for sample pairs with influent ≥100 mg/L.

[c] Sampled flow rate is calculated by averaging the flow rate associated with each aliquot in the composite sample.

[d] Bootstrapped estimate of the upper 95% confidence limit of the mean. Only calculated for effluent concentration with influent between 20 and 100 mg/L per the TAPE (Ecology 2011).

Bold values met influent screening criteria and were used in performance analyses

J = estimated value based on water quality data (Appendix I)

in/hr = inches per hour   gpm = gallons/minute   mg/L = milligram/liter   NC = not calculable

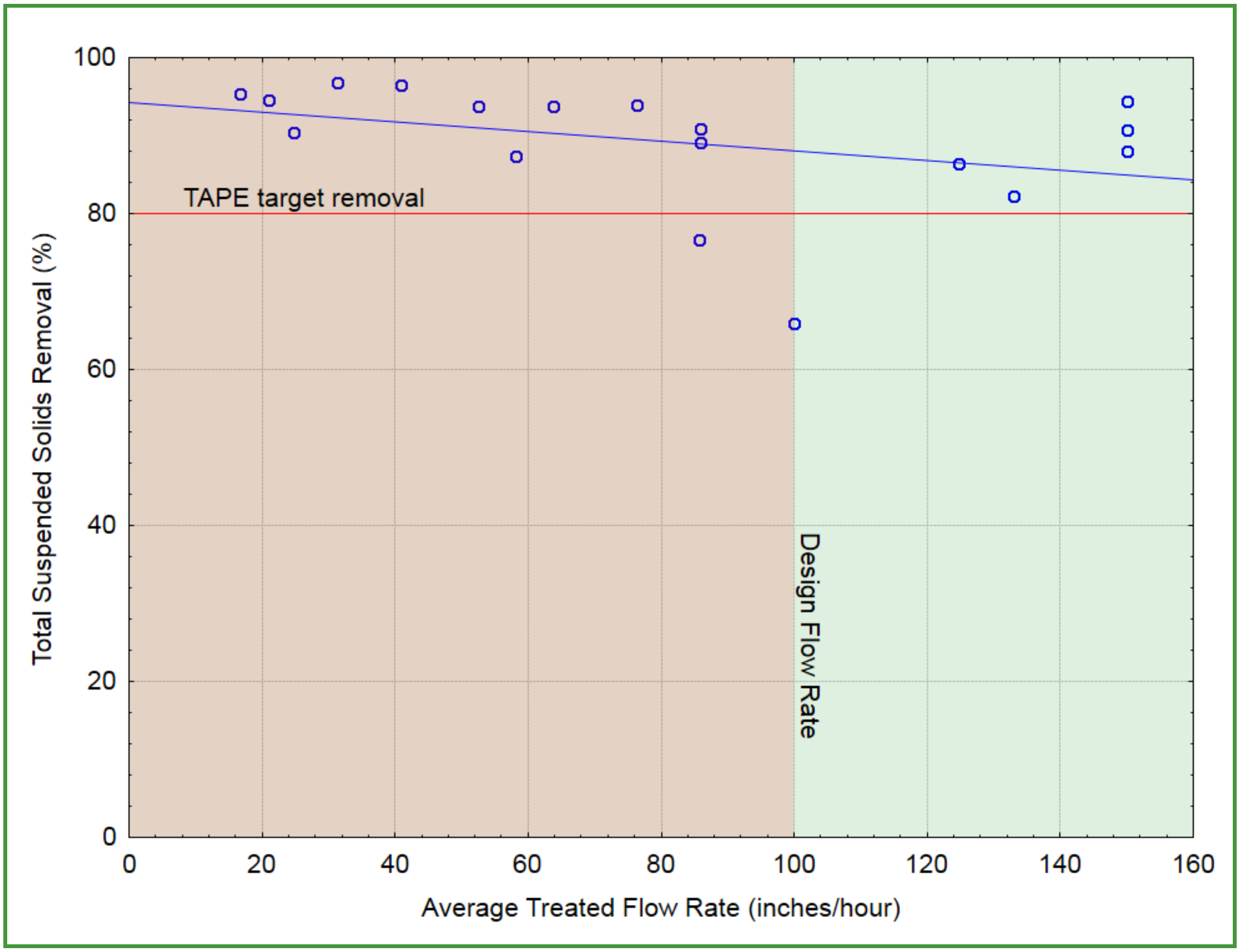

Figure 7. Total Suspended Solids Removal (%) as a Function of Average Treated Flow Rate.

The TAPE (Ecology 2011) indicates that a regression analysis should be conducted to determine the treatment efficiency varies as function of flow rate. The results of the regression analysis indicated there is no significant relationship between treatment efficiency and flow rate (p=0.822). As is apparent in Figure 7, the percent removal performance goal is achieved at and above the design infiltration rate of 100 in/hr. The highest observed infiltration rate at which the 80 percent removal performance goal was achieved was 150 in/hr.

Taken together, the above analyses indicate that the Basic Treatment criteria are met at 100 in/hr for the data collected at the Filterra test site.

Phosphorus Treatment

The Phosphorus Treatment goal listed in the TAPE guidelines indicate 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, it must be shown that a statistically significant difference between influent and effluent concentrations exists. 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.

This section describes the TP data in relation to the criteria identified above.

The 2011 TAPE indicates that only sample pairs with influent TP concentrations between 0.1 and 0.5 mg/L may be used for percent removal calculations and that a minimum of 12 sample pairs are required for analysis. The study basin produced concentrations between 0.1 and 0.5 mg/L for less than half of the monitored events (Table 13). After collecting 10 sample pairs which met all the TP criteria, a meeting was held with Ecology to determine options for completing the study. On June 26, 2013, Ecology agreed that data from a previous monitoring project at the same site could be used to augment the project dataset in order to meet the 12 storm event goal. The City of Bellingham monitoring was conducted on the same Filterra system from 2009 to 2010 (R. Hoover, personal communication, June 16, 2010). Of the 26 monitoring events, two met all the TAPE criteria for TP analysis, an event on April 7, 2010, and an event on April 27, 2010. Data from these two events are included in the following analyses and presented in Table 13 and Figure 8. The mean TP removal for these samples was 72.6 percent.

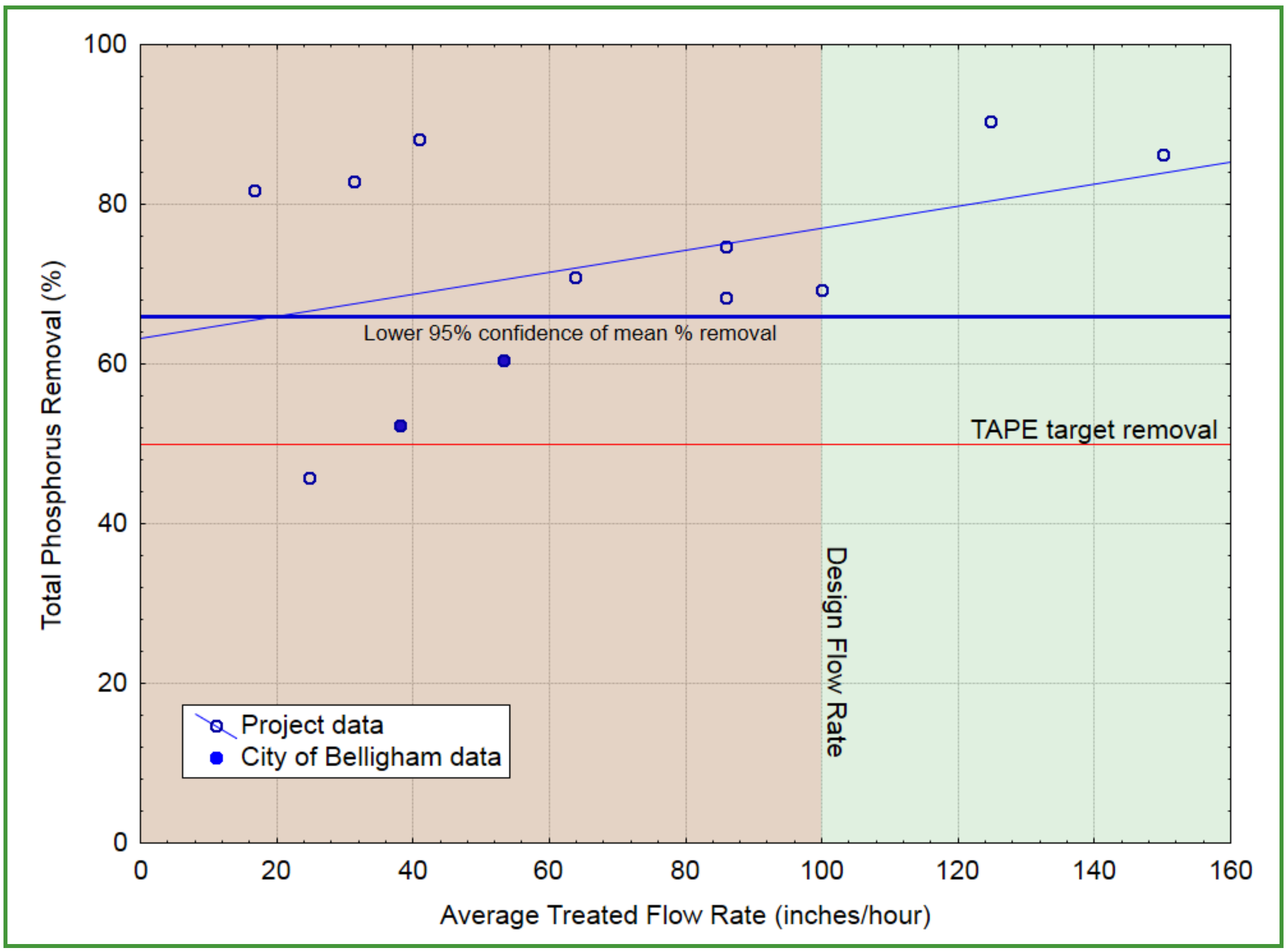

Figure 8. Total Phosphorus Removal (%) as a Function of Average Treated Flow Rate.

Table 13. Total Phosphorus Concentrations and Removal Efficiency Estimates for Valid Sampling Events at the Filterra Test System.

Storm Start Date & Time	Influent Concentration (mg/L)	QA	Effluent Concentration (mg/L)	QA	Percent Removal [b]	Sampled Flow Rate (gpm) [c]	Sampled Infiltration Rate (in/hr) [c]
1/8/2013 7:35	0.084		0.034			23.1	85.7
1/23/2013 9:30	0.047		0.035			6.1	22.7
1/24/2013 16:50	0.039		0.028			6.9	25.4
1/26/2013 5:20	0.031		0.022			11.0	41.1
1/28/2013 8:55	**0.329**		**0.060**		**81.8**	4.4	16.8
1/29/2013 15:15	**0.169**		**0.020**		**88.2**	10.6	40.9
2/22/2013 1:45	**0.105**		**0.057**		**45.7**	6.6	24.8
2/24/2013 23:20	**0.126**		**0.040**		**68.3**	22.8	85.9
2/28/2013 8:20	0.088		0.029			5.6	21
3/6/2013 10:45	0.041		0.023			4.4	16.7
3/12/2013 6:45	0.090		0.025			13.6	52.6
3/14/2013 9:15	**0.146**		**0.025**		**82.9**	8.1	31.4
3/16/2013 11:30	0.061		0.025			20.4	76.3
3/19/2013 17:00	**0.127**		**0.032**		**74.8**	22.4	85.9
4/5/2013 3:20	**0.175**		**0.051**		**70.9**	17.2	63.8
4/5/2013 18:25	**0.524**		**0.050**		**90.5**	33.7	125
4/10/2013 5:20	0.044		0.034			15.7	58.1
5/11/2013 22:20 [a]	**0.293**		**0.090**		**69.3**	27.2	100
5/21/2013 00:00 [a]	0.069		0.032			35.9	133
5/22/2013 18:55 [a]	**0.239**		**0.033**		**86.2**	40.5	150
6/12/2013 12:35 [a]	0.084		0.056			40.5	150
6/19/2013 23:50 [a]	0.062		0.048			40.5	150
4/7/2010 15:30 [d]	**0.105**		**0.042**		**60.5**	14.4	53.3
4/27/2010 16:00 [d]	**0.126**		**0.060**		**52.3**	10.3	38.0
Minimum	0.031		0.020		45.7	4.4	16.7
LCL95 Mean [e]					66.0		
Mean	0.134		0.040		72.6	18.4	68.7
Maximum	0.524		0.090		90.5	40.5	150

[a] All sampled events were flow-weighted composite sampled except these events, which consisted of samples collected above a high flow rate threshold.

[b] Percent removal is only calculated for sample pairs with influent ≥ 0.1 mg/L.

[c] Sampled flow rate is calculated by averaging the flow rate associated with each aliquot in the composite sample.

[d] Data from monitoring of the same Filterra system conducted by the City of Bellingham from 2009 to 2010.

[e] Bootstrapped estimate of the lower 95% confidence limit of the mean. Used to compare to the TAPE Phosphorus Treatment criteria of at least 50 percent removal.

Bold values met influent screening criteria and were used in performance analyses

J = estimated value based on water quality data (Appendix I)

in/hr = inches per hour gpm = gallons/minute mg/L = milligram/liter

A one-tailed Wilcoxon signed-rank test performed on the TP data with influent concentrations from 0.1 to 0.5 mg/L (n=12) indicated there was a statistically significant ($p < 0.001$) decrease in effluent TP concentrations compared to influent concentrations. Consequently, this aspect of the TAPE Phosphorus Treatment criteria is met.

The LCL95 mean percent reduction for the 12 qualifying TP sample pairs (including the two sample pairs from the prior monitoring conducted by the City of Bellingham) was 66.0 percent (Table 13), which is above the goal of ≥ 50 percent; consequently, these data achieve the TP removal goal.

To associate specific infiltration rates with measured TP removal efficiencies, the flow rate at the point when each aliquot was collected was calculated. These flow rates were then averaged for each sampled event. As shown in Table 13, these results indicate the mean sampled treated flow rate was 18.4 gpm (68.7 in/hr). As described in the *Test System Sizing* section above, the design flow rate for the system is 41 gpm (equivalent to an infiltration rate of 100 in/hr). Figure 8 displays percent removal versus average treated infiltration rate for all of the 12 qualifying TP sample pairs (including the two sample pairs from the City of Bellingham monitoring).

The results of the regression analysis on the percent removal versus infiltration rate data indicated there was no significant relationship between these variables ($p = 0.834$). A visual assessment of these data also indicated TP removal at greater than 50 percent is evident at the design infiltration rate of 100 in/hr and as high as 150 in/hr. Only one data point falls below the 50 percent removal goal line (Figure 8). Therefore, it can be safely assumed that the system can reduce TP by greater than 50 percent at the design infiltration rate of 100 in/hr.

Taken together, the above analyses indicate that the Phosphorus Treatment criteria are met for the data collected at the Filterra test site.

Other Parameters

The TAPE (Ecology 2011)indicates that in addition to required parameters mentioned above, screening parameters should be analyzed. The screening parameters consist of pH and orthophosphorus. The results for these parameters are presented in Table 14. The Filterra test system had a negligible effect on pH. The average pH concentrations were 6.80 and 7.06 at the inlet and outlet, respectively. The TAPE guidelines indicate that the test system should not increase of decrease pH by more than one unit for any given event or export pH less than 4 or greater than 9. The pH data presented in Table 14 indicate that these conditions were met for each sampled event.

The orthophosphorus data indicated that the Filterra test system had a negligible effect on orthophosphorus concentrations; however, the median influent orthophosphorus concentration was 0.010 mg/L which is the reporting limit for this method (Table 6). Due to the low influent concentrations, the system could not be properly evaluated for orthophosphorus performance. There is no treatment goal for orthophosphorus in the TAPE so these results are reported for reference purposes only.

Table 14. Summary Results for Screening Parameters.

Storm Start Date & Time	Influent pH (std. units)	QA	Effluent pH (std. units)	QA	Influent ortho-P (mg/L)	QA	Effluent ortho-P (mg/L)	QA
1/8/2013 7:35					0.018		0.011	
1/23/2013 9:30					0.010		0.010	
1/24/2013 16:50					0.008		0.009	
1/26/2013 5:20					0.009		0.008	
1/28/2013 8:55					0.011		0.110	
1/29/2013 15:15					0.008		0.009	
2/22/2013 1:45					0.011	J	0.010	J
2/24/2013 23:20					0.012		0.009	
2/28/2013 8:20					0.006	J	0.006	J
3/6/2013 10:45					0.009	J	0.007	
3/12/2013 6:45					0.007		0.006	
3/14/2013 9:15	7.02	J	7.18	J	0.005	J	0.005	J
3/16/2013 11:30	6.97		7.11		0.007		0.006	
3/19/2013 17:00	6.4		6.9		0.008		0.007	
4/5/2013 3:20					0.011	J	0.011	J
4/5/2013 18:25					0.012		0.009	
4/10/2013 5:20					0.013		0.014	
5/11/2013 22:20 [a]								
5/21/2013 00:00 [a]					0.012		0.012	
5/22/2013 18:55 [a]					0.011		0.013	
6/12/2013 12:35 [a]					0.001		0.022	
6/19/2013 23:50 [a]					0.020		0.028	

J = estimated value based on water quality data (Appendix I)
mg/L = milligram/liter

CONCLUSIONS

To obtain performance data to support the issuance of a GULD for the Filterra stormwater filtration system, Herrera conducted hydrologic and water quality monitoring at a test system in Bellingham, Washington from January 1, 2013, through July 23, 2013. During this monitoring period, 22 separate storm events were sampled.

Of the 22 sampled events, 18 qualified for TSS analysis. The data were segregated into sample pairs with influent concentration greater than and less than 100 mg/L. The UCL95 mean effluent concentration for the data with influent less than 100 mg/L was 5.2 mg/L, below the 20 mg/L threshold. Although the TAPE guidelines do not require an evaluation of TSS removal efficiency for influent concentrations below 100 mg/L, the mean TSS removal for these samples was 90.1 percent. In addition, the system exhibited TSS removal greater than 80 percent at and above the design flow rate of 27.6 gpm (100 in/hr). The highest observed infiltration rate at which the 80 percent removal performance goal was achieved was 150 in/hr. Based on these results we recommend the system be granted a Basic Treatment use level designation at 27.6 gpm (100 in/hr).

Ten of the 22 sampled events qualified for TP analysis. The dataset was augmented using two sample pairs from previous monitoring at the site. The mean TP removal for these samples was 72.6 percent. The LCL95 mean percent removal was 66.0, well above the TAPE goal of 50 percent. Treatment above 50 percent was evident at the design flow rate of 27.6 gpm (100 in/hr) and as high as 150 in/hr. Consequently, the Filterra test system met the TAPE Phosphorus Treatment goal at the target design flow rate of 27.6 gpm (100 in/hr).

REFERENCES

Davis, A.P. 2007. Field Performance of Bioretention: Water Quality Environ. Eng. Sci. 24(8):1048-1063.

Davis, A.P. 2008. Field Performance of Bioretention: Hydrology Impacts. J. Hydrology, ASCE. 13(2):90-95.

Davis, A.P., M. Shokouhian, H. Sharma, and C. Minami. 2006. Water Quality Improvement through Bioretention Media: Nitrogen and Phosphorus Removal. Water Environ. Res. 78(3):284-293.

Davison, A.C. and D.V. Hinkley. 1997. Bootstrap Methods and Their Application. Cambridge University Press, Cambridge; New York.

Ecology. 2004. Stormwater Management Manual for Eastern Washington. Ecology Publication No. 04-10-076. Washington State Department of Ecology, Olympia, Washington. September 2004.

Ecology. 2011. Technical Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol - Ecology (Tape). Publication No. 11-10-061. Washington State Department of Ecology, Olympia, Washington.

Ecology. 2012. Stormwater Management Manual for Western Washington. Publication No. 12-10-030. Prepared by the Washington State Department of Ecology, Olympia, Washington. August 2012.

Ecology. 2013. General Use Level Designation for Basic (TSS), Enhanced, and Oil Treatment and Conditional Use Level Designation for Phosphorus Treatment for Americast's Filterra. Washington State Department of Ecology. June 2013.

Facility for Advancing Water Biofiltration. 2008. Advancing the Design of Stormwater Biofiltration. Australia. June 2008.

FHWA. 2002. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. US Department of Transportation, Federal Highway Administration, Landover, Maryland.

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

Herrera. 2009. Filterra Bioretention Filtration System Performance Monitoring Technical Evaluation Report. Prepared for Americast, Inc. by Herrera Environmental Consultants, Inc., Seattle, Washington. December 3, 2009.

Herrera. 2012. Filterra Bioretention System Phosphorus Treatment and Supplemental Basic and Enhanced Treatment Performance Monitoring Quality Assurance Project Plan. Prepared for Americast by Herrera Environmental Consultants, Inc., Seattle, Washington. June 7, 2012.

Means, J. and R. Hinchee. 1994. Emerging Technology for Bioremediation of Metals. Battelle, Columbus, Ohio. 158 pp.

Reeves R.D. and A.J.M. Baker. 2000. Metal-accumulating plants. In: Phytoremediation of Toxic Metals. I. Raskin and B. Ensley (eds). John Wiley & Sons, New York. pp.193-230.

Ruby, M. and B. Appleton. 2009. Using Landscape Plants for Phytoremediation (Conference Proceedings presented at the 2009 International Society of Arboriculture and the 2009 North American Surface Water Quality Conference and Exposition).

Walkowiak, D.K. (Editor). 2006. Isco Open Channel Flow Measurement Handbook. Teledyne Isco, Inc., Lincoln, Nebraska. 520 pp.