APPLICATION FOR CONDITIONAL USE LEVEL DESIGNATION

THE KRAKEN™ MEMBRANE FILTER

Prepared for

Bio Clean Environmental Services, Inc.

Prepared by
Herrera Environmental Consultants, Inc.

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Note:

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CONTENTS

APPENDICES

TABLES

FIGURES

INTRODUCTION

The Washington State Department of Ecology (Ecology) has established specific use level designations for emerging stormwater treatment technologies in accordance with guidelines from the Technology Assessment Protocol-Ecology (TAPE) (Ecology 2011). There are three use level designations: pilot, conditional, and general. Pilot and conditional use level designations allow limited application of emerging stormwater treatment technologies in Washington to facilitate field testing. If this testing shows that the treatment technology meets minimum treatment goals identified in the TAPE, Ecology may issue a general use level designation (GULD) for the technology, permitting its more widespread use in Washington.

The Kraken™ Membrane Filtration System (the Kraken™ Filter) is a structural stormwater treatment system developed by Bio Clean Environmental Services, Inc. (Bio Clean). This document serves as the application for granting the Kraken™ Filter a conditional use level designation (CULD). This document was prepared by Herrera Environmental Consultants (Herrera) to demonstrate satisfactory performance of the Kraken™ Filter in meeting goals specified by Ecology (2011) for basic and phosphorus treatment. It specifically presents data from laboratory testing that was conducted at the Good Harbour Laboratories in Mississauga, Ontario and field testing that was performed in water year 2017 at the Washington State Department of Transportation (WSDOT) Ship Canal Test Facility (SCTF) in Seattle, Washington.

The SCTF is a dedicated facility for testing the pollutant removal effectiveness of emerging stormwater treatment devices. Up to four systems can be tested in parallel. Each system can receive runoff from a 31.6 acre basin, the majority of which is highway runoff from I-5. The flows are divided with a series of adjustable flow splitters and valves such that design storms can be directed to each device.

Testing of a Kraken™ Filter at the SCTF has been underway since November 2016 with the goal of obtaining at least 12 qualifying paired samples pursuant to requirements from the TAPE. After this testing was initiated, it quickly became apparent that the stormwater entering the system was associated with fine organic-rich suspended solids and oils which resulted in premature filter clogging. This rapid clogging was also observed in 3 other filters installed at the facility during the same period; hence, it is likely that this clogging is related to the pollutant profile of highway runoff rather than the filter design.

Bio Clean and Ecology have agreed that an interim dataset (14 paired samples) can be submitted with the aim of obtaining a CULD for the Kraken™ Filter. Bio Clean will then search for an additional site which is more representative of the urban runoff that Kraken™ Filter would typically encounter to conduct flow testing. Data obtained from flow testing at this additional site will be used to verify the maintenance cycle conforms with expectations under these more typical conditions. With the combined water quality dataset from the SCTF and the flow dataset from this yet-to-be-identified additional site, it is Bio Clean's goal to synthesize the data to support the issuance of GULD from Ecology at a later date.

TECHNOLOGY DESCRIPTION

The Kraken™ Filter stormwater treatment system provides water quality treatment of captured flows through several physical processes. This section describes the system's physical components, treatment processes, sizing methods, expected treatment capabilities, expected design life, and maintenance procedures. Note that the test system installed at the SCTF for the monitoring pursuant to the TAPE was designed with a slightly different bypass, which is discussed in more detail below (also see detailed design drawings Appendix A).

The Kraken™ Filter is an engineered stormwater quality treatment device that utilizes a reusable membrane filter designed to remove total suspended solids (TSS), hydrocarbons, particulate metals, and nutrients found in contaminated stormwater. Each filter contains a large surface area that is designed to deal with high TSS and particulate concentrations. The large surface area of each filter allows it to operate at a loading rate from one-fourth to one-twentieth the loading rate of other media filtration devices to improve longevity.

Figure 1 shows cutaway views of the system's pretreatment, filtration, and discharge chambers. The pretreatment chamber is portioned into primary and secondary separation chambers divided by a baffle wall. The secondary separation chamber contains a floatables/oil baffle wall that extends upward. That wall directs water to pass underneath it, thereby trapping floatables and free floating hydrocarbons. After water passes under the floatables/oil baffle wall, it travels upward to the filter chamber orifices and enters the filter chambers.

The Kraken™ Filter is different from other membrane filters in that it has separation chambers that are utilized as a form of pretreatment for floatables, oils, coarser sediments, and other suspended particulates. By filtering out the coarser material prior to reaching the membrane filters, the efficiency of the system is increased and maintenance requirements are reduced. The Kraken™ Filter pretreatment chamber is configured with two separation chambers. The physical height of both separation chambers is 2.5 feet for units with a 30.75-inch-tall cartridge. The secondary separation chamber contains a floatables/oil skimmer wall in the middle that protrudes down to a level of 1.25 feet off the floor of the chamber and up several feet above the pretreatment chamber. Entering stormwater must pass over a baffle separating the primary and secondary separation chambers, and then pass under the floatables/oil skimmer wall before being directed back up to the exit point.

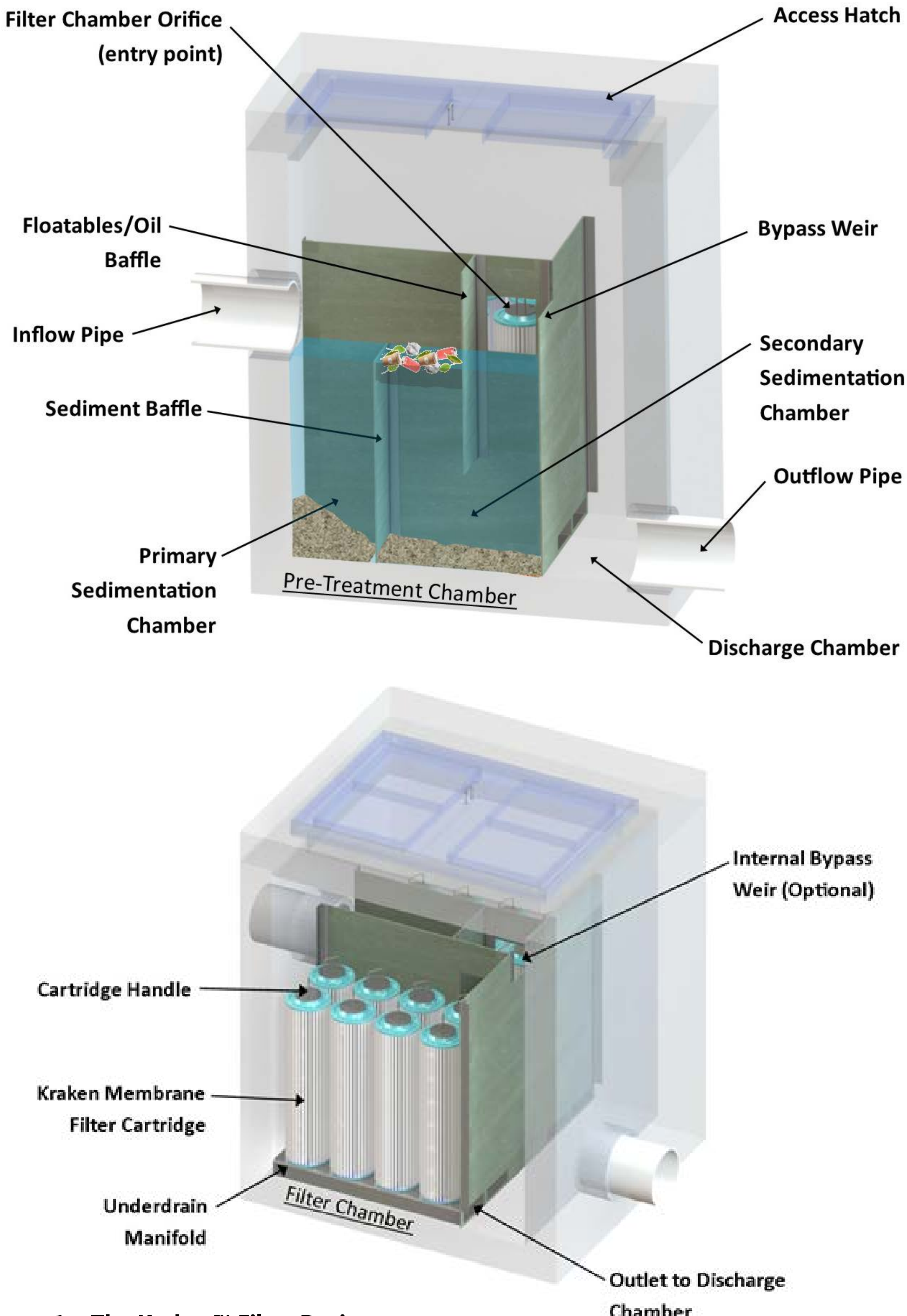


Figure 1. The Kraken™ Filter Design.

Once stormwater exits the pretreatment chamber of the Kraken™ Filter, it passes through the filter chamber orifices and into the filtration chambers where the membrane filters are located. The membrane is made of a pleated paper material designed specifically for treatment of stormwater. There are no additives, algaecides, or other compounds in the membrane that could impart toxicity to the effluent stormwater. Figures 2 and 3 illustrate the operation of the Kraken™ Filter once water enters the filtration chamber. The membrane filters sieve out finer micron sediments and associated contaminants. The Kraken™ Filter is a unique design in that the filter's efficiency is controlled by an internal riser tube, so the filters begin to process and discharge only when the water level reaches the top of the filter column, which is close to the maximum hydraulic grade line in the filtration chamber. The riser tubes also control the flow rate to a level substantially less than the maximum flow capacity of the membrane filters, which creates a built-in safety factor and promotes longevity of the system's treatment capacity. It also helps guard against clogging by ensuring the sediment loading is evenly distributed along the full height of the cartridge. Once the water level nears the top of the cartridge, it starts passing through the membrane and collecting in the center effluent tubing of each cartridge. Treated water then passes down the center of the riser tube, collects in the horizontal underdrain manifold, and flows toward the discharge chamber. After water enters the discharge chamber, it exits the system via the outlet pipe.

An optional, internal bypass weir, located at the effluent end of the secondary pretreatment chamber, is available (Figure 4). The Kraken™ Filter can be used in a traditional setup (that is, without the internal bypass feature) that uses an external flow splitter/diversion weir structure (not pictured). The optional, internal bypass weir allows runoff to pass directly from the secondary pretreatment chamber to the discharge chamber without passing through the filtration chamber. Figure 4 illustrates the bypass flow path within the system. Water passes over the bypass weir once incoming flow exceeds the system's treatment capacity, thereby preventing scouring of fine sediment and other pollutants previously captured in the filtration chamber. Because the system has a three–chamber design (pretreatment, filtration, and discharge) and internal bypass occurs directly from pretreatment to discharge without passing through the filtration chambers, the filter cartridges operate in the same manner with or without the optional, internal bypass weir.

For the Kraken™ Filter installed at the SCTF for monitoring pursuant to the TAPE, an 8-inch pipe replaced the bypass weir to connect to route bypass water directly from the filtration chamber through the downstream vault wall (Appendix A). This design change was included to prevent bypass water from mixing with treated water so the two flow rates could be measured independently (a TAPE requirement). Based on the designer's calculations, the head above the weir would be 1.25 inches at 125 percent of the design flow rate. At this same flow rate, head in the bypass pipe would be 1.62 inches. This 0.37-inch difference will create a minimal increase in treated flow rate at bypass with the piped bypass configuration. Though small, this higher-than-typical flow rate will result in a conservative estimate of treatment during bypass in the test system.

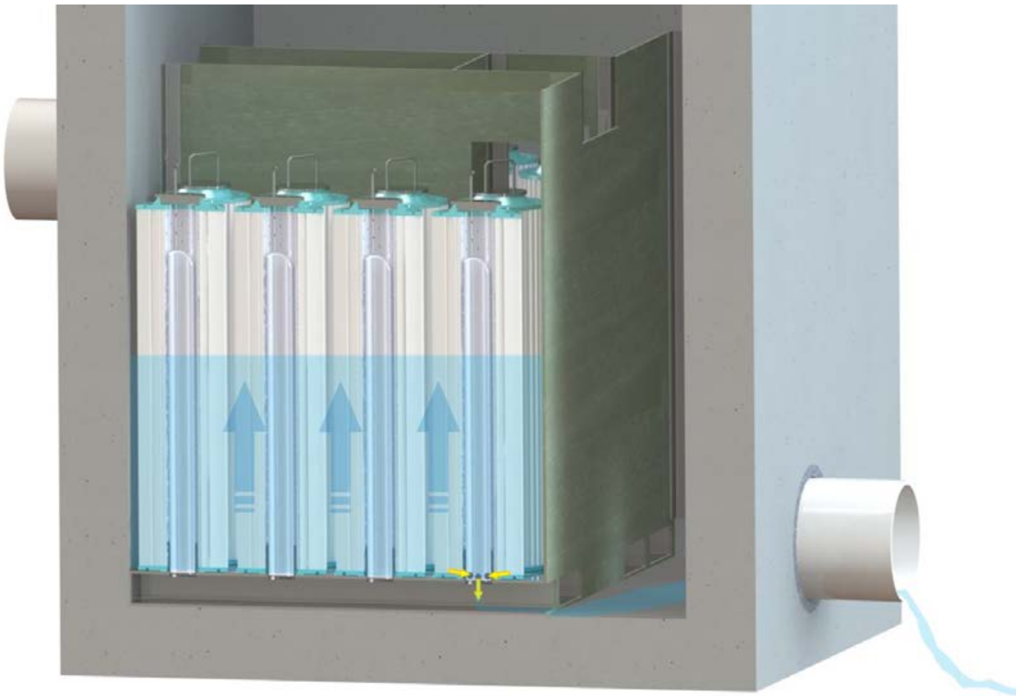


Figure 2. Fill-Up Period – Less Than Peak Treatment Capacity.

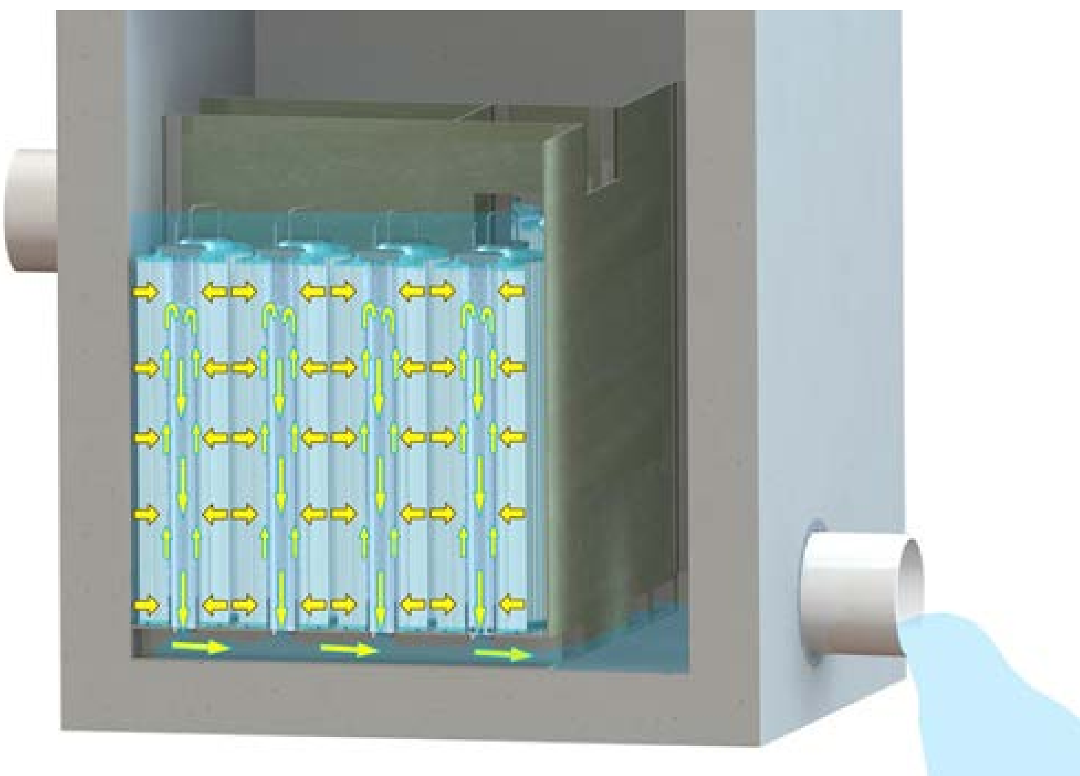


Figure 3. Max Operating Head – At Peak Treatment Capacity.

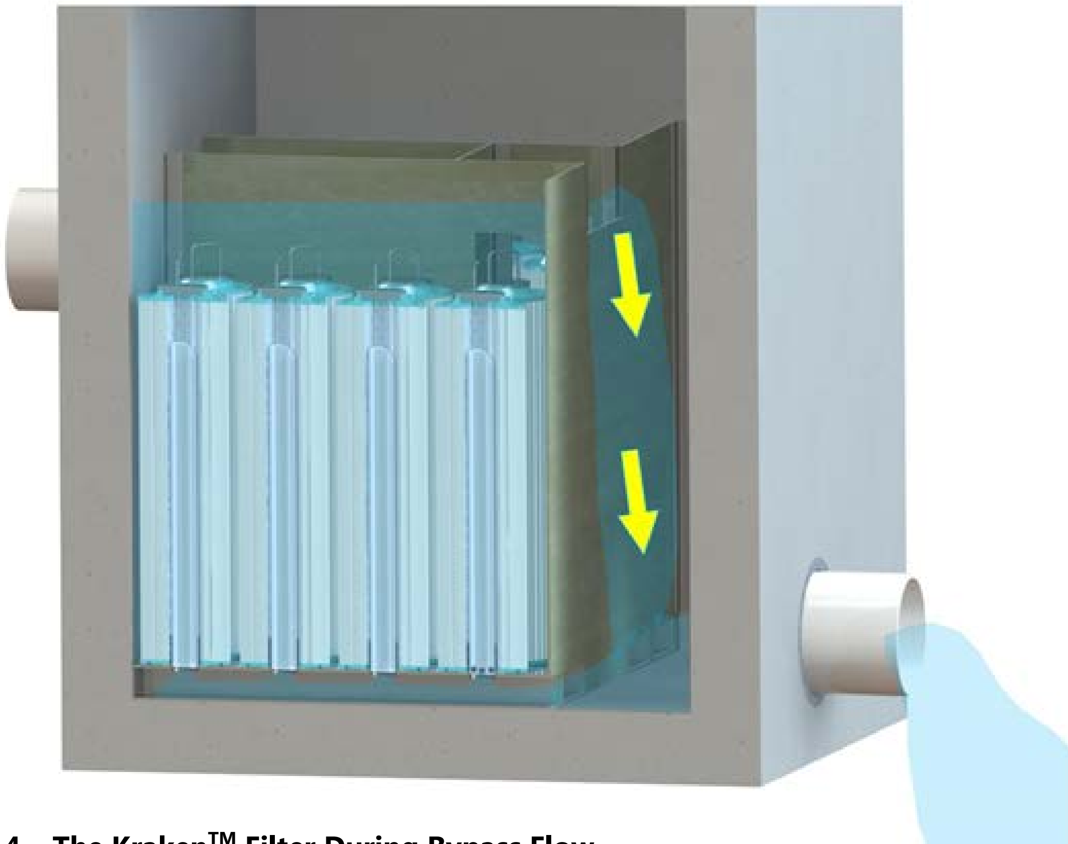


Figure 4. The Kraken™ Filter During Bypass Flow.

System Sizing

Table 1 provides design flow rates to achieve the basic and phosphorus treatment goal from the TAPE. These flow rates should be used in conjunction with the Western Washington Hydrology Model, Version 2012 (WWHM2012) or another continuous hydrologic model approved by Ecology to determine the drainage area which would result in treatment of 91 percent of the annual runoff volume. For sizing in eastern Washington, HydroCAD, StormSHED, or another approved single-event model should be used to size for the 6-month design storm.

Maintenance Requirements

Appendix B provides Bio Clean's Operations and Maintenance Manual for the Kraken™ Filter. The Kraken™ Filter is designed for easy maintenance. Handles are provided on each filter cartridge to facilitate their installation and removal. The pressure fitting at the bottom of the filter has been designed so the cartridge can be quickly removed and reattached without any tools. Large access hatches allow for cleaning the pretreatment and filtration chambers without entry into the system. The filter cartridges can be removed, held over a standard trash can, and sprayed clean. Completing all maintenance activities for a typical manhole Kraken™ Filter takes less than 1 hour.

Table 1. Specifications of Standard Kraken™ Filter Models.							
Kraken™ Model No.	Inside Width (feet)	Inside Length (feet)	Sedimentation Area (sq ft)	Design Flow Rate (cfs)	Effective Media Surface Area (sq ft)	Drainage Basin (acres)[a]	Number of Cartridges
KF-2.5-4	2.5	4	7.1	0.152	1360	1.85	8
KF-4-4	**4**	**4**	**11.7**	**0.303**	**2720**	3.7	**16**
KF-4-6	4	6	17.8	0.455	4080	5.55	24
KF-4-8	4	8	23.7	0.606	5440	7.45	32
KF-8-8	8	8	42.5	0.909	8160	11.15	48
KF-8-10	8	10	58.0	1.250	11220	15.3	66
KF-8-12	8	12	68.4	1.477	13260	18.1	78
KF-8-14	8	14	85.7	1.818	16320	22.3	96
KF-8-16	8	16	100.5	2.159	19380	26.5	114
KF-10-16	10	16	127.6	2.879	25840	35.2	152

Bold values indicate the system model tested as part of this TAPE study

[a] Drainage basin determined using WWHM2012, assuming Seattle climate region, 100% impervious, 1 percent slope, 91 percent treatment, and modeled as flow split (offline).

Annual maintenance includes using a vactor truck for oil removal and removal of sediment from the floor of the filter. Filter cartridges must be washed or replaced at least once a year. The minimum required frequency for removing accumulated sediment from the unit is dependent on sediment depth. Maintenance is recommended when the sediment level reaches 1.5 feet in the primary separation chamber (100 percent capacity) and 0.5 foot in the secondary separation chamber.

Site Installation Requirements

Necessary Soil Characteristics

Specific underlying soil characteristics are not required for the Kraken™ Filter, since it is a self-contained, watertight system and is fully enclosed. However, the manufacturer suggests following standard local municipal guidelines, which typically require compaction of the bedding under a vault or comparable water treatment device.

Hydraulic Grade Requirements

The Kraken™ Filter is manufactured with two types of cartridges; standard and low profile. If standard cartridges are used the hydraulic grade requirement is 2.86 feet. If the low profile cartridges are used, then this value is reduced to 1.92 feet.

Depth to Groundwater Limitations

The Kraken™ Filter concrete vaults are sealed so that they are watertight; therefore, they do not have depth to groundwater limitations.

Utility Requirements

The Kraken™ Filter is a passive system that requires no power, and has a free-draining outfall to an appropriate water conveyance or storage system (i.e., wet pond, storm sewer, or underground infiltration).

TREATMENT PROCESSES

The Kraken™ Filter provides water quality treatment of captured flows through physical unit processes. Runoff treatment is achieved through separation, sedimentation, and filtration.

Separation

The dual inlet sedimentation chambers and floatable/oil baffle intercept the majority of floatable gross solids, trash, litter, and oil before water enters the filtration chamber.

Sedimentation

The Kraken™ Filter contains a series of baffles and weir walls that promote gravity settling of entrained particles. The amount of sedimentation is a function of particle density, size, water density, turbulence, and residence time. Deposited sediment is collected on the floor of the two sedimentation chambers and on the floor of the cartridge chamber(s).

Filtration

Particulates are physically removed from suspension as they come into contact with the Kraken™ Filter's membrane. Pollutant removal rates achieved through the filter are a function of the stormwater composition, flow, and pretreatment effectiveness.

KRAKEN™ FILTER PERFORMANCE EVALUATION

This section presents methods and results from previous laboratory testing at the Good Harbour Laboratories in Mississauga, Ontario and from a field evaluation that is being conducted at the SCTF in Seattle, Washington.

LABORATORY TESTING

A series of laboratory tests were conducted at the Good Harbour Laboratories in Mississauga, Ontario to assess the pollutant removal performance of the Kraken™ Filter. The tests were conducted using synthetic TSS in accordance with the New Jersey Department of Environmental Protection (NJDEP) laboratory protocol for assessing TSS removal by a manufactured filtration treatment device (NJDEP 2013). TSS removal results from these tests were presented as part of the PULD application for the Kraken™ Filter (Appendix C) and are reproduced in Table 2. As is apparent from these results, the Kraken Filter achieved greater than 80 percent removal of synthetic TSS in a laboratory setting.

Table 2. TSS Mass Removal Results from Laboratory Testing.

	Average Influent	Average Effluent	Average Sediment Removal Efficiency
Run No.	mg/L	mg/L	Percent
1	203.5	39	80.5
2	199.3	34	82.5
3	207.0	42	79.1
4	203.6	38	81.1
5	204.9	38	81.2
6	196.8	40	79.4
7	199.0	49	75.3
8	197.1	33	83.0
9	202.3	33	83.5
10	204.2	38	81.5
11	200.4	30	84.8
12	197.4	31	84.1
13	201.5	28	86.2
14	195.5	26	86.9
15	203.5	22	89.4
16	200.8	18	91.1
LCL95 Mean	199.74	30.5	**81.5**

mg/L: milligrams per liter

FIELD EVALUATION

A field evaluation of a Kraken™ Filter has been ongoing at the SCTF since November 2016. The goal of this field evaluation is to obtain paired influent and effluent samples in accordance with the TAPE for assessing the performance of the system relative to the following treatment goals:

- Basic Treatment – 80 percent removal of total suspended solids for influent concentrations that are greater than 100 milligrams per liter (mg/L), but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L total suspended solids.

- Phosphorus Treatment – 50 percent removal of total phosphorus for influent concentrations ranging from 0.1 to 0.5 mg/L

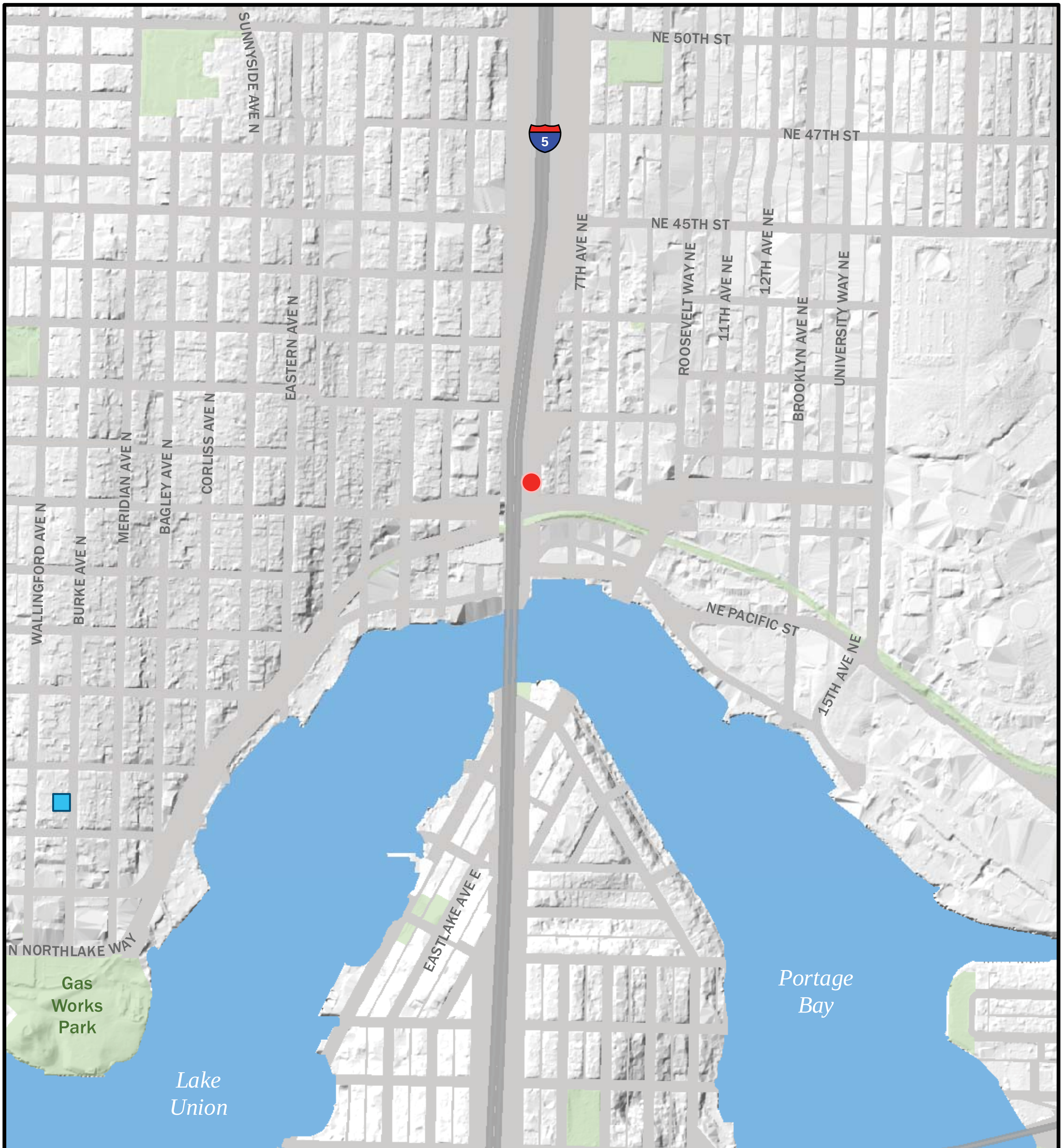
Separate sections below describe the sampling process design for this field evaluation and results from 14 separate influent/effluent composite samples that were collected between October 2016 and April 2017.

Sampling Process Design

This section describes the sampling process design for the field evaluation of a Kraken™ Filter at the SCTF. It begins with a description of the SCTF and the Kraken™ Filter installed at that location for testing. Separate sections then describe the ongoing field data collection procedures. Laboratory analytical methods, quality assurance/quality control (QA/QC) measures, data management procedures, and data analysis procedures that are being implemented for the field evaluation.

WSDOT Ship Canal Test Facility Description

The SCTF is located in Seattle, Washington below the Interstate 5 right-of-way on the north side of the Lake Union Ship Canal Bridge (Figure 5). The drainage basin to the facility is approximately 31.6 acres, with 22.7 acres of pavement and 8.9 acres of roadside landscaping. The WSDOT stormwater collection system for this drainage basin is separate from the City of Seattle's system; and collects runoff from the Interstate 5 northbound, southbound, express lanes, and the on- and off-ramps. All runoff in the drainage basin passes through 15 Type 1 and 53 Type 2 catch basins and is then consolidated in a 30 inch pipe that is routed to the facility.



Legend

- Project area
- Project rain gauge

Figure 5.
Location of the Ship Canal Test Facility in Seattle, Washington.

N

0 500 1,000 2,000 Feet

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WSDOT constructed the SCTF to allow the simultaneous testing of up to four stormwater treatment technologies. This is accomplished by diverting stormwater flow from the 30 inch pipe to the site using a "draw-bridge" half-pipe structure and a series of flow splitters. First, flow from the draw bridge enters an adjustable flow splitter that diverts water toward test bays 1 and 2 on one side, and toward test bays 3 and 4 on the other side (Figure 6). On each side, the divided water then enters a second flow splitter that further divides the flow such that each of the four test bays can be used independently. Flow to each test bay can be further controlled through the use of a gate valve located at the inflow to each test bay. To fine tune the flow into each the test bay even further, a bypass valve is installed immediately upstream of the influent pipe to each system being tested. This bypass valve can divert water around the individual systems without changing the flow rate into the neighboring systems (Appendix A).

Kraken™ Filter Test System Installation

To facilitate performance monitoring pursuant to the TAPE, a 4- by 4-foot (ID) Kraken™ Filter was installed for testing purposes at the SCTF. Automated equipment was also installed in conjunction with this system to facilitate continuous monitoring of influent, effluent, and bypass flow volumes (see Figures 7 and 8 and more detailed description below). In association with this hydrologic monitoring, automated samplers were installed to collect flow-weighted composite samples of the system's influent and effluent during discrete storm events for subsequent water quality analyses.

Field Data Collection Procedures

Ongoing hydrologic and water quality field data collection procedures for the Kraken™ Filter at the SCTF are described in the following subsections.

Hydrologic Data Collection Procedures

Continuous monitoring of effluent flow rates for the Kraken™ Filter at the SCTF is being conducted at a monitoring station, designated WK-OUT, that was established in the outlet pipe for the system (Figures 7 and 8). Continuous monitoring of bypass flow rates is also being conducted at a second monitoring station, designated WK-BP, that was established at the terminus of the bypass pipe. Thel-Mar weirs were installed in connection with both stations to facilitate the collection of these data. Influent flow (WK-IN) is being estimated by combining the flow from WK-OUT and WK-BP. This assumed inflow rate is considered accurate enough for pacing the influent automated sampler (see description below) because the residence time in the filter at the design flow rate is ~1 minute. This minimal amount of residence time will not significantly alter the effluent hydrograph relative to the influent. This method has been used for numerous previous TAPE certifications on similar filters.

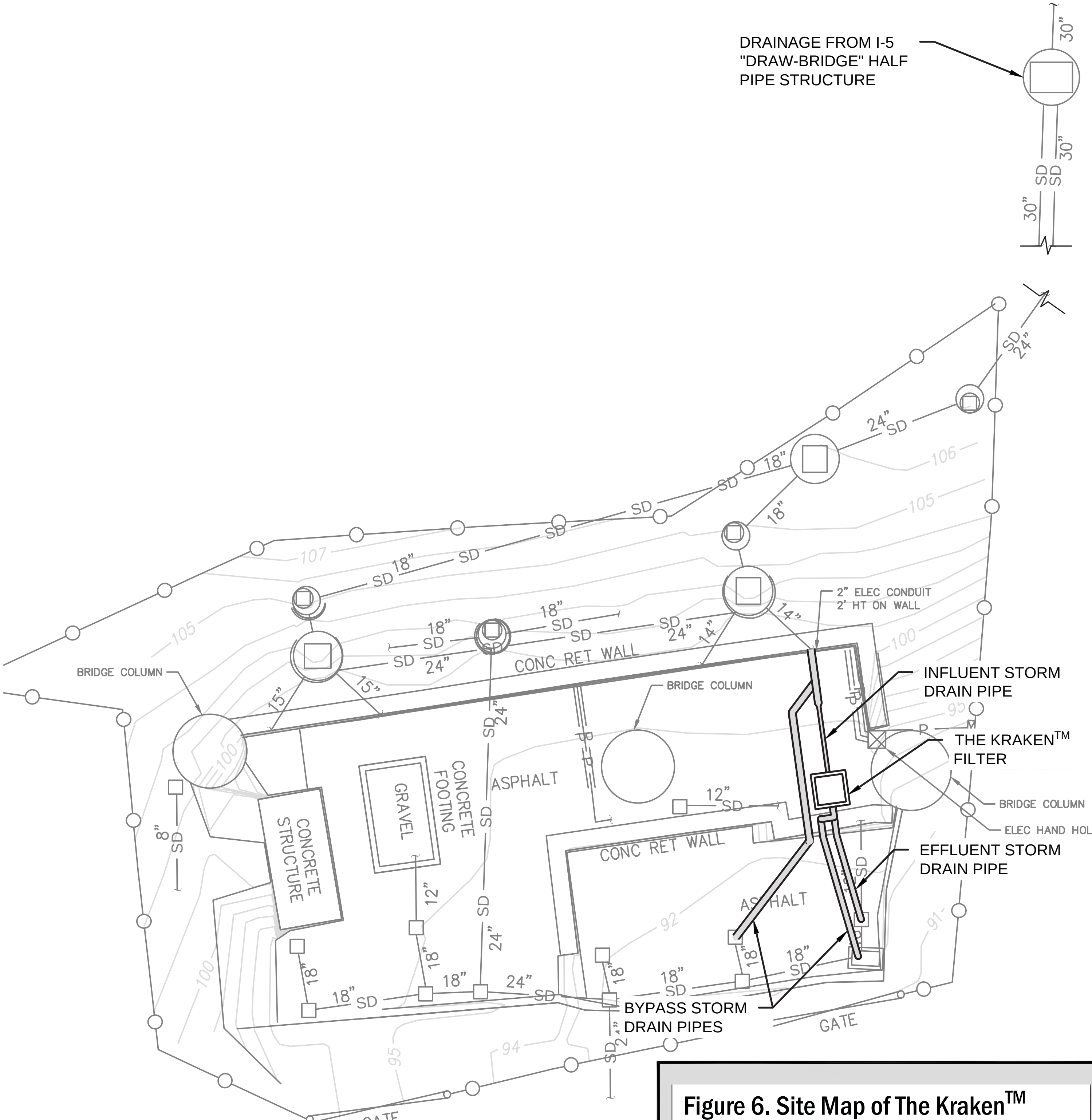

Figure 6. Site Map of The Kraken™ Filter Performance Evaluation Site at the Washington State Department of Transportation Ship Canal Test Facility in Seattle, Washington

N

0 15 30 60

scale in feet

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O:\proj\Y2015\15-06061-000\CAD\Dwg\Figures\Figure 7-Site Map.dwg

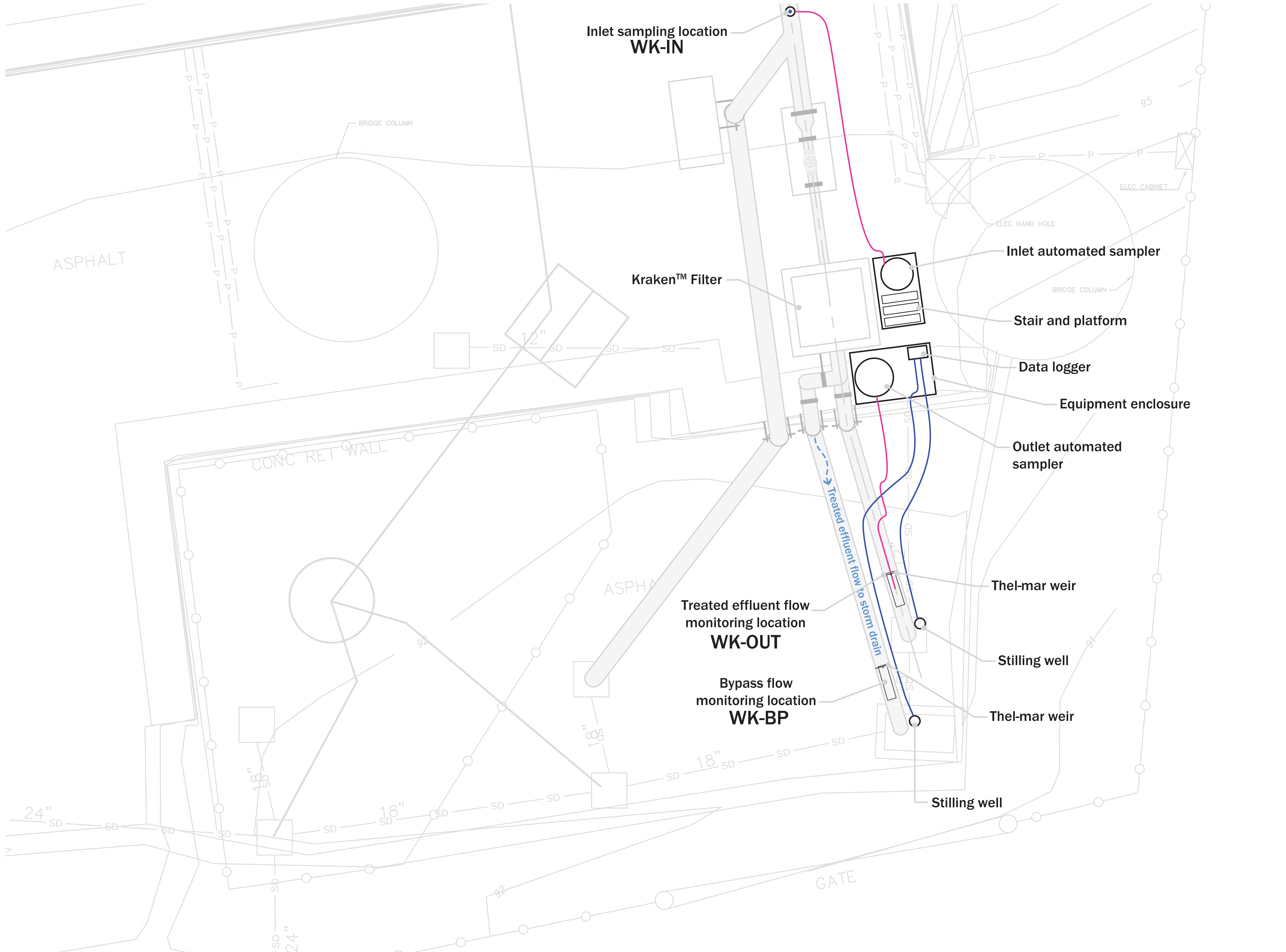
Stilling wells equipped with a pressure transducers (INW PS-9805) were installed in association with the Thel-Mar weirs described above to facilitate the accurate measurement of water levels above the weir crests. The pressure transducers are interfaced with a Campbell Scientific CR1000 datalogger programmed to scan every 10 seconds and record average water levels behind the Thel-Mar weirs on a 5-minute time step. The datalogger then converts these water level readings to estimates of discharge based on standard hydraulic equations (Walkowiak 2006). The datalogger is interfaced with a Raven XTV digital cellular modem. This communication system is configured to automatically download data and send text message alarms to field technicians and project managers. The monitoring equipment is housed in Knaack box model 69 enclosure. Conduit was installed to convey pressure transducer cabling and automated sampler suction lines from the base of the enclosure to each station. Power to the monitoring equipment is supplied using onsite AC power.

In addition to stations WK-OUT and WK-BP, a third hydrologic station, designated Wall-RG, was installed approximately 4,000 feet west of the SCTF in a residential yard (Figure 5) to facilitate continuous monitoring of precipitation depths. Precipitation depths are measured by a Texas Electronics TR525USW rain gauge. The rain gauge was installed on a 10-foot steel pole and interfaced with another Campbell Scientific CR1000 datalogger. The datalogger is programmed to scan every 10 seconds and record precipitation depth on a 5-minute time step. The datalogger is equipped with an Airlink Raven XTV digital cellular modem to allow communication with the Wall-RG station via remote access.

All flow and precipitation depth data stored on the dataloggers are remotely downloaded on a 5-minute basis via the digital cellular modems described above. These data are processed and validated in accordance with procedures described below.

Maintenance and calibration of the rain gauge and flow monitoring equipment was conducted on a routine basis during pre- and post-storm checks. Instrument maintenance and calibration activities were documented on standardized field forms. On July 25, 2016, a dynamic flow test was conducted using known flow rates from a nearby fire hydrant. The hydrant flows were used to calibrate the Thel Mar weir equations at WK-OUT and WK-BP. The adjusted weir equations which resulted from this testing were applied to the entire dataset prior to final analysis.

Figure 7.
Plan View Diagram of the Kraken™ Filter Installation at the Washington State Department of Transportation Ship Canal Test Facility in Seattle, Washington.



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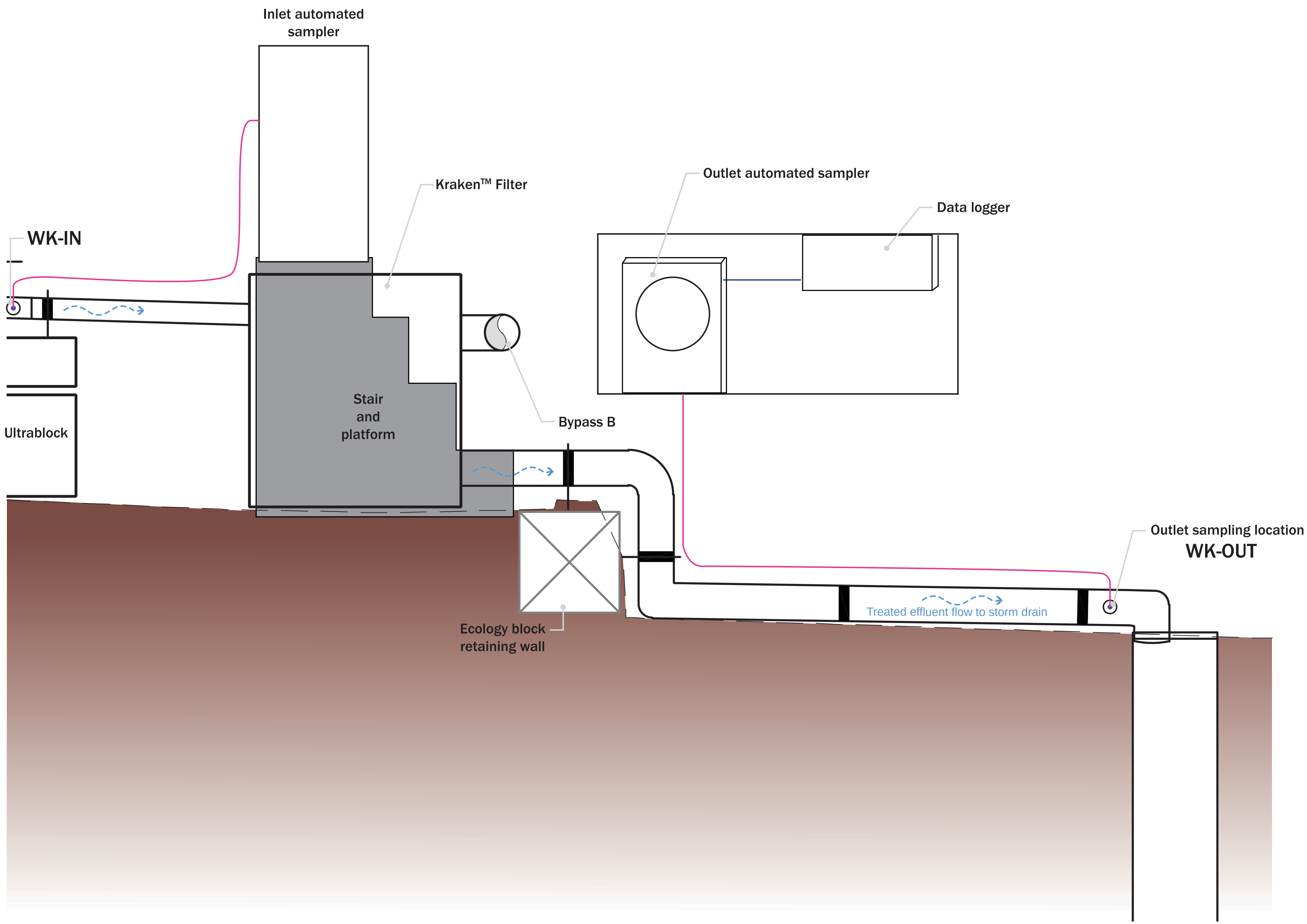

Figure 8. Cross Section Diagram of the Kraken™ Filter Installation at the Washington State Department of Transportation Ship Canal Test Facility in Seattle, Washington.

Legend
- Pressure transducer and cable
- Sampling tubing
- Direction of flow

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Water Quality Data Collection Procedures

To evaluate the water quality treatment performance of the Kraken™ Filter installed at the SCTF, water quality sampling was conducted at the WK-IN and WK-OUT stations (Figures 7 and 8) during discrete storm events. A general description of the procedures used for this monitoring is provided herein. A more detailed description of these procedures can also be obtained from the quality assurance project plan (QAPP) that was prepared for this project (Herrera 2016). To facilitate water quality sampling for this project, Isco 6712 portable automated samplers were installed in association with the WK-IN and WK-OUT stations. The intake strainer for the automated sampler at the WK-IN station was installed in the pipe upstream of the filter (Figures 7 and 8); the intake strainer for the automated sampler at the WK-OUT station was installed behind the station's associated Thel-Mar weir. In each case, the sampler intakes were positioned to ensure the homogeneity and representativeness of the collected samples. Specifically, sampler intakes were installed to make sure adequate depth was available for sampling and to avoid capture of litter, debris, and other gross solids that might be present. The sampler suction lines consisted of Teflon tubing with a 3/8-inch inner diameter.

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

- **Target storm depth**: A minimum of 0.15 inches of precipitation over a 24-hour period
- **Antecedent conditions**: A period of at least 6 hours preceding the event with less than 0.04 inches of precipitation
- **End of storm**: A continuous period of at least 6 hours after the event with less than 0.04 inches of precipitation

Antecedent conditions and storm predictions are monitored via the Internet, and a determination is made as to whether to target an approaching storm. Once a storm is targeted, field staff visit each station to verify that the equipment was operational and to start the sampling program. A clean 20-liter polyethylene carboy and crushed ice are also placed in the sampling equipment at this time. The speed and intensity of incoming storm events is tracked using Internet-accessible Doppler radar images. Actual rainfall totals during sampled storm events are quantified based on data from the rain gauge installed at the site. During the storm event sampling, the datalogger described above is programmed to enable the sampling routine in response to a predefined increase in water level (stage) at WK-OUT. The automated samplers are then programmed to collect 220-milliliter sample aliquots at preset flow increments. Based on the expected size of the storm, the flow increment is adjusted to ensure that the following criteria for acceptable composite samples were met at each station:

- A minimum of **10 aliquots**
- Sampling was targeted to capture **at least 75 percent** of the hydrograph

- Due to sample holding time considerations, the maximum duration of automated sample collection was **36 hours**.

After each targeted storm event, field personnel return to each station, make visual and operational checks of the sampling equipment, and determine the total number of aliquots composited. Pursuant to the sampling goals identified above, the minimum number of composites that constitute an acceptable sample is 10. If the sample is determined to be acceptable, the carboy is immediately capped, removed from the automated sampler, and kept below 6ºC using ice during transport to the laboratory. All samples are delivered to the laboratory with appropriate chain-of-custody documentation. Collected flow-weighted composite samples are then analyzed for the following parameters:

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

In addition, pH was measured on two occasions using a YSI 556 field meter. Additional parameters were also measured; however, this report only addresses those parameters that are pertinent to the issuance of CULD for basic and phosphorus treatment.

Laboratory Analytical Methods

Laboratory analytical methods for this project are summarized in Table 3. Analytical Resources, Inc. (ARI) in Tukwila, Washington, is the laboratory used for this project for all parameters except PSD. ARI is certified by Ecology, and participates in audits and inter-laboratory studies by Ecology and EPA. These performance and system audits have verified the adequacy of the laboratory's standard operating procedures, which include preventive maintenance and data reduction procedures. Environmental Technical Services (ETS) in Petaluma, California was used for PSD analysis.

Quality Assurance/Quality Control Measures

Field and laboratory QA/QC procedures used for the Kraken™ Filter field evaluation are discussed in the following sections.

Table 3. Methods and Detection Limits for Water Quality Analyses.									
Parameter	**Analytical Method**	**Method Number**[a]	**Field Sample Container**	**Pre-Filtration Holding Time**	**Total Holding Time**[b]	**Field Preservation**	**Laboratory Preservation**	**Reporting Limit/ Resolution**	**Units**
Total suspended solids	Gravimetric[c]	SM 2540D	20 L HDPE bottle	7 days	7 days	Maintain ≤ 6°C	Maintain ≤ 4°C	1.0	mg/L
Total phosphorus	Automated ascorbic acid	SM 4500P-F		NA	28 days		Maintain ≤ 4°C, H_2SO_4 to pH < 2	0.008	mg/L
Orthophosphorus	Automated ascorbic acid	SM 4500P E		12 hours[d]	48 hours		Maintain ≤ 4°C, H_2SO_4 to pH < 2	0.004	mg P/L
Hardness	Titration	SM 2340B		28 days	28 days		Maintain ≤ 4°C, HNO3 to pH < 2	0.05	mg/L as $CaCO_3$
pH	Potentiometric	SM 4500-H^+		24 hours[d]	24 hours		Maintain ≤ 4°C	0.01	std. units
Particle Size Distribution	Sieve and filter	ASTM D422		7 days	7 days		Maintain ≤ 4°C	NA	microns

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

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

[c] A G4 glass fiber filter will be used for the total suspended solids filtration.

[d] EPA requires filtering for orthophosphorus and dissolved metals and measurement of pH within 15 minutes of the collection of the last aliquot. This goal is exceedingly difficult to meet when conducting flow-weighted sampling. A more practical proxy goal for this study is 12 hours.

C = Celsius.

mg/L = milligrams per liter.

HDPE = High-Density Polyethylene

NA = not applicable.

Field Quality Assurance/Quality Control

This section summarizes the QA/QC procedures that are being implemented by field personnel to evaluate sample contamination and sampling precision.

Field Blanks

Automated sampler tubing is cleaned before the collection of each aliquot using an automated double rinse cycle. In addition, deionized water is back flushed through the sample tubing before each monitored event. Field blanks were also collected on June 1, 2016, prior to the first sampled storm event at both monitoring stations. A second set of field blanks was collected on April 17, 2017, to determine if the tubing was a source of contamination for monitoring conducted up to this date. The field blanks were collected by pumping reagent-grade water through the intake tubing into a pre-cleaned sample container. The volume of reagent grade water pumped through the sampler for the field blank was similar to the volume of water collected during a typical storm event.

Field Duplicate Samples

Field duplicates are collected for approximately 10 percent of the samples. The station where the field duplicates were collected is chosen at random in advance of the storm event. The resultant data from these samples is used to assess variation in the analytical results that is attributable to environmental (natural) and analytical variability.

Flow Measurements

The accuracy and precision of the automated flow measurement equipment were tested prior to the first monitoring event and again periodically throughout the project.

Laboratory Quality Control

The accuracy of the laboratory analyses is verified with blank analyses, duplicate analyses, laboratory control spikes, and matrix spikes in accordance with the analytical methods employed. ARI and ETS are responsible for conducting internal quality control and quality assurance measures in accordance with their own quality assurance plans.

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

Data are also reviewed and validated by Herrera within 7 days of receiving the results from the laboratory. This review is performed to ensure that all data are consistent, correct, and complete, and that all required quality control information was provided. Specific quality control elements for the data are also examined to determine if the method quality objectives (MQOs) for the project were met. Results from these data validation reviews are summarized in quality assurance worksheets prepared for each sample batch. Values associated with minor quality control problems are considered estimates and assigned *J* qualifiers. Values associated with major quality control problems are rejected and qualified with an *R*. In this report, estimated values were used for evaluation purposes, but rejected values were not used.

Data Management Procedures

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

ARI and ETS report the analytical results within 30 days of receipt of the samples. The laboratories provide sample and quality control data in standardized reports suitable for evaluating project data. These reports include all quality control results associated with the data, a case narrative summarizing any problems encountered in the analyses, corrective actions taken, any changes to the referenced method, and an explanation of data qualifiers. Laboratory data are subsequently entered into a Microsoft Access database for all subsequent data management and archiving tasks.

An independent review is performed to ensure that the data are entered into the database without error. Specifically, all of the sample values in the database are crosschecked to confirm they were consistent with the laboratory reports.

Data Analysis Procedures

Analysis procedures for the hydrologic and water quality data summarized in this report are described below.

Hydrologic Data Analysis Procedures

The compiled hydrologic data were analyzed to obtain the following information for each sampled and unsampled storm during the monitoring period covered by this report:

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

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

A subset of this information was examined in conjunction with sample collection data to determine if individual storm events met guidelines from the TAPE for valid storm events.

Water Quality Data Analysis Procedures

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

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

Each of these procedures is described in more detail in the following subsections.

Statistical Comparisons of Influent and Effluent Concentrations

Pollutant concentrations were compared for paired influent and effluent across all storm events using a 1-tailed Wilcoxon signed-rank test (Helsel and Hirsch 2002). The test was specifically used to evaluate the hypothesis that effluent pollutant concentrations were significantly lower than influent concentrations. In all cases, statistical significance was evaluated at an alpha level (α) of 0.05.

Calculation of the Pollutant Removal Efficiency using Bootstrap Analysis

The removal (in percent) in pollutant concentration during each individual storm (ΔC) was calculated as:

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

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

C_{eff} = Flow-weighted effluent pollutant concentration

After the percent removal for each qualifying event was calculated, the mean percent removal values and 95 percent confidence interval about the mean were estimated using a bootstrapping approach (Davison and Hinkley 1997). The lower confidence interval was used to determine if the mean percent removal was significantly higher than the percent removal targets presented in TAPE (e.g., 80 percent removal for TSS).

Calculation of Pollutant Removal Efficiency as a Function of Influent Flow

Analyses were conducted to evaluate whether pollutant removal efficiency varied as a function of influent flow rate. As a first step in these analyses, the influent flow rate when each sample was collected was calculated. Specifically, for composite samples the instantaneous flow rates associated with each aliquot were averaged over the sampled event to generate an average sampled flow rate. This value was then compared with the percent pollutant removal for the event. This process was repeated for each sampled event; the results were subsequently plotted to visually assess potential relationships between percent removal and sampled flow rate. Regression analyses were then conducted to determine if any observed relationships were statistically significant. In order to obtain a sampled flow rate near or at the design flow rate, a discrete sampling approach was also employed where the samplers were programmed to collect aliquots only when flow rates were at the design flow rate. The result is a sample which does not represent an EMC but instead the instantaneous performance of the filter when it is at its design flow rate. The EMC and discrete sample dataset were combined for this analysis.

Field Evaluation Results

Field evaluation results from 7 months of monitoring over the period from October 2016 to April 2017 are presented in this section. The section begins with a summary of results from quality assurance reviews that were conducted over this period. Results from hydrologic and water quality monitoring that occurred over 14 storm events during the period above are then presented in separate subsections. A database with all flow, precipitation, and water quality results from the sampled events is also provided in Appendix E. In addition, the field forms for each sampled event are provided in Appendix F while Appendix G provides individual storm reports (ISR) for each sampled event. ISRs are one page summaries consisting of a hydrologic and sampling statistics summary table, a hydrograph and hyetograph showing sample collection times, and a chemistry summary table. Finally, laboratory reports for each sampled event, including chain of custody forms, are provided in Appendix H.

Quality Assurance Review Results

The water quality data were assessed against the method quality objectives in the QAPP that was prepared for the project (Herrera 2016). The results of this assessment are reported in Appendix D. Based on this assessment, some of the collected data were qualified as estimates; however, no data were rejected and all individual values were carried forward into the analyses presented below.

As noted above, flow testing performed on June 25, 2016 using a closed channel flow meter resulted in adjusted weir equations for improved accuracy. After these adjustments, no major data gaps or anomalies were noted in the rain or flow data collected during the monitoring period.

Hydrologic Monitoring Results

In water year 2017, four separate stormwater treatment devices were tested at the SCTF. Rapid clogging of each of these four systems was observed with the filters lasting between 1 and 4 storm events before treated flow rates fell below 50% of the design flow rate. This was most likely due to the high oil and automobile pollutant loading from the basin which is dominated by runoff from Interstate 5. The Interstate has an Annual Average Daily Traffic count of 173,000 and consequently produces runoff with relatively high levels of pollution compared with typical basins (e.g., commercial parking lots, residential arterials) in which manufactured stormwater treatment devices would be installed.

Table 4 presents the hydrologic results from the 14 sampled storm events at the SCTF for the Kraken™ Filter. The valve controlling flow into the Kraken™ Filter was shut off between events to allow only stormwater from sampled events to enter the filter. This approach was employed once it became apparent that the system was rapidly clogging; in response, flow into the system was limited to allow the collection of water quality samples to continue for as long as possible. The objective was to generate a water quality data set which could be used to support TAPE approval with the assumption that an additional site would be selected to verify the maintenance interval using stormwater that is more representative of urban runoff (i.e., not highway runoff). As part of that effort, Bio Clean is seeking a CULD for the Kraken™ Filter as an interim measure until enough flow data can be collected at the additional site to support the application for a GULD.

As is apparent in Table 4, the system was maintained 5 times during the 7 months of testing from October 2016 to April 2017. Initially 10 micron filters were used in the Kraken™ Filter for treatment. When it was found that these filters were rapidly clogging, 20 micron filters were deployed. The washed 10 micron filter was reinstalled on March 28, 17. A comparison between the TSS and TP removal results for each of the filters (10 and 20 micron) is provided in the next section with the objective of pooling the data from both filters based on evidence that there is no significant difference in treatment performance. The design flow rate of the test system with either filter was 136 gallons per minute (gpm). The maximum treated flow rate only exceeded this level in 4 of the 14 events (Table 4). The average sampled flow rate ranged from a low of 7 gpm to a maximum of 170 gpm. These data are presented again in the next section with the results from the water quality monitoring in order to determine if there was a relationship between sampled flow rate and treatment performance.

Table 4. Summary Statistics for Sampled Storms at the SCTF Test System from October 6, 2016, through April 10, 2017.							
Storm Start Date and Time	Storm Depth (inches)	Peak Storm Intensity (in/hr)	Total Volume (gallons)	Bypass Volume (gallons)	% of Total Volume Bypassed	Peak Treated Flow Rate (gpm)[a]	Average Sampled Flow Rate (gpm)[a]
New Filters Installed 9/12/2016 (10 Micron Filters)							
10/6/2016 21:00	0.27	0.36	13,838	4,452	32	118	60
Filters Cleaned and Reinstalled 11/14/2016 (10 Micron Filters)							
11/14/2016 23:40	0.87	1.20	21,405	0	0	54	41
12/2/2016 6:25	0.15	0.24	7,342	1,906	26	61	32
12/9/2016 7:30	0.81	0.24	58,583	33,622	57	23	15
New Filters Installed 1/17/2017 (20 Micron Filters)							
1/17/2017 11:50	2.91	0.48	125,325	78,063	62	145	52
2/3/2017 1:55	1.55	0.24	14,088	1,985	14	25	12
2/8/2017 8:45	2.59	0.36	40,408	24,468	61	26	11
2/14/2017 21:40	2.45	0.60	36,845	20,578	56	13	7
Filters Cleaned and Reinstalled 3/16/2017 (20 Micron Filters)							
3/17/2017 13:15	1.38	0.24	2,750	0	0	139	133
3/23/2017 21:25	0.68	0.24	46,744	23,338	50	136.9	49.9
Filters Cleaned and Reinstalled 3/28/2017 (10 Micron Filters)							
3/29/2017 0:15	0.53	0.24	19,124	0	0	63.7	57.1
4/4/2017 21:25	0.62	0.12	8,857	352	4	147.0	170[b]
4/6/2017 5:25	0.19	0.12	4,463	1,592	36	23.6	12.7
4/10/2017 1:25	0.24	0.24	9,831	7,754	79	15.8	9.9

[a] Design flow rate is 136 gallons per minute (gpm)

[b] Sampled flow rate is greater than peak treated flow rate because the samples were discrete samples collected at the peak of the storm when instantaneous discharges were recorded by field staff. Peak treated flow rate data are 5-minute averages, thus the true peak flow was not recorded in the continuous dataset.

Water Quality Monitoring Results

This section presents the water quality monitoring results from the 14 sampled events that occurred over the monitoring period described above. Table 5 presents hydrologic and sampling summary statistics for each sampled event with a comparison to criteria for assessing their acceptability for samples from the TAPE; if a criterion was not met the value is bolded in the table. As is apparent, the criteria were met for all 14 sampled events with the following exceptions. The criteria were not met for the March 17, 2017 and April 4, 2017 events because the goal for these events was to target high flows using discrete sampling as opposed to an entire event using a flow-weighted composite sampling. Pursuant to the TAPE, discrete samples are not required to meet the sampling criteria (e.g., aliquot count, percent coverage). In addition, the March 23, 2017 event missed the percent coverage criteria for the inlet by 1 percentage point (Table 5). This was considered near enough to the goal to be considered qualifying. Considering the above, all the storm events define in Table 5 were carried forward to be screened by influent concentration.

Table 5. Sampled Events Versus TAPE Storm and Sampling Criteria.								
Storm Start Date and Time	Storm Depth (inches) Goal ≥ 0.15	Antecedent Dry Period (hr) Goal ≥ 6 hr	Number of Aliquots IN Goal ≥ 10[a]	Number of Aliquots OUT Goal ≥ 10[a]	Percent Storm Volume Sampled IN Goal ≥ 75	Percent Storm Volume Sampled OUT Goal ≥ 75	Sampling Duration IN Goal < 36	Sampling Duration OUT Goal < 36
New Filters Installed 9/12/2016 (10 Micron Filters)								
10/6/2016 21:00	0.27	65	28	20	96	89	5	4
Filters Cleaned and Reinstalled 11/14/2016 (10 Micron Filters)								
11/14/2016 23:40	0.87	19	100	100	93	88	9	8
12/2/2016 6:25	0.15	53	25	18	95	95	5	5
12/9/2016 7:30	0.81	87	92	77	98	98	28	28
New Filters Installed 1/17/2017 (20 Micron Filters)								
1/17/2017 11:50	2.91	176	100	68	91	92	23	23
2/3/2017 1:55	1.55	278	29	40	98	96	23	22
2/8/2017 8:45	2.59	40	55	25	93	89	23	23
2/14/2017 21:40	2.45	111	51	33	94	90	34	34
Filters Cleaned and Reinstalled 3/16/2017 (20 Micron Filters)								
3/17/2017 13:15[b]	1.38	50	**8**	**8**	**22**	**22**	0.1	0.1
3/23/2017 21:25	0.68	50	100	63	**74**	91	10	14
Filters Cleaned and Reinstalled 3/28/2017 (10 Micron Filters)								
3/29/2017 0:15	0.53	51	100	100	90	90	5	5
4/4/2017 21:25[b]	0.62	67	**1**	**1**	**0**	**0**	0	0
4/6/2017 5:25	0.19	10	16	13	91	86	6	4
4/10/2017 1:25	0.24	51	50	17	97	88	4	4

Bold values indicate results which did not meet the criteria

[a] Number of aliquot goal is 7 if all other sampling goals are met, otherwise 10.

[b] The 3/17/2017 and 4/4/17 events did not meet the sampling goals because they were high flow rate discrete sample events.

The basic treatment goal listed in the TAPE guidelines indicate that the bootstrapped 95 percent lower confidence interval (LCL95) of the mean total suspended solids (TSS) removal must be greater than or equal to 80 percent for influent concentrations ranging from 100 to 200 mg/L. For influent TSS concentrations less than or equal to 100 mg/L but greater than 20 mg/L, the upper 95 percent confidence interval (UCL95) of the mean effluent concentration must be less than or equal to 20 mg/L. There is no specified criterion for influent TSS concentrations less than 20 mg/L; consequently, those sample pairs (influent and effluent), cannot be used for assessment of TSS removal performance. For influent concentration that exceed 200 mg/L, the treatment goal is an LCL95 of greater than an 80 percent reduction. The phosphorus treatment goal listed in the TAPE guidelines indicate that the bootstrapped 95 percent lower confidence interval (LCL95) of the mean TP removal must be greater than or equal to 50 percent for influent concentrations ranging from 0.1 to 0.5 mg/L.

Additionally, it must be shown that a statistically significant difference between influent and effluent concentrations exists. Finally, pollutant removals that meet the TAPE goals must be shown for sample pairs across a range of treated flow rates up to and including the design flow rate. This section describes the sampling results in relation to these criteria based on data from 14 sampled events.

Total Suspended Solids

Unscreened TSS data from the 14 sampled events are summarized in Table 6. These results show that influent concentrations of TSS were above 100 mg/L for 5 of the events (the March 17,2017 event was included because the influent was 97 mg/L, very close to 100 mg/L) while the remaining 9 events had influent concentrations between 20 and 100 mg/L, with the exception of the March 29, 2017 event which had an influent concentration of only 10 mg/L. Table 6 provides summary statistics for all of the sampled events without screening any of the data out based on influent concentration. The overall average influent TSS concentration was 73 mg/L while the effluent averaged 7 mg/L. Table 7 presents the same data except this time they are screened by influent concentrations prior to calculating summary statistics. Because only 5 events had influent concentration greater than 100 mg/L the LCL95 mean percent reduction could not be calculated for comparison to the 80 percent reduction goal (as a rule of thumb a minimum of 10 samples are required to conduct the bootstrap analysis of mean percent reduction). The mean percent reduction of these 5 events is presented in Table 7 for reference. The TAPE requires a minimum n-value of 12 for use in comparing to the treatment goal. This was not possible for the 80 percent reduction goal because of the low influent concentrations. Consequently, the <20 mg/L goal was used for this assessment. Normally, only the data with influent concentration below 100 mg/L would be used for this analysis, but again that would create a situation where the n-value was below 12. Instead, all the storms were used in the analysis with the exception of the March 29, 2017 event and the April 4, 2017 event. The March 29, 2017 event had an influent TSS concentration of only 10 mg/L so it was not included. The April 4, 2017 event was a discrete event at 170 gpm which is 25% above the design flow rate. The TAPE only requires systems to meet the water quality goals for flows at and below the design flow rate, so this data point was excluded. After screening out those two events, the UCL95 mean effluent concentration was 7.8 mg/L (Table 7), well below the goal of less than 20 mg/L.

Table 6. Summary of Unscreened Chemistry Results from the Kraken™ Filter Configuration at the SCTF.

Date	TSS (mg/L)			Total Phosphorus (mg/L)			Ortho-Phosphorus (mg/L)		
	In	Out	%	In	Out	%	In	Out	%
10/6/2016	46	4.4	90	0.140	0.056	60	0.011	0.009	18
11/14/2016	31	4	87	0.062	0.024	61	0.06	0.006	90
12/2/2016	52	4	92	0.156	0.052	67	0.018	0.012	33
12/9/2016	116	2	98	0.290	0.024	92	0.019	0.004	79
1/17/2017	56	9	84	0.166	0.028	83	0.01	0.011	-10
2/3/2017	44	5	89	0.136	0.024	82	0.017	0.01	41
2/8/2017	103	4	96	0.166	0.018	89	0.016	0.006	63
2/14/2017	162	4	98	0.216	0.014	94	0.009	0.004	56
3/17/2017	97	9	91	0.144	0.074	49	0.021	0.022	-5
3/23/2017	50	18	64	0.078	0.030	62	0.007	0.006	14
3/29/2017	10	5	50	0.066	0.034	49	0.008	0.009	-13
4/4/2017[a]	54	23	57	0.120	0.070	42	0.012	0.011	8
4/6/2017	44	4	91	0.110	0.018	84	0.011	0.004	64
4/10/2017	158	2	99	0.264	0.012	96	0.008	0.004	50
Mean	73	7	85	0.151	0.034	72	0.016	0.008	35
Median	53	4	91	0.142	0.026	75	0.012	0.008	37
Min	10	2	50	0.062	0.012	42	0.007	0.004	-13
Max	162	23	99	0.290	0.074	96	0.06	0.022	90

[a] Sample collected at 170 gpm, above the design flow rate of 136 gpm

mg/L: milligrams per liter

Results from a Wilcoxon Signed Rank test (Helsel and Hirsch 2002) that was applied to the TSS data from the 14 events also indicated effluent concentrations were significantly lower than influent concentrations ($p = 0.007$).

Finally, the percent reduction data were plotted versus the average sampled treated flow rate (Figure 9). Because the regression (which is compared to the 80 percent reduction goal) should only be calculated for those events with influent concentration above 100 mg/L, there were only 5 data points defining the regression. Data from the March 17, 2017 event were included because it was necessary to have a data point at the design flow rate and the influent concentration was very close to the 100 mg/L threshold (97 mg/L, see Table 6 and 7). The 5 data points used in the regression are marked with filled circles in Figure 9, even though they are not used to define the regression, the remaining events are plotted on the figure for reference (open circles). As is apparent, the regression analysis indicates there was no significant relationship between percent reduction and sampled flow rate and that the system is able to reduce TSS levels by at least 80 percent up to and at the design flow rate.

Based on these analysis, it can be concluded that the Kraken™ Filter meets the basic treatment goal from the TAPE with a 136 gpm (or 8.5 gpm per cartridge) design flow rate.

Table 7. Screened Chemistry Results and Comparison to TAPE Criteria.							
	TSS (mg/L)			Total Phosphorus (mg/L)			Average Sampled Treated Flow Rate (gpm)
Date	In	Out	%	In	Out	%	Out
10/6/2016	46	**4**	90	0.140	0.056	**60**	59.7
11/14/2016	31	**4**	87	0.062	0.024	**61**	40.8
12/2/2016	52	**4**	92	0.156	0.052	**67**	31.8
12/9/2016	116	**2**	**98**	0.290	0.024	**92**	14.8
1/17/2017	56	**9**	84	0.166	0.028	**83**	52.2
2/3/2017	44	**5**	89	0.136	0.024	**82**	12.0
2/8/2017	103	**4**	**96**	0.166	0.018	**89**	11.1
2/14/2017	162	**4**	**98**	0.216	0.014	**94**	7.4
3/17/2017	97	**9**	**91**	0.144	0.074	**49**	133.3
3/23/2017	50	**18**	64	0.078	0.030	**62**	49.9
3/29/2017	~~10~~[a]	~~5~~[a]	~~50~~[a]	0.066	0.034	**49**	57.1
4/4/2017 [b]	54	23	57	0.120	0.070	42	170.0
4/6/2017	44	**4**	91	0.110	0.018	**84**	12.7
4/10/2017	158	**2**	**99**	0.264	0.012	**96**	9.9
n-value for TAPE assessment		12	5			13	
LCL95 Mean % Reduction			NC[c]			67.4[e]	
UCL95 Mean Effluent Conc.		7.8[d]					
Mean			96.4				

[a] Influent below 10 mg/L so data cannot be used for TAPE assessment

[b] Sample collected at 170 gpm, above the design flow rate of 136 gpm. So data were excluded from this assessment. However, the data were included for the regression analysis below because it is important to have high flow rate results to determine regression slope.

[c] Not calculable, only 4 values had influent above 100 mg/L. Mean concentration used in place of LCL95 Mean.

[d] In order to achieve an n-value of 12 or greater, all the data except the 3/29/17 and 4/4/17 events were used in this calculation

[e] In order to achieve an n-value of 12 or greater, all the data except the 4/4/17 events were used in this calculation

Bold indicates values used in the calculation to compare to TAPE criteria

Underlined indicates value meet TAPE criteria (>80% removal for TSS or <20 mg/L effluent TSS concentration; >50% total phosphorus removal)

mg/L: milligrams per liter

Total Phosphorus

The dataset for TP is presented in Table 6 for all of the sampled events (unscreened by influent concentration). The overall average influent concentration was 0.151 mg/L while the effluent averaged 0.034 mg/L. Normally, a minimum influent concentration of 0.1 mg/L would be used to screen the data, however, since only 11 events had influent exceeding 0.1 mg/L and a minimum of 12 are required for comparison to the TAPE goals, all of the data were used for this assessment with the exception of the April 4. 2017 event (the 170 gpm event). After screening of this one event the LCL95 mean percent reduction was calculated at 67.4 percent, above the goal of a 50 percent reduction (Table 7). Results from the Wilcoxon Signed Rank test also indicated that effluent concentrations from the 13 events were significantly lower than influent concentrations ($p = 0.012$). Figure 10 suggests that TP removal performance decreases somewhat with flow rate. A regression analysis confirmed this relationship was significant with removal performance approaching 50 percent at the design flow rate of 136 gpm. Based on this analysis, it can be concluded that the Kraken™ Filter meets the phosphorus treatment goal from the TAPE with a 136 gpm (or 8.5 gpm per cartridge) design flow rate.

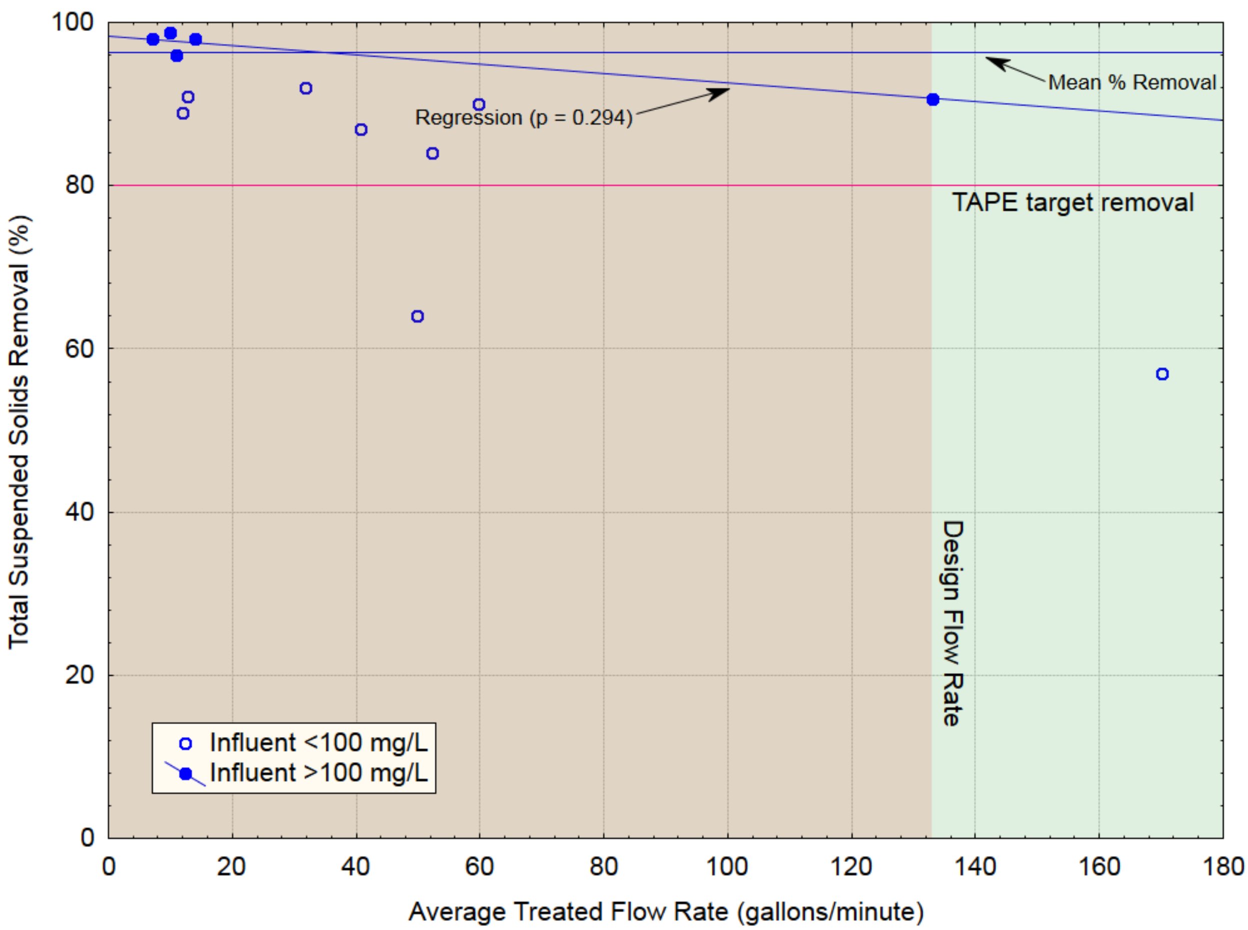


Figure 9. Total Suspended Solids Percent Reduction Versus Average Sampled Treated Flow Rate

Comparison of Datasets with Different Filters

The analyses presented above used data from 8 events with 10 micron filters installed in the Kraken™ Filter and 6 events with 20 micron filters. The filter types were switched during monitoring in order to try and troubleshoot the clogging issues that were identified during the study. In order to demonstrate there is no significant difference in treatment performance between the two filters, a Mann-Whitney U Test was used to compare the treatment performance for TSS and TP from both filters. As shown in Figure 11, results from these tests show there is no significant difference in TSS and TP removal performance between the two filters. When the Kraken™ Filter goes to market, the 20 micron filter will be employed because it is able to meet TAPE reduction goals while likely having providing an extended maintenance cycle relative to the 10 micron filters.

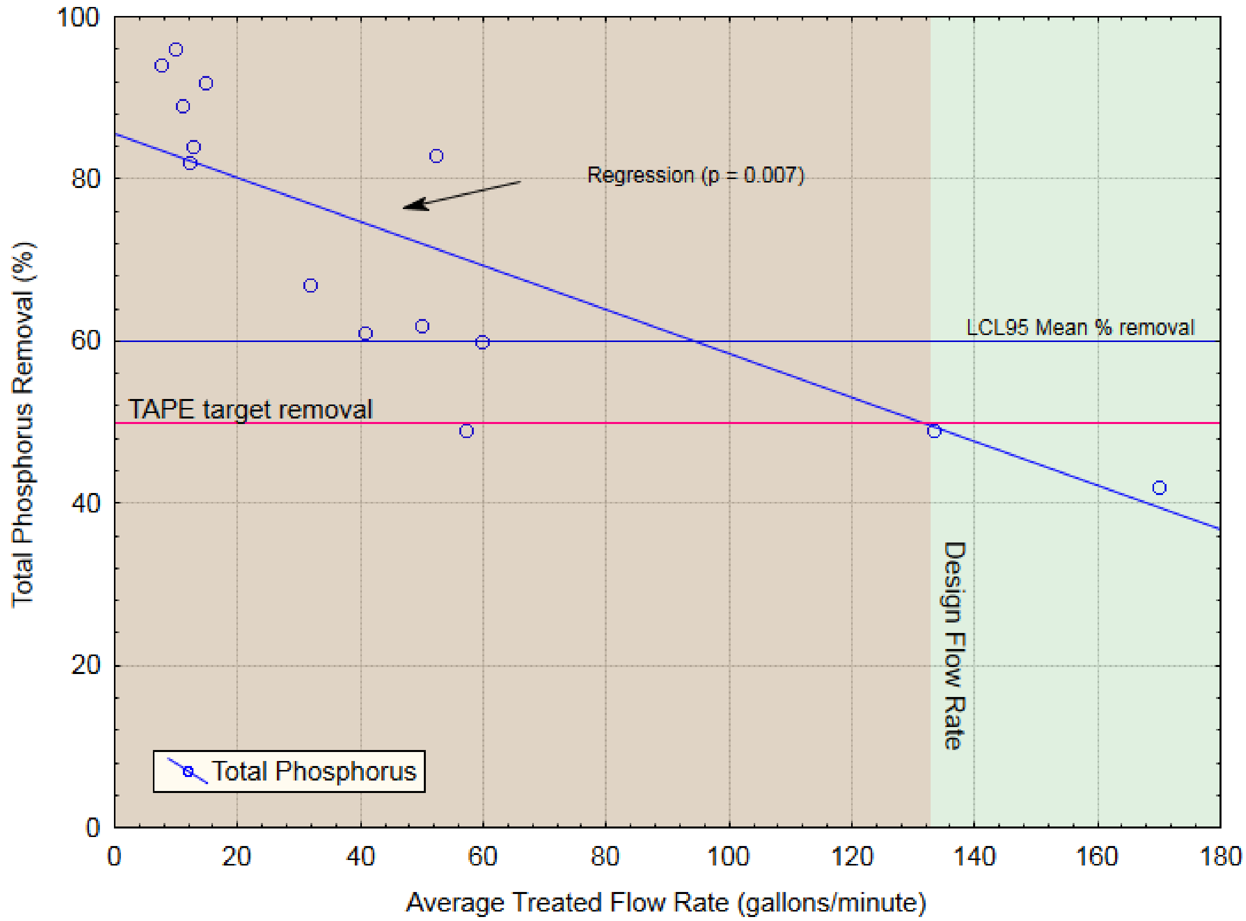


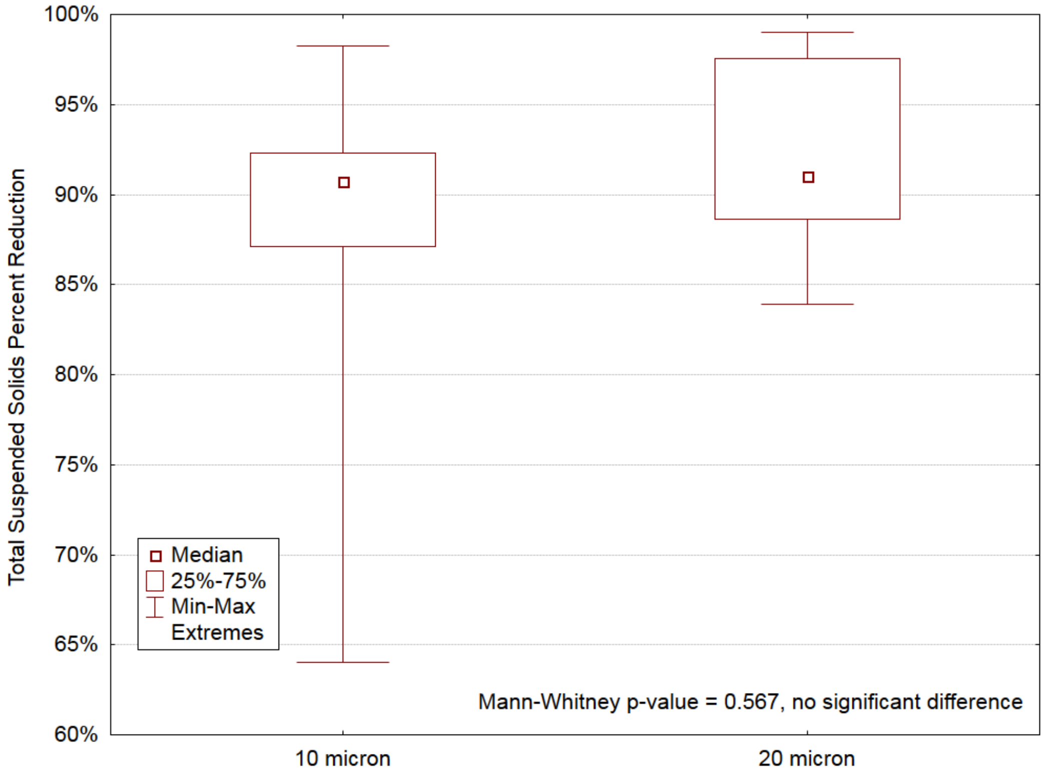
Figure 10. Total Phosphorus Percent Reduction versus Average Sampled Treated Flow Rate

Screening Parameters

For Basic and Phosphorus treatment verification through the TAPE, the following screening parameters must be analyzed during at least 3 events: PSD, pH, orthophosphorus, hardness, and total and dissolved copper. Orthophosphorus was analyzed for each of the 14 events with the results presented along with those for TSS and TP in Table 6. These data show the average orthophosphorus removal was 35 percent.

PSD measured at the influent station (WK IN) during the 14 sampled events are summarized in Figure 12. These results show the median particle diameter (D_{50}) for the influent to the Kraken™ Filter was approximately 21 microns (Figure 12). The influent water was highly variable with respect to PSD with the individual sample D_{50} ranging from 2 microns to 450 microns.

The results from the metals and hardness analyses are presented in Table 8 for the 14 sampled events. These results show the Kraken™ Filter was effective at treating total metals with a 52 and 58 percent reduction for total copper and total zinc, respectively. However, the system did not perform well at treating dissolved metals with a 2 and 5 percent reduction for dissolved copper and dissolved zinc, respectively.



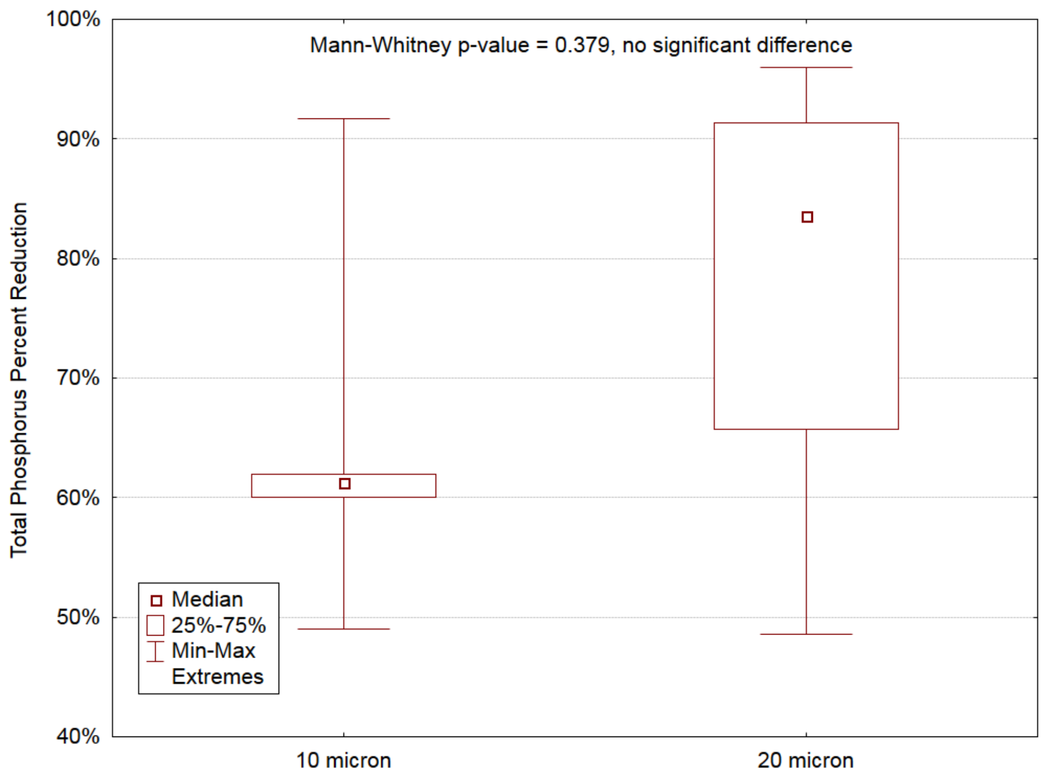


Figure 11. Results of the Comparison in Performance Between the 10 and 20 Micron Filters.

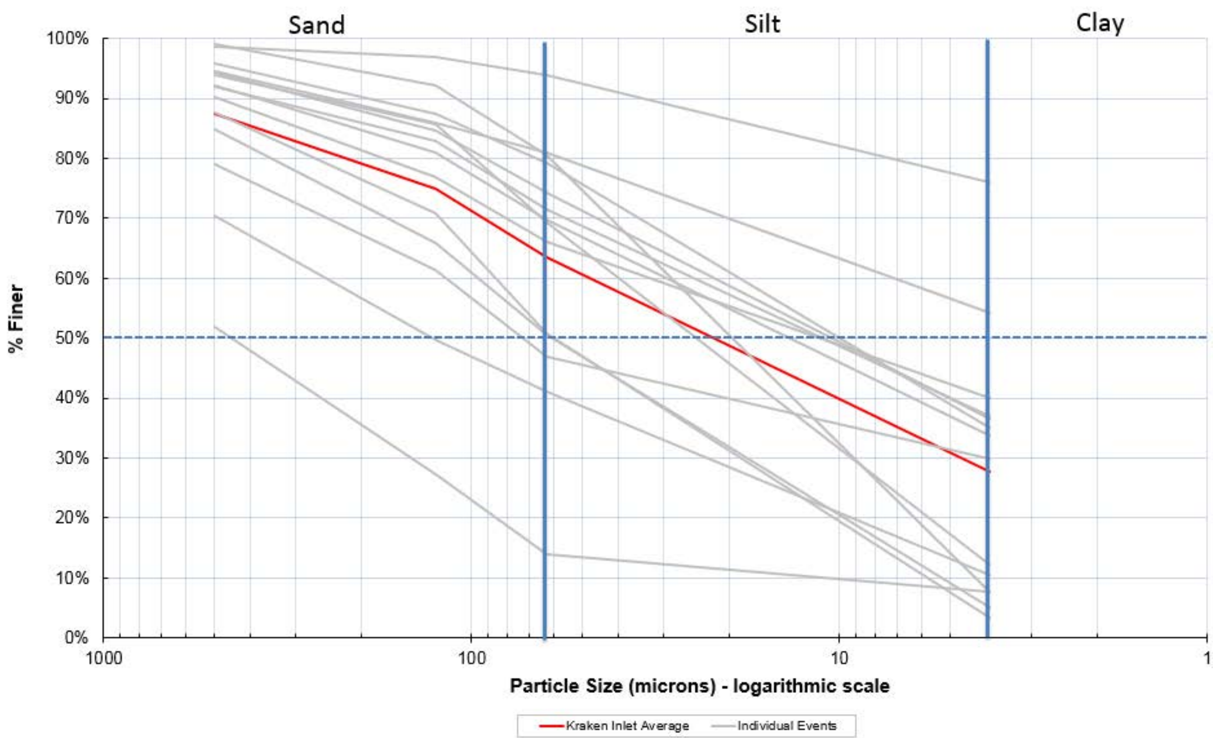


Figure 12. Influent particle size distribution for the sampled events at the SCTF.

Finally, Table 9 shows the results from the 3 events where pH was measured. These results indicate the Kraken™ Filter did not substantially alter pH values, reducing influent pH by between 1 and 3 percent.

Table 8. Summary of Screening Parameter Metals and Hardness Results from the Kraken™ Filter Configuration at the SCTF.															
	Total Copper (ug/L)			Dissolved Copper (ug/L)			Total Zinc (ug/L)			Dissolved Zinc (ug/L)			Hardness (mg CaCO3/L)		
Date	**In**	**Out**	**%**	**In**	**Out**	**%**	**In**	**Out**	**%**	**In**	**Out**	**%**	**In**	**Out**	**%**
10/6/2016	14.1	15.9	-13%	54.5	23.5	57%	34.8	33	5%	149	48.5	67%	33.6	32	5%
11/14/2016	29.4	12.1	59%	9.08	8.13	10%	98.4	36.8	63%	26.8	27.6	-3%	32.8	26.9	18%
12/2/2016	53.5	25.1	53%	13.6	17.8	-31%	174	56.1	68%	39.6	35.8	10%	49.6	50.6	-2%
12/9/2016	88.9	18.8	79%	21.1	16.2	23%	444	128	71%	121	110	9%	200	214	-7%
1/17/2017	37.7	16.7	56%	9.79	10.4	-6%	131	48.8	63%	34	35.5	-4%	32.4	27.4	15%
2/3/2017	38.4	13.2	66%	11.9	10.1	15%	137	50.9	63%	38.3	37.1	3%	42.5	43.6	-3%
2/8/2017	33.9	19.7	42%	11.3	18.6	-65%	248	54.1	78%	31.6	47.8	-51%	46.7	38.7	17%
2/14/2017	62.4	14.7	76%	13	12.2	6%	166	65	61%	48.7	42.6	13%	45.1	50.1	-11%
3/17/2017	52	25.6	51%	14	14.4	-3%	34.8	33	5%	35.1	32.8	7%	43.8	41.7	5%
3/23/2017	29	13.5	53%	10.6	10.7	-1%	62%	104	41	41.1	32.3	21%	48	55.9	-16%
3/29/2017	17.3	13.6	21%	7.62	9.06	-19%	48%	55.7	36.1	21.5	22.8	-6%	38.9	39.7	-2%
4/4/2017	44	28.2	36%	15.3	14	8%	42%	131	71.6	38.8	34	12%	50	48.2	4%
4/6/2017	36.4	12.1	67%	13	9.79	25%	84%	104	43.8	36	34.5	4%	45.3	45.7	-1%
4/10/2017	57.2	8.46	85%	8.6	7.78	10%	95%	252	33	27	30.8	-14%	37.2	37.2	0%
Mean	**42.4**	**17.0**	**52%**	**15.2**	**13.0**	**2%**	**157.7**	**54.3**	**58%**	**49.2**	**40.9**	**5%**	**53.3**	**53.7**	**2%**

Table 9. pH Screening Results.			
Date	**IN**	**OUT**	**Percent Change**
4/5/2017	7.36	7.31	1%
4/6/2017	7.64	7.4	3%
6/8/2017	7.69	7.56	2%

CONCLUSIONS

This document serves as the application for granting the Kraken™ Filter a CULD for basic and phosphorus treatment. It specifically summarizes testing that was performed in both the laboratory and field to quantify the treatment performance of the Kraken™ Filter. Data from both the laboratory and field testing indicate that the Kraken™ Filter can meet the basic treatment goal from the TAPE (i.e., 80 percent reduction of TSS) at the design flow rate of 136 gpm (or 8.5 gpm per cartridge). Field data also indicate that the Kraken™ Filter can meet the phosphorus treatment goal (i.e., 50 percent reduction of TP) at flow rates up to 136 gpm (or 8.5 gpm per cartridge).

The Kraken™ Filter rapidly clogged during testing at the SCTF; however, every other filter that has been tested at the SCTF since 2016 has also clogged prematurely. This indicates the runoff from this site may be unusually difficult for filters to treat without clogging. To support the issuance of a GULD for the Kraken™ Filter, Bio Clean will look for another location to conduct supplemental flow monitoring with the goal of demonstrating the system will not rapidly clog when receiving runoff from more typical land uses where manufactured treatment devices are deployed (e.g., commercial parking lots, residential streets, etc.).

REFERENCES

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

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

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

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

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

Herrera. 2016. Quality Assurance Project Plan: the Kraken™ Membrane Filter Performance Verification Project. Prepared for Bio Clean Environmental Services, Inc., by Herrera Environmental Consultants, Inc., Seattle, Washington.

NJDEP. 2013. New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device. New Jersey Department of Environmental Protection, Trenton, New Jersey.

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

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

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