Jellyfish® Filter
Dundee, OR

General Use Level Designation
Technical Evaluation Report

Prepared by

CONTECH Engineered Solutions
11815 NE Glenn Widing Drive
Portland, OR 97220
Telephone: 800-548-4667

December 28, 2020

Table of Contents

Appendices

1.0 Executive Summary

Contech currently holds both a Conditional Use Level Designation (CULD) for the Jellyfish® Filter as a basic treatment device for total suspended solids (TSS) removal and a Pilot Use Level Designation (PULD) for phosphorus removal. This Technical Evaluation Report summarizes the results of a field monitoring campaign conducted to support issuance of a General Use Level Designations (GULD) for both Basic Treatment (TSS removal) and Phosphorus Treatment.

Between March 2017 and April 2020, performance of a Jellyfish Filter treating runoff from an 86-acre basin in Dundee, Oregon, was evaluated following an approved Quality Assurance Project Plan (QAPP). This QAPP was written to ensure that the field evaluation would follow the procedures and guidelines described in the Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies Technology Assessment Protocol – Ecology (TAPE) as written by the Washington State Department of Ecology (WADOE, 2011) and is included in Appendix E.

1.1 Technology Description

The Jellyfish Filter (Figure 1) is a stormwater treatment technology featuring high surface area, high flow rate membrane filtration, at low driving head. By incorporating pretreatment with light-weight membrane filtration, the Jellyfish Filter removes a high level and a wide variety of stormwater pollutants. The high surface area membrane cartridges, combined with up-flow hydraulics, frequent passive backwashing, and rinseable/reusable cartridges ensures long-lasting performance.

Each lightweight Jellyfish Filter cartridge consists of multiple detachable membrane-encased filter elements (“filtration tentacles”) attached to a cartridge head plate. The pleated filtration tentacles provide a large amount of surface area within a small footprint, resulting in superior flow capacity and suspended sediment removal capacity. Cartridges are designated as either “hi-flo” or “draindown” depending on their design flow rate and location within the system.

Jellyfish cartridges are passively backwashed after each storm event. The backwash feature removes accumulated sediment from the membranes, significantly extending their service life. The lightweight cartridges can be removed by hand and externally rinsed. The rinsed cartridges can then be re-installed, thereby minimizing cartridge replacement costs and life-cycle treatment costs while ensuring long-term treatment performance.

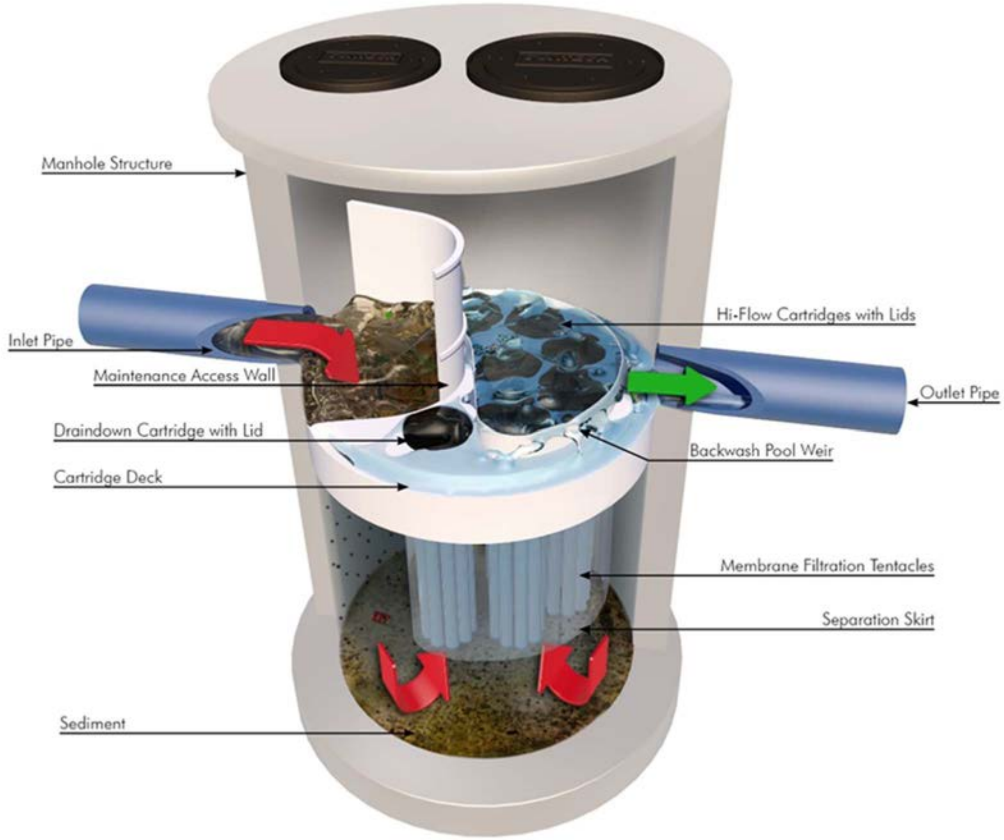

Figure 1. The Jellyfish Filter and Components

1.2 Sampling Procedures

The Jellyfish Filter evaluated, referred to as the City of Dundee Jellyfish Filter (Dundee Jellyfish Filter), is in Dundee, OR and sits approximately 200 feet above sea level. The site, located on city property, has a contributing drainage area of 86 acres and is 32% impervious. The land use is a mix of agricultural land, roadways, commercial areas, and residential development.

The Dundee Jellyfish Filter was designed to treat a total of 1.16 cfs (520 gpm) through a combination of 6 hi-flo cartridges at 80 gpm (specific flow rate of 0.21 gpm/ft2) and 1 draindown cartridge operating at a 40 gpm (specific flow rate of 0.11 gpm/ft2). The unit was installed in a 6-foot diameter manhole with an 8-inch diameter inlet pipe and an 8-inch diameter effluent pipe.

Automated sampling equipment was installed at the site to take flow-weighted composite influent and effluent samples from March 2017 to April 2020. Influent, effluent, and bypass flow rates were also measured during this time. Throughout the monitoring period, a total of 25 individual storm events were sampled. Sample pairs from these storm events were evaluated for total suspended solids (TSS), total phosphorus (TP), suspended sediment concentration (SSC), total volatile suspended solids (TVSS), orthophosphate phosphorous, hardness, pH, total copper, total zinc, total cadmium, total lead, magnesium, calcium, nitrate+nitrite, ammonia as N, total Kjeldahl nitrogen (TKN), and total nitrogen.

Data collected during the evaluation period was used to evaluate the water quality treatment performance of the system following procedures outlined in the TAPE. These procedures include:

- Statistical comparison of influent and effluent pollutant concentrations
- Pollutant removal efficiency estimation using bootstrap analysis
- Statistical evaluation of performance goals
- Analysis of pollutant removal performance as a function of flow rate

1.3 Hydrologic Performance

The water quality treatment goal of the Dundee Jellyfish Filter was to capture and treat 91% of the average annual runoff volume. Since the City of Dundee is located in Oregon and utilizes a different sizing methodology for flow-based treatment systems than is required in Washington, the system water quality flow rate was not determined according to the methods detailed in the Stormwater Management Manuals for western or eastern Washington. Instead, the large contributing drainage area was anticipated to consistently supply influent flows at or above the system design flow of 520 gpm, and the test unit was placed in an external bypass configuration with an upstream diversion structure allowing flows exceeding the treatment capacity of the Jellyfish Filter to bypass treatment. Additionally, an actuated slide gate was installed at the system inlet, which only allowed flow to enter the system during rain events. As detailed in section 7, this gate prohibited base flows and other non-stormwater runoff flows from impacting filter performance and permitted a continuous record of flow entering the unit, even when samples were not collected. Typical system sizing methodology is detailed in Section 3.4.

During the course of monitoring, construction activities at and around the site prompted the pausing of monitoring several times. Due to high concentrations of construction and roadway sediment which accumulated in the upstream storm drain during those periods, the system was maintained more frequently than recommended. In total, the unit was maintained 7 times during the 3 years of monitoring. Typical guidelines specify an annual maintenance interval of 12 months for normal sediment loading conditions. Detailed descriptions of maintenance activities and system performance over time is available in Section 7.

1.4 Water Quality Performance

In an effort to obtain the required total suspended solids (TSS) and total phosphorus (TP) data to support the issuance of a General Use Level Designations (GULD) for both Basic Treatment (TSS removal) and Phosphorus Treatment from the Washington State Department of Ecology, the Dundee Jellyfish Filter was evaluated from March 2017 to April 2020. During the evaluation period a total of 25 individual storm events were sampled and deemed qualified based on sampling criteria outlined in the 2011 Technology Assessment Protocol – Ecology (TAPE).

1.4.1 Basic Treatment

The Basic Treatment standard outlined in the TAPE requires ≥ 80% TSS removal at influent concentrations ranging from 100 to 200 mg/L. At influent TSS concentrations between 20 and 100 mg/L, a maximum effluent concentration of 20 mg/L is allowed. There is no specified treatment goal for influent concentrations less than 20 mg/L. Two of the 23 events had influent TSS concentrations less than 20 mg/L and were not analyzed relative to the Basic Treatment performance goal.

Influent TSS concentrations for 6 of the 23 qualified storm events were between 20 and 100 mg/L. These 6 sample pairs were analyzed relative to the Basic Treatment performance standard. Effluent TSS concentrations were less than 20 mg/L for all events, except for the 5/13/2017 and the 12/19/2019 events which had effluent concentrations of 33.2 mg/L and 31.0 mg/L respectively. Mean and median effluent TSS concentrations were 19.7 and 18.1 mg/L respectively. Due to the limited number of samples, data could not be analyzed using the TAPE bootstrap confidence interval calculator for TSS.

Influent TSS concentrations for 15 of the 23 qualified storm events were greater than 100 mg/L. These 15 sample pairs were analyzed relative to the Basic Treatment performance standard. Mean and median removal efficiencies were 84.2% and 85.1% respectively for events that had influent concentrations greater than 100 mg/L. Data were analyzed using the TAPE bootstrap confidence interval calculator for TSS. The lower 95% confidence interval for TSS removal efficiency was 82.0%.

Based on these results, the Jellyfish Filter met TAPE Basic Treatment requirements. Additionally, performance vs. flow rate results indicate that the Basic Treatment standard is projected to be consistently achieved above the design treatment rate of 1.16 cfs (520 gpm), as discussed in section 6.10.

1.4.2 Phosphorus Treatment

The Phosphorus Treatment standard outlined in the TAPE requires ≥ 50% removal of total phosphorus at influent concentrations ranging from 0.10 to 0.5 mg/L. The Basic Treatment performance standard must also be met.

Influent total phosphorus concentrations for 18 of the 23 qualified storm events were within the range of interest established in the phosphorus removal performance standard. These 18 sample pairs were analyzed relative to the total phosphorus treatment standard. Mean and median removal efficiencies were 74.2% and 74.6% respectively for events that had influent concentrations between 0.10 to 0.5 mg/L. Data was analyzed using the TAPE bootstrap confidence interval calculator for total phosphorus. The lower 95% confidence interval for total phosphorus removal efficiency was 70.1%.

Based on these results, the Jellyfish Filter met both TAPE Basic and Phosphorus Treatment requirements. Additionally, performance vs. flow rate results indicate that both Basic and Phosphorus Treatment standards are projected to be consistently achieved above the design treatment rate of 1.16 cfs (520 gpm).

2.0 Introduction

Contech currently holds both a Conditional Use Level Designation (CULD) for the Jellyfish Filter as a basic treatment device for total suspended solids (TSS) removal as well as a Pilot Use Level Designation (PULD) for phosphorus removal and oil treatment. This Technical Evaluation Report summarizes the results of a field monitoring campaign conducted to support issuance of General Use Level Designations (GULD) for both Basic Treatment (TSS removal) and Phosphorus Treatment.

The Dundee Jellyfish Filter was installed in April 2016. A field evaluation of the Jellyfish Filter was initiated in March 2017 following a site and system stabilization period. A total of 25 storm events were collected following the approved QAPP.

3.0 Technology Description

This section, and associated subsections, provides a detailed description of the Jellyfish Filter including design, sizing methods, treatment processes, treatment capabilities, expected design life, and maintenance procedures.

3.1 Physical Description

The Jellyfish Filter is a stormwater treatment technology featuring high surface area, high flow rate membrane filtration, at low driving head. By incorporating pretreatment with light-weight membrane filtration, the Jellyfish Filter removes a high level and a wide variety of stormwater pollutants. The high surface area membrane cartridges, combined with up-flow hydraulics, frequent passive backwashing, and rinseable/reusable cartridges ensures long-lasting performance. The system utilizes membrane filtration cartridges with very high surface area and flow capacity, which provide the advantages of high sediment capacity and low filtration flux rate (flow per unit surface area) at relatively low driving head compared to conventional filter systems. A typical Jellyfish Filter cartridge with eleven 54 inch (1372 mm) long filtration tentacles has 381 ft^2 (35.4 m^2) of membrane surface area. Hydraulic testing on a clean, unrestricted 54 inch (1372 mm) filter cartridge has demonstrated a flow rate of 180 gpm (11.3 L/s) at 18 inches (457 mm) of driving head.

Figure 2. Jellyfish Cartridge Detail

Each lightweight Jellyfish Filter cartridge consists of multiple detachable membrane-encased filter elements ("filtration tentacles") attached to a cartridge head plate. Four standard cartridge lengths between 15 and 54 inches are available, with design flow rates shown in Table 1. The cartridges are easy to install and remove by hand. No heavy lifting equipment is required.

The cartridge deck contains a receptacle for each filter cartridge. The cartridge is lowered down into the receptacle such that the cartridge head plate and rim gasket rest on the lip of the receptacle. A cartridge lid is fastened onto the receptacle to anchor the cartridge. Each cartridge lid contains a flow control orifice. The orifice in the hi-flo cartridge lid is larger than the orifice in the draindown cartridge lid, controlling the flux rate in hi-flo and draindown cartridges to 0.21 gpm/ft^2 and 0.11 gpm/ft^2, respectively. Influent stormwater enters the system and is directed below the cartridge deck where driving head builds upstream and forces the water to flow upwards through the tentacle membranes. Treated flow exits the system through an outlet pipe located above the cartridge deck.

Jellyfish Filter cartridges are designated as either hi-flo cartridges or draindown cartridges, depending on their placement position within the cartridge deck. Cartridges placed within the 6-inch (150 mm) high backwash pool weir that extends above the deck are automatically passively backwashed after each storm event and are designated as the hi-flo cartridges. Cartridges placed outside the backwash pool weir are not passively backwashed but facilitate the draindown of the backwash pool, and these are designated as the draindown cartridges. The design flow rate of a draindown cartridge is controlled by a cartridge lid orifice to one-half the design flow rate of a hi-flo cartridge of similar length. The lower design flow rate of the draindown cartridge reduces the likelihood of occlusion prior to scheduled maintenance. The lightweight cartridges can be removed by hand and externally rinsed. The rinsed cartridges can then be re-installed, thereby minimizing cartridge replacement and life-cycle treatment costs while ensuring long-term treatment performance.

Table 1. Jellyfish Filter Cartridge Surface Area and Flow Rates

Jellyfish Filter Cartridge Surface Area and Flow Rates			
Cartridge Length (in.)	Flow Rate per Hi-Flo Cartridge (gpm)	Draindown Cartridge Flow Rate (gpm)	Membrane Surface Area (ft^2)
15	22	11	106
27	40	20	191
40	60	30	282
54	80	40	381

Figure 3. Jellyfish Cartridge Deck and Backwash Pool

3.1.1 Container

The Jellyfish Filter is available in a range of sizes and configurations, as shown in Appendix A. The system is comprised of several structural and functional components. Whether housed in a cylindrical (manhole) or rectangular structure constructed of either precast concrete or fiberglass, the Jellyfish is available in a wide variety of sizes and configurations. The structure provides a number of functional benefits including; serving as a vessel that provides long-lasting structural support for the system; providing hydraulic connections to the inlet and outlet pipes; providing surfaces for structural attachment of the cartridge deck and maintenance access wall; providing influent water storage and flow-through volume for pollutant separation and membrane filtration treatment; and providing a high-volume sump for storage of accumulated sediment.

3.1.2 Inlet

The Jellyfish Filter is available in both the standard above-deck inlet pipe configuration and optional below-deck inlet pipe configuration. Specific site requirements generally determine the configuration that is most suitable for the site. In both configurations, the invert elevation of the outlet pipe is identical to the cartridge deck elevation. Please refer to Appendix A.

For the standard above-deck inlet pipe configuration, the invert elevation of the inlet pipe is typically set at least 6 inches higher than the invert elevation of the outlet pipe. This generally ensures that the inlet pipe will drain completely at the conclusion of each rainfall/runoff event, while providing sufficient volume within the maintenance access wall zone for surface accumulation of floatables below the inlet pipe. The elevation of the inlet pipe can be varied as required. Water is then directed below the cartridge deck to the filter tentacles through the area beneath the maintenance access wall. Below-deck inlet configurations are less common and use a deflector pan to inhibit turbulence in the sump. Some systems may require additional sump depth to ensure settling of heavy particles.

The Jellyfish Filter can accommodate a wide range of angles between the inlet and outlet pipes. For manholes, the inlet pipe can be located anywhere about the circumference of the structure. The separation angle relationship of the inlet pipe to the outlet pipe can vary from 0 to 360 degrees to provide maximum design flexibility. Typical off-line layouts (external bypass using an upstream diversion structure) will have an inlet to outlet separation angle of 90 to 120 degrees.

3.1.3 Bypass

The Jellyfish Filter can be designed in either an external bypass or internal bypass configuration. When the internal bypass option is utilized, influent flows receive membrane filtration treatment up to the filtration design flow rate, with influent flows exceeding the treatment capacity of the system receiving pre-treatment only. In order to minimize sump velocities and the potential for resuspension of previously captured materials at peak flow rates, flows in excess of the treatment capacity do not pass through the sump, but are instead conveyed directly to the discharge bay by passing over the maintenance access wall. The sump depth may be increased to allow for greater sediment storage capacity. A standard external bypass configuration utilizes a separate, upstream diversion structure. The elevation difference between the top of the diversion structure weir and the Jellyfish Filter outlet pipe invert establishes the design driving head associated with the design flow rate. Excess flow that overtops the diversion weir bypasses the Jellyfish Filter entirely and proceeds downstream.

3.2 Site Requirements

The following sections address the site requirements for Jellyfish Filter applications.

3.2.1 Soil Characteristics

Soils should be evaluated by the project engineer to ensure they can structurally support the system.

3.2.2 Hydraulic Grade Requirements

A minimum design driving head is selected to achieve design flow rates, while accounting for gradual increase in system head loss at the design flow rate due to long-term accumulation of sediment on the filtration membranes. Clean Jellyfish Filter tentacles have combined flow capacity far in excess of the cartridge design flow rate at the design driving head, but the actual flow through each cartridge is governed by a flow control orifice in the cartridge lid. This additional filter capacity ensures that design flow capacity is maintained even as sediment and other pollutants accumulate during the period between maintenance events.

Typically, a minimum 18 inches of driving head is designed into the system but may vary from 12 to 24 inches depending on specific site requirements. For systems that may experience submerged or backwater conditions due to dry weather base flow or tidal effects; driving head calculations will account for water elevation during the backwater condition.

3.2.3 Depth to Groundwater Limitations

The Jellyfish Filter does not have depth to groundwater limitations since it is fully enclosed.

3.3 Treatment Processes

A differential in upstream and downstream water elevation during an inflow event provides the minimal driving head required to overcome the minor cumulative friction loss through the system, at which point flow-through operation of the Jellyfish Filter commences. Inflow events with driving head that exceeds the 6 inch (150 mm) height of the backwash pool weir will cause continuous forward flow and filtration treatment through the hi-flo cartridges. Inflow events with driving head less than 6 inches results in filtration treatment through the draindown cartridges.

For systems using an external bypass with an upstream diversion structure, the maximum driving head for the treatment cartridges is the difference between the upstream bypass weir elevation and the invert of the outlet pipe. For systems using an internal bypass, the maximum driving head is calculated as the difference of the water surface elevation in the maintenance access wall and the invert of the outlet pipe. The Jellyfish Filter will continue to treat stormwater during forward flow despite backwater conditions. An increase in the maintenance access wall height may be required to ensure floatables capture.

3.3.1 Gravity Separation

Most coarse sediment, particulate bound pollutants attached to coarse sediment, oil and grease, and floatable trash and debris are removed by gravitational separation.

3.3.2 Membrane Filtration

The membrane filtration treatment component of the Jellyfish removes suspended particles and associated particulate bound pollutants.

3.4 Sizing Methodology

The Jellyfish filter is designed with an orifice control in the cover plate of each cartridge that restricts hydraulic loading rates through each cartridge to 0.21 gpm/ft2 for hi-flo cartridges and 0.11 gpm/ft2 for draindown cartridges. In western Washington, Jellyfish Filter systems are sized to capture and treat 91% of the average annual runoff volume, per the water quality design flow rate requirements for flow-based systems in section V-4.1.2 of the Stormwater Management Manual for Western Washington (SWMMWW) (Ecology, 2014). During high intensity storm events, every configuration of the Jellyfish system is designed to maintain treatment of the water quality flow rate while bypassing flows exceeding the treatment capacity of the system. This bypass may occur through internal or external hydraulic components, depending on the system configuration. Systems in western Washington are therefore sized according to the following design variables:

- Offline Water Quality Flow Rate, per SWMMWW V-4.1.2. (Ecology, 2014)
- Jellyfish filter cartridge flow rate, as controlled by filter length and cover plate orifice diameter

- Number of Jellyfish cartridges in system

For systems in eastern Washington, the Water Quality Flow Rate is the peak 15-minute flow rate as calculated using one of the three methods described in Chapter 2.2.5 of the Stormwater Management Manual for Eastern Washington (SWMMEW) or local manual (Ecology, 2004). The hydraulic loading rates for hi-flo and draindown Jellyfish filter cartridges are set in the Jellyfish GULD and remain constant. The Jellyfish Filter surface area can be increased as needed by adding cartridges to accommodate the water quality flow rate at the approved hydraulic loading rate.

Outside of the State of Washington, system sizing methodologies will follow local regulatory and project requirements. Section 5.2.1 details the sizing evaluation for the Dundee Jellyfish Filter location.

3.5 Installation

3.5.1 Installation Requirements

Jellyfish Filters are typically delivered to the site with internal components installed as specified. The contractor is responsible for base preparation, for providing excavation and installation equipment as needed, and for setting the precast unit as specified. The influent and effluent pipes are then connected by the contractor. The contractor shall also provide any other required cast-in-place concrete or related structures as specified. Backfill material and placement shall be in accordance with approved plans. Precast units are delivered to the site with inlet protection in place. Once construction is complete, paving is finalized, surrounding landscaping is in place, and the site has been stabilized, Contech will activate the system upon request from the contractor. Depending on the system configuration, this step may include removal of inlet protection devices and installation of the tentacles.

3.5.2 Provisions for other factors (structural integrity, water tightness, buoyancy)

- Structural integrity: For precast units, stamped structural calculations can be provided by Contech upon request. For systems installed in cast-in-place containers, structural calculations are the responsibility of the site engineer or contractor.
- Water tightness: For precast units, structure joints are typically filled with Conseal. When applied correctly, vaults can be considered watertight.
- Buoyancy: Buoyancy calculations can be performed for vaults that will be located in areas with suspected high groundwater levels, upon request.

3.5.3 Potential problems that can occur during design and installation

Potential design issues:

- Backwater: Downstream hydraulic conditions should be evaluated during the design process.
- Long-duration flows: Base flows, seepage flows or other long-duration flows should be eliminated or bypassed around the system to ensure proper functionality and design life of the system.
- Excessive solids loading: Unusually high sediment loading should be addressed during the design phase of the project to determine if pretreatment is needed or if there are opportunities for better site design or source control.

Potential installation issues:

- Invert elevations: Correct installation of the system inlet piping and outlet piping is crucial for proper operation of the system.
- Construction sediment: If the system is activated before the site is stabilized, construction sediment may impair the performance and/or longevity of the treatment cartridges. If construction sediment is allowed to enter the system, the warranty is void and more frequent maintenance or rehabilitation of the system may be required.

3.5.4 Methods for diagnosing and correcting potential problems

- The Stormwater Design Engineering team at Contech offers full technical support for all applications of Contech products. During the design phase, Contech Stormwater Design Engineers can assist with plan preparation and provide a technical review of the system design. This review provides an opportunity to review elevation requirements, system sizing and placement, backwater conditions, as well as maintenance access.
- Contech also provides design overview and construction support directly to the contractor and/or owner during the bidding and construction phases of the project.
- If there are problems with the structure or components during delivery, Contech will work to resolve these issues prior to installation of the system.
- If problems develop during or due to the installation of the system, Contech will work with the contractor to effect repairs to ensure proper operation of the system.

3.5.5 Impacts to effectiveness if problems are not corrected

- Backwater: Backwater will reduce the driving head across the system and will reduce treatment flow rates.
- Long-duration flows: If long-duration flows such as base flows enter the system, the filter elements may become exhausted prematurely as these flows do not possess typical concentrations and/or mix of pollutants. This will affect the life of the system and more frequent maintenance will be required.
- Excessive solids loading: Heavy solids loading without pretreatment may cause premature occlusion of the system. Required maintenance frequency may increase in this case.
- Invert elevations: If the system is incorrectly installed and insufficient driving head is provided above the system, the system may experience early bypass and may not be able to fully treat the design flow rate.

3.5.6 Technology availability (sourcing and lead time)

- Precast units: The concrete structures for precast units can be provided by many precasters throughout the region. Typical lead time required for delivery is 4 to 6 weeks from contract drawing approval.
- Jellyfish Filter components are supplied by Contech and typically require 2 to 3 weeks lead time.

3.6 Inspection and Maintenance Procedures

The primary purpose of the Jellyfish Filter is to capture and remove pollutants from stormwater runoff. As with any filtration system, captured pollutants must be removed from the system periodically to maintain the filter’s maximum treatment performance. Regular inspection and maintenance are required to ensure the system continues to function properly. Maintenance and inspection procedures should follow the procedures outlined in the Jellyfish Filter Maintenance Guide located in Appendix B.

3.6.1 Inspections – Frequency and methodology

Inspection of the Jellyfish Filter is key in determining maintenance frequencies and requirements, which are site specific and can vary depending on pollutant loading. In general, inspections should be performed at the times listed below:

- Post-construction and prior to putting the Jellyfish Filter into service
- A minimum of two inspections during the first year of operation to assess the sediment and floatable pollutant accumulation and to ensure the system is functioning properly
- After the first year, inspections should occur, at a minimum, once per year
- After a major storm event
- Immediately after an upstream oil, fuel, or other chemical spill

Tools required for an onsite system inspection include an access cover lifting tool, sediment probe, tape measure, flashlight, camera, safety cones and caution tape, and PPE equipment (hard hat, safety shoes, safety glasses, and chemical resistant gloves). Detailed inspection procedures can be found in the Jellyfish® Filter Manhole Installations Inspection and Maintenance Manual located in Appendix B.

3.6.2 Maintenance triggers and rationale

The need for maintenance is typically determined based on results of an inspection. A history of maintenance events should be kept on file. This helps provide an understanding of maintenance frequency and requirements over time. The following criteria should be used as guidelines for identifying when maintenance is required:

- Measuring a sediment depth of 12 inches or greater in the sump area suggests maintenance is required.
- Standing water inside the backwash pool, but not outside the backwash pool, indicates that maintenance is required.
- Large amounts of floatable pollutants such as trash, debris, and the presence of an oil sheen within the maintenance access wall (MAW) or inlet bay indicates maintenance is required.
- During a runoff event, if the depth of water above the deck elevation within the MAW or inlet bay is 18 inches or greater and relatively low flow is exiting the cartridge lids and outlet pipe, maintenance is required.
- The presence of hazardous materials could indicate a spill. If hazardous materials release is observed or reported, maintenance is required.

3.6.3 Maintenance methodology

Detailed maintenance procedures can be found in the Jellyfish® Filter Maintenance Guide located in Appendix B. Required maintenance is based on the most recent inspection, historical maintenance records, or a site-specific water quality management plan; whichever is more frequent. In general, maintenance of a Jellyfish unit requires some combination of the following action items:

- Sediment removal for depths reaching 12 inches or greater, or within 3 years of the most recent sediment cleaning, whichever occurs sooner.
- All floatable trash, debris, and oil must be removed.

- Filter cartridges rinsed and re-installed as required by the most recent inspection results, or within 12 months of the most recent filter rinsing, whichever occurs first.
- Replacement of filter cartridges is recommended, if rinsing does not adequately remove accumulated sediment from tentacles or if tentacles are damaged or missing. It is also recommended that tentacles should not remain in service longer than 5 years before replacement.
- Damaged or missing cartridge deck components must be repaired or replaced as indicated in the most recent inspection report.
- The unit must be evacuated, and filter cartridges inspected immediately after an upstream oil, fuel, or chemical spill. Filter cartridges should be replaced if damaged by the spill or following prolonged exposure to heavy concentrations of oil.

3.6.4 Maintenance area accessibility by people and equipment

Maintenance equipment and personnel should have full access to the system. Maintenance should follow the procedures outlined in the Jellyfish Filter Maintenance Guide.

3.6.5 Estimated maintenance frequency and basis for determination

Generally, Jellyfish Filters are designed for an annual maintenance frequency. Maintenance should follow the procedures outlined in the Jellyfish® Filter Inspection and Maintenance Manual located in Appendix B. On a site-by-site basis however, maintenance frequency should be determined during the site evaluation and inspection process. Additionally, maintenance should be performed in the event of a spill or other catastrophic loading event.

3.6.6 Estimated capacity for pollutant removal

Laboratory testing using a standard test sediment demonstrated sediment mass loading capacity of 125 pounds of sediment per 54-inch long hi-flo cartridge at 18 inches of driving head, as shown in Table 2. Specific site conditions will influence the sediment mass loading capacity of the Jellyfish Filter due to the variable nature of sediment characteristics, rainfall intensity, time intervals between runoff events and frequency of backwash cycling. The oil and sediment pollutant capacities for each standard Jellyfish Filter model are shown in Table 2.

Table 2. Dry Weight, Treatment Flow Rate, and Sediment Mass Loading Capacity of Various Cartridge Lengths

Cartridge Length (in)	Cartridge Dry Weight (lbs)	Design Treatment Flow Rate (gpm)	Design Sediment Mass Loading Capacity [1, 2] (lbs)
15	10	Draindown 11 / Hi-Flo 22	Draindown 17 / Hi-Flo 35
27	14.5	Draindown 20 / Hi-Flo 40	Draindown 31 / Hi-Flo 63
54	55	Draindown 40 / Hi-Flo 80	Draindown 63 / Hi-Flo 125

[1] Design flow rates and sediment mass loading capacities based on 18 inches (457 mm) of driving head
[2] Based on laboratory testing submitted to Ecology in Jellyfish CULD application April 27th, 2012

Note: Actual sediment mass loading capacity will vary depending on specific site characteristics

3.6.7 Estimated design life of facility and components

The design life of the concrete structure is typically 50 years.

3.6.8 Maintenance equipment and materials

Typical tools used for system maintenance:

- Vacuum truck
- Garden hose and low pressure sprayer
- Mechanism to mobilize cartridges from the cartridge deck to the surface and back
- Receptacle for collecting effluent from rinsed filter cartridge tentacles
- Access cover lifting tool
- All required inspection equipment (see above section 3.6.1)
- Proper safety equipment for confined space entry
- Replacement filter cartridge tentacles, if required
- Copy of system drawings to confirm cartridge location and type (hi-flo/draindown)

3.6.9 Maintenance service contract availability

Maintenance service contracts are available through a list of Contech Certified Maintenance Providers. These independent providers have been trained to provide inspections and maintenance of all Contech systems. Contech can offer some replacement parts directly to the owner, or to a service provider. Some parts may only be provided through Certified Maintenance Providers. The service provider typically provides all field services related to maintenance. Costs vary by size and type of the system, as well as location of the site, and are managed by the service provider.

3.6.10 Solids and media disposal

Solids should be disposed of according to local rules and regulations for materials containing stormwater pollutants and debris. In most areas, the sediment and spent filtration tentacles, once dewatered, can be disposed of in a sanitary landfill. Petroleum-based pollutants captured by the Jellyfish, such as oils and fuels, should be removed and disposed of by a licensed waste management company.

3.6.11 Impacts of delayed maintenance

Delayed filter maintenance can negatively impact the system's hydraulic capacity, thereby increasing the proportion of flows that bypass treatment.

3.6.12 History, availability of materials and parts from manufacturer

The history of Contech is available at www.ContechES.com. Contech has been in business for over 100 years. The Jellyfish Filter cartridge tentacles are the primary replaceable component required to keep the system functioning properly and are available to Contech Certified Maintenance Providers for remediation purposes. In the event that Contech should no longer exist, Certified Maintenance Service Providers will be able to assist the owners in maintenance of the system.

3.7 Reliability

3.7.1 Other Factors That Affect Performance

Excessive solids loading due to unaccounted for sources (such as vehicle washing, disposal of materials in upstream gutters and catch basins, generally poor housekeeping on a site) could affect the performance of the system. Addition of surfactants to the influent stream could also prevent the system from providing removal of pollutants as expected.

Accumulated pollutants may be released during extreme events, as with all treatment systems, unless the system contains an external bypass. However, the first flush from extreme events, which typically contains the greatest concentration of pollutants, will be treated.

3.7.2 Warranty

A limited warranty is available at www.ContechES.com.

3.7.3 Provision of user support

Contech provides complete support of all Jellyfish Filters. This includes support throughout system design phase, product delivery, and installation of the system. Once the system is online, support is also available through a network of certified maintenance providers. Additional support pertaining to engineering, maintenance, research, or other aspects may be available depending on the client's needs.

3.8 Other Benefits or Challenges

The Jellyfish Filter may be designed to provide other benefits to potentially relevant areas, such as groundwater recharge, thermal effects on surface waters, safety, and efficacy on redevelopment sites.

- The precast Jellyfish Filter alone does not impact groundwater recharge. Where infiltration is desired, the Jellyfish Filter can be designed to discharge to infiltration BMPs like infiltration galleries or drywells.
- The Jellyfish Filter does not have negative thermal effects on surface waters.
- The Jellyfish Filter can increase the clarity of treated water and reduce odor associated with anaerobic conditions from standing water, which would improve the aesthetics of receiving waters. Additionally, the use of the Jellyfish Filter may prevent the destruction of habitat since the required system footprint is smaller than that of larger, land-based systems.
- The same care with regards to safety should be taken with Jellyfish Filter as with any filtration system or underground stormwater drainage facility.
- The Jellyfish Filter has been used in redevelopment and retrofit applications due to its low driving head, minimal required elevation drop, compact size and flexible configuration.

3.8.1 Copper, lead, or zinc components

The Jellyfish Filter has no copper, lead, or zinc components that may be exposed to stormwater runoff and could potentially leach into the effluent.

3.8.2 Concrete components

There is no evidence that the concrete vault impacts the pH or causes pH fluctuations in the effluent.

4.0 Results from Previous Studies

4.1 TARP Field Testing 2010-2011

Field testing of the Jellyfish Filter was conducted at the University of Florida over a period of 13 months and encompassed 25 monitored storm events with 15 inches of cumulative rainfall, including multiple high intensity events. Throughout the course of this study, the Jellyfish Filter demonstrated consistently high pollutant removal performance (median TSS removal efficiency of 89%, median TP removal efficiency of 59%) as designed with a Maximum Treatment Flow Rate (MTFR) of 80 gpm (5.0 L/s) for the 54-inch (1372 mm) long hi-flo cartridge and 40 gpm (2.5 L/s) for the 54-inch (1372 mm) long draindown cartridge. These values translate to a design membrane filtration flux rate (flow per unit surface area) of 0.21 gpm/ft^2 (0.14 Lps/m^2) for the hi-flo cartridge and 0.11 gpm/ft^2 (0.07 Lps/m^2) for the draindown cartridge.

4.2 Field Testing 2014 Humes Australia

Field testing of a Jellyfish filter was conducted by Queensland University of Technology at a site located in West Ipswich, Australia over a 6-month period in 2014. The drainage area to the Jellyfish Filter included 1678 m^2 (18,062 ft^2) of impervious area made up of roof and parking lot/ driveway surfaces, and the system MTFR was equivalent to the TARP study. A total of seven qualified runoff events were sampled during the testing period. The mean removal efficiency for total suspended solids, total nitrogen, and total phosphorus were 89%, 55%, and 65% respectively.

4.3 TAPE PULD Laboratory Testing 2008

In 2008, Imbrium Systems (now Contech Engineered Solutions) applied for and received a Pilot Use Level Designation (PULD) from the Washington State Department of Ecology (Ecology) for Basic Treatment. For this approval, Gary Minton of Resource Planning Associates was hired as a consultant for Imbrium Systems to review laboratory testing and prepare and submit the PULD submittal to Ecology. Laboratory testing was performed in accordance with conditions set forth by the Washington State Department of Ecology for BMP qualifications for Basic Treatment PULD. Testing was completed at the Monteco research and Development Centre in Mississauga, Ontario. AMEC Earth and Environmental Laboratory in Mississauga was used for solids analysis and Maxxam Analytical in Calgary, Alberta was used for particle size distribution analysis. All tests were run using Sil-Co-Sil 106.

Following the completion and review of laboratory testing of the Jellyfish Filter system, the consultant, Gary Minton, concluded that the data supported the Jellyfish Filter performance clam submitted by Imbrium Systems. The claim is as follows: *"A Jellyfish filter system fitted with a single Jellyfish cartridge or multiple Jellyfish cartridges can remove greater than 86% Sil-Co-Sil (mean particle size 22 microns) within a 95% confidence interval of +/- 1.3% at the system's 100% operating rate with influent sediment concentrations ranging from 100 to 300 mg/L. For systems using 12-inch diameter cartridges, each cartridge containing 11 filtration tentacles of 54-inch length, the 100% operating rate is 50 gpm per cartridge."* Laboratory testing also concluded that the Jellyfish system is capable of removing most particles above 15 microns in size.

4.4 Villanova University 2016 Case Study

A case study focusing on the redesign of a failed infiltration trench was completed in 2016 at Villanova University in Pennsylvania. This study included the evaluation of a Jellyfish Filter which was designed as pretreatment to the new infiltration trench. The unit is located upstream of the infiltration trench and treats runoff from a 5850-ft^2 impervious drainage area. The Jellyfish Filter system evaluated was a JF4 containing 3 cartridges with 40-inch tentacles and Maximum Treatment Flow Rate (MTFR) of 0.33-cfs (148-gpm).

The new infiltration trench and upstream Jellyfish Filter were evaluated over a five-month period between July and December 2016. During this time a total of 23 storms were recorded which included 17.5 inches of precipitation. Water quality samples were collected for seven of these events to evaluate total suspended solids (TSS) and total dissolved solids (TDS) removal abilities of the Jellyfish filter. TSS removal efficiencies ranged from 62% to 89% with Influent concentrations between 4.3 and 25.3 mg/L. TDS removal efficiencies ranged from 22% to 78% with influent concentrations between 72.3 mg/L and 114.7 mg/L. No maintenance was required during this period.

5.0 Sampling Procedures

5.1 Experimental Design

This field monitoring campaign evaluated the performance of a Jellyfish Filter located at the City of Dundee site in Dundee, Oregon. Throughout the monitoring period, flow and precipitation data was collected and flow weighted composite influent and effluent samples were collected for water quality analysis during discrete storm events. This section provides detailed information on the experimental design elements associated with this Jellyfish Filter performance evaluation.

5.2 Monitoring Site Description

The City of Dundee Jellyfish Filter site is located in Dundee, Oregon and sits approximately 200 feet above sea level. The site, owned by the City of Dundee, is located at the intersection of SW 10th street and OR 99W (Lat: 45.275491°, Lon: -123.013214°). Flow is directed to the site by an 18 inch storm drain that runs along OR 99W and collects roadway runoff via periodic curb inlets. An aerial view of the system location is shown in Figure 4.

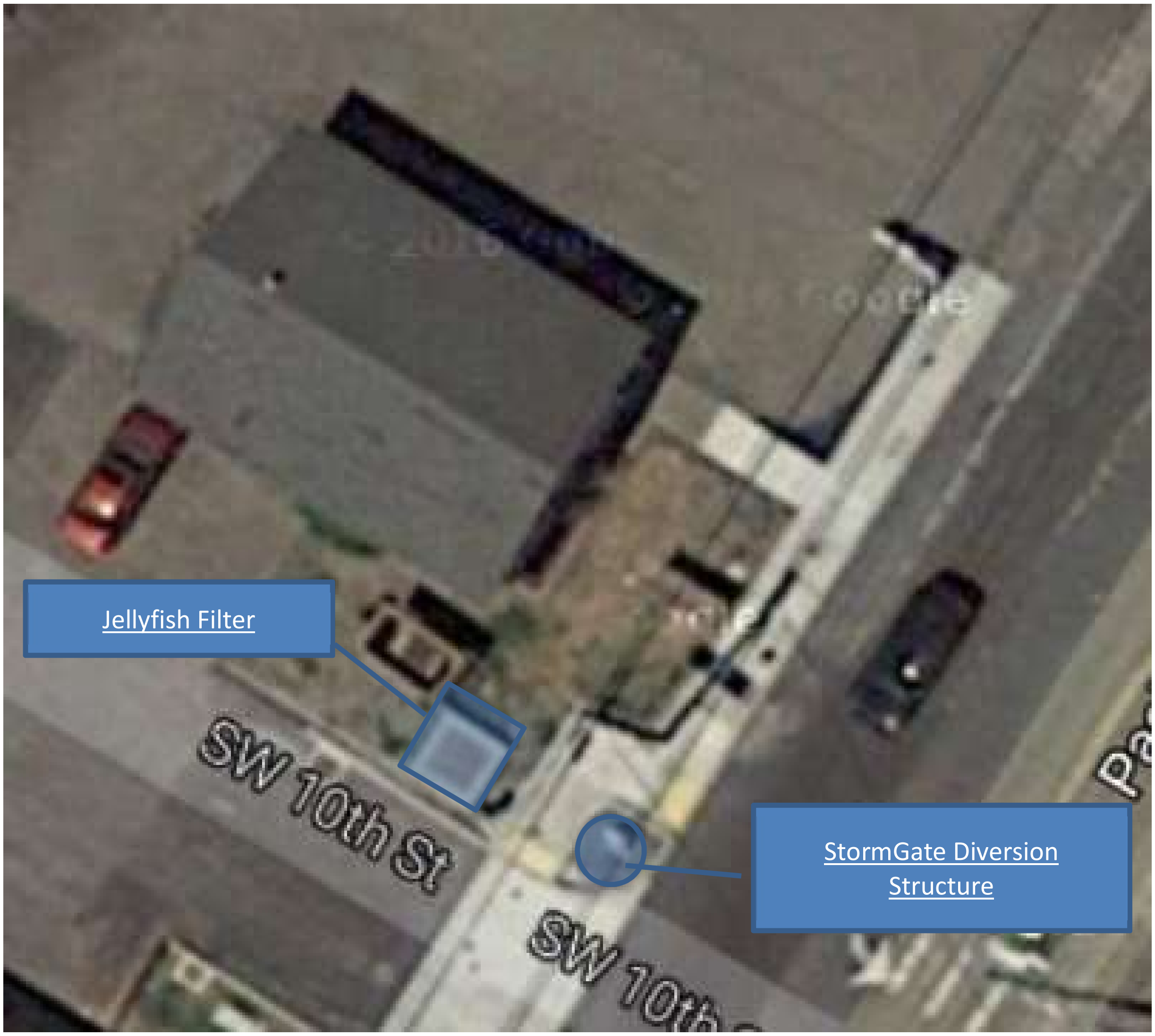

Figure 4. Aerial View of Dundee Jellyfish Filter Location

The site is swept periodically, however significant amounts of sediment and organic debris are typically present on site. A view of a portion of the roadway within the treatment area immediately upstream of the Dundee Jellyfish Filter inlet can be seen in Figure 5. The site plan is located in Appendix C.

Figure 5. View of roadway drainage area looking northeast on OR-99W

5.2.1 Site Sizing Procedure

The City of Dundee follows standards for design and selection of stormwater quality facilities from the City of Portland which use the rational method for determination of the water quality flow rate. However, the rational method is not recommended for drainage areas exceeding 25 acres. Therefore, historical SBUH records from the City Master Plan were referenced, as prepared by Westech Engineering, Inc. These data predict a 2 year flow of 4.65 cfs at the installation location. As the Dundee Jellyfish Filter was installed for testing only and was not required for permit purposes, there was flexibility in selecting a unit size and no need to conduct a site water quality flow rate calculation. The Dundee Jellyfish Filter is designed to treat a total of 1.16 cfs (520 gpm) through a combination of 6 hi-flo cartridges at 80 gpm (specific flow rate of 0.21 gpm/ft2) and 1 draindown cartridge operating at a 40 gpm (specific flow rate of 0.11 gpm/ft2). The unit evaluated was a 6 foot diameter manhole with an 8 inch diameter inlet pipe and an 8 inch diameter effluent pipe. This system size allowed functional access for the installation of monitoring equipment but was small enough to ensure that site runoff would regularly meet or exceed the water quality flow rate. The unit was installed in an external bypass orientation, using a StormGate diversion manhole directly upstream of the system to direct treatment flows to the filter while bypassing flows in excess of its capacity. Additionally, an actuated slide gate was installed at the filter system inlet to control periods of flow into the system. This gate was designed to simply open or close, not to control specific influent flow quantities, and is described in further detail in section 7. Storm events were targeted to match flows between 50% and 125% of the design rate, as per TAPE guidelines. A view of the system filter deck and maintenance access wall from the surface is shown in Figure 6.

Figure 6. Surface View of the Dundee Jellyfish Filter

5.2.2 Site Area

The 86 acre contributing drainage area is 32% impervious and is comprised of agricultural lands, streets, roadways, and commercial and residential development. An aerial view of the drainage basin from 2016 is shown in Figure 7, with the drainage area superimposed and Jellyfish Filter location identified.

Figure 7. Aerial view of the City of Dundee Jellyfish Filter evaluation site

5.3 Monitoring Equipment Information and Locations

5.3.1 Effluent and Bypass Flow Monitoring

Effluent and bypass flows were measured using ISCO 750 Area Velocity Flow Modules with Low Profile Area Velocity Flow Sensors connected to ISCO 6712 Portable Automated Samplers. The samplers were connected to individual 12 VDC, deep cycle power supplies recharged with solar panels. Samplers were

Effluent and bypass flows were monitored throughout the evaluation period at a 5-minute data recording interval. Figures 8 and 9 show the flow measurement locations, flow path within the system, and sampling locations.

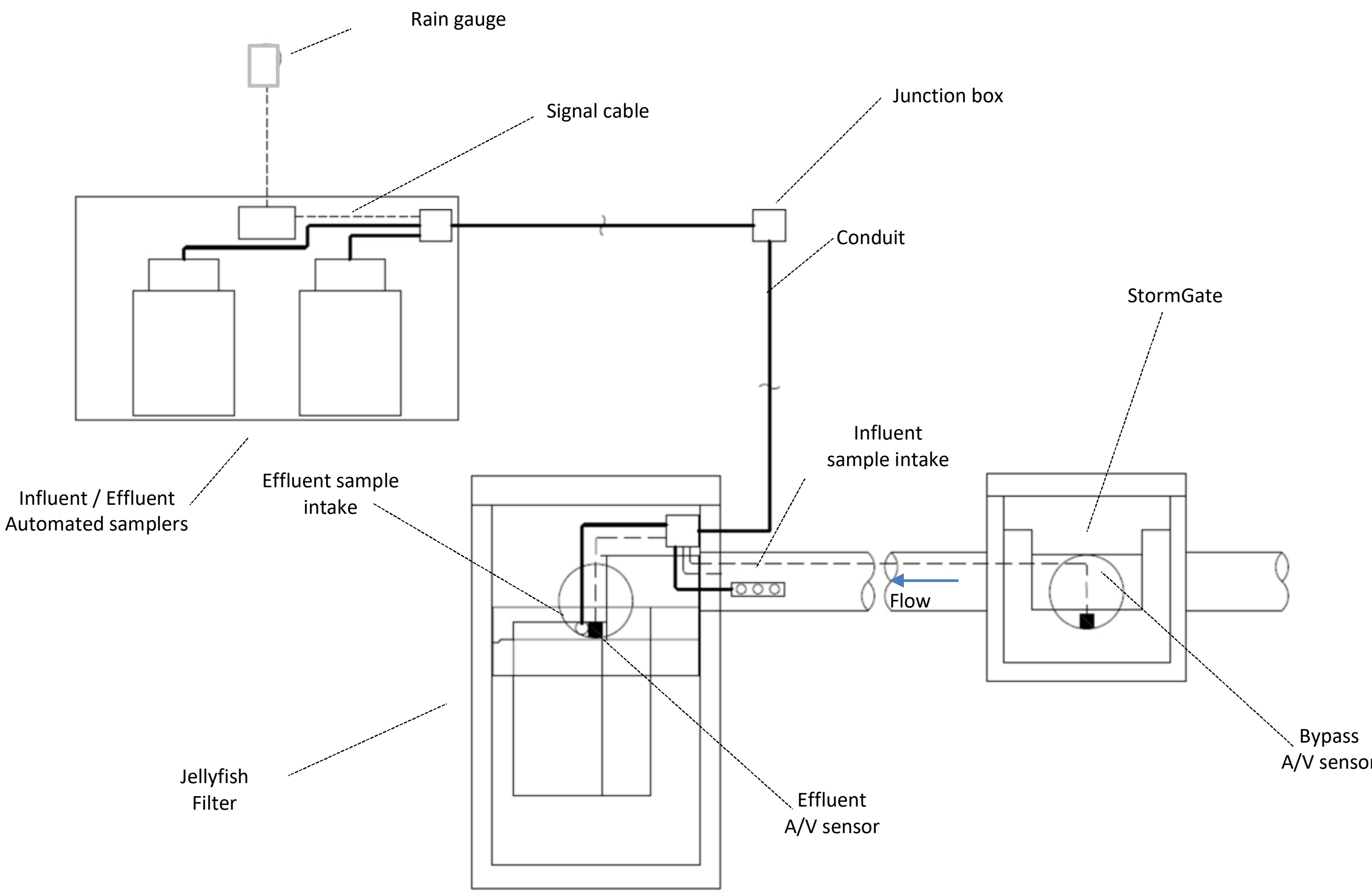

Figure 8. Profile view of the monitoring equipment locations at the project site

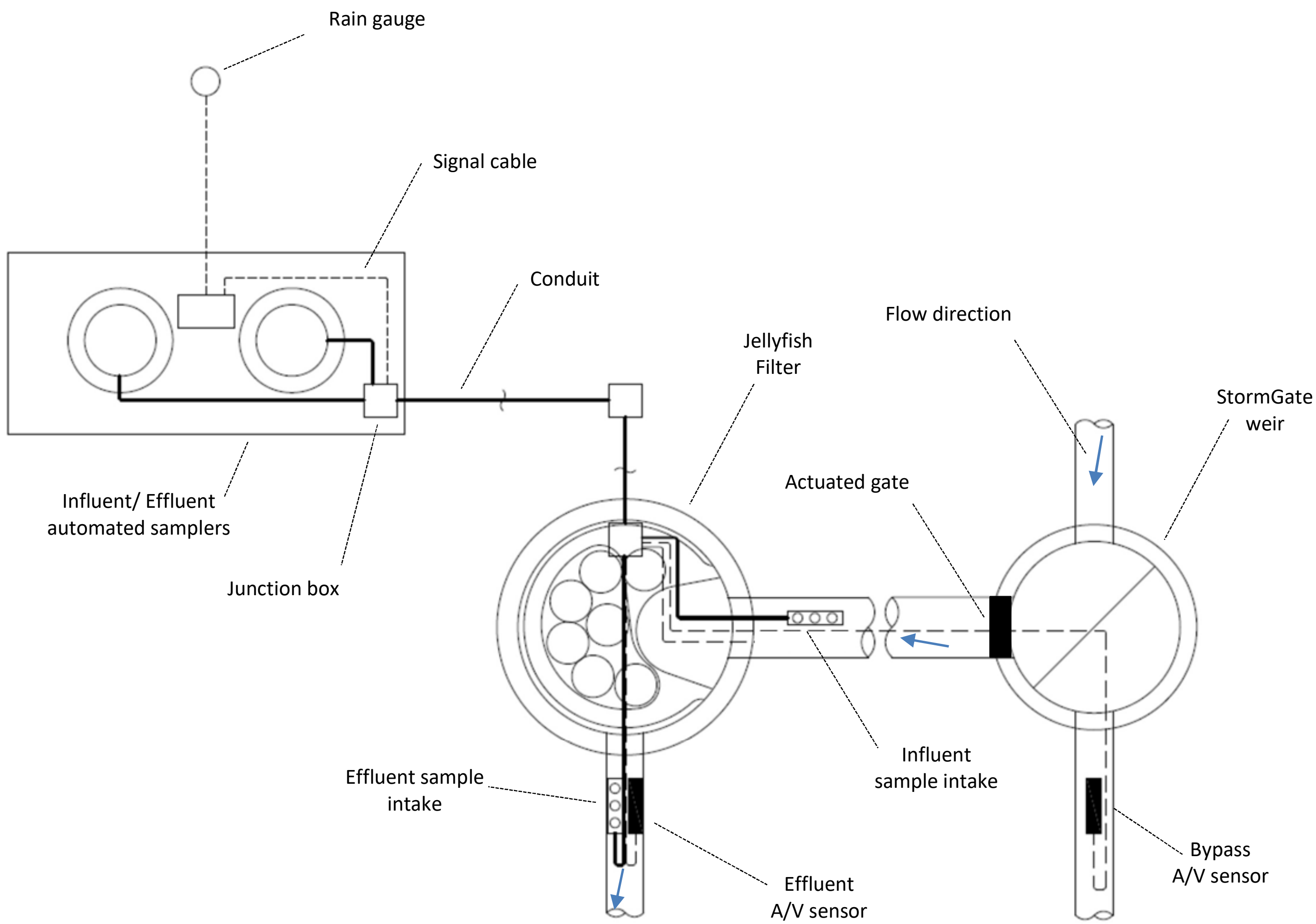

Figure 9. Plan view of the monitoring equipment locations at the project site

5.3.2 Precipitation Monitoring

Precipitation was monitored throughout the evaluation period using a Texas Electronics 525 Rainfall Sensor with a 0.01-inch resolution tipping bucket. A second rain gage was installed at the City of Dundee site as a backup in the event the primary rain gage malfunctioned, however that situation did not occur during the evaluation period. Both rain gauges were located 25 feet from the system on an 8 foot instrument pole connected to the monitoring equipment shelter.

In addition, a third-party public weather station was identified as a reference and backup for the gages located at the monitoring site. This station is located at the Newberg, Oregon, approximately 3 miles northeast of the monitoring site. Hourly precipitation data for this weather station can be found using the National Climatic Data Center website (http://www.ncdc.noaa.gov) but was not utilized for this evaluation.

5.3.3 Water Sampling

Influent and effluent water quality samples were collected using individual ISCO 6712 portable automated samplers. Each sampler was connected to a 12 VDC deep cycle battery. Sample pacing was based upon effluent flow readings in a paired sampler configuration using an ISCO SPA 1026 cable. Each sampler also had an ISCO SPA 1489 Digital Cell Phone Modem System to allow for remote communication and data access. Sample tubing, 3/8-in ID Acutech Duality FEP/LDPE tubing, was routed from each automated sampler to the specified influent and effluent sample locations. Sample intakes were located at the invert of both the influent and effluent sample locations. Sampling locations can be seen in Figures 8 and 9.

The automated sampling equipment was used to collect individual influent and effluent volume-paced aliquots which were composited to represent influent and effluent event mean concentrations (EMC). This same equipment was also used to collect discrete influent and effluent peak flow grab samples. Discrete peak flow grab samples were collected during periods of high flow to demonstrate performance near the peak operating rate of the system.

5.3.4 Equipment Installation and Calibration

All measurement equipment was installed and calibrated according to the manufacturer’s instructions. An equipment inspection, calibration, and maintenance schedule can be seen in Table 3. Rain gage and level calibration data can be found in the hydraulic data quality assurance summary in Appendix D.

All water sampling equipment and sample processing equipment was decontaminated between each sampling event using deionized water acquired from the analytical laboratory. Suction tubing was replaced once during the evaluation period as a precaution against possible contamination on 10/25/2019.

Table 3. Instrument and equipment testing, inspection, and calibration schedule

Equipment	Inspection Items	Procedure	Frequency (minimum)
ISCO 6712 Portable Automated Sampler	Desiccant	Check color- change when pink	Every site visit
	Sample and pump tubing	Check integrity	At installation and monthly
	Calibration	Calibrate according to manufacture's instructions	At installation and monthly
ISCO 750 Area Velocity Flow Module	Desiccant	Check color- change when pink	Every site visit
	Calibration	Calibrate according to manufacture's instructions	At installation and twice annually.[a]
Power sources	12VDC Batteries	Check charge	Every site visit
Texas Electronics Tipping Bucket Rain Gauge Series 525	Funnel and screen	Check for debris	monthly
	Calibration	Calibrate according to manufacture's instructions	At installation and once annually
HI 98121 Waterproof pH / ORP & Temperature Meter	Calibration	Calibrate according to manufacture's instructions	Every site visit

[a] Level calibration only carried out during monitoring period as per approved QAPP.

5.4 Water Quality Sampling Methodology

Specific monitoring procedures are described in greater detail in the approved QAPP for this project which is located in Appendix E. During this evaluation a total of 25 individual storm events were sampled, of which 5 were collected as peak flow grab samples.

5.4.1 Water Quality Sampling

To evaluate water quality performance of the City of Dundee Jellyfish Filter, sampling was conducted following sampling methodology #1, automated flow-proportional composite sampling, as described in the TAPE (2011).

Storm event guidelines and sample collection requirements used during this evaluation followed TAPE (2011) representation requirements. The following guidelines were used in defining a qualified runoff event at the site:

- Minimum storm depth of 0.15 inches
- Minimum storm duration of 1 hour

- An antecedent dry period of at least 6 hours proceeding the event with less than 0.04 inches of precipitation
- 6-hour continuous post event dry period with less than 0.04 inches of precipitation

Storm predictions and antecedent conditions were monitored remotely by the field evaluation team. Once a potential storm was identified, the automated sampling equipment was remotely turned on and sampling programs were updated as needed. Flow pacing programed into the automated samplers was determined based on predicted rainfall amounts. Automated samplers were programmed to collect a minimum of 10 flow-weighted aliquots. The sample collection program input into each automated sampler was a one-part program. Once the program was run, it was active for a period of 36 hours to ensure capture of a single event.

A single HDPE composite bottle was used to collect volume-paced aliquots.   Following a storm event, the field evaluation test team remotely communicated with the equipment to confirm sample collection. After sample collection confirmation, samples were retrieved, sample bottles replaced, and the automated sampling equipment was reset.

Upon sample collection, the bulk composite samples were thoroughly shaken and emptied into a churn splitter. The churn splitter was used to create the EMC subsamples that were submitted to the analytical laboratory for analysis.   All compositing was completed at an offsite sample processing trailer using clean techniques.

Subsamples were then transported to the analytical laboratory in coolers containing gel-based ice packs. Subsamples were handled by the analytical laboratory using clean techniques and processed according to the specified analytical requirements. Standard chain-of-custody documentation accompanied the submittal and transfer of all samples to the analytical laboratory was per laboratory protocol.

5.4.2 Discrete Peak Flow Sampling

Discrete influent and effluent peak flow grab samples were collected when flow to the system was greater than or equal to 100% of the design flow to demonstrate performance at peak flow rates.

Upon sample collection, each peak flow grab sample was thoroughly shaken and emptied into a churn sample splitter. The churn sample splitter was used to create equal subsamples that were then submitted to the analytical laboratory for pollutant analysis. Subsamples were transported to the analytical laboratory in coolers containing gel-based ice packs as per EPA sample submittal guidelines. Subsamples were handled by the analytical laboratory using clean techniques and processed according to the specified analytical requirements. Standard chain-of-custody documentation accompanied the submittal and transfer of all samples to the analytical laboratory as per laboratory protocol.

5.5 Analytical Parameters and Methods

The required water quality parameters for each of the treatment goals, as per TAPE, are listed in Table 4. Analytical methods, and associated reporting limit targets, are shown in Table 5. The required screening parameters are also listed in Table 4. Influent and effluent samples were collected during 4 qualified storm events to satisfy the screening parameter data collection requirements in the TAPE.

Apex Laboratories in Tigard, Oregon was used as the analytical laboratory for this project. Analytical data was received from the laboratory in the form of electronic reports. These reports included all analytical results, as well as the date and time of sampling, date of preservation (when required), date of filtration (when required), date of extraction and date of analysis. These reports also contained all laboratory quality control (QC) samples and information associated with those samples.

As shown in Table 4, particle size distribution analysis was performed on influent and effluent samples following the procedure described in the TAPE. This procedure required that each 1-liter sample first be filtered through a 250-µm (#60) sieve followed by filtration through a 62.5-µm (#230) sieve and finally though 1.5-µm glass fiber filter. These size fractions were used to determine the percent of the sediment load comprised of medium sand and larger (>250-µm), very fine to fine sand (62.5-250-µm) and silt and clay (<62.5-um).

Table 4. Required water quality and screening parameters for this evaluation as per 2018 TAPE

Performance Goal	Required Parameters	Required Screening Parameters
Basic	TSS	PSD, pH [a], TP, orthophosphate, hardness, total and dissolved Cu and Zn
Phosphorus	TP, orthophosphate	PSD, pH [a], hardness, total and dissolved Cu and Zn

[a] In situ sample only. If a substantial change in pH is measured (>1 standard unit difference between influent and effluent) or an abnormal pH value is measured (<4 or >9 standard units), additional storm events will be monitored.

Table 5. Analytical methods and reporting limits for water quality parameters analyzed during this evaluation as per 2011 TAPE

Parameter	Matrix	Method	Reporting limit target [a]
Susp. Sediment Conc. (SSC)	Water	ASTM D3977	NA
Tot. Susp. Solids (TSS)	Water	SM2540 D	1.0 mg/l
Tot. Vol. Susp. Solids (TVSS)	Water	SM 2540 D/E	NA
Total Phosphorus	Water	SM 4500 P E	0.01 mg/l
Orthophosphate	Water	SM 4500 P E	0.01 mg/l
Total and Dissolved Copper	Water	EPA 200.8	0.5 µg/L[c]
Total and Dissolved Zinc	Water	EPA 200.8	0.5 µg/L
Hardness	Water	EPA Method 200.8	1.0 mg/l
pH[b]	Water	EPA 150.1	0.2 units
Particle Size Distribution	Water	TAPE SOP[d]	NA
Percent Solids	Sediment	SM 2540G	NA
Percent Volatile Solids	Sediment	SM 2540G	0.1%
Grain Size	Sediment	ASTM D422	NA

[a] Reporting limits may vary with each lab. To the extent possible, reporting limits for the analytical laboratory will be the same or below those listed here. All results below reporting limits will be reported and identified as such.
[b] pH collected onsite
[c] Per November 19, 2014 email communication 0.5 ug/L is acceptable for this project.
[d] TAPE SOP (Method C at 62.5 & 250 µm, filtrate per Method B)

5.6 Quality Assurance and Quality Control

Quality control samples were used to assess the quality of both field sampling and analytical activities, as per the approved QAPP provided in Appendix E. Parameters tested and testing frequency are detailed in Table 6 and include equipment rinsate blanks, field duplicates, laboratory control samples, method blanks, duplicate analysis (laboratory), and MS/MSDs. Equipment rinsate blanks and field duplicates were collected by the field evaluation team and analyzed by the Analytical Laboratory. All other quality control samples were the responsibility of the Analytical Laboratory. Quality assurance reports for both hydraulic and water quality data can be found in Appendices D and F respectively.

5.6.1 Field Quality Assurance and Quality Control

Equipment rinsate blanks were collected for the purpose of verifying that the sampling equipment was not a source of sample contamination. Equipment rinsate blanks were collected twice throughout the evaluation period including:

1) during the evaluation period,
2) near the end of the evaluation period.

Rinsate blanks were not collected at the beginning of the evaluation period as all sampling equipment, including bottle liners, pump tubing, and sample tubing, were shipped directly from the manufacturer in sealed containers with a cleanliness certification that required no additional decontamination. Rinsate blanks were collected using laboratory-supplied deionized water that was drawn using the automated sampler pump from the inlet of the sample tubing, through the entire automated sampler system and into a clean sample bottle. Samples were then collected from this bottle using decontaminated composite sampling equipment and standard sampling procedures, as per the approved QAPP. Samples were then submitted to the analytical laboratory for analysis.

Field duplicate samples were collected as a second independent sample collected at the same time and location as the original sample. Field duplicate samples provide a way to assess possible errors associated with the sample collection and processing procedure as well as analytical activities. The total number of field duplicate samples collected was at least 10% of the total number of samples collected throughout the evaluation period. Field duplicate samples were split from collected composite samples of qualified storm events, as per the approved QAPP. A total of 4 duplicates were collected over the course of the monitoring period representing 11% of the 36 composite samples collected. Results of field rinsate and duplicate samples are available in Appendix K, with third-party review detailed in the analytical QA memo of Appendix F.

Table 6. Quality control parameters evaluated and the frequency of collection

Water Quality Parameter	Field QC		Laboratory QC			
	Equipment Rinsate Blank (number)	Field Duplicate	Laboratory Control Sample	Method Blank	Laboratory Duplicate	MS/MSDs
TSS	4	10% of Samples	1 per batch	1 per batch	1 per batch	---
PSD	---	10% of Samples	---	---	1 per batch	---
pH	---	10% of Samples	---	---	---	---
Total Phosphorus	4	10% of Samples	1 per batch	1 per batch	1 per batch	1 per batch
Orthophosphate	4	10% of Samples	1 per batch	1 per batch	1 per batch	1 per batch
Total and Dissolved Cu and Zn	4	10% of Samples	1 per batch	1 per batch	1 per batch	1 per batch
Hardness	4	10% of Samples	1 per batch	1 per batch	1 per batch	1 per batch
Percent Solids	---	10% of Samples	---	---	1 per batch	---
Percent Volatile Solids	---	10% of Samples	---	---	1 per batch	---
Grain Size	---	10% of Samples	---	---	1 per batch	---

5.6.2 Equipment Maintenance and Calibration

As discussed in subsection 5.3.4, and shown in Table 3, all field equipment was inspected regularly and adequately maintained throughout the entire evaluation period.

5.6.3 Laboratory Quality Control

Apex Laboratories, the analytical laboratory used for this evaluation, was responsible for its own quality control assessment and response according to its own quality assurance (QA) program. All quality control sample analysis was provided by the analytical laboratory including laboratory control samples, method blank, duplicate analysis, and MS/MSDs. Parameters tested for QC purposes and testing frequency are shown in Table 6. The QA/QC manual for the analytical laboratory is included in Appendix G. The field evaluation team Project Manager was responsible for checking analytical reports for completeness following the delivery of analytical reports throughout the project.

5.7 Deviations from Approved QAPP

There were no deviations to the water quality sampling methods described in the approved QAPP. An actuated slide gate was added to the system layout in order to minimize influent due to baseflows or other non-stormwater runoff flows. Residual solids assessment of material in the system was not conducted during maintenance. The 2011 TAPE lists sediment sampling as optional. Only two equipment rinsate blanks were taken instead of three, as detailed in section 5.6.1.

5.8 Summary of Challenges

There were numerous challenges encountered during the evaluation. A summary of unanticipated events and challenges are below:

- The Jellyfish system was taken offline and monitoring was suspended during construction activities from September 2017 through January 2018, and April 2018 through February 2019 to avoid atypical loading of sediments. These activities included paving, sidewalk construction, and underground utility work on major roadways throughout the drainage basin. The system remained offline until construction was completed and affected areas were swept and stabilized. Despite these precautions, construction-related sediments were observed to impact system maintenance longevity, as discussed in Section 7.

- During the winter months, monitoring equipment was susceptible to damage, given that equipment shelters were not heated and equipment was exposed. Unheated and exposed shelters often result in frozen suction lines and sampling equipment shutdown at temperatures below 32°F. Samplers were typically taken offline or removed during extended periods of below-freezing weather. Additionally, increased condensation during winter months required the temporary removal of equipment for replacement of internal desiccant cartridges. Monitoring activities were typically suspended until equipment could be repaired or replaced.

- As a result of a September 2018, cyber-attack, Contech network storage drives containing hydraulic and precipitation data were lost and/or corrupted. Only data that had been exported and stored locally was unaffected, leading to a loss of approximately 15% of non-sampled flow and precipitation data. No water quality results were lost.

- Significant baseflows associated with groundwater were present during the fall, winter and spring months. In an effort to mitigate base flows, an actuated slide gate was installed at the inlet to the Jellyfish Filter at the beginning of the evaluation period. The gate was controlled by an ISCO 6712 portable automated sampler and programed to open and close based on precipitation measured by the rain gauge installed on site, as detailed in section 7

6.0 Data Summaries and Analysis

This section summarizes the water quality data collected during the evaluation. Data have been compiled and compared to the guidance provided in the TAPE and outlined in the approved QAPP, located in Appendix E.

6.1 Storm Event Criteria

A total of 25 storm events were sampled at the site from March 2017 to April 2020. Field recordkeeping forms for these events can be seen in Appendix N. There were zero disqualifications to the sample population related to the storm event criteria. Table 7 provides a summary of the storm event criteria.

The following findings summarize compliance with the storm event criteria:

- Storm event depth was greater than the TAPE rainfall depth guideline of 0.15 inches for all events sampled, except for the 3/21/2017, 3/22/2019, 3/26/2019, and 04/13/2019 events. Given the size of the drainage basin, storm events below this threshold produced adequate runoff volume for sampling. Only two of these events were used to evaluate performance, and all had rainfall depths of 0.11 inches or greater. These events were included as their runoff volumes, precipitation durations, and influent TSS concentrations were all within range of the total data set.
- Storm duration was greater than 1 hour for all events sampled.
- A range of average rainfall intensities were observed from 0.05 to 0.33 inches per hour.
- Antecedent dry periods greater than 6 hours were observed prior to all sampled events.
- All sampled events were followed by 6 hours with rainfall less than 0.04 inches.

Table 7. Summary of Storm Event Criteria

Event Date	Total precipitation depth (in.)	Max precipitation intensity (in/hr.)	Avg. precipitation intensity (in/hr.)	Precipitation duration (hr.)	Antecedent dry period (hr.)	Post event dry period (hr.)
3/20/2017	0.15	0.12	0.12	8.3	>6	>6
3/21/2017	0.12	0.24	0.13	10.8	>6	>6
4/7/2017	0.27	0.28	0.14	2.7	>6	>6
4/12/2017	0.27	0.84	0.22	11.8	>6	>6
4/19/2017	0.35	0.24	0.14	16.7	>6	>6
4/26/2017	0.66	0.24	0.13	27.2	>6	>6
5/13/2017	0.17	0.12	0.12	5.4	>6	>6
5/16/2017	0.34	0.24	0.12	8.7	>6	>6
6/8/2017	0.17	0.36	0.20	8.5	>6	>6
6/15/2017	0.33	0.12	0.12	15.6	>6	>6
3/8/2018	0.33	0.12	0.06	14.5	>6	>6
3/14/2018	0.56	0.16	0.06	20.3	>6	>6
3/16/2018	0.18	0.08	0.05	6.2	>6	>6
3/22/2018	0.76	0.16	0.07	6.3	>6	>6
3/22/2019 SCRN	0.11	0.12	0.12	8.0	>6	>6
3/26/2019 SCRN	0.12	0.12	0.12	16.3	>6	>6
3/27/2019	0.24	0.36	0.14	11.9	>6	>6
4/5/2019 PEAK	0.38	0.36	0.15	8.1	NA	NA
4/13/2019 PEAK	0.12	0.24	0.13	8.3	NA	NA
05/18/2019 PEAK	0.56	1.20	0.33	10.7	NA	NA
12/7/2019	0.53	0.24	0.13	10.5	>6	>6
12/11/2019	0.55	0.12	0.12	20.9	>6	>6
12/19/2019	0.61	0.24	0.15	8.7	>6	>6
3/30/2020 PEAK	0.20	0.36	0.15	6.2	NA	NA
4/22/2020 PEAK	0.21	0.24	0.14	6.3	NA	NA
Min	0.11	0.08	0.05	2.7		
Max	0.76	1.20	0.33	27.2		
Min	0.11	0.08	0.05	2.7		
Max	0.76	1.20	0.33	27.2		
Mean	0.34	0.30	0.14	11.4		

6.2 Sampling Collection Criteria

Appendix I contains Individual Storm Reports for each event. Table 8 provides a summary of the sample collection criteria.

The following findings summarize compliance with the sample collection criteria:

- A minimum of 10 aliquots were collected for each event except for the 3/21/17 and 4/19/17 events. Both of these events had 9 aliquots and were included in the analysis.
- A minimum storm event coverage goal of 75% was met for each event listed in Table 8, with the exception of the 03/22/2019 event which was 62%. The 3/22/19 event was included as it was used for screening parameters only and not included in the performance evaluation.
- The sampling duration was less than 36 hours for all events sampled.
- The minimum number of qualified storm events sampled met or exceeded 12 for all parameters of interest.

Table 8. Summary of Sampling Requirement Criteria

Event Date	Number of aliquots (Influent)	Coverage basis (hr.)	Coverage (%)	Sampling duration (hr.)
3/20/2017	10	24	97%	6.9
3/21/2017	9	24	100%	1.6
4/7/2017	49	24	86%	1.2
4/12/2017	47	24	90%	11.8
4/19/2017	9	24	88%	0.7
4/26/2017	13	24	92%	10.3
5/13/2017	49	24	96%	3.3
5/16/2017	42	24	95%	12.8
6/8/2017	24	24	98%	4.8
6/15/2017	14	24	83%	7.6
3/8/2018	14	24	95%	13.9
3/14/2018	17	24	93%	15.8
3/16/2018	10	24	92%	7.7
3/22/2018	50	24	75%	9.0
3/22/2019 SCRN	26	24	62%	7.1
3/26/2019 SCRN	10	24	97%	10.4
3/27/2019	26	24	99%	11.6
4/5/2019 PEAK	NA	NA	NA	NA
4/13/2019 PEAK	NA	NA	NA	NA
05/18/2019 PEAK	NA	NA	NA	NA
12/7/2019	42	24	99%	11.9
12/11/2019	18	24	95%	18.6
12/19/2019	17	24	93%	6.2
3/30/2020 PEAK	NA	NA	NA	NA
4/22/2020 PEAK	NA	NA	NA	NA
Min	9	24	62%	0.7
Max	50	24	100%	18.6
Min	9	24	62%	0.7
Max	50	24	100%	18.6
Mean	25	24	90%	8.8

6.3 Hydraulic Data

The hydraulic evaluation of the system includes analysis of the treated and bypassed volume and flow rates associated with sampled events as well as the entire evaluation period.

6.3.1 Hydraulic Data for Sampled Events

As shown in Table 9, the volume recorded for the sampled events ranged between 1,317 and 101,703 gallons. The total volume for all sampled events was 916,941 gallons with a mean of 29,993 gallons per event. No indicators of internal bypass, such as high water marks above the elevation of the MAW, or sediment/debris accumulation on the cartridge deck, were observed over the course of the study. Given the external bypass configuration of the system, no internal bypass was expected. A total of 7,190,217 gallons was bypassed upstream of the system in the StormGate structure from March 2017 thru April 2020.

Large discrepancies between treated and bypassed flows were observed throughout the study. For example, the events of 4/12/17, 5/13/17, 6/8/17, and 6/15/17 all recorded similar treated volumes; however, 4/12 and 5/13 saw significant bypass flows while 6/8 and 6/15 saw zero bypass flows. Given the location of the bypass flow sensor, it is likely that debris transported over the StormGate weir impacted the accuracy of these readings and that bypass was occurring during these events.

Throughout the early years of the study, bypass was consistently observed at treatment flows below the system design capacity. Given the large catchment area and the prevalence of construction activity during the first two years of monitoring, it was assumed that the restriction in flow through the filters was related to atypically high influent sediment concentrations, not necessarily a lack of driving head. As shown in Table 10, influent EMCs exceeded 200 mg/L for over 33% of sampled events during this period, reaching as high as 755 mg/L during the event of 3/8/18. In comparison, typical TSS concentrations for roadway runoff average 169 mg/L per SWMMWW III-1.3. After construction activities finally concluded in early 2019, and flow rates associated with peak grab samples failed to reach the design flow, the site was surveyed, and the weir was adjusted to provide 21 in of driving head. Following this adjustment, 4 out of 5 events exceeded the design flow through the system. The event of 12/11/19 recorded a peak treated flow of only 63 gpm (~12% of design capacity) with significant bypass flows—it is likely that the actuated slide gate was obstructed by debris during this event, limiting flow into the system. Following this observation, the event of 12/19/19 resulted in a peak treatment flow of 551 gpm with no maintenance activity taking place in between, indicating that the obstruction was no longer present.

Table 9. Hydraulic Data for storm events sampled (System design flow = 520 gpm)

Event Date	Total treated volume (gal)	Bypass volume (gal)	Peak treated flow (gpm)	Average treated flow (gpm)
Gate valve installed/ full maintenance 3/7/2017				
3/20/2017	34870	185785	380	56
3/21/2017	18357	239631	409	23
Cartridges replaced 4/5/2017				
4/7/2017	16572	90057	349	74
4/12/2017	25818	274550	274	18
4/19/2017	4772	155767	144	4
4/26/2017	11514	1310743	135	6
5/13/2017	25806	446730	326	32
5/16/2017	45891	905495	376	23
6/8/2017	23615	0	282	26
6/15/2017	27469	0	207	26
Taken offline during construction activities 9/2017 thru 10/2017				
Full maintenance 10/18/2017				
Taken offline during construction activities 10/2017 thru 1/2018				
3/8/2018	24622	2845	169	16
3/14/2018	28250	75424	175	10
3/16/2018	5875	17265	24	4
3/22/2018	29652	146702	142	19
Taken offline during construction activities 4/2018 thru 2/2019				
Full maintenance 8/22/2018				
3/22/2019 SCRN	32938	4525	141	41
3/26/2019 SCRN	19981	199	95	14
3/27/2019	46190	15020	441	58
Cartridges replaced 4/2/2019				
4/5/2019 PEAK	1317	111751	413	74
4/13/2019 PEAK	101703	573994	498	48
05/18/2019 PEAK	29733	285926	483	51
Sight surveyed/ verified weir height was < 21 in. 10/9/2019				
Full maintenance 10/21/2019				
Weir height increased to 21 in. 10/25/19				
Downstream drainage ditch cleared 12/1/2019				
12/7/2019	70929	158071	533	97
12/11/2019	27972	124931	63	25
12/19/2019	46406	324347	551	52
Full maintenance 3/24/2020				
3/30/2020 PEAK	31704	24945	531	54
Cartridges replaced 4/17/2020				
4/22/2020 PEAK	16362	0	524	29
Min	1317	0	24	4
Max	101703	1310743	551	97
Mean	29933	218988	307	35
Median	34870	185785	380	56

Full maintenance: includes the replacement of cartridges as well as the removal of captured material in the sump.
Cartridge replacement: includes the replacement of cartridges only.

6.4 Individual Storm Reports

The Individual Storm Reports (ISRs) for the 25 storm events sampled during this evaluation are attached in Appendix I. Each ISR contains general site and system information, hydrology information for the specific event, and all raw data collected for the specific storm event.

6.5 Laboratory QA/QC Results

Data were reviewed and validated according to the approved QAPP. A detailed quality control/quality assurance analysis is enclosed in Appendix G. The 23 storm events used to evaluate performance did not contain any disqualified data.

6.6 Performance Evaluation

Of the 25 storm events sampled during this study, 23 were used to evaluate system performance. The remaining 2 events were analyzed for screening parameters as part of the TAPE QC requirements. Total suspended solids (TSS) and total phosphorus were the primary parameters of interest for the system investigation. A copy of the raw data in tabular form for all the parameters evaluated can be seen in Appendix J. Appendix K contains copies of the analytical reports for each event.

6.6.1 Suspended Solids

TSS results are shown in Table 10. Suspended sediment concentration (SSC) and total volatile suspended solids results are shown in Table 11.

Influent EMCs for TSS ranged from 13.0 mg/L to 755.0 mg/L with a mean of 191.4 mg/L and a median of 134.0 mg/L. Corresponding effluent EMCs for TSS ranged from 5.0 mg/L to 51.0 mg/L with a mean of 23.2 mg/L and a median of 22.0 mg/L.

Influent EMCs for SSC ranged from 18.4 mg/L to 2560.0 mg/L with a mean of 419.5 mg/L and a median of 191.0 mg/L. Corresponding effluent EMCs for SSC ranged from 6.1 mg/L to 52.8 mg/L with a mean of 24.4 mg/L and a median of 23.8 mg/L.

Influent EMCs for TVSS ranged from 4.2 mg/L to 473.0 mg/L with a mean of 87.1 mg/L and a median of 51.1 mg/L. Corresponding effluent EMCs for TVSS ranged from 1.7 mg/L to 8.9 mg/L with a mean of 5.3 mg/L and a median of 6.0 mg/L.

Suspended sediment concentration less than 500 microns (SSC <500 µm) from 12 of the 23 events as well as solids representing the silt and clay fraction (SSC <62.5µm) for 12 of the 21 are shown in Table 12. Only a portion of the events were analyzed for subsets of the total SSC load due to limited sample volume availability. Additional solids data can be found in the ISRs for each event in Appendix J.

Influent EMCs for SSC <500µm ranged from 25.0 mg/L to 696.0 mg/L with a mean of 217.5 mg/L and a median of 178.0 mg/L. Corresponding effluent EMCs for SSC <500µm ranged from 4.2 mg/L to 53.9 mg/L with a mean of 23.2mg/L and a median of 21.6mg/L.

Influent EMCs for SSC <62.5 µm ranged from 25.0 mg/L to 312.0 mg/L with a mean of 115.2mg/L and a median of 103.0 mg/L. Corresponding effluent EMCs for SSC <62.5 µm ranged from 4.1 mg/L to 55.2 mg/L with a mean of 23.3 mg/L and a median of 24.9 mg/L.

In general, SSC influent concentrations tended to be greater than paired TSS results. Both methods involve measuring the dry weight of sediment in a sample of water to calculate a suspended solids concentration (typically reported in mg/L). The key difference between the two methods is that for the TSS method only a sub-sample of the original sample is used for analysis, whereas for the SSC method the whole original sample is used. The TSS test procedure is known to underestimate the concentration of sand size and coarser particles since these particles are disproportionately excluded by the various subsampling techniques. This underreporting bias has been well documented by the United States Geologic Survey who recommends use of the SSC method for more accurate sediment concentration results (Gray 2000).

Table 10. Total Suspended Solids (TSS) Results

Total Suspended Solids (TSS)									
Event ID	**Sample Type**		**Influent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Influent load (kg)**	**Effluent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Effluent load (kg)**	**Individual storm reduction (RE) (%)**
3/20/2017	Comp.	IN_COMP	51.2	2.0	6.8	19.4	2.1	2.6	62.1
3/21/2017	Comp.	IN_COMP	102.0	2.0	7.1	22.0	2.0	1.5	78.4
4/7/2017	Comp.	IN_COMP	201.0	2.0	12.6	30.8	2.0	1.9	84.7
4/12/2017	Comp.	IN_COMP	108.0	2.0	10.6	24.4	2.0	2.4	77.4
4/19/2017	Comp.	IN_COMP	452.0	2.0	8.2	44.6	2.1	0.8	90.1
4/26/2017	Comp.	IN_COMP	257.0	2.3	11.2	10.0	2.4	0.4	96.1
5/13/2017	Comp.	IN_COMP	66.0	2.0	6.4	33.2	2.0	3.2	49.7
5/16/2017	Comp.	IN_COMP	24.0	2.0	4.2	6.8	2.0	1.2	71.7
6/8/2017	Comp.	IN_COMP	73.6	2.0	6.6	16.8	2.0	1.5	77.2
6/15/2017	Comp.	IN_COMP	134.0	2.5	13.9	10.4	2.0	1.1	92.2
3/8/2018	Comp.	IN_COMP	755.0	3.3	70.4	47.2	2.0	4.4	93.7
3/14/2018	Comp.	IN_COMP	181.0	5.0	19.4	27.0	5.0	2.9	85.1
3/16/2018	Comp.	IN_COMP	19.0	5.0	0.4	ND	5.0	0.1	73.7
3/22/2018	Comp.	IN_COMP	224.0	5.0	25.1	20.0	5.0	2.2	91.1
3/27/2019	Comp.	IN_COMP	94.0	5.0	16.4	11.0	5.0	1.9	88.3
4/5/2019	Peak	PEAK_IN	171.0	5.0	0.9	23.0	5.0	0.1	86.5
4/13/2019	Peak	PEAK_IN	117.0	5.0	45.0	25.0	5.0	9.6	78.6
5/18/2019	Peak	PEAK_IN	254.0	5.0	28.6	20.0	5.0	2.3	92.1
12/7/2019	Comp.	IN_COMP	200.0	5.0	53.7	17.0	5.0	4.6	91.5
12/11/2019	Comp.	IN_COMP	13.0	5.0	1.4	10.0	5.0	1.1	23.1
12/19/2019	Comp.	IN_COMP	91.0	5.0	16.0	31.0	5.0	5.4	65.9
3/30/2020	Peak	PEAK_IN	605.0	5.0	72.6	51.0	5.0	6.1	91.6
4/20/2020	Peak	PEAK_IN	210.0	5.0	13.0	29.0	5.0	1.8	86.2
Min			13.0	2.0	0.4	5.0	2.0	0.1	23.1
Max			755.0	5.0	72.6	51.0	5.0	9.6	96.1
Mean			191.4	3.7	19.6	23.2	3.6	2.6	79.4
Median			134.0	5.0	12.6	22.0	5.0	1.9	85.1
Sum					450.4			59.2	

Table 11. SSC and TVSS Results

		Suspended Solids Concentration (SSC)							Total Volatile Suspended Solids (TVSS)						
Event ID	Sample Type	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)
3/20/2017	Comp.	131.0	4.5	17.3	22.5	3.6	3.0	82.8	63.4	2.2	8.37	6.4	1.8	0.85	89.9
3/21/2017	Comp.	112.0	3.7	7.8	28.0	3.3	1.9	75.0	30.4	1.9	2.11	8.0	1.7	0.56	73.7
4/7/2017	Comp.	373.0	4.2	23.4	36.9	3.9	2.3	90.1	108.0	2.1	6.78	6.9	1.9	0.43	93.6
4/12/2017	Comp.	191.0	3.6	18.7	23.2	3.5	2.3	87.9	44.6	1.8	4.36	3.9	1.8	0.38	91.3
4/19/2017	Comp.	443.0	3.6	8.0	14.4	4.0	0.3	96.7	150.0	1.8	2.71	6.0	2.0	0.11	96.0
4/26/2017	Comp.	365.0	3.9	15.9	8.6	4.6	0.4	97.6	96.9	2.0	4.22	ND	2.3	0.10	97.7
5/13/2017	Comp.	88.9	1.0	8.7	36.5	1.0	3.6	58.9	28.8	0.5	2.81	6.7	0.5	0.65	76.7
5/16/2017	Comp.	46.5	1.0	8.1	6.3	1.0	1.1	86.4	18.9	0.5	3.28	1.7	0.5	0.30	90.9
6/8/2017	Comp.	69.6	0.9	6.2	17.6	1.0	1.6	74.7	17.8	0.5	1.59	5.3	0.5	0.47	70.4
6/15/2017	Comp.	157.0	4.8	16.3	11.4	3.9	1.2	92.7	39.0	2.4	4.06	2.0	2.0	0.20	95.0
3/8/2018	Comp.	2560.0	4.8	238.6	40.3	3.1	3.8	98.4	473.0	2.4	44.08	7.1	1.5	0.66	98.5
3/14/2018	Comp.	825.0	4.6	88.2	25.2	4.0	2.7	96.9	77.7	2.3	8.31	4.8	2.0	0.51	93.8
3/16/2018	Comp.	24.9	4.7	0.6	6.1	5.1	0.1	75.4	4.2	2.4	0.09	3.6	2.6	0.08	15.6
3/22/2018	Comp.	311.0	4.1	34.9	23.8	4.0	2.7	92.3	51.1	1.9	5.74	3.2	2.0	0.36	93.7
3/27/2019	Comp.	122.0	4.1	21.3	6.5	3.8	1.1	94.7	35.1	2.0	6.14	ND	1.9	0.33	94.6
4/5/2019	Peak	253.0	3.8	1.3	29.7	3.9	0.1	88.3	81.1	1.9	0.40	7.0	2.0	0.04	91.3
4/13/2019	Peak	129.0	4.1	49.7	38.3	4.0	14.7	70.3	40.4	2.0	15.55	8.5	2.0	3.26	79.0
5/18/2019	Peak	1930.0	3.6	217.2	30.9	3.6	3.5	98.4	189.0	1.8	21.27	8.9	1.8	1.00	95.3
12/7/2019	Comp.	241.0	3.8	64.7	21.3	3.3	5.7	91.2	65.5	1.9	17.59	3.7	1.7	0.99	94.4
12/11/2019	Comp.	18.4	3.5	1.9	11.0	3.7	1.2	40.2	4.2	1.8	0.45	ND	1.8	0.19	56.6
12/19/2019	Comp.	138.0	4.1	24.2	33.8	4.3	5.9	75.5	45.0	2.1	7.90	6.0	2.1	1.05	86.7
3/30/2020	Peak	904.0	3.6	108.5	52.8	3.8	6.3	94.2	260.0	1.8	31.20	6.8	1.9	0.81	97.4
4/20/2020	Peak	215.0	3.3	13.3	37.0	3.7	2.3	82.8	79.7	1.6	4.94	8.4	1.8	0.52	89.4
Min		18.4	0.9	0.6	6.1	1.0	0.1	40.2	4.2	0.5	0.09	1.7	0.5	0.04	15.6
Max		2560.0	4.8	238.6	52.8	5.1	14.7	98.4	473.0	2.4	44.08	8.9	2.6	3.26	98.5
Mean		419.5	3.6	43.3	24.4	3.5	2.9	84.4	87.1	1.8	8.87	5.3	1.7	0.60	85.3
Median		191.0	3.8	17.3	23.8	3.8	2.3	88.3	51.1	1.9	4.94	6.0	1.9	0.47	91.3
Sum				994.8			67.8				203.96			13.86	

Table 12. SSC (<500µm and <62.5µm) Results

		Suspended Solids Concentration (SSC) (<500µm)							Suspended Solids Concentration (SSC) (<62.5µm)						
Event ID	Sample Type	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	271.0	3.8	17.0	38.4	4.0	2.4	85.8	150.0	3.6	9.4	25.7	3.8	1.6	82.9
4/12/2017	Comp.	153.0	3.3	15.0	25.3	4.1	2.5	83.5	98.7	3.2	9.6	24.9	4.4	2.4	74.8
4/19/2017	Comp.	249.0	4.4	4.5	14.0	4.0	0.3	94.4	127.0	4.8	2.3	11.6	4.4	0.2	90.9
4/26/2017	Comp.	203.0	4.2	8.8	8.7	5.4	0.4	95.7	103.0	5.3	4.5	7.9	5.3	0.3	92.3
5/13/2017	Comp.	70.3	3.5	6.9	36.1	3.9	3.5	48.6	54.7	3.8	5.3	35.6	4.0	3.5	34.9
5/16/2017	Comp.	35.6	4.4	6.2	4.2	4.2	0.7	88.3	25.0	3.9	4.3	ND	4.1	0.7	83.5
6/8/2017	Comp.	80.0	3.5	7.2	18.8	3.9	1.7	76.5	59.6	4.4	5.3	18.3	4.4	1.6	69.3
6/15/2017	Comp.	135.0	4.6	14.0	9.7	4.4	1.0	92.8	86.2	6.9	9.0	9.7	4.4	1.0	88.8
3/8/2018	Comp.	696.0	4.4	64.9	53.9	4.4	5.0	92.3	312.0	4.7	29.1	55.2	4.0	5.1	82.3
3/14/2018	Comp.	450.0	4.7	48.1	38.1	4.4	4.1	91.5	108.0	4.4	11.5	37.5	3.7	4.0	65.3
3/16/2018	Comp.	25.0	15.6	0.6	ND	6.8	0.2	72.8							
3/22/2018	Comp.	242.0	4.9	27.2	24.4	4.7	2.7	89.9	143.0	4.2	16.1	25.7	4.1	2.9	82.0
Min		25.0	3.3	0.6	4.2	3.9	0.2	48.6	25.0	3.2	2.3	4.1	3.7	0.2	34.9
Max		696.0	15.6	64.9	53.9	6.8	5.0	95.7	312.0	6.9	29.1	55.2	5.3	5.1	92.3
Mean		217.5	5.1	18.4	23.2	4.5	2.0	84.3	115.2	4.4	9.7	23.3	4.2	2.1	77.0
Median		178.0	4.4	11.4	21.6	4.3	2.0	89.1	103.0	4.4	9.0	24.9	4.1	1.6	82.3
Sum				220.3			24.4				106.5			23.5	

6.6.2 Total Phosphorus

Total phosphorus and orthophosphate phosphorous (ortho phosphorous) were analyzed for 21 of the sampled storm events. These results are shown in Tables 13 and 14.

Influent EMCs for total phosphorus ranged from 0.0806 mg/L to 1.7500 mg/L with a mean of 0.4711 mg/L and a median of 0.3380 mg/L. Corresponding effluent EMCs for total phosphorus ranged from 0.030mg/L to 0.1730 mg/L with a mean of 0.0836 mg/L and a median of 0.0915 mg/L.

Influent EMCs for ortho phosphorous ranged from 0.0100 mg/L to 0.0360 mg/L with a mean of 0.0179 mg/L and a median of 0.0150 mg/L. Corresponding effluent EMCs for ortho phosphorous ranged from 0.0100 mg/L to 0.0541 mg/L with a mean of 0.0192 mg/L and a median of 0.0160 mg/L.

Table 13. Total Phosphorus Results

Total Phosphorus								
Event ID	**Sample Type**	**Influent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Influent load (g)**	**Effluent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Effluent load (g)**	**Individual storm reduction (RE) (%)**
4/7/2017	Comp.	0.7060	0.0100	44.3	0.0920	0.0100	5.8	87.0
4/12/2017	Comp.	0.3380	0.0100	33.0	0.0760	0.0100	7.4	77.5
4/19/2017	Comp.	0.5000	0.0100	9.0	0.0360	0.0100	0.7	92.8
4/26/2017	Comp.	0.5040	0.0100	22.0	0.0420	0.0100	1.8	91.7
5/13/2017	Comp.	0.2560	0.0100	25.0	0.1100	0.0100	10.7	57.0
5/16/2017	Comp.	0.0940	0.0100	16.3	0.0420	0.0100	7.3	55.3
6/8/2017	Comp.	0.2560	0.0100	22.9	0.1040	0.0100	9.3	59.4
6/15/2017	Comp.	0.3620	0.0100	37.6	0.0520	0.0100	5.4	85.6
3/8/2018	Comp.	1.7500	0.0100	163.1	0.1300	0.0100	12.1	92.6
3/14/2018	Comp.	0.6520	0.0100	69.7	0.0940	0.0100	10.1	85.6
3/16/2018	Comp.	0.0820	0.0100	1.8	0.0300	0.0100	0.7	63.4
3/22/2018	Comp.	0.3640	0.0100	40.9	0.0720	0.0100	8.1	80.2
3/27/2019	Comp.	0.2260	0.0500	39.5	0.0699	0.0500	12.2	69.1
4/5/2019	Peak	0.3370	0.0500	1.7	0.0915	0.0500	0.5	72.8
4/13/2019	Peak	0.2490	0.0500	95.9	0.0870	0.0500	33.5	65.1
5/18/2019	Peak	1.0900	0.2500	122.7	0.1730	0.0500	19.5	84.1
12/7/2019	Comp.	0.3350	0.0500	89.9	0.1050	0.0500	28.2	68.7
12/11/2019	Comp.	0.0806	0.0500	8.5	0.0523	0.0500	5.5	35.1
12/19/2019	Comp.	0.2110	0.0500	37.1	0.0925	0.0500	16.2	56.2
3/30/2020	Peak	1.0500	0.0500	126.0	0.0921	0.0500	11.1	91.2
4/20/2020	Peak	0.4510	0.0500	27.9	0.1120	0.0500	6.9	75.2
Min		0.0806	0.0100	1.7	0.0300	0.0100	0.5	35.1
Max		1.7500	0.2500	163.1	0.1730	0.0500	33.5	92.8
Mean		0.4711	0.0367	49.3	0.0836	0.0271	10.1	73.6
Median		0.3380	0.0100	37.1	0.0915	0.0100	8.1	75.2
Sum				1034.9			213.0	

Table 14. Orthophosphate Phosphorus Results

Ortho Phosphorus								
Event ID	Sample Type	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	ND	0.0100	0.63	0.0140	0.0100	0.88	-40.0
4/12/2017	Comp.	0.0220	0.0100	2.15	0.0190	0.0100	1.86	13.6
4/19/2017	Comp.	ND	0.0100	0.18	ND	0.0100	0.18	0.0
4/26/2017	Comp.	0.0140	0.0100	0.61	ND	0.0100	0.44	28.6
5/13/2017	Comp.	0.0190	0.0100	1.86	0.0190	0.0100	1.86	0.0
5/16/2017	Comp.	0.0110	0.0100	1.91	0.0170	0.0100	2.95	-54.5
6/8/2017	Comp.	0.0360	0.0100	3.22	0.0160	0.0100	1.43	55.6
6/15/2017	Comp.	0.0190	0.0100	1.98	0.0130	0.0100	1.35	31.6
3/8/2018	Comp.	0.0230	0.0050	2.14	0.0300	0.0050	2.80	-30.4
3/14/2018	Comp.	0.0250	0.0050	2.67	0.0180	0.0050	1.92	28.0
3/16/2018	Comp.	0.0250	0.0050	0.56	0.0120	0.0050	0.27	52.0
3/22/2018	Comp.	0.0150	0.0050	1.68	0.0150	0.0050	1.68	0.0
3/27/2019	Comp.	0.0194	0.0100	3.39	0.0162	0.0100	2.83	16.5
4/5/2019	Peak	ND	0.0100	0.05	ND	0.0100	0.05	0.0
4/13/2019	Peak	ND	0.0100	3.85	0.0110	0.0100	4.23	-10.0
5/18/2019	Peak	ND	0.0100	1.13	0.0541	0.0100	6.09	-441.0
12/7/2019	Comp.	0.0300	0.0100	8.05	0.0423	0.0100	11.36	-41.0
12/11/2019	Comp.	0.0133	0.0100	1.41	0.0287	0.0100	3.04	-115.8
12/19/2019	Comp.	0.0315	0.0100	5.53	0.0277	0.0100	4.87	12.1
3/30/2020	Peak	0.0120	0.0100	1.44	ND	0.0100	1.20	16.7
4/20/2020	Peak	ND	0.0100	0.62	ND	0.0100	0.62	0.0
Min		0.0100	0.0050	0.05	0.0100	0.0050	0.05	-441.0
Max		0.0360	0.0100	8.05	0.0541	0.0100	11.36	55.6
Mean		0.0179	0.0090	2.15	0.0192	0.0090	2.47	-22.8
Median		0.0150	0.0100	1.86	0.0160	0.0100	1.86	0.0
Sum				45.06			51.90	

6.6.3 Hardness, pH, and Metals

Hardness was analyzed for 21 events, and pH was measured for 12 events. These results are shown in Table 15. Total copper and total zinc were analyzed for 21 events, and total cadmium and total lead were analyzed for 16 events sampled, with results shown in Tables 16 and 17 respectively. Total magnesium and total calcium were analyzed for 21 events, and results are shown in Table 18.

For the 21 sample pairs evaluated, influent EMCs for hardness ranged from 13.9 mg/L to 61.4 mg/L with a mean of 25.6 mg/L and a median of 22.5 mg/L. Corresponding effluent EMCs for hardness ranged from 6.7 mg/L to 28.9 mg/L with a mean of 17.0 mg/L and a median of 15.3 mg/L.

For the 12 sample pairs evaluated, influent EMCs for pH ranged from 6.30 to 7.40 with a mean of 6.99 and a median of 6.97. Corresponding effluent EMCs for pH ranged from 6.67 to 8.40 with a mean of 7.12 and a median of 6.98.

For the 21 sample pairs evaluated, influent EMCs for total zinc ranged from 0.0381 mg/L to 1.8900 mg/L with a mean of 0.2397 mg/L and a median of 0.1300 mg/L. Corresponding effluent EMCs for total zinc ranged from 0.0166 mg/L to 1.2400 mg/L with a mean of 0.1010 mg/L and a median of 0.0372 mg/L.

For the 21 sample pairs evaluated, influent EMCs for total copper ranged from 0.0060 mg/L to 0.1360 mg/L with a mean of 0.0292 mg/L and a median of 0.0182 mg/L. Corresponding effluent EMCs for total copper ranged from 0.0019 mg/L to 0.0172 mg/L with a mean of 0.0069 mg/L and a median of 0.0065 mg/L.

For the 16 sample pairs evaluated, influent EMCs for total lead ranged from 0.00116 mg/L to 0.03630 mg/L with a mean of 0.00824 mg/L and a median of 0.00661 mg/L. Corresponding effluent EMCs for total lead ranged from 0.00029 mg/L to 0.00284 mg/L with a mean of 0.00130mg/L and a median of 0.00110 mg/L.

For the 16 sample pairs evaluated, influent EMCs for total cadmium ranged from 0.00013 mg/L to 0.00134 mg/L with a mean of 0.00047 mg/L and a median of 0.00030 mg/L. Corresponding effluent EMCs for total cadmium ranged from 0.00007 mg/L to 0.00053 mg/L with a mean of 0.00021 mg/L and a median of 0.00020 mg/L.

For the 21 sample pairs evaluated, influent EMCs for total magnesium ranged from 1.010 mg/L to 5.150 mg/L with a mean of 1.982 mg/L and a median of 1.660 mg/L. Corresponding effluent EMCs for total magnesium ranged from 0.450 mg/L to 2.510 mg/L with a mean of 1.287 mg/L and a median of 1.130 mg/L.

For the 21 sample pairs evaluated, influent EMCs for total calcium ranged from 3.90 mg/L to 16.10mg/L with a mean of 6.99 mg/L and a median of 5.81 mg/L. Corresponding effluent EMCs for total calcium ranged from 1.93 mg/L to 8.28 mg/L with a mean of 4.70 mg/L and a median of 4.31 mg/L.

6.6.4 Nitrogen

Ammonia as N and nitrate + nitrite nitrogen results for the 16 of the 23 events sampled are shown in Table 19. Total Kjeldahl nitrogen (TKN) and calculated total nitrogen (TKN+ NO2_NO3 as N) results for 16 of the 23 events sampled are shown in Table 20.

For the 16 sample pairs evaluated, influent EMCs for ammonia as N ranged from 0.043 mg/L to 0.267 mg/L with a mean of 0.085 mg/L and a median of 0.067 mg/L. Corresponding effluent EMCs for ammonia as N ranged from 0.020 mg/L to 0.201 mg/L with a mean of 0.080 mg/L and a median of 0.075 mg/L.

For the 16 sample pairs evaluated, influent EMCs for nitrate + nitrite nitrogen ranged from 0.138 mg/L to 1.590 mg/L with a mean of 0.732 mg/L and a median of 0.582 mg/L. Corresponding effluent EMCs for nitrate + nitrite nitrogen ranged from 0.131 mg/L to 1.510 mg/L with a mean of 0.777 mg/L and a median of 0.635 mg/L.

For the 16 sample pairs evaluated, influent EMCs for TKN ranged from 0.25 mg/L to 2.00 mg/L with a mean of 0.81 mg/L and a median of 0.76 mg/L. Corresponding effluent EMCs for TKN ranged from 0.10 mg/L to 0.76 mg/L with a mean of 0.34 mg/L and a median of 0.33 mg/L.

For the 16 sample pairs evaluated, influent EMCs for calculated total nitrogen (TKN+ NO2_NO3 as N) ranged from 0.79 mg/L to 3.44 mg/L with a mean of 1.55 mg/L and a median of 1.36 mg/L. Corresponding effluent EMCs for calculated total nitrogen ranged from 0.51 mg/L to 2.27 mg/L with a mean of 1.12mg/L and a median of 0.84 mg/L.

Table 15. Hardness and pH Results

Event ID	Sample Type	Hardness					pH				
		Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Individual storm reduction (RE) (%)	Influent result (pH units)	Method reporting limit (MRL) (pH units)	Effluent result (pH units)	Method reporting limit (MRL) (pH units)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	25.1	0.5	18.8	0.5	25.1	6.30	0.00	8.40	0.00	-33.3
4/12/2017	Comp.	24.6	0.5	18.5	0.5	24.8	7.40	0.00	7.30	0.00	1.4
4/19/2017	Comp.	25.1	0.7	15.3	0.7	39.0	6.82	0.00	6.80	0.00	0.3
4/26/2017	Comp.	19.0	0.7	13.7	0.7	27.9	6.86	0.00	6.86	0.00	0.0
5/13/2017	Comp.	15.6	0.5	15.0	0.5	3.8	6.87	0.00	6.81	0.00	0.9
5/16/2017	Comp.	13.9	0.5	13.5	0.5	2.9	6.71	0.00	6.67	0.00	0.6
6/8/2017	Comp.	18.8	0.5	22.1	0.5	-17.6	7.21	0.00	6.97	0.00	3.3
6/15/2017	Comp.	21.5	5.2	14.1	0.7	34.4	7.07	0.00	6.98	0.00	1.3
3/8/2018	Comp.	61.4	0.5	26.3	0.5	57.2					
3/14/2018	Comp.	32.8	0.5	19.5	0.5	40.5	7.35	0.00	7.30	0.00	0.7
3/16/2018	Comp.	28.3	0.7	28.9	0.7	-2.1					
3/22/2018	Comp.	20.5	0.5	13.2	0.5	35.6	7.38	0.00	7.31	0.00	0.9
3/27/2019	Comp.	27.9	0.5	27.9	0.5	0.0					
4/5/2019	Peak	18.2	0.5	11.2	0.5	38.5					
4/13/2019	Peak	21.0	0.5	16.5	0.5	21.4					
5/18/2019	Peak	30.6	0.5	6.7	0.5	78.2					
12/7/2019	Comp.	26.4	0.5	21.1	0.5	20.1	7.31	0.00	7.34	0.00	-0.4
12/11/2019	Comp.	22.5	0.5	18.8	0.5	16.4					
12/19/2019	Comp.	19.2	0.5	13.8	0.5	28.1					
3/30/2020	Peak	48.1	1.9	11.2	1.9	76.7					
4/20/2020	Peak	17.3	1.9	11.8	1.9	31.8	6.58	0.00	6.75	0.00	-2.6
Min		13.9	0.5	6.7	0.5	-17.6	6.30	0.00	6.67	0.00	-33.3
Max		61.4	5.2	28.9	1.9	78.2	7.40	0.00	8.40	0.00	3.3
Mean		25.6	0.9	17.0	0.6	27.8	6.99	0.00	7.12	0.00	-2.2
Median		22.5	0.5	15.3	0.5	27.9	6.97	0.00	6.98	0.00	0.6
Sum											

Table 16. Total Zinc and Total Copper Results

Event ID	Sample Type	Total Zn							Total Cu						
		Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	0.1450	0.0020	9.1	0.0399	0.0020	2.5	72.5	0.0258	0.0005	1.62	0.0085	0.0005	0.54	66.9
4/12/2017	Comp.	0.0797	0.0020	7.8	0.0317	0.0020	3.1	60.2	0.0126	0.0010	1.23	0.0032	0.0010	0.32	74.3
4/19/2017	Comp.	0.1460	0.0020	2.6	0.0209	0.0020	0.4	85.7	0.0248	0.0005	0.45	0.0032	0.0005	0.06	87.2
4/26/2017	Comp.	0.0875	0.0020	3.8	0.0166	0.0020	0.7	81.0	0.0160	0.0005	0.70	0.0019	0.0005	0.08	87.9
5/13/2017	Comp.	0.0637	0.0020	6.2	0.0423	0.0020	4.1	33.6	0.0109	0.0005	1.06	0.0073	0.0005	0.71	33.4
5/16/2017	Comp.	0.0381	0.0020	6.6	0.0244	0.0020	4.2	36.0	0.0060	0.0005	1.04	0.0036	0.0005	0.62	40.3
6/8/2017	Comp.	1.8900	0.0020	168.9	1.2400	0.0020	110.8	34.4	0.0164	0.0005	1.47	0.0071	0.0005	0.63	57.0
6/15/2017	Comp.	0.2220	0.0020	23.1	0.1040	0.0020	10.8	53.2	0.0230	0.0005	2.39	0.0070	0.0005	0.72	69.7
3/8/2018	Comp.	0.3740	0.0020	34.9	0.0518	0.0020	4.8	86.1	0.0597	0.0005	5.56	0.0172	0.0005	1.60	71.2
3/14/2018	Comp.	0.1300	0.0020	13.9	0.0412	0.0020	4.4	68.3	0.0225	0.0005	2.41	0.0058	0.0005	0.62	74.3
3/16/2018	Comp.	0.0444	0.0020	1.0	0.0282	0.0020	0.6	36.5	0.0180	0.0005	0.40	0.0023	0.0005	0.05	87.1
3/22/2018	Comp.	0.1170	0.0020	13.1	0.0305	0.0020	3.4	73.9	0.1360	0.0005	15.27	0.0040	0.0005	0.45	97.0
3/27/2019	Comp.	0.0675	0.0020	11.8	0.0345	0.0020	6.0	48.9	0.0133	0.0005	2.33	0.0047	0.0005	0.82	64.7
4/5/2019	Peak	0.1100	0.0020	0.5	0.0313	0.0020	0.2	71.5	0.0196	0.0005	0.10	0.0065	0.0005	0.03	66.8
4/13/2019	Peak	0.0826	0.0020	31.8	0.0366	0.0020	14.1	55.7	0.0182	0.0005	7.01	0.0098	0.0005	3.77	46.2
5/18/2019	Peak	0.4560	0.0020	51.3	0.0356	0.0020	4.0	92.2	0.0601	0.0005	6.76	0.0068	0.0005	0.76	88.7
12/7/2019	Comp.	0.1990	0.0020	53.4	0.0815	0.0020	21.9	59.0	0.0167	0.0005	4.48	0.0055	0.0005	1.48	66.9
12/11/2019	Comp.	0.0959	0.0020	10.2	0.0805	0.0020	8.5	16.1	0.0081	0.0005	0.85	0.0070	0.0005	0.74	13.6
12/19/2019	Comp.	0.1500	0.0020	26.3	0.0697	0.0020	12.2	53.5	0.0125	0.0005	2.20	0.0064	0.0005	1.13	48.7
3/30/2020	Peak	0.4050	0.0020	48.6	0.0432	0.0020	5.2	89.3	0.0625	0.0010	7.50	0.0109	0.0010	1.31	82.6
4/20/2020	Peak	0.1310	0.0020	8.1	0.0372	0.0020	2.3	71.6	0.0315	0.0010	1.95	0.0154	0.0010	0.95	51.1
Min		0.0381	0.0020	0.5	0.0166	0.0020	0.2	16.1	0.0060	0.0005	0.10	0.0019	0.0005	0.03	13.6
Max		1.8900	0.0020	168.9	1.2400	0.0020	110.8	92.2	0.1360	0.0010	15.27	0.0172	0.0010	3.77	97.0
Mean		0.2397	0.0020	25.4	0.1010	0.0020	10.7	60.9	0.0292	0.0006	3.18	0.0069	0.0006	0.83	65.5
Median		0.1300	0.0020	11.8	0.0372	0.0020	4.2	60.2	0.0182	0.0005	1.95	0.0065	0.0005	0.71	66.9
Sum				533.2			224.4				66.77			17.41	

Table 17. Total Lead and Total Cadmium Results

Event ID	Sample Type	Total Pb							Total Cd						
		Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	0.01400	0.00020	0.88	0.00236	0.00020	0.15	83.1	0.00021	0.00020	0.013	ND	0.00020	0.013	5.2
4/12/2017	Comp.	0.00759	0.00020	0.74	0.00156	0.00020	0.15	79.4	0.00026	0.00020	0.025	ND	0.00020	0.020	21.9
4/19/2017	Comp.	0.01270	0.00020	0.23	0.00108	0.00020	0.02	91.5	0.00134	0.00020	0.024	ND	0.00020	0.004	85.1
4/26/2017	Comp.	0.00857	0.00020	0.37	0.00094	0.00020	0.04	89.0	0.00053	0.00020	0.023	ND	0.00020	0.009	62.5
5/13/2017	Comp.	0.00448	0.00020	0.44	0.00242	0.00020	0.24	46.0	ND	0.00020	0.020	ND	0.00020	0.020	0.0
5/16/2017	Comp.	0.00198	0.00020	0.34	0.00061	0.00020	0.11	69.1	0.00043	0.00020	0.075	0.00053	0.00020	0.093	-23.1
6/8/2017	Comp.	0.00416	0.00020	0.37	0.00111	0.00020	0.10	73.3	ND	0.00020	0.018	ND	0.00020	0.018	0.0
6/15/2017	Comp.	0.00771	0.00020	0.80	0.00096	0.00020	0.10	87.6	0.00107	0.00020	0.111	ND	0.00020	0.021	81.3
3/8/2018	Comp.	0.03630	0.00010	3.38	0.00284	0.00010	0.26	92.2	0.00065	0.00004	0.061	0.00033	0.00004	0.031	49.2
3/14/2018	Comp.	0.00914	0.00010	0.98	0.00129	0.00010	0.14	85.9	0.00084	0.00004	0.090	0.00025	0.00004	0.027	70.6
3/16/2018	Comp.	0.00214	0.00010	0.05	0.00029	0.00010	0.01	86.5	0.00022	0.00004	0.005	0.00013	0.00004	0.003	40.1
3/22/2018	Comp.	0.00771	0.00010	0.87	0.00112	0.00010	0.13	85.5	0.00034	0.00004	0.038	0.00013	0.00004	0.014	61.9
3/27/2019	Comp.	0.00331	0.00010	0.58	0.00040	0.00010	0.07	87.9	0.00013	0.00004	0.023	0.00016	0.00004	0.028	-22.1
12/7/2019	Comp.	0.00563	0.00010	1.51	0.00107	0.00010	0.29	81.0	0.00014	0.00004	0.037	0.00007	0.00004	0.018	50.5
12/11/2019	Comp.	0.00116	0.00010	0.12	0.00090	0.00010	0.10	22.2	0.00016	0.00004	0.017	0.00013	0.00004	0.014	17.3
12/19/2019	Comp.	0.00529	0.00010	0.93	0.00183	0.00010	0.32	65.4	0.00079	0.00004	0.139	0.00030	0.00004	0.053	62.2
Min		0.00116	0.00010	0.05	0.00029	0.00010	0.01	22.2	0.00013	0.00004	0.005	0.00007	0.00004	0.003	-23.1
Max		0.03630	0.00020	3.38	0.00284	0.00020	0.32	92.2	0.00134	0.00020	0.139	0.00053	0.00020	0.093	85.1
Mean		0.00824	0.00015	0.79	0.00130	0.00015	0.14	76.6	0.00047	0.00012	0.045	0.00021	0.00012	0.024	35.2
Median		0.00661	0.00015	0.66	0.00110	0.00015	0.12	84.3	0.00030	0.00012	0.025	0.00020	0.00012	0.019	44.6
Sum				12.59			2.21				0.718			0.382	

Table 18. Total Magnesium and Total Calcium Results

Event ID	Sample Type	Total Mg							Total Ca						
		Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	1.870	0.050	0.117	1.350	0.050	0.085	27.8	6.96	0.10	0.44	5.31	0.10	0.33	23.7
4/12/2017	Comp.	1.680	0.050	0.164	1.260	0.050	0.123	25.0	7.10	0.10	0.69	5.32	0.10	0.52	25.1
4/19/2017	Comp.	1.650	0.050	0.030	0.974	0.050	0.018	41.0	7.32	0.20	0.13	4.52	0.20	0.08	38.3
4/26/2017	Comp.	1.390	0.050	0.061	0.820	0.050	0.036	41.0	5.30	0.20	0.23	4.12	0.20	0.18	22.3
5/13/2017	Comp.	1.190	0.050	0.116	1.130	0.050	0.110	5.0	4.29	0.10	0.42	4.15	0.10	0.41	3.3
5/16/2017	Comp.	1.010	0.050	0.175	0.947	0.050	0.165	6.2	3.90	0.10	0.68	3.85	0.10	0.67	1.3
6/8/2017	Comp.	1.230	0.050	0.110	1.380	0.050	0.123	-12.2	5.51	0.10	0.49	6.56	0.10	0.59	-19.1
6/15/2017	Comp.	1.530	0.050	0.159	0.869	0.050	0.090	43.2	6.09	2.00	0.63	4.22	0.20	0.44	30.7
3/8/2018	Comp.	5.150	0.025	0.480	2.030	0.025	0.189	60.6	16.10	0.05	1.50	7.18	0.05	0.67	55.4
3/14/2018	Comp.	2.700	0.025	0.289	1.480	0.025	0.158	45.2	8.68	0.05	0.93	5.37	0.05	0.57	38.1
3/16/2018	Comp.	2.130	0.025	0.047	1.990	0.025	0.044	6.6	7.81	0.10	0.17	8.28	0.10	0.18	-6.0
3/22/2018	Comp.	1.610	0.025	0.181	0.925	0.025	0.104	42.5	5.57	0.05	0.63	3.78	0.05	0.42	32.1
3/27/2019	Comp.	2.380	0.025	0.416	2.290	0.025	0.400	3.8	7.25	0.05	1.27	7.41	0.05	1.30	-2.2
4/5/2019	Peak	1.460	0.025	0.007	0.876	0.025	0.004	40.0	4.89	0.05	0.02	3.04	0.05	0.02	37.8
4/13/2019	Peak	1.660	0.025	0.639	1.260	0.025	0.485	24.1	5.66	0.05	2.18	4.54	0.05	1.75	19.8
5/18/2019	Peak	2.290	0.025	0.258	0.450	0.025	0.051	80.3	8.50	0.05	0.96	1.93	0.05	0.22	77.3
12/7/2019	Comp.	2.880	0.025	0.773	2.510	0.025	0.674	12.8	5.81	0.05	1.56	4.31	0.05	1.16	25.8
12/11/2019	Comp.	2.070	0.025	0.219	1.730	0.025	0.183	16.4	5.60	0.05	0.59	4.68	0.05	0.50	16.4
12/19/2019	Comp.	1.440	0.025	0.253	1.060	0.025	0.186	26.4	5.31	0.05	0.93	3.79	0.05	0.67	28.6
3/30/2020	Peak	3.070	0.050	0.368	0.874	0.050	0.105	71.5	14.20	0.30	1.70	3.03	0.30	0.36	78.7
4/20/2020	Peak	1.240	0.050	0.077	0.826	0.050	0.051	33.4	4.89	0.30	0.30	3.37	0.30	0.21	31.1
Min		1.010	0.025	0.007	0.450	0.025	0.004	-12.2	3.90	0.05	0.02	1.93	0.05	0.02	-19.1
Max		5.150	0.050	0.773	2.510	0.050	0.674	80.3	16.10	2.00	2.18	8.28	0.30	1.75	78.7
Mean		1.982	0.037	0.235	1.287	0.037	0.161	30.5	6.99	0.20	0.78	4.70	0.11	0.53	26.6
Median		1.660	0.025	0.175	1.130	0.025	0.110	27.8	5.81	0.10	0.63	4.31	0.10	0.44	25.8
Sum				4.940			3.385				16.46			11.23	

Table 19. Ammonia as N and Nitrate+Nitrite Nitrogen (NO2_NO3 as N) Results

		Ammonia as N							NO2_NO3 as N						
Event ID	Sample Type	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (g)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (g)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	0.043	0.020	2.70	ND	0.020	1.25	53.5	0.640	0.020	0.04	1.160	0.020	0.07	-81.25
4/12/2017	Comp.	0.050	0.020	4.89	0.039	0.020	3.81	22.0	1.360	0.020	0.13	1.290	0.020	0.13	5.15
4/19/2017	Comp.	0.048	0.020	0.87	0.030	0.020	0.54	37.5	0.470	0.020	0.01	0.660	0.020	0.01	-40.43
4/26/2017	Comp.	0.059	0.020	2.57	0.077	0.020	3.36	-30.5	0.610	0.020	0.03	0.610	0.020	0.03	0.00
5/13/2017	Comp.	0.072	0.020	7.03	0.078	0.020	7.62	-8.3	0.570	0.020	0.06	0.600	0.020	0.06	-5.26
5/16/2017	Comp.	0.048	0.020	8.34	0.076	0.020	13.20	-58.3	0.540	0.020	0.09	0.550	0.020	0.10	-1.85
6/8/2017	Comp.	0.267	0.020	23.87	0.173	0.020	15.46	35.2	0.500	0.020	0.04	0.770	0.020	0.07	-54.00
6/15/2017	Comp.	0.048	0.020	4.99	0.090	0.020	9.36	-87.5	0.450	0.020	0.05	0.380	0.020	0.04	15.56
3/8/2018	Comp.	0.098	0.010	9.13	0.122	0.010	11.37	-24.5	1.440	0.010	0.13	1.510	0.010	0.14	-4.86
3/14/2018	Comp.	0.160	0.010	17.11	0.201	0.010	21.49	-25.6	0.838	0.020	0.09	0.956	0.020	0.10	-14.08
3/16/2018	Comp.	0.083	0.010	1.85	0.048	0.010	1.07	42.2	1.590	0.020	0.04	1.490	0.020	0.03	6.29
3/22/2018	Comp.	0.085	0.010	9.54	0.083	0.010	9.32	2.4	0.467	0.010	0.05	0.538	0.020	0.06	-15.20
3/27/2019	Comp.	0.095	0.010	16.61	0.053	0.010	9.27	44.2	1.050	0.010	0.18	1.160	0.010	0.20	-10.48
12/7/2019	Comp.	0.046	0.020	12.35	0.065	0.020	17.45	-41.3	0.138	0.010	0.04	0.131	0.010	0.04	5.07
12/11/2019	Comp.	0.093	0.020	9.85	0.074	0.020	7.84	20.4	0.593	0.010	0.06	0.218	0.010	0.02	63.24
12/19/2019	Comp.	0.061	0.020	10.72	0.046	0.020	8.08	24.6	0.463	0.010	0.08	0.405	0.010	0.07	12.53
Min		0.043	0.010	0.87	0.020	0.010	0.54	-87.5	0.138	0.010	0.01	0.131	0.010	0.01	-81.3
Max		0.267	0.020	23.87	0.201	0.020	21.49	53.5	1.590	0.020	0.18	1.510	0.020	0.20	63.2
Mean		0.085	0.017	8.90	0.080	0.017	8.78	0.4	0.732	0.016	0.07	0.777	0.017	0.07	-7.5
Median		0.067	0.020	8.74	0.075	0.020	8.67	11.4	0.582	0.020	0.05	0.635	0.020	0.06	-3.4
Sum				142.41			140.49				1.13			1.17	

Table 20. Total Kjeldahl Nitrogen (TKN) and Calculated Total Nitrogen (TKN+ NO2_NO3 as N) Results

Event ID	Sample Type	TKN							Calculated TN (TKN+ NO2_NO3 as N)						
		Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Individual storm reduction (RE) (%)
4/7/2017	Comp.	1.10	0.20	0.07	0.33	0.10	0.02	70.00	1.74		0.11	1.49		0.09	14.4
4/12/2017	Comp.	0.70	0.20	0.07	0.34	0.10	0.03	51.43	2.06		0.20	1.63		0.16	20.9
4/19/2017	Comp.	0.92	0.10	0.02	0.17	0.10	0.00	81.52	1.39		0.03	0.83		0.01	40.3
4/26/2017	Comp.	0.61	0.10	0.03	0.24	0.10	0.01	60.66	1.22		0.05	0.85		0.04	30.3
5/13/2017	Comp.	0.29	0.10	0.03	ND	0.10	0.01	65.52	0.86		0.08	0.70		0.07	18.6
5/16/2017	Comp.	0.25	0.10	0.04	0.20	0.10	0.03	20.00	0.79		0.14	0.75		0.13	5.1
6/8/2017	Comp.	1.30	0.10	0.12	0.56	0.10	0.05	56.92	1.80		0.16	1.33		0.12	26.1
6/15/2017	Comp.	0.61	0.10	0.06	0.44	0.10	0.05	27.87	1.06		0.11	0.82		0.09	22.6
3/8/2018	Comp.	2.00	0.20	0.19	0.76	0.20	0.07	62.00	3.44		0.32	2.27		0.21	34.0
3/14/2018	Comp.	0.99	0.20	0.11	0.46	0.10	0.05	53.54	1.83		0.20	1.42		0.15	22.5
3/16/2018	Comp.	0.51	0.10	0.01	0.21	0.10	0.00	58.82	2.10		0.05	1.70		0.04	19.0
3/22/2018	Comp.	0.86	0.10	0.10	0.29	0.10	0.03	66.28	1.33		0.15	0.83		0.09	37.6
3/27/2019	Comp.	0.67	0.20	0.12	0.25	0.20	0.04	62.44	1.72		0.30	1.41		0.25	18.0
12/7/2019	Comp.	0.90	0.20	0.24	0.38	0.20	0.10	57.85	1.04		0.28	0.51		0.14	50.9
12/11/2019	Comp.	0.49	0.20	0.05	0.33	0.20	0.04	32.17	1.08		0.11	0.55		0.06	49.2
12/19/2019	Comp.	0.82	0.20	0.14	0.35	0.20	0.06	57.56	1.28		0.23	0.75		0.13	41.3
Min		0.25	0.10	0.01	0.10	0.10	0.00	20.00	0.79		0.03	0.51		0.01	5.1
Max		2.00	0.20	0.24	0.76	0.20	0.10	81.52	3.44		0.32	2.27		0.25	50.9
Mean		0.81	0.15	0.09	0.34	0.13	0.04	55.29	1.55		0.16	1.12		0.11	28.2
Median		0.76	0.15	0.07	0.33	0.10	0.03	58.34	1.36		0.14	0.84		0.11	24.4
Sum				1.39			0.61				2.51			1.78	

6.7 Statistical comparison of influent and effluent pollutant concentrations

Water quality results were analyzed to determine whether there were significant differences in pollutant concentrations between the influent and effluent across individual storm events. The specific null hypothesis (H_o) and alternative hypothesis (H_a) for these analyses are as follows:

H_o: Effluent pollutant concentrations are equal to or greater than influent concentrations

H_a: Effluent concentrations are less than influent concentrations

A one-tailed Wilcoxon signed-rank test was performed on the events that met TAPE storm qualification requirements. Results indicated that for TSS, SSC, TVSS, hardness, total cadmium, total copper, total lead, total zinc, total phosphorus, TKN, and total nitrogen there was a statistically significant difference between the influent and effluent concentrations (P = <0.001). Complete results for this test can be seen in Appendix M.

Results indicated that for Orthophosphate Phosphorous there was not a statistically significant difference between the influent and effluent concentrations (P = 0.980). Results indicated that for nitrate + nitrite nitrogen there was not a statistically significant difference between the influent and effluent concentrations (P = 0.175). Results indicated that for ammonia as N there was not a statistically significant difference between the influent and effluent concentrations (P = 0.978). Results indicated that for pH there was not a statistically significant difference between the influent and effluent concentrations (P = 0.054). Complete results for this test can be seen in Appendix M.

6.8 Pollutant removal efficiency calculations

Pollutant removal efficiencies for the sampled storm events that were determined to meet the sample collection criteria have been calculated using TAPE Method #1: Individual Storm Reduction in Pollutant Concentration (TAPE, 2011). This method calculates the individual storm reductions in pollutant concentration assuming no water losses in the treatment system between the influent and effluent sampling points.

Pollutant removal efficiencies for the study period were also calculated using the Summation of Loads (SOL) efficiency calculation method. The SOL method defines the efficiency as a percentage based on the ratio of the summation of all influent loads to the summation of all effluent loads.

The sum of loads is calculated accordingly:

$$sum\ of\ loads = \sum_{j=1}^{m}\left(\sum_{i=1}^{n} C_i V_i\right) = \sum_{j=1}^{m} EMC_j \cdot V_j$$

Where:

V = volume of flow during period
C = average concentration associated with period
EMC = event mean concentration

The Summation of Loads (SOL) efficiency is calculated accordingly

$$SOL = 1 - \frac{sum\ of\ effluent\ loads}{sum\ of\ influent\ loads}$$

The SOL method assumes; 1) monitoring data accurately represents the actual entire total loads in and out of the BMP for a period long enough to overshadow any temporary storage or export of pollutants and 2) any significant storm events that were not monitored had a ratio of inlet to effluent loads similar to the storms events that were monitored (URS/ EPA 1999).

Individual event removal efficiencies per TAPE Method #1 for qualified TSS sample pairs can be found in Table 21. The mean and median effluent individual storm reductions for TSS are 84.2% and 85.1% respectively. Total event loadings for TSS for qualified TSS sample pairs were 450.4 kg at the influent and 59.2 kg at the effluent, resulting in a SOL efficiency of 86.9%.

Individual event removal efficiencies per TAPE Method #1 for qualified total phosphorus sample pairs can be found in Table 22. The mean and median effluent individual storm reductions for total phosphorus are 74.2% and 74.6% respectively. Total event loadings for sampled storm events determined to meet the sample collection criteria for total phosphorus were 1034.9 g and the influent and 213.0 g at the effluent, resulting in a SOL efficiency of 79.4%

6.8.1 Basic Treatment

The Basic Treatment performance goal is defined by the TAPE as 80% TSS removal for influent concentrations between 100 and 200 mg/L and an effluent TSS concentration of 20 mg/L or less for influent concentrations from 20 to 100 mg/L.

A total of 23 sample pairs were analyzed for compliance with the Basic Treatment performance goal.
For all events with influent TSS concentrations greater 100 mg/L, the calculated lower one-sided 95% confidence limit (LCL95) for removal efficiency was 82.0%. For events with influent TSS concentrations between 20 and 100 mg/L, the TAPE bootstrap confidence interval calculator could not be used due to the limited number of events available. For events with influent TSS concentrations between 20 and 100 mg/L, mean and median effluent TSS concentrations were 19.7 and 18.1 mg/L, respectively.

6.8.2 Solids Performance

TSS, SSC, and TVSS were evaluated as shown in Tables 10, 11, and 12. Total event loadings for the study SSC sample pairs were 994.8 kg at the influent and 67.8 kg at the effluent, resulting in a SOL efficiency of 93.2%. Total event loadings for TVSS were 203.96 kg at the influent and 13.86 kg at the effluent, resulting in a SOL efficiency of 93.2%. Total event loadings for SSC <500 µm, were 220.3 kg at the influent and 24.4 kg at the effluent, resulting in a SOL efficiency of 88.9%. Total event loadings for SSC <62.5 µm were 106.5 kg at the influent and 23.5 kg at the effluent, resulting in a SOL efficiency of 78%.

Table 21. Basic Treatment TSS results

Total Suspended Solids (TSS)									
Event ID	Sample Type	Influent result (mg/L)	Method reporting limit (MRL) (mg/L)	Influent load (kg)	Effluent result (mg/L)	Method reporting limit (MRL) (mg/L)	Effluent load (kg)	Basic Criteria 1 20-100 mg/l Eff. conc. ≤ 20mg/l	Basic Criteria 2 100-200 mg/l ≥80% RE (%) [a]
3/20/2017	Comp.	51.2	2.0	6.8	19.4	2.1	2.6	19.4	
3/21/2017	Comp.	102.0	2.0	7.1	22.0	2.0	1.5		78.4
4/7/2017	Comp.	201.0	2.0	12.6	30.8	2.0	1.9		84.6
4/12/2017	Comp.	108.0	2.0	10.6	24.4	2.0	2.4		77.4
4/19/2017	Comp.	452.0	2.0	8.2	44.6	2.1	0.8		77.7
4/26/2017	Comp.	257.0	2.3	11.2	10.0	2.4	0.4		95.0
5/13/2017	Comp.	66.0	2.0	6.4	33.2	2.0	3.2	33.2	
5/16/2017	Comp.	24.0	2.0	4.2	6.8	2.0	1.2	6.8	
6/8/2017	Comp.	73.6	2.0	6.6	16.8	2.0	1.5	16.8	
6/15/2017	Comp.	134.0	2.5	13.9	10.4	2.0	1.1		92.2
3/8/2018	Comp.	755.0	3.3	70.4	47.2	2.0	4.4		76.4
3/14/2018	Comp.	181.0	5.0	19.4	27.0	5.0	2.9		85.1
3/16/2018	Comp.	19.0	5.0	0.4	ND	5.0	0.1		
3/22/2018	Comp.	224.0	5.0	25.1	20.0	5.0	2.2		90.0
3/27/2019	Comp.	94.0	5.0	16.4	11.0	5.0	1.9	11.0	
4/5/2019	Peak	171.0	5.0	0.9	23.0	5.0	0.1		86.5
4/13/2019	Peak	117.0	5.0	45.0	25.0	5.0	9.6		78.6
5/18/2019	Peak	254.0	5.0	28.6	20.0	5.0	2.3		90.0
12/7/2019	Comp.	200.0	5.0	53.7	17.0	5.0	4.6		91.5
12/11/2019	Comp.	13.0	5.0	1.4	10.0	5.0	1.1		
12/19/2019	Comp.	91.0	5.0	16.0	31.0	5.0	5.4	31.0	
3/30/2020	Peak	605.0	5.0	72.6	51.0	5.0	6.1		74.5
4/20/2020	Peak	210.0	5.0	13.0	29.0	5.0	1.8		85.5
Min		13.0	2.0	0.4	5.0	2.0	0.1	6.8	74.5
Max		755.0	5.0	72.6	51.0	5.0	9.6	33.2	95.0
Mean		191.4	3.7	19.6	23.2	3.6	2.6	19.7	84.2
Median		134.0	5.0	12.6	22.0	5.0	1.9	18.1	85.1
Lower 95% for RE [b]									82.0
Sum				450.4			59.2		

[a] Influent TSS concentrations capped at 200 mg/L for Basic Criteria 2 RE calculation purposes
[b] confidence interval calculated using TAPE bootstrap confidence interval calculator

6.8.3 Total Phosphorus Performance

Phosphorus Treatment performance goals as defined by the TAPE include meeting all Basic Treatment goals as well as demonstrating at least 50% total phosphorus removal for events with influent concentrations between 0.1 and 0.5 mg/L.

A total of 21 sample pairs were analyzed for compliance with Phosphorus Treatment performance goal. For all events with influent total phosphorus influent concentrations between 0.1 and 0.5 mg/L, the calculated lower one-sided 95% confidence limit (LCL95) for removal efficiency was 70.1%.

The mean and median effluent individual storm reductions for total phosphorus were 74.2% and 74.6% respectively. Total event loadings for qualified total phosphorus sample pairs were 1,034.9 g at the influent and 213.0 g at the effluent, resulting in a SOL efficiency of 79.4%

6.8.4 Ortho Phosphorus Treatment

Ortho phosphorus was evaluated as shown on Table 14. The mean and median effluent individual storm reductions for ortho phosphorus were -22.8% and 0.0% respectively. Total event loadings for ortho phosphorus sample pairs were 45.06 g at the influent and 51.9 g at the effluent, resulting in a SOL efficiency of -15.2%

Table 22. Phosphorus Treatment results

Total Phosphorus							
Event ID	**Sample Type**	**Influent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Influent load (g)**	**Effluent result (mg/L)**	**Method reporting limit (MRL) (mg/L)**	**Total Phosphorus Criteria 0.1 - 0.5 mg/l ≥50% RE (%) [a]**
4/7/2017	Comp.	0.706	0.010	44.3	0.092	0.010	81.6
4/12/2017	Comp.	0.338	0.010	33.0	0.076	0.010	77.5
4/19/2017	Comp.	0.500	0.010	9.0	0.036	0.010	92.8
4/26/2017	Comp.	0.504	0.010	22.0	0.042	0.010	91.6
5/13/2017	Comp.	0.256	0.010	25.0	0.110	0.010	57.0
5/16/2017	Comp.	0.094	0.010	16.3	0.042	0.010	
6/8/2017	Comp.	0.256	0.010	22.9	0.104	0.010	59.4
6/15/2017	Comp.	0.362	0.010	37.6	0.052	0.010	85.6
3/8/2018	Comp.	1.750	0.010	163.1	0.130	0.010	74.0
3/14/2018	Comp.	0.652	0.010	69.7	0.094	0.010	81.2
3/16/2018	Comp.	0.082	0.010	1.8	0.030	0.010	
3/22/2018	Comp.	0.364	0.010	40.9	0.072	0.010	80.2
3/27/2019	Comp.	0.226	0.050	39.5	0.070	0.050	69.1
4/5/2019	Peak	0.337	0.050	1.7	0.092	0.050	72.8
4/13/2019	Peak	0.249	0.050	95.9	0.087	0.050	65.1
5/18/2019	Peak	1.090	0.250	122.7	0.173	0.050	65.4
12/7/2019	Comp.	0.335	0.050	89.9	0.105	0.050	68.7
12/11/2019	Comp.	0.081	0.050	8.5	0.052	0.050	
12/19/2019	Comp.	0.211	0.050	37.1	0.093	0.050	56.2
3/30/2020	Peak	1.050	0.050	126.0	0.092	0.050	81.6
4/20/2020	Peak	0.451	0.050	27.9	0.112	0.050	75.2
Min		0.081	0.010	1.7	0.030	0.010	56.2
Max		1.750	0.250	163.1	0.173	0.050	92.8
Mean		0.471	0.037	49.3	0.084	0.027	74.2
Median		0.338	0.010	37.1	0.092	0.010	74.6
Lower 95% for RE [b]							70.1
Sum				1034.9			

[a] Influent TP concentrations capped at 0.5 mg/L for Total Phosphorus Criteria RE calculation purposes
[b] confidence interval calculated using TAPE bootstrap confidence interval calculator

6.8.5 Metals Performance

Total copper and total zinc results are shown in Table 16. Total lead and total cadmium results are shown in Table 17. Total magnesium and total calcium results are shown in Table 18.

The mean and median effluent individual storm reductions for total zinc were 60.9% and 60.2% respectively. Total event loadings for total zinc sample pairs were 533.2 g at the influent and 224.4 g at the effluent, resulting in a SOL efficiency of 57.9%

The mean and median effluent individual storm reductions for total copper were 65.5% and 66.9% respectively. Total event loadings for total copper sample pairs were 66.77 g at the influent and 17.41 g at the effluent, resulting in a SOL efficiency of 73.9%

The mean and median effluent individual storm reductions for total lead were 76.6% and 84.3% respectively. Total event loadings for total lead sample pairs were 12.59 g at the influent and 2.21 g at the effluent, resulting in a SOL efficiency of 82.4%.

The mean and median effluent individual storm reductions for total cadmium were 35.2% and 44.6% respectively. Total event loadings for total cadmium sample pairs were 0.718 g at the influent and 0.382 g at the effluent, resulting in a SOL efficiency of 46.8%.

The mean and median effluent individual storm reductions for total magnesium were 30.5% and 27.8% respectively. Total event loadings for total magnesium sample pairs were 4.940 kg at the influent and 3.385 kg at the effluent, resulting in a SOL efficiency of 31.5%.

The mean and median effluent individual storm reductions for total calcium were 26.6% and 25.8% respectively. Total event loadings for total calcium sample pairs were 16.46 kg at the influent and 11.23 kg at the effluent, resulting in a SOL efficiency of 31.8%.

6.8.6 Nitrogen Performance

The mean and median effluent individual storm reductions for ammonia as N were 0.4% and 11.4% respectively. Total event loadings for ammonia as N sample pairs were 142.41 g at the influent and 140.49 g at the effluent, resulting in a SOL efficiency of 1.34%

The mean and median effluent individual storm reductions for nitrate + nitrite nitrogen were -7.5% and -3.4% respectively. Total event loadings for nitrate + nitrite nitrogen sample pairs were 1.13 kg at the influent and 1.17 kg at the effluent, resulting in a SOL efficiency of -3.83%

The mean and median effluent individual storm reductions for TKN were 55.3% and 58.3% respectively. Total event loadings for TKN sample pairs were 1.388 kg at the influent and 0.608 kg at the effluent, resulting in a SOL efficiency of 56.2%.

The mean and median effluent individual storm reductions for calculated TN (TKN+ NO2_NO3 as N) were 28.2% and 24.4% respectively. Total event loadings for calculated TN sample pairs were 2.51 kg at the influent and 1.78 kg at the effluent, resulting in a SOL efficiency of 29.3%

6.9 Statistical evaluation of performance goals

The TAPE requires bootstrapping to be used to compute the lower one-sided 95% confidence limit (LCL95) for pollutant removal efficiency for TSS and total phosphorus. Calculated limits are then compared to associated performance goals. If the computed LCL95 is higher than the treatment goal, it can be concluded that the stormwater treatment system met the specified performance goal with the required 95% confidence.

Select data from the 23 qualified events were analyzed using the TAPE bootstrap confidence interval calculator (bootstrap calculator) for TSS (Basic Treatment) and total phosphorus (Phosphorus Treatment). Printed screenshots showing the TSS and total phosphorus bootstrap calculator results can be seen in Appendix L.

The 15 sample pairs with influent TSS concentrations greater than 100 mg/L were analyzed to determine if the Basic Treatment performance goal was met. Influent concentrations greater than 200 mg/L were capped at that amount for the purposes of this calculation. Since the computed LCL95 of 82.0% is higher than the specified treatment goal of 80%, it is concluded that the treatment performance goal for this study was met.

The 18 total phosphorus sample pairs with concentrations between 0.1 and 0.5 mg/L were analyzed to determine if the total phosphorus treatment goal was met. Influent concentrations greater than 0.5 mg/L were capped at that amount for the purposes of this calculation. Since the computed LCL95 of 70.1% is higher than the specified treatment goal of 50%, it is concluded that the total phosphorus treatment performance goal for this study was met.

6.10 Pollutant Removal as a Function of Flow Rate

To evaluate pollutant removal as a function of flow rate, individual event EMCs for qualified TSS and total phosphorus sample pairs were compared to the corresponding aliquot-weighted influent flow rates. A regression analysis was then performed on these data points to determine how the treatment efficiency varies as flow rate increases. The aliquot-weighted influent flow rate was calculated by determining the flow rate at the time each influent aliquot was collected and then taking an average of these values. Removal efficiencies are plotted versus aliquot-weighted influent flow rate for TSS and total phosphorus. The linear regressions for each data set are shown relative to the current design treatment rate of 1.16 cfs (520 gpm). The diagnostic reports (scatter plots, residuals, regression analysis, etc.) used to determine the suitability for using regression are included in Appendix M. Several iterations of the linear regressions were explored, as detailed in the following sections.

As the typical rainfall distribution of the Pacific Northwest does not generate extended periods of high intensity precipitation, system performance as a function of aliquot-weighted influent flow rate does not adequately capture performance of the system at its design capacity. In an effort to address this issue, the updated TAPE guidelines of 2018 have revised the regression analysis to demonstrate performance at the 90th percentile flow rate at time of sample collection instead of the averaged rate. While the Dundee Jellyfish Filter is being evaluated under the 2011 TAPE, the 90th percentile analysis is also included. To better understand system performance at higher flows, the aliquot-weighted data set was supplemented with the discrete grab samples as discussed in Section 5.5.2. Performance data and associated flow rates for aliquot-weighted and discrete grab samples are provided in Table 23.

Table 23. Performance as a function of flow rate results

				Total Suspended Solids (TSS)			Total Phosphorus (TP)		
Event ID	Sample Type	Mean effluent flow rate at time of sample collection (gpm)	90th Percentile Flow at time of sample collection (gpm)	Influent result (mg/L)	Effluent result (mg/L)	Basic Criteria 2 100-200 mg/l ≥80% RE (%)	Influent result (mg/L)	Effluent result (mg/L)	Individual storm reduction (RE) (%) b
3/20/2017	Comp.	246	312	51.2	19.4				
3/21/2017	Comp.	294	397	102.0	22.0	78.4			
4/7/2017	Comp.	194	339	201.0	30.8	84.6	0.7060	0.0920	81.6
4/12/2017	Comp.	80	233	108.0	24.4	77.4	0.3380	0.0760	77.5
4/19/2017	Comp.	99	140	452.0	44.6	77.7	0.5000	0.0360	92.8
4/26/2017	Comp.	65	134	257.0	10.0	95.0	0.5040	0.0420	91.6
5/13/2017	Comp.	224	324	66.0	33.2		0.2560	0.1100	57.0
5/16/2017	Comp.	232	356	24.0	6.8		0.0940	0.0420	
6/8/2017	Comp.	139	210	73.6	16.8		0.2560	0.1040	59.4
6/15/2017	Comp.	130	199	134.0	10.4	92.2	0.3620	0.0520	85.6
3/8/2018	Comp.	61	158	755.0	47.2	76.4	1.7500	0.1300	74.0
3/14/2018	Comp.	60	133	181.0	27.0	85.1	0.6520	0.0940	81.2
3/16/2018	Comp.	13	24	19.0	ND		0.0820	0.0300	
3/22/2018	Comp.	86	123	224.0	20.0	90.0	0.3640	0.0720	80.2
3/27/2019	Comp.	207	386	94.0	11.0		0.2260	0.0699	69.1
4/5/2019	Peak	345		171.0	23.0	86.5	0.3370	0.0915	72.8
4/13/2019	Peak	256		117.0	25.0	78.6	0.2490	0.0870	65.1
5/18/2019	Peak	483		254.0	20.0	90.0	1.0900	0.1730	65.4
12/7/2019	Comp.	73	276	200.0	17.0	91.5	0.3350	0.1050	68.7
12/11/2019	Comp.	30	37	13.0	10.0		0.0806	0.0523	
12/19/2019	Comp.	380	529	91.0	31.0		0.2110	0.0925	56.2
3/30/2020	Peak	520		605.0	51.0	74.5	1.0500	0.0921	81.6
4/20/2020	Peak	524		210.0	29.0	85.5	0.4510	0.1120	75.2
Min		13	24	13.0	6.8	74.5	0.0806	0.0300	56.2
Max		524	529	755.0	51.0	95.0	1.7500	0.1730	92.8
Mean		206	239	191.4	24.1	84.2	0.4711	0.0836	74.2
Median		194	222	134.0	22.5	85.1	0.3380	0.0915	74.6

[a] Influent TSS concentrations capped at 200 mg/L for Individual Storm Reduction calculation purposes
[b] Influent TP concentrations capped at 0.5 mg/L for Individual Storm Reduction calculation purposes

6.10.1 Flow Rate Regression Analysis—Basic Treatment

The TAPE indicates that a regression analysis should be conducted to determine if TSS removal efficiency concentration varies as function of flow rate. The 10 qualified composite samples with influent concentrations above 100 mg/L and 5 discrete grab samples were used for this analysis. The results of the TSS regression analysis indicate that there is no significant relationship between individual storm TSS percent removal and the average sampled flow rate (P=0.302). As shown in Figure 10, regression of the individual storm TSS percent removal remains above the treatment goal of 80% at and above the design flow of 520 gpm. Two of the discrete grab samples had influent flow rates near the design flow rate, as seen by the data points at 520 gpm and 524 gpm.

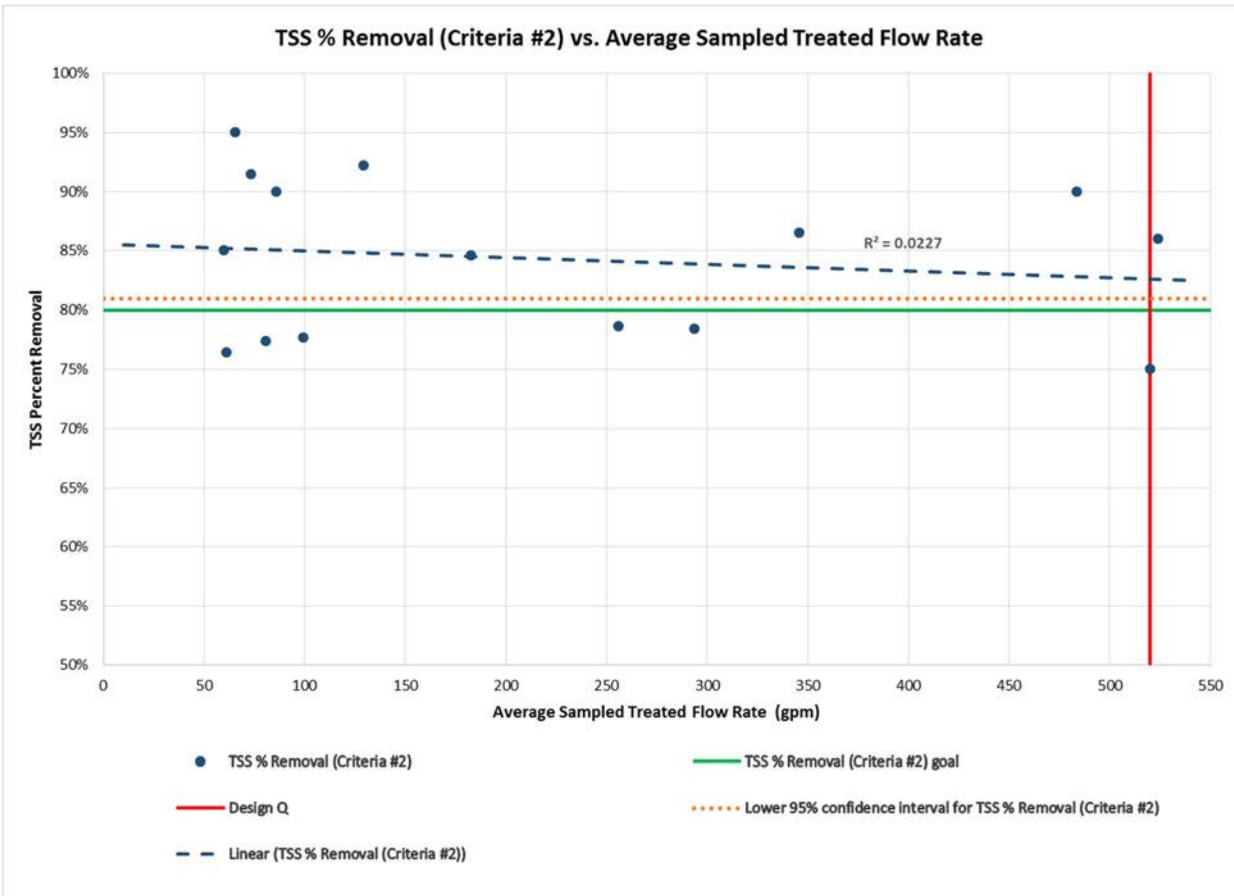

Figure 10.

Figure 11 shows TSS removal as a function of the 90th percentile sampled flow rate. Discrete grab sample flows were included. As shown, regression of the individual storm TSS percent removal continues to remain above the treatment goal of 80% at and above the design flow rate of 520 gpm.

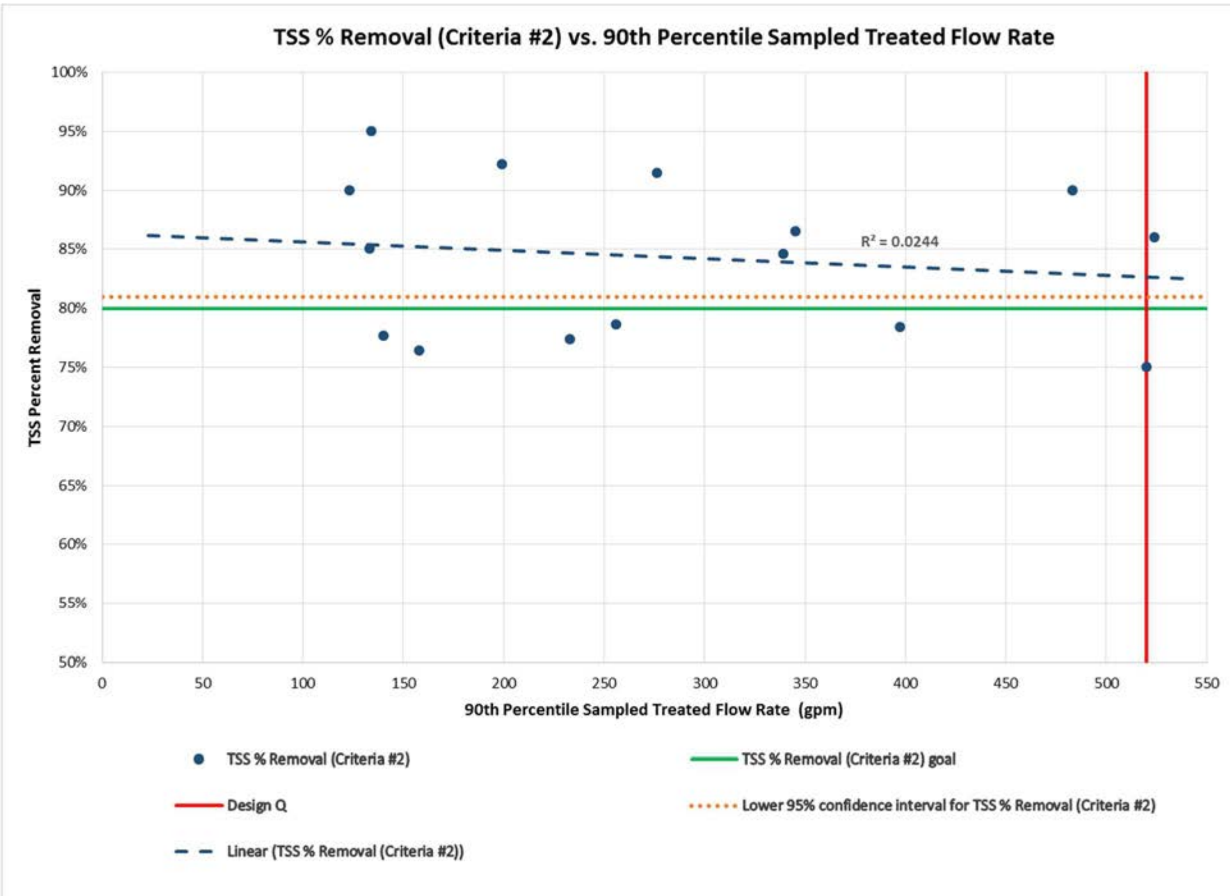

Figure 11.

6.10.2 Flow Rate Regression Analysis Total Phosphorus

The 13 qualified composite samples and 5 discrete grab sample were used for regression analysis of total P. The results of the total P regression analysis indicate there is no significant relationship between effluent concentration and flow rate (P=0.129). As shown in Figure 12, most of the data is weighted below the design flow rate, and regression of the individual storm total P percent removal remains above the treatment goal of 50% at and above the design flow of 520 gpm. Two of the discrete grab samples had average sampled flows equal to or greater than the design rate, with values of 520 and 524 gpm.

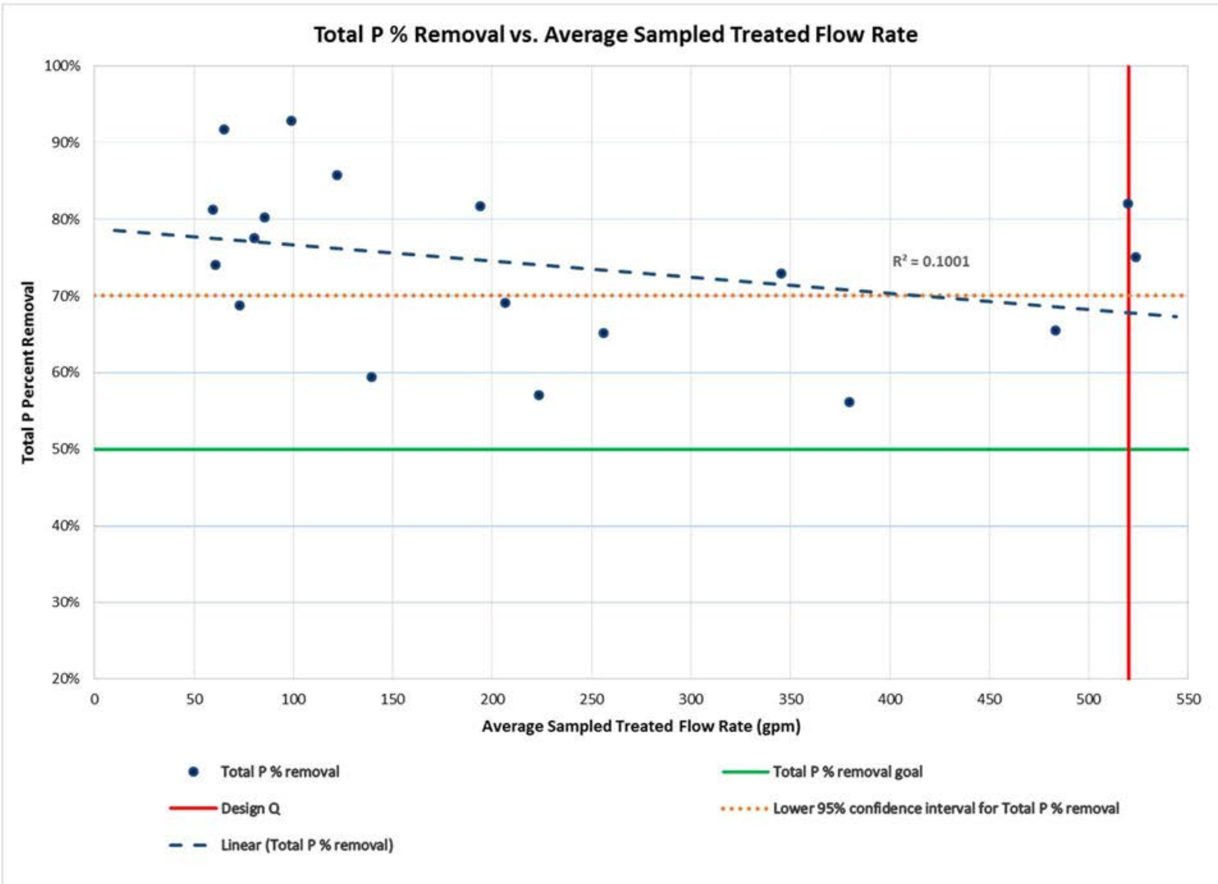

Figure 12.

Figure 13 shows total P removal as a function of the 90th percentile sampled flow rate. Discrete grab sample flows were included. As shown, regression of the individual storm total P percent removal continues to remain above the treatment goal of 50% at and above the design flow of 520 gpm. In the case of one of the events, the 90th percentile rate exceeded the design flow, as demonstrated by the sample point at 529 gpm.

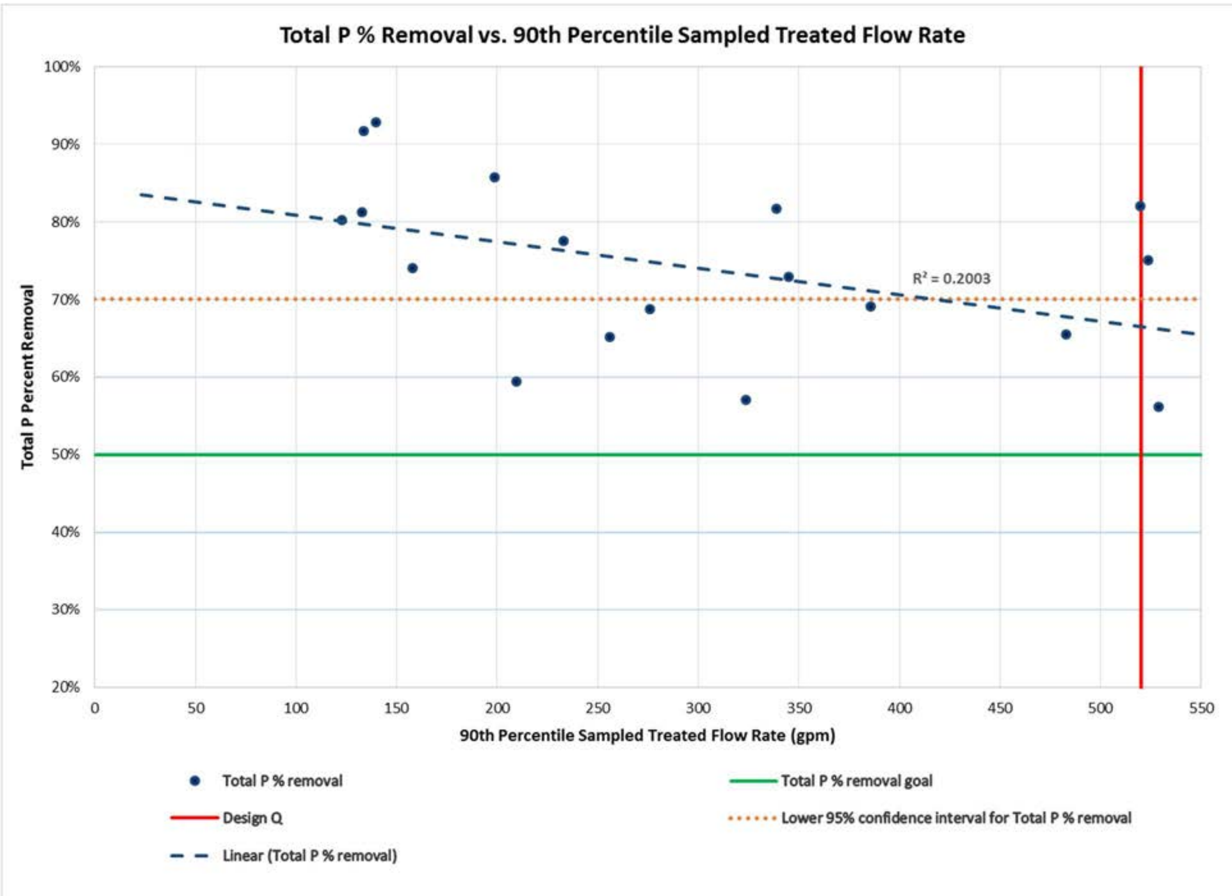

Figure 13.

6.11 Particle Size Distribution

Particle Size Distribution (PSD) is listed in the TAPE as a screening parameter and was required to be sampled for a minimum of three events (Ecology, 2018). The TAPE PSD method used is a modification of ASTM Method D3977-97 and defines particles larger than 250 µm in size as medium sand and larger, particles between 250 and 62.5 µm in size as very fine to fine sand, and particles smaller than 62 µm as silt and clay.

In addition to the TAPE PSD method, a second PSD procedure, serial filtration, was utilized for the PSD characterization as per the approved QAPP. Samples from 11 events were analyzed for influent and effluent PSD using this alternative procedure. For this serial filtration procedure, a composite sample was split into subsamples using a churn splitter. A storm by storm analysis was conducted to understand removal effectiveness over the range of particles segregated using 53µm, 100µm, 250µm, 500µm, and 2000µm sieves. Samples passing through each sieve were analyzed using the ASTM D3977-97 method. Due to sample volume requirements, only 11 sample pairs were analyzed. Appendix M includes additional particle size distribution data for individual events.

Based on influent TAPE PSD results, the median percentage of medium sand and larger, very fine to fine sand, and silt and clay sized material were 20%, 31%, and 51% respectively. Based on effluent TAPE PSD results, the mean percentage of medium sand and larger, very fine to fine sand, and silt and clay sized material were 17%, 18%, and 61% respectively. Interpolated D50 values for the influent and effluent median TAPE PSD results were 58 µm and 32 µm respectively, demonstrating that the majority of influent sediment particles fell within the silt/clay range per TAPE guidelines.

Samples were also analyzed for influent and effluent PSD using the serial filtration procedure to understand removal effectiveness over a broader range of particle sizes. There was a statistically significant difference between influent and effluent SSC results for all size ranges (P = <0.001).

Given that influent SSC concentrations for storm events used for the TAPE PSD analysis were all less than 200 mg/l, only storm events with influent concentrations less than 200 mg/l were evaluated for comparison purposes using the serial filtration procedure. Based on influent serial filtration results, the median percentage of silt and clay sized material at the influent sample location was 54%. Based on effluent serial filtration results the median percentage of silt and clay sized material at the effluent sample location was 99%. Interpolated D50 values for the influent and effluent median TAPE PSD results were 45 µm and 12 µm respectively.

A comparison of TAPE PSD and serial filtration particle size distribution results plotted on the TAPE (2011) defined scale is provided in Figure 14. Appendix M includes additional particle size distribution data for individual events.

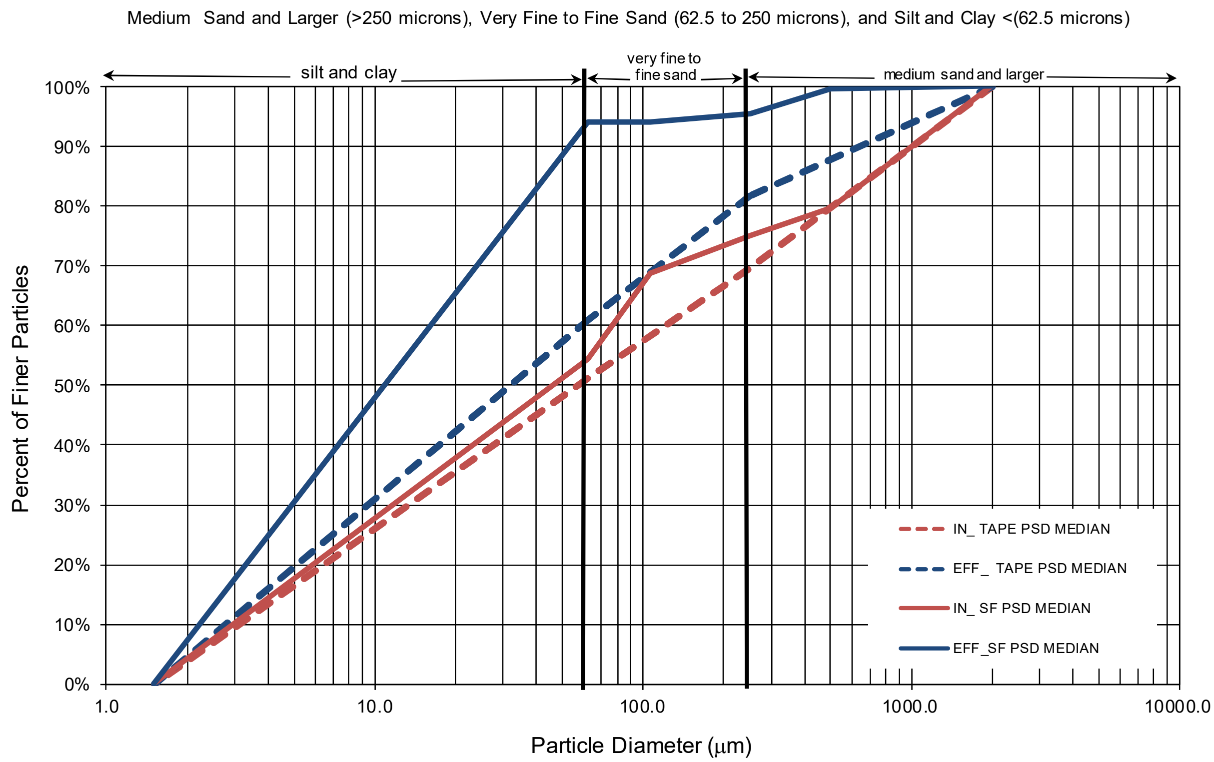

Figure 14. DJF PSD Results plotted on TAPE 2011 Defined Scale

In general, serial filtration PSD results yielded a higher percentage of silt and clay sized material then the TAPE PSD method. That said, it is possible that sand sized material is more difficult to keep in suspension using the churn splitter as the sample volume in the churn splitter decreases (Barr, 2018). The relatively low percentages of silt and clay sized material could also be due to losses during sample handling and transferal processes. The loss of material less than 62.5 um would be small with respect to absolute mass but substantial with respect to relative percentage of total mass. (Barr, 2018).

7.0 Operation and Maintenance Information

7.1 System Maintenance

Maintenance of the Jellyfish Filter was based upon results of the most recent inspection, historical maintenance records, or the site-specific water quality management plan. A total of seven system maintenance events occurred throughout the evaluation period, as shown in Table 9. Mean and median time periods between maintenance events were 3.2 and 3.0 months respectively. Mean and median cumulative precipitation amounts between maintenance activities were 4.7 in and 4.1 in respectively. Mean and median cumulative treated flow volumes between maintenance activities were 560,719 and

332,156 gallons respectively, including non-sampled flows. Table 24 shows the cumulative precipitation, total treated volume, and active months that the Jellyfish Filter was online between maintenance events. The chronology of this information is graphically displayed in Figure 15.

Table 24. Dundee Jellyfish Filter Maintenance History

Maintenance Event	Cumulative precip. between events (in.)	Cumulative treated volume (gal.) between events	Months Online
Cartridges replaced 4/5/2017	2.26	242,365	0.7
Full maintenance 10/18/2017	8.36	1,196,847	5.5
Full maintenance 8/22/2018	4.05	332,157	3.0
Cartridges replaced 4/2/2019	1.71	984,094	2.0
Full maintenance 10/21/2019	5.49	858,432	6.6
Full maintenance 3/24/2020	10.12	249,964	3.7
Cartridges replaced 4/17/2020	1.22	61,176	0.8
Mean	4.7	560,719	3.2
Median	4.1	332,157	3.0

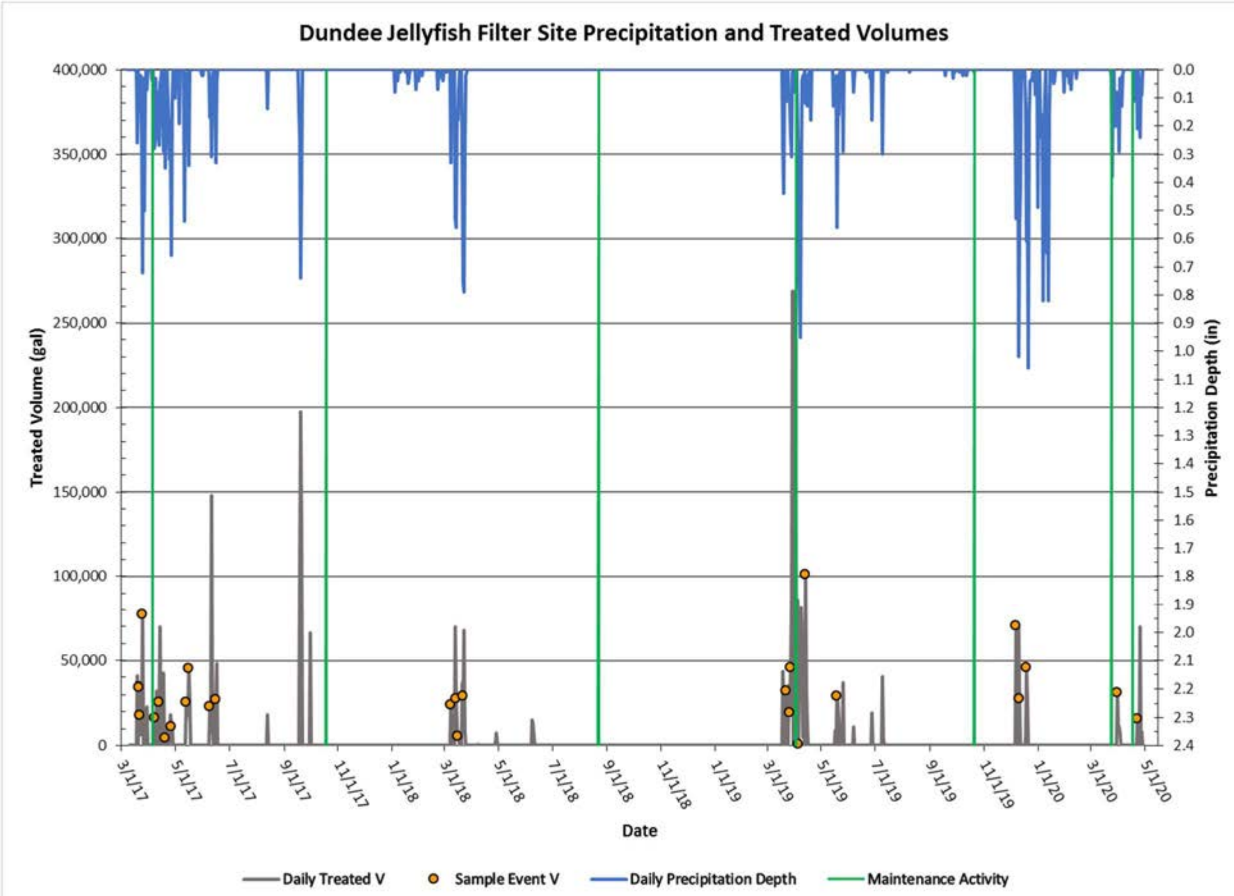

Figure 15. Dundee Jellyfish Filter Hydrologic and Maintenance Chronology

The Jellyfish Filter was installed on 3/8/2016 as depicted in Figure 16. Due to construction activities occurring on and adjacent to the site over the following year, the influent to the Jellyfish Filter unit was capped prior to the start of the monitoring period. As the system was designed in an external bypass configuration, runoff during the construction period was able to bypass the Jellyfish Filter through the StormGate diversion structure, but residual sediment accumulation was observed upstream of the unit after construction ended. This situation occurred multiple times during testing, prompting a number of maintenance events after periods of construction activity in the area.

Figure 16. Installation of the Jellyfish Filter in Dundee, OR

Following completion of construction activities on site and prior to the start of the evaluation period, the system was fully maintained on 3/7/2017, including the installation of new filter cartridges. Due to significant baseflows associated with groundwater present during the fall, winter, and spring months, an actuated slide gate was installed at the inlet to the Jellyfish Filter at this time. The slide gate, as seen in Figure 17, was controlled by an ISCO 6712 portable automated sampler and programed to open and close based on precipitation measured by the rain gauge installed on site, targeting a rainfall intensity of 0.04 in/hr prior to allowing flow into the unit. This rainfall quantity corresponded to the maximum allowed within the 6 hr antecedent/postcedent period defined by the TAPE. Once the rain gage registered 0.04 in/hr, a qualifying storm event was anticipated, and the gate was opened.

Figure 17. Actuated slide gate installed on the inlet to the JellyFish Filter

Filter cartridges were replaced on 4/5/2017 following a brief operational period when standing water inside but not outside the backwash pool was observed, indicating that the filter cartridges needed to be rinsed or replaced. Based on observations made on site, it was likely that portions of the drainage area were not swept and were not stabilized prior to putting the Jellyfish Filter back online. Filter cartridge occlusion was likely due to sediment loading associated with construction activities in the area.

Due to continued construction activities as well as a car accident occurring adjacent to the site, the influent to the Jellyfish Filter unit was again capped on 9/21/2017, and monitoring was paused. The system was fully maintained on 10/18/2017. Maintenance involved the replacement of filter cartridges as well as the removal of floatable trash, debris, oil, and accumulated sediments in the sump. After an inspection of the drainage area to ensure it had been swept and was stabilized, the system was placed back online on 01/01/2018.

Once monitoring resumed, it was observed that runoff associated with construction activities was still able to enter the system as seen in Figure 18. It was during this period that some of the heaviest influent TSS concentrations were measured, including an EMC of 755 mg/L on 3/8/2018. On 4/1/2018, the influent to the Jellyfish Filter unit was capped once more, and the system was fully maintained on 8/22/2018. Upon conclusion of construction activities, the site was again inspected to ensure that it had been swept and was stabilized, and the system was placed back online on 02/1/2019.

Figure 18. Runoff observed during construction activities entering the inlet directly upstream of the Jellyfish.

Following a brief operational period, standing water was again observed inside but not outside the backwash pool, indicating a need for maintenance. While the site appeared to be stabilized, it was likely that residual construction sediment was continuing to be transported to the Jellyfish Filter from the large catchment area upstream. While brief, this timeframe saw high-intensity events that delivered the 2nd largest cumulative treatment volume to the system between maintenance events. Cartridges were replaced on 04/02/2019.

Following an extended operational period, the site was surveyed on 10/9/2019 in effort to determine why the system was not consistently reaching the design operating rate of 1.16 cfs (520 gpm). Based on the results of the survey, it was determined that the weir in the StormGate diversion manhole was set too low to deliver the required driving head to the filter cartridges. In preparation to adjust the weir height to enable the system to operate at its design operating rate, the system was fully maintained on 10/21/2019.

Figure 19. Replacement Filter cartridge next to occluded cartridge on site

After maintenance, the StormGate weir height was increased from 18 in to 21 in above the deck of the Jellyfish Filter on 10/25/19. Following the weir height adjustment, an in-situ cartridge flow test was performed to determine if the adjustment would enable the system to operate at its design treatment rate. The cartridge flow test confirmed that a driving head of 21 in sufficiently achieved cartridge design flows. Subsequent monitoring yielded treatment flows exceeding system design for 80% of sampled events, verifying the required driving head. Designs in Western Washington will use 21 in as the minimum required driving head.

The Jellyfish Filter was maintained on 03/24/2020 following an extended fall and winter weather operational period that produced 10.1 in of measured precipitation. Maintenance involved the replacement of filter cartridges as well as the removal of floatable trash, debris, oil, and accumulated sediments in the sump.

Cartridges were replaced on 04/17/2020 following a brief operational period when field observations indicated that the filter cartridges needed to be rinsed or replaced. During this time, a peak grab sample event with an influent TSS concentration of 605 mg/L was captured, demonstrating the atypically high sediment loading periodically associated with the area. As discussed in section 6.3.1, the SWMMWW lists a typical TSS concentration for roadway runoff of 169 mg/L.

7.2 Bypass

The Jellyfish filter was installed in an external bypass orientation, using a StormGate diversion manhole directly upstream of the system to direct treatment flows to the Jellyfish filter while bypassing flows in excess of its capacity. Thus, no internal bypass was observed over the course of the study. However, external bypass was recorded for nearly all sampled events, with discrepancies in bypass volumes attributed to site influences such as high sediment and debris loading as discussed in section 6.3.1.

7.3 Screening Parameter Results

Screening parameters were collected for a minimum of 3 sampled events, as required in the approved QAPP. The analytes evaluated were PSD, total phosphorus, orthophosphate, hardness, and pH, total and dissolved copper, and total and dissolved zinc. The above listed screening parameters were evaluated for four events. Results for all screening parameters tested except for PSD, can be seen in Tables 25, 26, and 27. PSD results are discussed in Section 6.11. All screening parameter results showed removal of the specified pollutants for all three sampled events except for the 3/22/2019 event during which an increase in hardness, pH, total and dissolved copper, and total and dissolved zinc was observed.

Table 25. Screening parameter results for SSC, total phosphorus, and orthophosphate

Event ID	TSS_SSC (mg/L)		TP (mg/L)		Otho_P (mg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
3/22/2019	32.8	5.97	0.143	ND (0.1)	0.0119	ND (0.01)
3/26/2019	15.3	9.52	ND (0.1)	ND (0.1)	0.0294	0.0266
3/27/2019	53.8	6	0.223	0.0637	0.0192	0.0156
12/19/2019	74.2	35.6	0.199	0.0921	0.0341	0.0287

Table 26. Screening parameter results for hardness and pH

Event ID	Hardness (mg/L)		pH (mg/L)	
	Influent	Effluent	Influent	Effluent
3/22/2019	36.8	39.1	7.17	6.95
3/26/2019	35.7	32.6	7.25	7.16
3/27/2019	29	27.1	6.76	6.81
12/19/2019	18.5	15.4	7.08	7.03

Table 27. Screening parameter results total and dissolved copper and total and dissolved zinc

Event ID	Total Cu (mg/L)		Diss. Cu (mg/L)		Total Zn (mg/L)		Diss. Zn (mg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
3/22/2019	0.0119	0.0143	0.00513	0.0113	0.0566	0.0499	0.025	0.043
3/26/2019	0.011	0.0103	0.00605	0.00744	0.0385	0.0325	0.0198	0.0263
3/27/2019	0.0134	0.00479	0.00396	0.00376	0.0681	0.0336	0.0199	0.0325
12/19/2019	0.014	0.00708	0.00299	0.00369	0.152	0.0764	0.0582	0.0508

8.0 Discussion

The TAPE (2011) requires the following information to be included in the discussion section.

8.1 Statistical Data Evaluation

A one-tailed Wilcoxon signed-rank test performed on qualified TSS and total phosphorus data indicated there was a statistically significant reduction between the influent and effluent concentrations for all parameters based on an alpha (α) level of 0.05.

The lower 95% confidence limit (LCL95) mean percent reductions for TSS and total phosphorus were 82.0% and 70.1% respectively.

8.2 Explanation of any deviations from sampling procedures

There were no deviations from water sampling procedures. The actuated slide gate was added to the system layout in order to minimize influent due to baseflows or other non-stormwater runoff flows. An optional sediment sampling procedure was not implemented as listed in the QAPP.

8.3 Information about anticipated performance in relation to climate, design storm, or site conditions

As described in the QAPP, the site was selected for evaluation to allow for the evaluation of the system at peak operating rates. A full range of operating rates was experienced throughout the evaluation period. The design flow rate of 1.16 cfs (520 gpm) was met or exceeded in 4 of the evaluated storm events.

8.4 Information on recommended operation and maintenance schedules

Excluding the time period when the system was taken offline during construction activities on site, the system has exhibited a mean and median maintenance cycle of 3.2 and 3.0 months respectively, with a maximum online period of 6.6 months. Extreme weather and construction activities triggered spot inspections and subsequent maintenance as discussed in section 7.1. Influent TSS loadings were found to be very high at various points throughout the study period, and the composition of construction sediment likely caused the Dundee Jellyfish Filter to become occluded more frequently than would be expected under normal site conditions.

8.5 Identification of any special disposal requirements

There were no special disposal requirements associated with the captured materials in the system. Materials can be disposed of in accordance with local regulations.

9.0 Conclusions

A Jellyfish Filter treating runoff from and 86 acres site, comprised of a mix of roadway and commercial/residential development in Dundee OR, was evaluated over a 37-month evaluation period. During this field monitoring campaign, the system was placed offline for a total of approximately 15 months, as detailed in Table 9. 23 storm events were sampled for evaluation and met the storm event and sampling collection criteria.

For TSS, 6 of the 23 sampled storm events met the sample collection criteria and had influent concentrations between 20 and 100 mg/L. Mean and median effluent concentrations for those storms were 19.7 and 18.1 mg/L respectively. Influent TSS concentrations for 15 of the 23 qualified storm events were greater than 100 mg/L. These 15 sample pairs were analyzed relative to the Basic Treatment performance goal. Mean and median removal efficiencies were 84.2% and 85.1% respectively for events that had influent concentrations greater than 100 mg/L. Data for events that had influent concentrations greater than 100 mg/L were analyzed using the TAPE bootstrap confidence interval calculator for TSS. The computed lower 95% confidence interval (LCL95) for TSS removal efficiency was 82.0%. Since the computed LCL95 was greater than the TAPE specified treatment goal of 80 % removal for TSS, it is concluded that the Basic Treatment goal was met. Performance vs. flow rate results indicate that the Basic Treatment goal is projected to be consistently achieved at or above the design treatment rate of 1.16 cfs (520 gpm).

Total event loadings for the sampled storm events that were determined to meet the sample collection criteria for TSS were 450.4 kg at the influent and 59.2 kg at the effluent, resulting in a summation of loads efficiency of 86.9%.

For Total Phosphorus, 18 of the 23 qualified storm events were determined to meet the sample collection criteria and had influent concentrations between 0.1 and 0.5 mg/L. A total of 18 sample pairs were analyzed for performance relative to the Phosphorus Treatment performance goal. Mean and median removal efficiencies were 74.2 % and 74.6 % respectively for events that had influent concentrations between 0.1 and 0.5 mg/L. The computed LCL95 for Total Phosphorus removal efficiency was 70.1%. Since the computed LCL95 was higher than the specified treatment goal of greater than or equal to 50 % Total Phosphorus removal efficiency, it is concluded that the Total Phosphorus treatment performance goal was met. Performance vs. flow rate results indicate that the Phosphorus Treatment performance goal is projected to be consistently achieved at or above the design treatment rate of 1.16 cfs (520 gpm).

Total event loadings for sampled storm events that were determined to meet the sample collection criteria for Total Phosphorus were 1,034.9 g at the influent and 213.0 g at the effluent, resulting in a SOL efficiency of 79.4%

Influent EMCs for TVSS ranged from 4.23 mg/L to 473.0 mg/L with a mean of 79.2 mg/L and a median of 45.0 mg/L. Corresponding effluent EMCs for TVSS ranged from 1.72 mg/L to 8.87 mg/L with a mean of 5.03 mg/L and a median of 5.26 mg/L. The mean and median individual storm reductions for TVSS were 91.3 and 93.4% respectively. Total event loadings for TVSS for qualified TVSS sample pairs were 167.82 kg at the influent and 12.52 kg at the effluent, resulting in a SOL efficiency of 92.5%.

Influent EMCs for Suspended Sediment Concentration (SSC) less than 62.5µm (SSC <62.5µm) ranged from 25.0 mg/L to 312.0 mg/L with a mean of 115.2 mg/L and a median of 103.0 mg/L. Corresponding effluent EMCs for SSC (<62.5 µm) ranged from 4.13 mg/L to 55.2 mg/L with a mean of 23.29 mg/L and a median of 24.9mg/L. Total event loadings for SSC (<62.5µm) for qualified SSC (<62.5µm) sample pairs was 106.5 kg at the influent and 23.5 kg at the effluent, resulting in a SOL efficiency of 78.0%

Influent EMCs for TKN ranged from 0.25 mg/L to 2.00 mg/L with a mean of 0.81 mg/L and a median of 0.76 mg/L. Corresponding effluent EMCs for TKN ranged from 0.10 mg/L to 0.76 mg/L with a mean of 0.34 mg/L and a median of 0.33. The mean and median effluent individual storm reductions for TKN are 55.3% and 58.3% respectively. Total event loadings for TKN were 1.388 kg at the influent and 0.608 kg at the effluent, resulting in a SOL efficiency of 56.2%.

Influent EMCs for calculated TN (TKN+ NO2_NO3 as N) ranged from 0.79 mg/L to 3.44 mg/L with a mean of 1.55 mg/L and a median of 1.36 mg/L. Corresponding effluent EMCs for calculated TN (TKN+ NO2_NO3 as N) ranged from 0.51 mg/L to 2.27 mg/L with a mean of 1.12mg/L and a median of 0.85 mg/L. The mean and median effluent individual storm reductions for calculated TN (TKN+ NO2_NO3 as N) are 28.2% and 24.4% respectively. Total event loadings for calculated TN (TKN+ NO2_NO3 as N) sample pairs were 2.513 kg at the influent and 1.776 kg at the effluent, resulting in a SOL efficiency of 29.3%

Influent EMCs for total zinc ranged from 0.0381 mg/L to 1.8900 mg/L with a mean of 0.2397 mg/L and a median of 0.1300 mg/L. Corresponding effluent EMCs for total zinc ranged from 0.0166 L to 1.2400 mg/L with a mean of 0.1010 mg/L and a median of 0.0372 mg/L. The mean and median effluent individual storm reductions for total zinc are 60.9% and 60.2% respectively. Total event loadings for total zinc sample pairs were 533.2 g at the influent and 224.4 g at the effluent, resulting in a SOL efficiency of 57.9%

Influent EMCs for total copper ranged from 0.0060 L to 0.1360 mg/L with a mean of 0.0292 mg/L and a median of 0.0182 mg/L. Corresponding effluent EMCs for total copper ranged from 0.0019 mg/L to 0.0172 mg/L with a mean of 0.0069 mg/L and a median of 0.0065 mg/L. The mean and median effluent individual storm reductions for total copper are 65.5% and 66.9% respectively. Total event loadings for total copper sample pairs were 66.77 g at the influent and 17.41 g at the effluent, resulting in a SOL efficiency of 73.9%

Influent EMCs for total lead ranged from 0.00116 mg/L to 0.03630 mg/L with a mean of 0.00824 mg/L and a median of 0.00661 mg/L. Corresponding effluent EMCs for total lead ranged from 0.00029 mg/L to 0.00284 mg/L with a mean of 0.00130mg/L and a median of 0.00110 mg/L. The mean and median effluent individual storm reductions for total lead are 76.6% and 84.3% respectively. Total event loadings for total lead sample pairs were 12.59 g at the influent and 2.21 g at the effluent, resulting in a SOL efficiency of 82.4%

Influent EMCs for total cadmium ranged from 0.00013 mg/L to 0.00134 mg/L with a mean of 0.00047 mg/L and a median of 0.00030 mg/L. Corresponding effluent EMCs for total cadmium ranged from 0.00007 mg/L to 0.00053 mg/L with a mean of 0.00021 mg/L and a median of 0.00020 mg/L. The mean and median effluent individual storm reductions for total cadmium are 35.2% and 44.6% respectively. Total event loadings for total cadmium sample pairs were 0.718 g at the influent and 0.382 g at the effluent, resulting in a SOL efficiency of 46.8%

10.0 Appendices

- Appendix A - System Configuration Information
- Appendix B - Operation and Maintenance Manual
- Appendix C - Site Plan
- Appendix D- Hydrological Data QA
- Appendix E - Approved QAPP
- Appendix F - Analytical QA
- Appendix G - Analytical Lab QA
- Appendix H - Field Recordkeeping Forms
- Appendix I- Individual Storm Reports
- Appendix J - Raw Data Tables
- Appendix K - Analytical Laboratory Reports
- Appendix L - Statistical Test Results
- Appendix M- Particle Size Distribution
- Appendix N - Field Maintenance Record keeping Forms

11.0 References

Barr, M.N., 2018, Evaluation of Whole-Water Churn Splitters for Suspended Sediment Sample Collection and Analysis, approved for publication, U.S. Geological Survey.

Gray, J.R., Glysson, G.D., and Conge, L.M., 2000, Comparability of Total Suspended Solids and Suspended Sediment Concentration Data, approved for publication, U.S. Geological Survey.

Imbrium Systems Corporation, 2012. Application Letter for CULD for Jellyfish Filter Basic Treatment, Phosphorus Treatment, and Oil Treatment. Submitted to Washington Ecology.

Imbrium Systems Corporation, 2008a (February, Revised March 28), Jellyfish Fine Sediment Filter Laboratory Evaluation, submitted to the New Jersey Corporation for Advanced Technology (NJCAT).

Imbrium Systems Corporation, 2008b (January), Laboratory Performance Testing Quality Assurance Project Plan For Imbrium Systems' Jellyfish™ Filter, submitted to the New Jersey Corporation for Advanced Technology (NJCAT).

Müller, Tobias. 2017. Forensic Analysis of an Aged Infiltration Trench and Evluation of its Retrofit. Villanova University. Villanova, Pennsylvania.

2011, TARP field test performance monitoring of a Jellyfish® Filter JF4-2-1, Engineering School of Sustainable Infrastructure and Environment (ESSIE), University of Florida, Gainesville, Florida.

2014, Evaluation of Treatment Performance of The JellyFish Filter Installation at Ipswich Interim Report on the Field Monitoring Program, Science and Engineering Department, Queensland University of Technology, Queensland, Australia.

URS Greiner Woodward Clyde, Urban Drainage and Flood Control District, Urban Water Resources Research Council (UWRRC) of ASCE, Office of Water, US Environmental Protection Agency (URS/EPA) (1999). Development of Performance Measures Task 3.1 – Technical Memorandum Determining Urban Stormwater Best Management Practice (BMP) Removal Efficiencies. Washington, D.C.: Author.

Washington State Department of Ecology (Ecology). (2011). Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE). Olympia, Washington. (Referred to as TAPE)

Washington State Department of Ecology (Ecology). (2018). Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE). Olympia, Washington. (Referred to as TAPE)