EvTEC Ultra-Urban Stormwater Technology Evaluation
AquaShield™, Inc. Aqua-Filter™ Stormwater Filtration System

Final Report

March 23, 2011

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Photos courtesy of Taylor Associates, Inc.

Funding Acknowledgements:
Federal Highway Administration Grant Project No. E3WA02
ACKNOWLEDGEMENTS

The City of Tacoma would like to recognize the participation and assistance from others during this study. We would like to thank in particular the following organizations for assisting us with this project:

- Taylor Associates, Inc. – For preparing the QAPP and collecting all the data used in the study.
- Washington State Department of Transportation – For allowing us the use of the facility.
- Seattle Public Utilities – For letting us use your equipment.
- AquaShield – For providing assistance throughout the study.
- Federal Highway Administration – For providing us the opportunity to conduct this study.
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EXECUTIVE SUMMARY

Project Overview. This report summarizes the methods and results of data collected from the AquaShield™, Inc. Aqua-Filter™ (Aqua-Filter) Stormwater Treatment System installed at the Washington State Department of Transportation (WSDOT) Lake Union/Ship Canal Test Facility (Test Facility). The Test Facility is located in a City of Seattle ultra-urban basin and receives runoff from 22.7 acres of pavement and 8.9 acres of roadside landscaping. WSDOT, Seattle Public Utilities (SPU), and the City of Tacoma (COT) conducted the study to assess the ability of Aqua-Filter to remove contaminants, especially metals and organics, from stormwater. Taylor Associates, Inc. (Taylor) was hired to facilitate development of the study design and implement the study. A grant received by COT from the Federal Highway Administration Grant (Project No. E3WA02) paid for the study.

Technology Description. The Aqua-Filter technology is a stand-alone, custom-engineered, two-component structure that uses a treatment train approach for stormwater pollutant removal. The patented configuration of the Aqua-Filter always includes both pretreatment and filtration structures. The Aqua-Filter installed at the Test Facility was model AF-4.2 which was filled with a proprietary blend of high conductivity filter media. The overall treatment capacity of the system installed at the Test Facility was approximately 125 gpm.

Sampling Approach. Rainfall, flow, and water quality data were collected for 22 sampling periods1 across 15 separate storm events from March 2007 through October 20082. Of the 22 sampling periods, 19 were accepted for analysis because they either completely satisfied the Quality Assurance Project Plan (QAPP, Taylor 2006) criteria or only had minor deviations from the criteria. For each sampling period, samples were collected following the Washington State Department of Ecology’s Technology Assessment Protocol (TAPE, Ecology 2008) discrete flow composite (DFC) sampling approach. For each discrete sampling period, the system was operated at either 50% (62.8 gpm), 100% (125.7 gpm), or 125% (156.3 gpm) of the technology's filtration capacity.

Influent Concentrations. When looking at all influent flow rates (50%, 100%, and 125%) collectively, a statistically significant (p < 0.05) difference (influent concentration greater than effluent concentration) was observed for total suspended solids, total volatile suspended solids, nitrate/nitrite, total phosphorus, NWTPH-Diesel, total and dissolved copper, total and dissolved lead, total zinc, and diethyl phthalate.

Influent concentrations at the Test Facility compare reasonably well with stormwater data collected in Thea Foss Basins 237A and 243 (basins receiving significant runoff from roadways), with the exceptions of slightly higher values for bis(2-ethylhexyl)phthalate and di-n-octyl phthalate at the WSDOT Test Facility.

1 Portion of the storm over which samples were collected at a target inflow rate.
2 Five storm events were sampled by AquaShield™, Inc. during project startup. These storm events were not included in this report since the results are not representative of the technology under normal operating conditions.
Removal Efficiencies. Removal efficiencies were calculated for each storm and for the entire study. Results, when looking at all flow rates (50%, 100%, and 125%) collectively, generally indicate:

- Total Suspended Solids: The Aqua-Filter technology removed between -47.1% and 60.4% of TSS with a median removal rate of 9.3%. Influent concentrations ranged from 18.8 to 112 mg/L with a median concentration of 52.8 mg/L.
- Nutrients: Median removal efficiencies for nitrogen and phosphorus species ranged from -5.7% to 3.1%.
- Petroleum Hydrocarbons: Median removal efficiencies for NWTPH-Diesel and NWTPH-Heavy Oil were -10.3% and 4.0% respectively.
- Metals: Median removal efficiencies for total copper and dissolved cadmium were 12.6% and 25.0% respectively. Median removal efficiencies for all other metals, including dissolved metals, were less than or equal to 10%.
- PAHs: The Aqua-Filter technology removed (median removal) less than 6% of all PAHs.
- Phthalates: Median removal efficiencies for phthalates were all less than 8%, with the exception of diethyl phthalate which had a median removal of 12.7%.

Flow Rate Comparison. Statistically significant (p < 0.05) differences in removal efficiencies were observed for total suspended solids, total volatile suspended solids, total phosphorus, total zinc, naphthalene, phenanthrene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(a)anthracene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, pyrene, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, and di-n-octyl phthalate. Post-hoc tests (Dunn’s or Tukey’s) identified statistically significant differences (p < 0.05) between the 50% flow and the 100% flow rates for all of these analytes, except total phosphorus and total zinc. Several statistically significant differences (p < 0.05) were also observed between the 50% and 125% flow rates.

Costs. The AquaShield™, Inc. unit installed at the Test Facility cost approximately $35,000 excluding installation. Installation costs for the unit were fairly minimal due to it being placed on an existing concrete pad. The twelve replacement filter bags for the system cost approximately $2,900 plus taxes; cleaning of the unit during the study occurred on an annual basis.

Recommendations. Several statistically significant differences in removal efficiency were detected between flow rates during this study; additional sampling would be needed to determine if there are additional statistically significant differences between the other analytes based on flow rate. Based on the overall low removal efficiencies seen by the Aqua-Filter unit, this unit is not recommended as a stormwater treatment device in stormwater basins with influent concentrations similar to the Test Facility or the Thea Foss Waterway.
1.0 PROJECT OVERVIEW

This report summarizes the methods and results of data collected for the AquaShield™, Inc. Aqua-Filter™ Stormwater Treatment System (Aqua-Filter) installed at the Washington State Department of Transportation (WSDOT) Lake Union/Ship Canal Test Facility (Test Facility). The Aqua-Filter technology is a stand-alone, custom-engineered, two-component structure that uses a treatment train approach for stormwater pollutant removal. The patented configuration of the Aqua-Filter always includes both pretreatment and filtration structures – an Aqua-Swirl™ (Aqua-Swirl) and an Aqua-Filter respectively.

The purpose of this project was to evaluate the effectiveness of the Aqua-Filter technology to remove contaminants, especially metals and organics, from stormwater at selected flow rates. Removing these contaminants from stormwater will reduce potential impacts on our streams and waterways.

1.1 PROBLEM STATEMENT

The presence of metals and organics in receiving waters is a concern both locally and globally due to the threat they pose to ecosystems. Metals are a common pollutant in urban runoff and can be toxic to the ecosystem in low concentrations. The primary organic pollutants of interest during this study were polycyclic aromatic hydrocarbons (PAHs) and phthalates. PAHs are commonly associated with coal, crude oil, and their by-products. They are also commonly formed during the incomplete combustion of organic materials. Phthalates are known to cause biological affects in the environment and have been widely used as plasticizers since the 1930s; they are found in a variety of products ranging from plastic materials to cosmetics.

The Aqua-Filter technology received Pilot Use Level Designation (PULD) after writing of the Quality Assurance Project Plan (Taylor 2006) from the Washington State Department of Ecology (Ecology) for Basic, Enhanced, Phosphorus, and Oil treatment. The PULD conditions required the following (Ecology 2009):

- For Basic treatment:
  - Using a coarse perlite filter media as specified by AquaShield™, Inc.
  - Sized at an operating rate of no more than 5 gpm/ft² per cartridge (surface area of about 4 square feet).

- For Enhanced, Phosphorus, and Oil treatment:
  - Using Aqua-Blend™ C filter media as specified by AquaShield™, Inc.
  - Sized at an operating rate of no more than 5 gpm/ft² per cartridge (surface area of about 4 square feet).

AquaShield™, Inc. has also received General Use Level Designation (GULD) from the Washington State Department of Ecology (Ecology) for pretreatment (TSS) for the Aqua-Swirl concentrator. The Aqua-Swirl is the pretreatment unit used in the Aqua-Filter system. The GULD conditions for Aqua-Swirl (Ecology 2006) require that the unit either be used (a) ahead of infiltration treatment or (b) to protect and extend the maintenance cycle of a Basic or Enhanced Treatment device. The Aqua-Swirl unit must be sized at an operating rate of no more than 23
GPM/sf at the Water Quality design flow rates as determined using the Western Washington Hydrology Model.

To assess the ability of the Aqua-Filter technology to remove phthalates and PAHs from stormwater, WSDOT, SPU, and COT conducted a study at the Test Facility using the Aqua-Filter technology. Taylor worked with WSDOT, SPU, and COT on developing the study design and was responsible for implementing the study. This study was designed to assess the ability of the Aqua-Filter to remove phthalates and PAHs from stormwater at 50, 100, and 125 percent of design capacity. Data collection was targeted for fifteen storm events. Funding received by COT from a Federal Highway Administration Grant (Project No. E3WA02) paid for sample collection.

1.2 MONITORING OBJECTIVES

The objectives of this study, as outlined in the Quality Assurance Project Plan (QAPP) (Taylor 2006) were to:

1. Evaluate pollutant removal efficiencies, especially for metals and organics, for the Aqua-Filter. This was accomplished by collecting influent and effluent samples and flow data during storm events.

2. Conduct a maintenance needs evaluation based on qualitative maintenance inspections in the Aqua-Filter chamber and sediment depth measurements in the Aqua-Swirl. This was accomplished by conducting routine maintenance inspections. In addition, sediment samples were collected and analyzed prior to the removal of accumulated sediments from the filtration bay and at the end of the study period.
2.0 PROJECT DESCRIPTION

This section describes the Test Facility site, the Aqua-Filter technology, and the Aqua-Filter installation at the Test Facility.

2.1 TEST FACILITY DESCRIPTION

The Test Facility is located in Seattle, Washington in the Interstate 5 right-of-way beneath the north side of the Lake Union Ship Canal Bridge (Figure 1). The drainage area contributing to the site is approximately 31.6 acres, with 22.7 acres of pavement and 8.9 acres of roadside landscaping. The WSDOT stormwater collection system is separate from the City of Seattle collection system, and it includes runoff from the Interstate 5 northbound, southbound, express lanes, and the on- and off-ramps. All runoff in the drainage basin pass through catch basins prior to entering the stormwater collection system. The drainage basin contains 15 Type 1 and 53 Type 2 catch basins (EvTEC 2001).

WSDOT constructed the Test Facility to allow the simultaneous testing of up to four ultra-urban stormwater treatment technologies. This is accomplished by diverting stormwater flow from the 30-inch pipe to the site using a “draw-bridge” half-pipe structure. Once flow passes the upstream monitoring station, flow enters an adjustable flow splitter that diverts stormwater to test bays 1 and 2 or test bays 3 and 4 (Figure 2). A second flow splitter is located upstream of each set of test bays and is used to partition flow between the two test bays. Flow to each test bay is controlled through the use of a gate valve, which is located at the inflow to each test bay. A detailed description of the Test Facility site is provided in the EvTEC Evaluation Plan (EvTEC 2001).

2.2 AQUA-FILTER TECHNOLOGY DESCRIPTION

The Aqua-Filter is a stand-alone, custom-engineered, two-component structure that utilizes a treatment-train approach for stormwater pollutant removal. The Aqua-Filter system is a rapid or high flow rate filtration device that has no moving parts and operates on gravity flow or movement of stormwater runoff through the system. The unit always includes both pretreatment and filtration structures. The unit is constructed of high-density polyethylene (HDPE) materials, which allows for fast and simple installation in a variety of locations.

The Aqua-Filter system typically operates in an “off-line” configuration as recommended by most municipalities to provide for full treatment of the designed water quality flow rate. The off-line configuration requires the use of a separate diversion structure or weir device up-stream of the system to direct only the designated water quality flow rate for treatment. The Aqua-Filter system can also be installed in-line, when desired, with the stormwater conveyance pipe allowing for the complete storm event to flow through the system.

2.2.1 Aqua-Swirl Concentrator (Pretreatment)

The pretreatment structure is the Aqua-Swirl Concentrator which uses hydrodynamic vortex enhanced sedimentation technology (Figure 3). The inlet pipe is welded to the Swirl Concentrator on a tangent, which induces the circular motion needed for vortex enhanced sedimentation. Quiescent settling also occurs within the Aqua-Swirl Concentrator between storm events.
The diameter of the Swirl Chamber varies from 2.5 to 12 feet depending on the (1) peak storm event and (2) the intended water quality treatment flow rates for the site. A typical unit varies from 8.67 to 9.5 feet in height with the length of the access risers influenced by the site’s final design and drainage pipe elevations. The bottom of the Swirl Chamber is approximately 5.67 feet below the invert of the inlet pipe; this provides water and sediment storage within the chamber. Multiple Aqua-Swirl units can also be combined in parallel to process very high flow rates.

2.2.2 Filter Chamber

Once pretreated stormwater leaves the Aqua-Swirl Concentrator, the runoff enters the Filter Chamber (Figure 4). The chamber is designed to remove dissolved oils, finer sediments, nutrients, and organically bound heavy metals through media filtration technology. Water is distributed evenly along the filter bed. The filtration process is accomplished by gravity, similar to sand filters. Sediment is trapped in the interstitial spaces throughout the media as stormwater moves through the fibers. Depending on the type of media used in the chamber, ion exchange and absorption may also occur within the chamber.

The Filter Chamber has an inside diameter of approximately 72 inches (an outside diameter of 80.75 inches) with porous filter containers positioned horizontally in the center of the chamber and perpendicular to the water flow. There are three filter holders per row that have a surface area of approximately four square feet, therefore supplying a total of 12 square feet of surface area per row of filters. There are open grates on the bottom of each filter hold where four, 6-inch thick filters are placed to form two layers in a compact pattern to avert short-circuiting of the water flow. Accordingly, there is approximately 12 cubic feet of filter media per row of filters. Similar 1-inch thick open grates are firmly fixed above the filters to facilitate distribution of the pretreated water across the filter bed. The length of the Filter Chamber can be extended up to 35 feet to accommodate additional rows of filters increasing the surface area based on the calculated water quality flow rate to be treated. Filter Chambers have also been customized in parallel design to process exceptionally large flow rates.

The inside of the Filter Chamber is designed to facilitate distribution of the pretreated water above the filter bed and control the flow rate to each row using proprietary post-filtration hydraulic restraints. The design includes two bulkheads, one at each end of the Filter Chamber. The bulkhead just upstream of the filter bed event distributes stormwater across the filters and the downstream bulkhead restrains incoming stormwater which creates gravitational pressure for water to permeate the underlying filters. The bulkhead inside the Filter Chamber allows for a maximum of 10-inch water level above the filters. The post-filtration hydraulic restraints ensure each row of filters receives a flow of 60 gpm per row (20 gpm per filter) for fine silt particles (<50 microns) or a flow of 240 gpm per row (80 gpm per filter) for typical sediment (<150 microns).

2.2.3 Aqua-Filter Sizing

The Aqua-Filter is sized according to the calculated water quality flow rate, the individual drainage area entering the stormwater conveyance system, and the anticipated particle size distribution of the sediment in the runoff. Depending on the model installed, the water quality flow rate for a single Swirl Concentrator ranges from 0.22 to 5.8 cfs (AquaShield™, Inc. 2005a). For a single Filter Chamber, the water quality flow rate ranges from 0.13 to 1.6 cfs, depending on the model installed (AquaShield™, Inc. 2005b). Multiple Filter Chambers and/or Swirl Concentrators can be installed in parallel to achieve greater treatment flow rates.
2.2.4 Filter Media

The two types of media commonly used in the Aqua-Filter are the Aqua-Blend™ C and a natural medium-to-course grain perlite. The perlite media is used most often in the Aqua-Filter unit due to its overall performance characteristics. Other filtration media, such as granular activated carbon and zeolite, are used when requested for certain pollutants.

2.3 AQUA-FILTER INSTALLED AT THE TEST FACILITY

The Aqua-Filter selected for evaluation at the Test Facility was a Model AF-4.2 filled with a proprietary blend of high conductivity filter media (Aqua-Blend™ C). Detailed drawings of the Model AF-4.2 installed at the Test Facility as well as a typical Model AF-6.12 are provided in Appendix D of the QAPP (Appendix B).

The model at the Test Facility consisted of a Swirl Concentrator with a 4-foot inside diameter and a Filter Chamber with an approximate diameter of 6.5 feet by 12 feet in length. The storage capacity of the Swirl Concentrator and the Filter Chamber was approximately 517 gallons (69 cubic feet) and 476 gallons (64 cubic feet) respectively. The total storage capacity of the Aqua-Filter installed at the Test Facility was the storage capacity of the Swirl Concentrator and the Filter Chamber. This equates to approximately 993 gallons (133 cubic feet) for the entire treatment train.

The Aqua-Blend™ C media is enclosed in 24 filter containers aligned in two rows on the Filter Chamber's bed. This allows the system installed at the Test Facility to have an overall treatment capacity (100 percent filtration capacity) of approximately 0.28 cfs (125 gpm). This specific media was selected for the Test Facility because of the expected sediment particle size and the anticipated pollutants in the runoff.

Cost for the Aqua-Filter technology installed at the Test Facility including shipping was approximately $35,000. This cost was for the unit only and did not include installation. The unit was placed on an existing concrete slab when it was installed, so installation costs were fairly minimal.

Facility maintenance and bag replacement must be conducted periodically. The frequency of maintenance activities is dependent on the site conditions. Replacement of the twelve bags in the Aqua-Filter unit installed at the Test Facility cost (material cost only) approximately $2,900 plus taxes.
3.0 MONITORING METHODS

This section provides an overview of the monitoring methods, including sampling approach, qualifying events, stormwater quality parameters, sample collection, sample handling, quality control procedures, and equipment maintenance. A more detailed description of the monitoring methods is provided in the Quality Assurance Project Plan (QAPP, Appendix B) developed for this project (Taylor 2006). The monitoring approach for this study was adapted from the EvTEC Evaluation Plan (EvTEC 2001) and from the Technology Assessment Protocol – Ecology (TAPE, Ecology 2008\(^3\)).

3.1 SAMPLING APPROACH

Sampling approaches considered for this Aqua-Filter technology as outlined by TAPE (Ecology 2008) were:

- **Event Mean Concentration (EMC)** - The EMC sampling approach collects samples over the duration of a storm event and composites them in proportion to flow. This method involves sampling throughout a storm hydrograph (the rising and falling limbs) and generates a removal efficiency associated with the entire storm event.

- **Discrete Flow Composite (DFC)** - The DFC sampling approach involves collecting flow-weighted composite samples over relatively constant inflow periods, which enables the assessment of removal efficiencies at specific flow conditions.

Because the volume of runoff generated in the drainage basin for the Test Facility (approximately 1,980 gpm for a 6-month storm) is much larger than the capacity of the test system (125 gpm), the EMC sampling approach would have required that the Test Facility’s flow splitters partition off 1/24 (approximately 4 percent) of the inflow received at the facility during a storm event. Based on the results of a hydraulic evaluation for a stormwater treatment technology installed previously at this site (Tacoma 2008), this cannot be accomplished using the existing flow splitters in their current configuration. Therefore, testing of the Aqua-Filter technology was conducted using the DFC method.

To assess the average influent and effluent water quality under varying operating conditions, samples were collected at flow rates equivalent to 50 percent (62.8 gpm), 100 percent (125.7 gpm), and 125 percent (156.3 gpm) of the system’s design flow rate. These target inflow rates encompassed the range suggested by the TAPE guidelines (Ecology 2008).

When storm conditions allowed (that is, a storm event’s duration and intensity were at least 5 hours and 0.03 inches per hour), two inflow rates were sampled during the storm event. Because 15 storm events were targeted during the course of the study, it was hoped that the data set would contain 30 paired influent and effluent stormwater samples. If the samples were evenly distributed among the three target inflow rates, ten paired influent and effluent stormwater samples would have been collected for each target inflow rate.

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\(^3\) The QAPP was developed based on the 2004 version of the TAPE. Minimal changes have occurred in the sampling design in the 2008 version of TAPE.
Because different portions of the storm hydrograph are sampled using the DFC approach (compared to the entire storm hydrograph with the EMC approach), pollutant concentrations are expected to be different for each sampling period within each storm and between different storms. Since pollutant removal efficiencies may be affected by the influent concentration, comparison of removal efficiencies between storms and between flow rates within storms may be difficult. Graphical presentations (box and whisker plots) were used for this analysis in addition to numerical calculations.

Relatively constant inflow rates were maintained through the use of the upstream gate valve and splitter. A constant inflow rate was maintained by closing down the gate valve to force the upstream flow splitter to overflow into the flow splitter’s vertical, overflow standpipe. This creates a relatively constant hydraulic head upstream of the gate valve. The gate valve is manually adjusted (gradually opened or closed) to maintain the inflow rate targeted for the sampling period. This inflow management technique could only be achieved if inflow rates to the Test Facility were great enough to maintain overflow conditions in the gate valve’s upstream flow splitter.

To control inflow rates during the sampling period, sampling personnel were on-site during the storm event to monitor and adjust the gate valve position and to remove debris when the gate valve opening clogged. Having staff on-site during the storm event also enabled the reset of samplers for sample collection during a second target inflow rate. Two sampling periods per storm event only occurred if runoff flows to the site were adequate for the targeted inflow rate.

3.2 QUALIFYING EVENTS

3.2.1 Qualifying Storm Event

A qualifying storm event was defined for this project as having a minimum of 0.15 inches of rain over a five hour period. This average intensity (0.03 inches per hour) and duration were selected to (1) be great enough to mobilize pollutants and (2) provide adequate duration and storm runoff rates for testing the Aqua-Filter at a minimum of two target inflow rates.

The required antecedent dry period for this project was defined as a minimum of 24 hours with less than 0.10 inches of rainfall and an antecedent dry period of at least 6 hours with no more than 0.04 inches of rain. These requirements were made based on a combination of the EvTEC (2001) and the TAPE (Ecology 2008) recommendations. Antecedent rain data was collected from a rooftop rain gauge on top of the Atmospheric Sciences (ATG) building at the University of Washington. The ATG gauge measured rainfall in 0.01 inch increments and logged in 1 minute intervals.

3.2.2 Qualifying Sampling Period

A qualifying sampling period (portion of the storm over which samples were collected at a target inflow rate) was defined in the QAPP as:

1. Runoff volume was sufficient to provide the target inflow rate;
2. Target inflow rate was within a 20% variation from the median flow throughout the sampling period; and
3. Duration of the storm allowed a minimum of eight storage volumes to pass through the Aqua-Filter.

Although the beginning of the storm and periods of high intensity were specifically targeted for sample collection, samples collected during any portion of the storm qualified.

### 3.3 Water Quality and Sediment Parameters

Water quality parameters evaluated as part of this study were selected by study participants for several reasons. Typical stormwater runoff parameters (e.g., TSS, zinc, lead, copper) were included in the study due to their common occurrence in urban runoff and their potential for impact to receiving waters. Additional metals and organics parameters (e.g., PAHs, phthalates) were included in this study because study participants are facing challenges in their urban drainage basins with one or more of these parameters. Water quality parameters selected for evaluation are listed in Table 1.

Sediment samples were collected from the Swirl Concentrator and the Filter Chamber prior to accumulated sediment removal (Aqua-Filter maintenance) and at the end of the study period. The sediment parameters evaluated as part of this study were based on TAPE’s recommendations (Ecology 2008). These parameters are listed in Table 2.

### 3.4 Sampling Equipment and Collection

#### 3.4.1 Flow and Water Level Monitoring

Flow was monitored using ISCO low-profile, A-V sensors which measure both water depth and water velocity. This data was used in conjunction with the conveyance structure dimensions to calculate flow rate. The A-V sensors were interfaced with ISCO 6712 samplers and 750 A-V module to measure and record flow rates in the inlet and outlet pipes of the Aqua-Filter system.

Inflow was measured in the 12-inch pipe between the upstream mixing tank and inlet to the Swirl Concentrator. Outflow was measured in the 12-inch pipe downstream of the Filter Chamber. Flows were logged for both the inlet and outlet at one minute intervals during each sampling period and inlet flow monitored at five-minute periods during non-sampling periods. Outflow was not monitored during non-sample periods.

An ISCO 6700 sampler with 730 bubbler module was installed in the Filter Chamber upstream of the filter bed’s flow spreader to measure water level inside the Filter Chamber. Water level inside the chamber was logged at one minute intervals during each sample period and was not monitored during non-sampling periods. This meter was used to determine when and if flow bypassed the filter bed. Based on the hydraulic evaluation (Appendix F of the QAPP), the unit was not expected to go into bypass until flows exceeded approximately 250 gpm.

#### 3.4.2 Sample Collection Locations

The influent sample was collected within the upstream mixing tank from a point just below the invert of the tank’s outlet pipe. An ISCO 6712 sampler equipped with a 3/8-inch diameter Teflon sample line and four, 4-liter (approximately) bottles (two plastic, two glass) were used to collect the composite samples. Two composite samples were collected; one for conventional parameters and one for organic parameters. The inlet sampler was flow paced by the inlet flow monitoring equipment.
A second ISCO 6712 was used to collect field duplicate samples. The duplicate sampler was setup similar to the primary sampler and an ISCO SPA 1026 sampler trigger cable was used to link the primary sampler to the secondary (field duplicate) sampler. The cable was used to transmit a “sample” pulse from the primary to the secondary sampler. This pulse triggered the secondary sampler to collect a sample at the same time as the primary sampler collected a sample.

Effluent samples were collected from within the Filter Chamber just below the invert of the Filter Chamber’s outlet pipe. This location was selected because:

- Flow depths in the outlet conveyance pipe (downstream of the Filter Chamber outlet) were too low to reliably collect an effluent sample.
- Adequate flow depth always existed at the invert elevation of the outlet pipe for sample collection.
- At the invert elevation of the outlet pipe, filtered and unfiltered water (stormwater that bypassed the Filter Chamber’s filtration bed) had mixed and thus the effluent sample was representative of the stormwater flowing out of the technology.
- Access to the inside of the Filter Chamber allowed for ease of installation and maintenance of the sample lines.

This outlet sampler was also equipped with a 3/8-inch diameter Teflon sample line and four, 4-liter (approximately) bottles (two plastic, two glass) were used to collect the composite samples. Two composite samples were collected; one for conventional parameters and one for organic parameters. The outlet sampler was flow paced by the outlet flow meter described in Section 3.4.1.

In accordance with TAPE protocols (Ecology 2008), all organics samples were collected through Teflon® intake lines into 1-gallon glass jars with Teflon®-lined lids. This approach was used because these materials are known to be the most inert in terms of adsorption and desorption of organic compounds (CDOT 2000). Sample bottles were cleaned by the analytical laboratory using a dilute sulfuric acid rinse followed by a deionized (DI) water rinse.

This sampling method, however, did not allow for the collection of manual grab samples for NWTPH samples. NWTPH samples were instead collected using the automatic samplers, which may have resulted in some additional error in these measurements because some TPH may have adhered to the sampling equipment. This could have resulted in analytical results that were lower than would otherwise be measured and could have complicated comparisons of removal efficiencies.

3.4.3 Sampling Methods

3.4.3.a Influent and Effluent Sample

During storm events, Taylor staff visited the site to open the gate valve and allow flow to flow through the Aqua-Filter device at the flow rate being tested. The samplers were not activated until two detention volumes passed through the unit and inflow was relatively constant. Once the samplers were activated, field staff stayed onsite to adjust the gate valve, as needed, during the sampling period. The samplers were then manually started and flow paced to collect a 500 mL subsample.
every 332 gallons. The 500 mL subsample was equally distributed into four 4-liter plastic and four 4-liter glass bottles (a 125 mL subsample in each bottle). The pacing rate of 332 gallons allowed for the collection of at least 24 subsamples over the minimum sampling duration needed to allow eight sample volumes to pass through the Aqua-Filter unit. At the end of the sampling period, the glass bottles were composited into an 8 liter glass bottle for analysis of organic parameters and the two plastic bottles were composited into an 8 liter plastic bottle for analysis of conventional parameters.

As recommended by TAPE (Ecology 2008), each composite sample was collected throughout a time period during which the volume of water passing through the technology was equal to or greater than eight times the storage volume in the Aqua-Filter. This addresses the lag time within the device that affects the comparability of the influent and effluent data. By selecting eight storage volumes, the potential error introduced to the paired influent and effluent composite samplers is approximately 25 percent. The Aqua-Filter that was tested holds about 993 gallons of water between the inlet to the vault and the effluent sample location.

### 3.4.3.b Particle Size Distribution

A portion of the influent and effluent composite sample was submitted for particle size distribution (PSD) analysis whenever the composite sample had sufficient volume and the TSS concentration was high enough. A PSD sample size of 500 mL is the volume required by SPECTRA for analysis using the laser defraction method recommended by TAPE (Ecology 2008).

Prior to splitting off the PSD sample, the composite sample was thoroughly mixed and during splitting was continuously agitated. This was performed to ensure a representative sample was submitted for analysis.

### 3.4.3.c Sediment Samples

Sediment samples were collected at the end of the project and anytime sediment was removed from the unit for maintenance. Sediment samples were collected from both the Swirl Concentrator and the Filter Chamber. For each sample collection, a minimum of six sediment subsamples were collected. Sampling locations were selected with consideration of where the greatest sediment depths exist to ensure the sample is representative of the total sediment volume in the technology (Ecology 2008).

### 3.5 Sample Handling

Proper sample collection, handling, preservation, transport, and custody procedures were followed as described in the QAPP (Appendix B). Sample containers were appropriately labeled and logged on the chain-of-custody forms. Samples were iced during sample collection.

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4 Refer to the QAPP (Appendix B) for additional information on the automated sampling programs used during the project.
(by adding ice to the sampler base). No sample preservation was done prior to delivery to the laboratory.

Samples were composited in the on-site trailer prior to delivery at the laboratory. All samples were delivered to the laboratory within 24 hours of the onset of sample collection to ensure holding times for pH and metals were not exceeded. A detailed description of sample handling procedures, container types, and holding times is provided in the QAPP (Appendix B).

3.6 QUALITY CONTROL PROCEDURES

Quality control samples were collected and analyzed for field and laboratory activities to estimate bias and precision. The quality control procedures were conducted to determine if any of the sample containers, preservation methods, handling procedures, or sampling equipment contributed constituents to the sample. This section provides a brief description of the field and laboratory quality control samples and their associated frequency, acceptance criteria, and corrective actions.

3.6.1 Field Quality Control

Quality control samples consisted of field blanks and field duplicates collected at the inlet to the Aqua-Filter technology. Because the influent sample point should receive higher pollutant concentrations than the effluent sample point, Ecology’s TAPE guidelines (Ecology 2008) recommend that equipment rinse blanks and duplicates be collected at this point.

Field duplicates were collected for two of the 19 sampling events accepted for analysis, which met the requirement of 10 percent of the total number of sampling periods defined in the QAPP. Relative percent differences were calculated for the field duplicates and compared to the guidelines in the QAPP. In general, a little over 30% of the analytes exceeded the QAPP criteria (less than 20 relative percent difference (RPD) for concentrations greater than five times the detection limit). This is indicative of the inherent variability of stormwater data.

Equipment rinse blanks were collected two times over the course of the study (beginning of the project and midway through the sampling timeline). The equipment rinse blanks collected had a few exceedances with several parameters (Table 3).

The same quality control procedures were implemented for blank sample collection as were in place for all other sample collection: the sample line was rinsed to clean it before each sampling period. The sample line was rinsed with DI water by running the sampler pump in reverse with a volume of DI water equal to at least three times the suction line volume. After cleaning the sample line, the field blank was collected by drawing DI water through the cleaned sample intake line.

3.6.2 Laboratory Quality Control

Samples were submitted to the City of Tacoma’s Environmental Services laboratory and Spectra Laboratories. Both laboratories are accredited by the Washington State Department of Ecology, for analysis. Laboratory procedures followed those developed and currently implemented as described in the City of Tacoma Science and Engineering QA Manual (City of Tacoma, 2005) and in the Spectra Laboratories’ Quality Assurance Manual, Revision 3 (Spectra 2002) for sample analysis and reporting.
Laboratory quality control checks included method blanks, laboratory replicates, laboratory control samples, and matrix spikes. Quality control results for laboratory activities were reviewed by the Laboratory Quality Assurance Officer and summarized in a case narrative. Laboratory reports included the case narrative which identified any discrepancies with analysis or QC samples, a laboratory QC results summary, and laboratory results for both storm and QC samples. Data were deemed acceptable for use.

3.7 Equipment Inspections and Maintenance

Maintenance inspections were performed to document the sediment and debris accumulation in the Aqua-Filter and to evaluate the maintenance needs during the course of this study. Base and storm flows were allowed to pass through the Aqua-Filter during non-sampling events in order to help create a better picture of the maintenance needs of the unit. During non-sampling events, the upstream flow splitters were set to direct partial flow to the unit and the gate valve was opened to a setting to prevent overflow with the unit.

The flow monitoring and water quality sampling equipment were inspected prior to each sampling period to make sure they were operational. Inspections and preventative maintenance activities on the automated samplers and A-V sensors occurred as part of the pre-storm setup activities and during monthly site visits for routine data downloads. Maintenance records and calibration activities were documented on field sheets kept on file in both the field and office notebooks. A summary of the maintenance activities were documented in regular maintenance reports prepared by Taylor and submitted to the COT project manager (Appendix C).

3.8 Instrument Calibration

Calibration of the flow monitoring equipment was conducted prior to each storm event and as needed based on field inspection and data review. Prior to initiation of the first sample for each storm event, the water level and the upstream and downstream A-V sensor locations were measured and checked against the monitoring equipment readings. The level in the Filter Chamber was measured and checked against the 730 module reading. The subsample volume collected by each sampler was checked immediately prior to the start of the first sample period. All equipment was recalibrated as needed and recorded in the field notebook.

3.9 Site Maintenance

To prevent debris from clogging the partially open gate valve during the sampling period, regular maintenance to clean out the debris accumulations in the flow splitter and inlet pipe was conducted. Maintenance occurred as needed (no more than once per week) during the wet season and prior to each sampled storm event. Clogging of the flow splitter during sampling was an issue during the hydraulic testing for both the Aqua-Filter and other treatment technologies tested at the site.
4.0 DATA VALIDATION, ANALYSIS, AND USABILITY

This section provides an overview of the data validation and analysis procedures that occurred during and after collection of the field data. The application of these procedures to data collected during this study is provided in Section 5.0.

4.1 DATA REVIEW, VERIFICATION, AND VALIDATION

Rainfall, flow, Filter Chamber level, water quality, sediment, and maintenance inspection data underwent data review, verification, and validation as described below.

4.1.1 Data Review

Rainfall, flow, and Filter Chamber level data were reviewed by the site manager for gross errors such as spikes or data gaps to determine the completeness of the data set. Rainfall and flow measurements were verified by comparing the hyetograph and hydrograph at the Test Facility’s most upstream flow monitoring station for consistency during the sampled storm event as well as consistency with previously collected rainfall and flow data for the Test Facility. Flow measured at the upstream and downstream A-V sensors was compared for consistency. Filter Chamber level was compared with inflow for consistency between overflow conditions and inflow rate.

4.1.2 Data Verification

The Laboratory Quality Assurance Officer verified that all laboratory Quality Control results were in compliance with acceptable criteria. The site manager verified that field water quality QC results were in compliance with acceptance criteria. The site manager validated project data by determining whether procedures in the QAPP were followed during data collection.

4.1.3 Data Validation

The site manager validated that the stormwater samples were collected in accordance with the target inflow rate for the sampling period. The COT reviewed all laboratory data to ensure that results were appropriately qualified. All results were suitable for use as qualified.

4.2 DATA ANALYSIS

This section describes the data analysis conducted on the storm events and on the water quality and sediment data.

4.2.1 Storm Event Data

Hydrologic data from sampled storms were analyzed for the following information:

- Storm Event Antecedent Conditions (measured rainfall, duration);
- Storm Event Conditions (total precipitation, duration); and
- Sampling Period Conditions (precipitation, duration, water volume through treatment technology).
This information was then compared to the storm and sampling period criteria in the QAPP to determine what sampling periods should be accepted. Water quality data from accepted sampling periods were analyzed using the methods discussed below.

4.2.2 Water Quality

4.2.2.a Influent and Effluent Data

Influent and effluent concentrations for each analyte were analyzed to determine if a statistically significant difference ($p < 0.05$) exists between the two values. A two-tailed test was conducted for hardness because a change in either direction (increase or decrease) between the influent and effluent concentrations was possible. All other analytes were analyzed using a one-tailed test because the effluent concentration was expected to be less than, but not greater than, the influent concentration.

The following tests were performed using SYSTAT® Version 11 (SYSTAT) based on the distribution of the influent and effluent concentrations:

- Normal Distribution (Shapiro-Wilks p-value $\geq 0.10$): Paired t-test
- Non-Normal Distribution (Shapiro-Wilks p-value $< 0.10$): Sign test\(^5\).

4.2.2.b Pollutant Removal Calculations and Statistical Methods

Removal efficiencies were calculated using Method #4 as recommended by TAPE (Ecology 2008) and EvTEC (2001) for a DFC sampling approach. Method #4 is a modified application of TAPE Method #1 to the DFC approach since it applies Method #1 to “partial storm data”. It compares influent and effluent discrete flow composites for relatively steady-state flow periods within storms to evaluate the removal efficiency at a specific flow rate. Removal efficiencies are reported along with mean influent and effluent concentrations for each target inflow rate sampled.

**Method #4: Individual Storm Pollutant Removal Efficiency (SRE)**

The individual storm pollutant removal efficiency (SRE) method is used to calculate the removal efficiency for each water quality parameter during each individual storm.

\[
SRE_i = 100 \times \left( \frac{C_{i,in} - C_{i,eff}}{C_{i,in}} \right)
\]  

\(^{(1)}\)

\(^5\) A Sign test was used instead of a Wilcoxon Signed Rank test because the majority of the distributions were asymmetric.
Results were analyzed to determine if a statistically significant difference in removal efficiency (SRE) exists between flow rates. The following statistical tests were used based on the distribution of SRE:

- Normal Distribution (Shapiro-Wilks p-value ≥ 0.10): Parametric ANOVA with a Tukey post-hoc test; and
- Non-Normal Distribution (Shapiro-Wilks p-value < 0.10): Non-parametric ANOVA (Kruskal-Wallis) with a Dunn post-hoc test.

The ANOVA analysis looks to see if a statistically significant difference in mean SRE exists in flow rate combinations. If a statistically significant difference is found using an ANOVA analysis, a post-hoc test on the mean SRE values is used to determine which flow rates are significantly different from each other. The Dunn test was performed in Excel using the equations in Zar (1999). The ANOVA tests and the Tukey test were performed using SYSTAT.

Box plots were also used to visually look at the differences in removal efficiency between flow rates.

### 4.2.3 Sediment Data

Sediment samples were collected from the Swirl and Filter Chamber before sediment was removed from unit for maintenance and at the end of the study period. The samples were analyzed to determine pollutant concentrations on a dry weight basis. Sediment accumulation volumes in the Swirl and Filter Chamber were also determined at least once per month for the entire study duration (Appendix C).

### 4.2.4 Maintenance Data

Maintenance inspections conducted at least once per month and the maintenance summary reports document the volume of flow through the technology, sediment accumulation, and provide a qualitative description of the field conditions (Appendix C).

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6 Since a maximum of 6 pairs of influent and effluent samples were collected for each target inflow rate, statistically significant results are not expected for this project.

7 Section 10.2 of the QAPP (Taylor 2006) suggests that pollutant removal efficiency be plotted against flow rate, inflow concentration, and technology deployment time. Box plots were deemed a better way of comparing the data due to the low removal efficiencies seen for almost all analytes.
5.0 RESULTS

This section summarizes the data collected at the Test Facility. Results presented include storm event characteristics, water quality data, removal efficiencies, sediment data, and maintenance data. Section 6.0 provides a more detailed discussion of the data collected for each type of analyte (i.e., PAHs, phthalates).

5.1 STORM EVENTS

Twenty storms were sampled between June 2006 and December 2008, resulting in the collection of 30 stormwater samples. Table 4 summarizes the storm and sampling period characteristics and identifies whether or not each sampling period met the criteria outlined in the QAPP (Taylor 2006). Detailed storm event summaries are provided in Appendix D.

Storms #1 through #5 were rejected since they occurred while AquaShield™, Inc. was testing the technology and media installation to ensure proper operation. The flow and water quality results for these storms are not representative of the unit’s operation during normal operating conditions. Therefore, these events were excluded from analysis.

5.1.1 Target Inflow

TAPE guidelines (Ecology 2008) recommend that DFC sampling be conducted during relatively constant inflow periods (less than 20% variation from the median flow). Table 4 shows that only a small number of sampling periods met this criterion 100% of the time. This was due to difficulties in maintaining a constant flow at the Test Facility due to the facility setup and clogging that occurred near the inflow.

Flow was within 20% of the median flow during a majority (greater than 60%) of the sampling period for all of the sampling periods. All storms (#6 - #20) were accepted for analysis based on flow.

5.1.2 Flow Volume

TAPE (Ecology 2008) recommends selecting only storms that generate more than eight times the storage volume of the test system. For this project, however, volumes greater than seven times the storage volume were included because the increase in error introduced by this change (increase to 28.6% potential error from 25% potential error) is minimal. All storms (#6 - #20) were accepted for analysis based on the flow volume criteria.

5.1.3 Storm Depth and Duration

The QAPP (Taylor 2006) defines a qualifying storm event as having a minimum depth of 0.15 inches over 5 hours. However, the TAPE guidelines (Ecology 2008) recommend that total rainfall during the storm event have a minimum depth of 0.15 inches with a duration greater than 1 hour and that the average rainfall intensity should exceed 0.03 inches per hour for at least half of the sampled storms.

The QAPP developed for this project set stricter guidelines for storm duration to allow the collection of at least two flow rates during each storm. This allowed for a greater number of samples to be collected at a lower cost. For data analysis, however, all storms that met the
TAPE duration guidelines (minimum 1-hour storm duration) were accepted for analysis. No storms were excluded based on storm duration.

Storms with less than 0.10 inches were not accepted for analysis because these storms were considered too small to mobilize pollutants. This resulted in Storm #6, Storm #14, and Storm #17 being excluded because only 0.03, 0.07, and 0.09 inches of rainfall fell respectively during those storm events (Table 4). All other storm events were accepted based on this criterion of greater than 0.10 inches during the storm event.

5.1.4 Antecedent Rainfall

All storms (#6 - #20) met the criteria of an antecedent dry-period with less than 0.10 inches in the 24 hours prior to the event and with less than 0.04 inches in the 6 hours prior to the storm event.

5.2 WATER QUALITY DATA

5.2.1 Influent and Effluent Data – Water Quality

Table 5 provides the summary statistics for accepted storms for each water quality parameter.

Influent concentrations observed at the Test Facility were compared to Thea Foss Basins 237A and 243 (Table 6) because these Thea Foss basins collect significant runoff from highways and other high traffic roadways. Concentrations at both locations are generally similar with the exception of slightly higher bis(2-ethylhexyl)phthalate (DEHP) and di-n-octyl phthalate concentrations at the Test Facility. Median DEHP was 12.7 ug/L at the Test Facility and 2.8 ug/L and 1.9 ug/L at the Thea Foss Basins 237A and 243 respectively. Median di-n-octyl phthalate was 3.56 ug/L at the Test Facility and less than 0.5 ug/L at the Thea Foss basins.

A statistical comparison (paired t-test or sign test as described in Section 4.2.2.a) of influent and effluent concentrations for each analyte is provided in Table 7. Censored data (i.e., pollutants that were below analytical reporting limits) were included in the analysis using the analytical detection limit for all censored values. Among the various approaches to dealing with censored data (i.e., using the detection limit, one half the detection limit, a random number between zero and one times the detection limit), the detection limit was used in these analyses because this is what was specified in the QAPP (Appendix B, Taylor 2006).

If both the influent and effluent concentration were below the detection limit, samples were excluded from all calculations because it is not possible to look for any differences between influent and effluent concentrations. P-values less than 0.05 were considered significant enough to reject the null hypothesis (influent concentration = effluent concentration [two-tailed analysis] or influent concentration ≤ effluent concentration [one-tailed analysis]).

Statistically significant (p < 0.05) differences (influent concentration greater than effluent concentration) were observed for total suspended solids, total volatile suspended solids, nitrate/nitrite, total phosphorus, NWTPH-Diesel, total and dissolved copper, total and dissolved lead, total zinc, and diethyl phthalate. This indicates that the Aqua-Filter was effective in removing these types of compounds. The absence of a statistical difference between inlet and outlet concentrations for other parameters was likely related to the relatively small sample size and the number of samples that were collected that were below the detection limit.
5.2.2 Removal Efficiencies – Water Quality

Removal efficiencies were calculated for each parameter as described in Section 4.2.2.b. Concentrations reported as less than the detection limit were included in the analysis by using the detection limit as the concentration as recommended by the QAPP. If both the influent and effluent concentration were below the detection limit, samples were excluded from all removal efficiency analyses.

Table 8 provides summary statistics for SRE for all parameters. Analysis of variance (ANOVA) was performed on SRE (see Section 4.2.2.b) to determine whether or not statistically significant differences exist between flow rates. Statistically significant differences \( p < 0.05 \) between flow rates were observed for total suspended solids, total volatile suspended solids, total phosphorus, total zinc, naphthalene, phenanthrene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo fluoranthenes, chrysene, fluoranthenes, indeno(1,2,3-cd)pyrene, pyrene, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, and di-n-octyl phthalate. Post-hoc tests (Tukey or Dunn as described in Section 4.2.2.b) were then conducted on these analytes to determine the differences between the individual flow rates (Table 9). The post-hoc tests identified a statistically significant difference \( p < 0.05 \) in flow for all of these analytes, except total phosphorus and total zinc, between the 50% and the 100% flow rates. Several statistically significant differences \( p < 0.05 \) were also observed between the 50% and 125% flow rates. A larger sample size is needed to determine if additional differences in treatment effectiveness exist between flow rates.

5.2.3 Influent and Effluent Data – Particle Size Distribution

Figure 5 shows the mean particle size for influent and effluent samples collected for accepted storms. The mean particle size for all the accepted storms ranged from 6.38 µm to 14.71 µm for the influent samples and from 6.50 µm to 12.81 µm for the effluent samples. The data (Appendix E) shows that the influent stormwater had a significant silt fraction as expected for stormwater in the Pacific Northwest.

As can be seen in Figure 5, the Aqua-Filter technology did not appear to affect the mean particle size of the stormwater as it passed through the treatment device. Since the Aqua-Filter technology relies heavily on gravity/mechanical filtration, the technology struggled to remove the small silt particles that were present in the influent stormwater. Given that the Aqua-Filter technology is not a water retention device and small silt particles exhibit low settling velocities, the influent particles did not have adequate time for effective settling within the technology.

Since the Aqua-Filter technology exhibited a limited ability to remove the small silt particles present in the influent stormwater at the test site, the low removal efficiencies observed for various pollutants (Table 8) are not unexpected.

5.3 Sediment Data

Sediment was collected from the AquaSwirl and the Filter Chamber just prior to cleaning as described in the QAPP (Taylor 2006). Results are presented in Table 10. Since only two samples were collected at each location, no statistical analyses were performed.
5.4 Maintenance Data

The Aqua-Filter technology generally underwent maintenance inspections at least once per month. Reports summarizing observations and sediment depth during the inspections are included in Appendix C. The AquaSwirl and filter media were replaced in September 2006, March 2007, and March 2008.

Figure 6 and Figure 7 show the sediment accumulation in the AquaSwirl versus date and cumulative flow since the last cleaning. As can be seen in the figures, minor sediment accumulation (less than 0.3 foot) occurred in the approximately one year period between cleaning. The low sediment accumulation observed is likely due to the small size of the particles seen in the influent stormwater.
6.0 TREATMENT ANALYSIS

This section provides a more detailed discussion of the impact of the Aqua-Filter technology on each type of analyte. Where appropriate, the implications of these removal efficiencies were applied to the Thea Foss basin.

The data is presented in a “box and whiskers” plot format. The bottom of the lower “whisker” represents the smallest non-outlier observation of the ranked SRE values, the lower end of the box represents the 25th percentile, the heavy horizontal line in the middle of the box is the median of the values, the upper end of the box is the 75th percentile, and the top of the upper whisker is the largest non-outlier observation. Outliers were defined as anything greater than 1.5 times the interquartile range (75% percentile value minus the 25% percentile value) away from either the 25% percentile or 75% percentile value. Outliers are not shown on the box plots. This format presents the range of values in a convenient manner.

6.1 CONVENTIONAL PARAMETERS

Figure 8 shows box plots for the conventional analytes (hardness, solids, total suspended solids (TSS), total volatile suspended solids (TVSS), and turbidity). The Aqua-Filter technology does not appear to significantly impact hardness, total solids, or turbidity with median SREs less than 10%. At the 50% flow rate, the Aqua-Filter technology removes a portion of the TSS and TVSS (median 26.1% and 32.3% respectively) of the influent concentration. The removal for TSS and TVSS at the 50% flow rate was significantly (p < 0.05) higher than the removal rates at the 100% and 125% flow rates (Table 9).

TSS in the influent ranged from 18.8 mg/L to 112 mg/L with a median concentration of 52.8 mg/L (Table 5). This value is very similar to values observed in Thea Foss Basins 237A and 254 (median 40 mg/L and 58 mg/L respectively) and to other stormwater data from the region. Median SRE for the Aqua-Filter technology for TSS for all flows was 9.3%.

Due to the low TSS numbers seen in the influent to the Aqua-Filter, additional TSS and TVSS samples were collected from the (1) flow-splitter (up-stream of the gate valve), (2) the mixing tank inlet, and the (3) mixing tank outlet during the August 19, 2008 and the October 6, 2008 sampling events. Results are presented in Table 11. From the limited data collected, it does not appear that the upstream configuration (flow-splitter, small gate-valve opening, and mixing tank) was causing sediment particles to settle out prior to reaching the Aqua-Filter technology.

Ecology’s basic treatment performance goals (Ecology 2008) are an effluent concentration of less than 20 mg/L for influent concentrations less than 100 mg/L and 80% TSS removal for influent concentrations between 100 mg/L and 200 mg/L. These performance goals are meant to apply to stormwater with a typical particle size distribution and to the water quality design storm volume or flow rate. The particle size distribution results (Appendix E and Section 5.2.3) show that the influent stormwater had a significant silt fraction as expected for stormwater in the Pacific Northwest.

Table 12 provides a comparison of the data to Ecology’s basic treatment performance goals. This comparison is for informational purposes only, because this project was not designed to test the ability of the technology to meet Ecology’s basic treatment goals. For influent TSS concentrations less than 100 mg/L, the mean effluent concentration was 49.7 mg/L. Based on the limited number of samples collected (18 paired data sets), this technology does not appear
to satisfy Ecology’s performance requirement of less than 20.0 mg/L effluent TSS concentration. Only one paired data set was collected for influent concentrations greater than 100 mg/L; this single event did not meet Ecology’s goal of 80% TSS removal.

6.2 **NUTRIENTS**

Figure 9 shows box plots for the nutrient analytes (nitrate/nitrite, total nitrogen, ortho-phosphate, and total phosphorus). Median removal efficiencies for all flow rates combined were near zero for all nutrients (Table 8). These results do not show significant nutrient removal.

The removal of total phosphorus at the 50% flow rate was significantly (p < 0.05) higher than the removal rates at the 125% flow rate (Table 9).

6.3 **PETROLEUM HYDROCARBONS**

Figure 10 shows box plots for NWTPH-Diesel and NWTPH-Heavy Oil. These samples were not collected as grab samples as suggested by TAPE. The samples were collected as composites throughout the storm in glass bottles along with the other organic parameters. This deviation from TAPE recommendations may have resulted in some additional error in these measurements because some TPH may have adhered to the sampling equipment. If TPH did adhere to the sampling equipment, the analytical results would be lower than would otherwise be measured and would have affected removal efficiency calculations.

NWTPH-Heavy Oil influent concentrations were significantly (p << 0.05) higher than effluent concentrations (Table 7). No statistically significant difference between influent and effluent concentrations was observed for NWTPH-Diesel.

Median SRE for NWTPH-Diesel and NWTPH-Heavy Oil were near or below zero (Table 8). No statistically significant differences in SRE between flow rates were observed for these analytes (Table 8).

6.4 **METALS**

Figure 11 shows box plots for the metal analytes (cadmium, copper, lead, and zinc). Copper (total and dissolved), lead (total and dissolved), and zinc (total only) were significantly (p < 0.05) greater than effluent concentrations (Table 7).

Statistically significant differences (p < 0.05) in removal efficiencies between flow rates were only observed for total zinc. Total zinc at the 50% flow rate was significantly (Table 9) different than the 125% flow rate. Cadmium (total and dissolved) had four or fewer paired samples that were above the detection limit which hindered the statistical analysis (Table 8).

Median removal rates for all metals (dissolved and total) were less than 13% with the exception of dissolved cadmium which had a median removal rate of 25.0%. Dissolved cadmium, however, only had three paired samples for analysis which makes this removal number unreliable (Table 8).
6.5 PAHs

Figure 12 and Figure 13 show box plots for low and high molecular weight PAHs (LPAHs and HPAHs). The influent concentrations when looking at all flows collectively were not significantly (p < 0.05) higher than effluent concentrations (Table 7) for all analytes. Removal efficiencies for all PAHs were generally near or less than zero when looking at all flows collectively (Table 8). Acenaphthene had only six paired samples that were above the detection limit (Table 8) which hindered the statistical analysis and likely led to the wide range of removal efficiencies (minimum -670%, maximum 3.8%) observed.

There were several statistically significant (p < 0.05) differences between flow rates for PAHs (Table 8). Napthalene, phenanthrene, benzo(a)anthracene, benzo(g,h,i)perylene, chrysene, and indeno(1,2,3-cd)pyrene had statistically significant differences between the 50% and the 100% flow rates (Table 9). Benzo(a)pyrene, benzofluoranthenes, fluoranthene, and pyrene had statistically significant (p < 0.05) differences between the 50% and 100% and the 50% and the 125% flow rates (Table 9).

Influent concentrations at the Test Facility compare fairly well with Thea Foss Basins 237A and 243 (Table 8). Similar removal efficiencies would be expected for the Aqua-Filter technology installed in either of these Thea Foss basins.

6.6 Phthalates

Box plots for phthalate analytes are shown in Figure 14. Influent concentrations were not significantly (p < 0.05) higher than effluent concentrations (Table 7) for all analytes except for diethyl phthalate. Median removal efficiencies when looking at all flow rates collectively were less than 13% for all phthalates (Table 8), but were higher (range of 11.2% to 23.2%) when just looking at the 50% flow rate. A statistically significant difference (p < 0.05) exists (Table 9) between the 50% and the 100% flow rates for bis(2-Ethylhexyl)phthalate, butylbenzylphthalate, and di-n-octyl phthalate.

Influent concentrations at the Test Facility compare reasonably well with Thea Foss Basins 237A and 253 with the exception of bis(2-ethylhexyl)phthalate (DEHP) and di-n-octyl phthalate which are slightly higher at the Test Facility. Because median DEHP levels in Thea Foss are approximately 4 ug/L compared to approximately 17 ug/L at the Test Facility, removal efficiencies for an Aqua-Filter unit in Thea Foss may be lower than those seen at the Test Facility due to increased difficulties in reducing concentrations at very low values. Median SRE for DEHP at the Test Facility for all flow rates combined was only 0.9%.
7.0 CONCLUSIONS

This section discusses the overall results of the project, including a discussion on removal efficiencies, maintenance requirements, and the applicability of the treatment technology to the Thea Foss basin.

7.1 REMOVAL EFFICIENCIES

Removal efficiencies for the Aqua-Filter technology were generally fairly low (25% or less) when looking at all flow rates collectively. In general, the technology appeared to perform better at the 50% flow rate than at the 100% and 125% flow rates with statistically significant differences in removal efficiencies for 17 of the analytes. Additional sampling would be required to determine if additional differences actually exist between flow rates.

7.2 MAINTENANCE

The Aqua-Filter technology required periodic maintenance during the study to maintain the technology’s performance. The twelve filter bags were all replaced annually during the study with an approximate cost of $2,900 plus tax each time. Overall, the maintenance efforts for the Aqua-Filter system are similar to those of other stormwater treatment devices.

7.3 IMPLICATIONS TO THEA FOSS

Removal efficiencies for DEHP, one of the primary concerns for the Thea Foss basin, ranged from -108.3% to 55.8% with a median of 0.9%. Influent concentrations in the Thea Foss basin are generally slightly lower than those seen at the Test Facility, which may result in lower removal rates if the technology was applied in the Thea Foss basin. Since we are looking for a regional treatment system in the Thea Foss basin, this technology is not an appropriate choice.
8.0 REFERENCES

AquaShield™, Inc., Chattanooga, Tennessee.

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