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Environmental Technology Verification Report

In-Drain Treatment Device

The Hydro International Up-Flo™ Filter

Prepared by

Penn State Harrisburg
Middletown, Pennsylvania

Under a Cooperative Agreement with
 U.S. Environmental Protection Agency

ET ✓ ET ✓ ET ✓

**THE ENVIRONMENTAL TECHNOLOGY VERIFICATION
PROGRAM**



U.S. Environmental Protection Agency



NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	UPFLOW WATER TREATMENT	
APPLICATION:	IN-DRAIN TREATMENT DEVICE	
TECHNOLOGY NAME:	UP-FLO™ FILTER WITH CPZ MIX™ FILTER MEDIA	
TEST LOCATION:	PENN STATE HARRISBURG	
COMPANY:	HYDRO INTERNATIONAL	
ADDRESS:	94 Hutchins Drive Portland, Maine 04102	PHONE: (207) 756-6200 FAX: (207) 756-6212
WEB SITE:	http://www.hydrointernational.biz/us/	
EMAIL:	stormwaterinquiries@hil-tech.com	

NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center (WQPC), one of six centers under the Environmental Technology Verification (ETV) Program. The WQPC recently evaluated the performance of the Up-Flo™ Filter, manufactured by Hydro International. The Up-Flo™ Filter was tested at the Penn State Harrisburg Environmental Engineering Laboratory in Middletown, Pennsylvania.

EPA created ETV to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permittees; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

TECHNOLOGY DESCRIPTION

The following description of the Up-Flo™ Filter was provided by the vendor and does not represent verified information.

The Up-Flo™ Filter is a passive, modular filtration system that incorporates multiple elements of a treatment train into a single, small-footprint device. The Up-Flo™ Filter uses a sedimentation sump and screening system to pretreat runoff before it flows up through the filter media, housed in one to six filter modules, where final polishing occurs. A high-capacity, siphonic bypass safeguards against upstream ponding during high-flow events. The siphon also serves as a floatables baffle to prevent the escape of floatable trash and debris from the Up-Flo™ Filter chamber.

The Up-Flo™ Filter is self-activating and operates by simple hydraulics. Challenge water enters the chamber from an inlet pipe or an overhead grate and flows into the sump region where gross debris and coarse grit are removed by settling. Runoff continues to fill the chamber until there is enough driving head to initiate flow through the filter media. At this point, the water flows up through the angled screen into the filter module. In the filter module, flow passes up through the filter media and is conveyed to the outlet module via the flow conveyance channel. Flows in excess of the filtration capacity are discharged directly to the outlet module by the siphonic bypass. The siphon also serves as a floatables baffle to prevent the escape of buoyant litter and debris. The Up-Flo™ Filter is equipped with a drain-down mechanism to ensure that the filter media sits above the standing water level during no-flow conditions, to prevent anoxic conditions that could promote bacterial growth in the filter media and the release of harmful leachates. As flows subside, water slowly drains out of the chamber through four small drain-down ports located at the base of the outlet module. The drain-down ports are covered with a layer of filter fabric to provide treatment to the drain-down flows.

Performance of a regularly maintained Up-Flo™ Filter should provide removal of over 80% of total suspended solids (TSS) from challenge water runoff. It will also remove a portion of metals, organics and other pollutants commonly found sorbed to the surface of suspended sediment particles. Each filter module filled with the CPZ Mix™ will have a flow rate of 20-25 gpm when the water level in the chamber provides 20 in. of driving head. Water will continue to be filtered up through the filter media until the water level in the chamber falls to zero inches of driving head. When the inflows exceed the filtration capacity, the excess flows will discharge through the bypass siphon directly to the outlet module.

VERIFICATION TESTING DESCRIPTION

Methods and Procedures

The testing methods and procedures employed during the study were outlined in the *Test Plan for Hydro International, Inc. Up-Flo™ Filter for Stormwater Treatment* (February 2006). The Up-Flo™ Filter was installed in a specially designed testing rig to simulate a catch basin receiving surface runoff. The rig was designed to provide for controlled dosing and sampling, and to allow for observation of system performance.

The Up-Flo™ Filter was challenged by a variety of hydraulic flow and contaminant load conditions to evaluate the system's performance under normal and elevated loadings. The test conditions are summarized in Table 1. Additional tests were conducted at the vendor's request to determine the media's sediment removal capabilities with challenge water consisting of only sediments and nutrients (no hydrocarbons) at continuous flow. The results of these tests will be published in an addendum at a later time.

Table 1. Test Phase Summary

Phase and Flow Condition		Flow	Loadings	Test Duration
I	Intermittent Flow	11 gpm, 15 min on, 15 min off	Normal	40 hr
II	Contaminant Capacity	16 gpm continuous	Normal	Continue until exhaustion
III-1	Hydraulic Capacity, Clean Water	10 to 45 gpm, increased in 5 gpm increments	None	15 min at each flow interval
III-2	Hydraulic Capacity, Synthetic Wastewater	10 to 45 gpm, increased in 5 gpm increments	Normal	15 min at each flow interval
III-3	Hydraulic Capacity, Spiked Wastewater	10 to 45 gpm, increased in 5 gpm increments	Spiked (4X)	15 min at each flow interval
IV	Contaminant Capacity at High Hydraulic Throughput	32 gpm continuous	Normal	Continue until exhaustion

A synthesized wastewater mixture containing petroleum hydrocarbons (gasoline, diesel fuel, motor oil, and brake fluid), automotive fluids (antifreeze and windshield washer solvent), surfactants, and sediments (sand, topsoil and clay), was used to simulate constituents found in surface runoff from a commercial or industrial setting. Influent and effluent samples were collected and analyzed for several parameters, including TSS, suspended sediment concentration (SSC), total phosphorus (TP), and chemical oxygen demand (COD). Complete descriptions of the testing and quality assurance/quality control (QA/QC) procedures are included in the verification report.

PERFORMANCE VERIFICATION

System Installation and Maintenance

The Up-Flo™ Filter was found to be durable and easy to install, requiring no special tools. Maintenance on the system during testing consisted of replacing the filter media bags, and removing sediment and water collected in the sump. Maintenance took approximately 30-45 minutes, with the most difficult activity being removal of the filter media bags, due to their size and weight.

Hydraulic Capacity

The hydraulic capacity of the Up-Flo™ Filter was determined using clean water (Phase III-1), synthetic wastewater (Phase III-2), and synthetic wastewater with spiked constituents (Phase III-3). Capacity was evaluated as a function of influent and effluent flow rates, and water levels in the sump. The testing determined the effluent flow rates were comparable to the influent for all flow rates tested, up to and past the point where the bypass was activated. The hydraulic capacity results are expressed graphically in Figure 1.

An Up-Flo™ with new filter media can accept a hydraulic flow of up to approximately 30 gpm with no bypass, depending on the concentration of contaminants in the wastewater. At flows greater than 30 gpm the water elevation in the sump approaches the bypass siphon elevation, and a portion of the influent flow exits the system as untreated bypass. The maximum treated flow decreases as the filter media trap contaminants, preventing water from flowing through the filter bags. This was particularly evident with the Phase III-3 (spiked contaminant loadings), where the effluent flow diminished prior to eventually reaching bypass conditions.

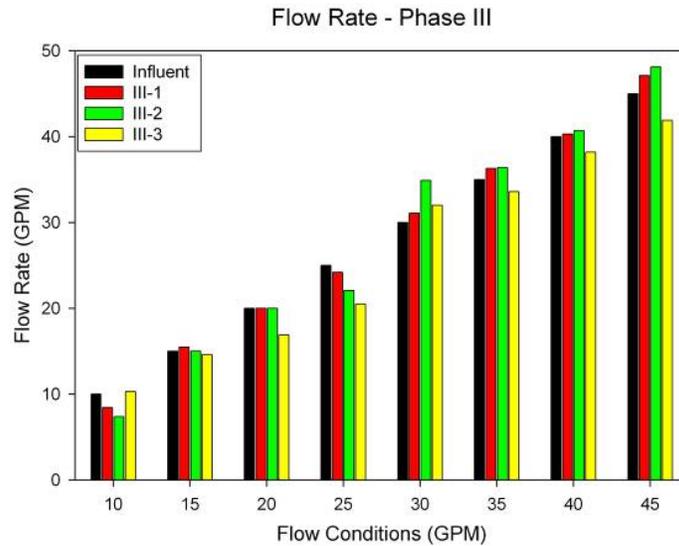


Figure 1. Comparison of influent versus effluent flow rates for Phase III hydraulics testing.

Contaminant Removal

Table 2 summarizes the influent and effluent constituent concentrations and the respective removal efficiencies for the Phase I (intermittent flow) and Phase II (continuous flow tests). During both of these tests, the flow was held constant at 11 gpm for Phase I and 16 gpm for Phase II, both of which are less than the Up-Flo™ Filter’s 20 gpm rated capacity. These tests were done consecutively, and were completed when filter media exhaustion or blinding was observed. During testing, the filter media was blinded off by contaminant loading prior to breakthrough occurring. In general, the effluent constituent concentrations remained constant throughout testing.

Table 2. Up-Flo™ Filter Treatment Efficiency Summary for Phase I and Phase II Tests

	<u>Influent Concentration Results (mg/L)</u>				<u>Effluent Concentration Results (mg/L)</u>				<u>Removal Efficiency (%)¹</u>			
	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.
TSS	136	112	492	<5	36	30	100	9	73	73	92	-1,280
SSC	147	130	555	<5	39	30	108	<5	74	77	99	-480
TP	47	44	183	0.6	38	38	81	0.6	19	14	91	-530
COD	157	134	523	60	63	65	89	33	60	51	88	-3.3

1. Mean and median removal efficiencies are calculated using the calculated mean and median influent and effluent concentrations, while maximum and minimum removal efficiencies are evaluated from the paired sample data points.

The median sediment removal efficiency is 73% and 77% for TSS and SSC, respectively, which is slightly below the vendor’s 80% sediment removal efficiency performance claim. The Up-Flo™ Filter was also shown to be capable of reducing TP and COD, demonstrated by median removal efficiencies of 14% and 51%, respectively.

Media Blinding/Bypass

During the Phase II and Phase IV tests, the testing organization observed that when the filter media reached capacity, it would shift within the filter module. This shift opened a preferential pathway in the corner of the filter module for water to pass through the system without passing through the filter media. This failure mechanism was not anticipated by the vendor. The vendor indicated that the Up-Flo™ Filter would fail as the filter bags clog, forcing a rise of the water level in the tank to an elevation that would eventually reach the bypass siphon and flow out through the bypass.

Quality Assurance/Quality Control

NSF personnel completed a technical systems audit during testing to ensure that the testing was in compliance with the test plan. NSF also completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing. In addition to QA/QC audits performed by NSF, EPA personnel conducted an audit of NSF's QA Management Program.

<i>Original signed by</i>		<i>Original signed by</i>
<u>Sally Gutierrez</u>	<u>October 15, 2007</u>	<u>Robert Ferguson</u>
Sally Gutierrez	Date	Robert Ferguson
Director		Vice President
National Risk Management Research Laboratory		Water Systems
Office of Research and Development		NSF International
United States Environmental Protection Agency		

<i>Original signed by</i>		<i>Original signed by</i>
<u>Robert Ferguson</u>	<u>October 3, 2007</u>	<u>Robert Ferguson</u>
Robert Ferguson	Date	Robert Ferguson
Vice President		Vice President
Water Systems		Water Systems
NSF International		NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents
Copies of the *Protocol for the Verification of In-Drain Treatment Technologies, April 2001*, the verification statement, and the verification report (NSF Report Number 07/30/WQPC-SWP) are available from:

- ETV Water Quality Protection Center Program Manager (hard copy)
- NSF International
- P.O. Box 130140
- Ann Arbor, Michigan 48113-0140

NSF website: <http://www.nsf.org/etv> (electronic copy)
EPA website: <http://www.epa.gov/etv> (electronic copy)
Appendices are not included in the verification report, but are available from NSF upon request.

Environmental Technology Verification Report

In-Drain Treatment Device

**The Hydro International Up-Flo™ Treatment
Device**

Prepared by:
Penn State Harrisburg
Middletown, Pennsylvania 17057

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey

September 2007
Revised April 2009 with Supplemental Vendor Testing (Chapter 6)

Notice

This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use or certification by NSF.

Foreword

The EPA is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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Abbreviations and Acronyms

cfs	Cubic feet per second
COD	Chemical oxygen demand
d ₅₀	Diameter of 50 th percentile particle
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ft ²	Square feet
ft ³	Cubic feet
g	Gram
gal	Gallon
gpm	Gallon per minute
hr	Hour
in.	Inch
L	Liter
LAS	Linear alkylbenzene sulfonate (represented by Dodecylbenzenesulfonic acid)
lb	Pound
NRMRL	National Risk Management Research Laboratory
mg/L	Milligram per liter
min	Minute
mL	Milliliter(s)
µm	Micron
NIST	National Institute of Standards and Technology
NSF	NSF International
OBC	Oil-based constituents
O&M	Operations and maintenance
P	Phosphorus
PI	Principal Investigator
PSH	Penn State Harrisburg
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
SAP	Sampling and Analysis Plan
SSC	Suspended sediment concentration
STPP	Sodium tripolyphosphate
TCLP	Toxicity Characteristic Leachate Procedure
TO	Testing Organization (Penn State Harrisburg)
TP	Total phosphorus
TSS	Total suspended solids
USGS	United States Geological Survey
VO	Verification Organization (NSF)
WQPC	Water Quality Protection Center
WSC	Water-soluble constituents

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Penn State Harrisburg was responsible for all elements in the testing sequence, including test setup, calibration and verification of instruments, data collection and analysis, data management, data interpretation, and the preparation of this report.

Penn State Harrisburg
777 W. Harrisburg Pike
Middletown, Pennsylvania 17057
Contact Person: Shirley Clark

The vendor of the equipment is:

Hydro International
94 Hutchins Dr.
Portland, Maine 04102-1930
Contact Person: Kwabena Osei

The Testing Organization thanks J. Bradley Mikula for his planning of the testing apparatus, James Elligson, Julia Hafera and David Spyker for their assistance in assembling the test apparatus and Christopher Roenning, Kelly Franklin, Christine Siu and Brett Long for their many hours testing the Up-Flo™ Filter and analyzing the resulting samples. The TO also thanks the Environmental Engineering Program for its support and patience during the testing period as we occupied a large portion of the wastewater laboratory.

Chapter 1

Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV Program's goal is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations (TOs); stakeholders groups that consist of buyers, vendor organizations, and permittees; and the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance/quality control (QA/QC) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) operates the Water Quality Protection Center (WQPC) in cooperation with EPA. The Source Water Protection Area of the WQPC evaluated the performance of the Hydro International's Up-Flo™ Filter, which is an in-drain device designed to remove hydrocarbons, organically bound metals, sediments, and other organic chemical compounds from commercial or industrial runoff and wet weather flow. This document provides the verification test results for the Hydro International Up-Flo™ Filter.

It is important to note that verification of the equipment does not mean that the equipment is “certified” by NSF or “accepted” by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the TO.

1.2 Testing Participants and Responsibilities

The ETV testing of the Up-Flo™ Filter was a cooperative effort between the following participants: EPA, NSF, PSH, and Hydro International.

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 U.S. Environmental Protection Agency

The EPA Office of Research and Development, through the Urban Watershed Branch, Water Supply and Water Resources Division, NRMRL, provides administrative, technical, and QA

guidance and oversight on all ETV WQPC activities. This peer-reviewed document has been reviewed by NSF and EPA and recommended for public release.

The key EPA contact for this program is:

Mr. Ray Frederick, Project Officer, ETV Source Water Protection Program
(732) 321-6627 e-mail: Frederick.Ray@epamail.epa.gov
USEPA, NRMRL
Urban Watershed Management Research Laboratory
2890 Woodbridge Ave. (MS-104)
Edison, NJ 08837-3679

1.2.2 NSF International – Verification Organization (VO)

NSF is EPA’s verification partner organization for administering the WQPC. NSF is a not-for-profit testing and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo, or Mark meet those standards.

NSF’s responsibilities as the VO include:

- Review and comment on the test plan;
- Review the quality systems of all parties involved with the TO and subsequently, qualify the TO;
- Oversee the TO activities related to the technology evaluation and associated laboratory testing;
- Carry out an on-site audit of test procedures;
- Oversee the development of a Verification Report and Verification Statement;
- Coordinate with EPA to approve the Verification Report and Verification Statement;
- Provide QA/QC review and support for the TO.

Key contacts at NSF for the test plan and program are:

Mr. Thomas Stevens, Program Manager
(734) 769-5347
e-mail: Stevenst@NSF.org

Mr. Patrick Davison, Project Coordinator
(734) 913-5719
davison@nsf.org

NSF International
789 Dixboro Road
Ann Arbor, Michigan 48105

1.2.3 Testing Organization – Penn State Harrisburg

Penn State Harrisburg (PSH) acted as the TO for the verification testing. The PSH Environmental Engineering Wastewater Laboratory had the space and large-scale equipment (tanks, pumps, etc.) to perform the testing on the Up-Flo™ unit, and the PSH Stormwater Management Research Group Laboratory has the equipment and experience to perform the analytical work for this test plan.

The TO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The TO was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The TO prepared the test plan; oversaw the testing; managed, evaluated, interpreted, and reported on the data generated by the testing; and reported on the performance of the technology.

TO employees manufactured and prepared the testing rig, assured the required test conditions were met, and measured and recorded data during the testing. The TO's Project Manager provided oversight of the daily tests.

The key personnel and contacts for the TO are:

Shirley E. Clark, Ph.D., P.E.
Assistant Professor of Environmental Engineering
Penn State Harrisburg Environmental Engineering Program
777 W. Harrisburg Pike TL-105
Middletown, PA 17057

1.2.4 Vendor – Hydro International

Hydro International is the vendor of the Up-Flo™ Filter. The vendor was responsible for supplying a field-ready Up-Flo™ unit and filter media, and was available during all tests to provide technical assistance as needed.

The primary contact for the vendor is:

Kwabena Osei, Research & Development Manager
(207) 756-6200
e-mail: kosei@hil-tech.com

Hydro International
94 Hutchins Dr.
Portland, Maine 04102-1930

1.3 Verification Testing Site

The verification testing was performed at PSH's campus in Middletown, Pennsylvania. The testing rig was set up in the PSH Environmental Engineering Wastewater High-Bay Laboratory, which is capable of performing a wide array of research programs. The laboratory was equipped with the necessary storage tanks and equipment to provide flows up to 50 gpm with storage of 1,700 gal in the clean-water tank.

Samples of the synthetic wastewater mixture used for testing were created and analyzed in the Environmental Engineering Program's Stormwater Research Laboratory, which is located in the same building as the Wastewater High-Bay Laboratory.

Chapter 2

Up-Flo™ Filter Equipment Description and Operating Processes

2.1 Equipment Description

The Up-Flo™ Filter is a passive, modular filtration system that incorporates multiple elements of a treatment train into a single, small-footprint device. The Up-Flo™ Filter uses a sedimentation sump and screening system to pretreat runoff before it flows up through the filter media where final polishing occurs. A high-capacity, siphonic bypass safeguards against upstream ponding during high-flow events. The siphon also serves as a floatables baffle to prevent the escape of floatable trash and debris from the Up-Flo™ Filter chamber.

2.1.1 Up-Flo™ Filter Components

The Up-Flo™ Filter has no moving parts and no external power requirements. It consists of a cylindrical concrete vessel with plastic internal components and a stainless steel support frame. The concrete vessel is a standard cylindrical manhole with an inlet pipe or a grate opening. An inspection port at ground level provides access to the sump for sediment removal. The internal components consist of angled stainless steel screens, wedge-shaped filter modules, a bypass siphon with a floatables baffle, and an outlet module. The base of the outlet module is equipped with a drain-down port design that enables standing water to drain out of the filter media between storm events, preventing the re-release of captured pollutants. The Up-Flo™ Filter components are shown in Figure 2-1.

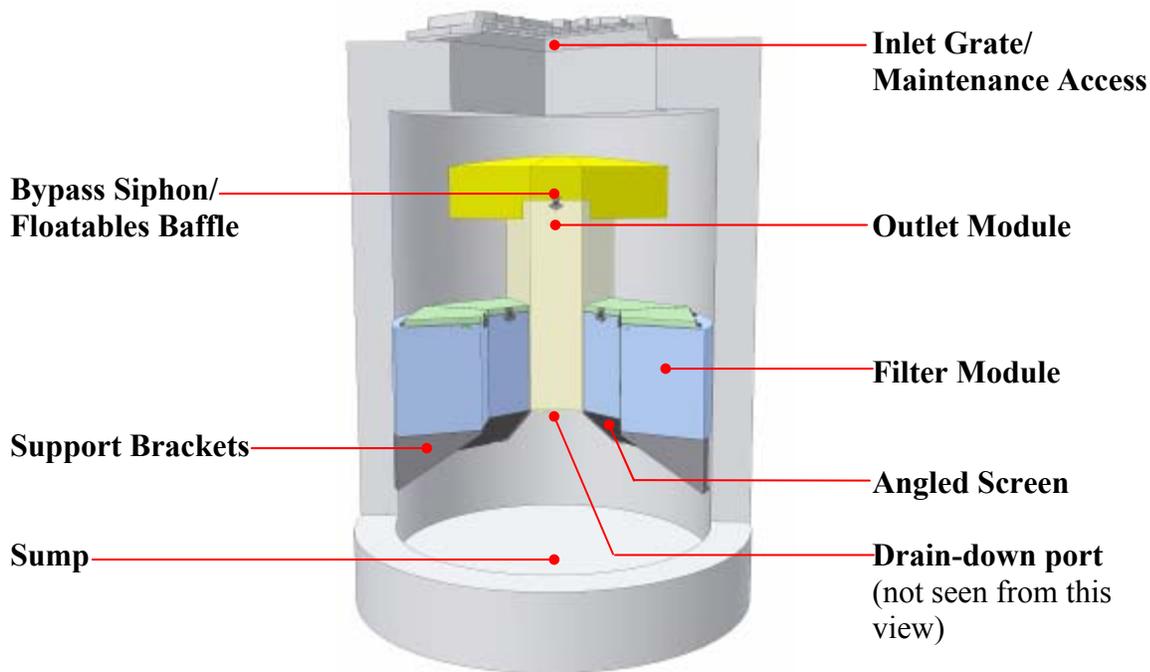


Figure 2-1. Up-Flo™ Filter components.

The filter module houses the media pack. The media pack consists of two filter media bags and two layers of flow distributing media. The internal components of the filter module are shown in Figure 2-2.

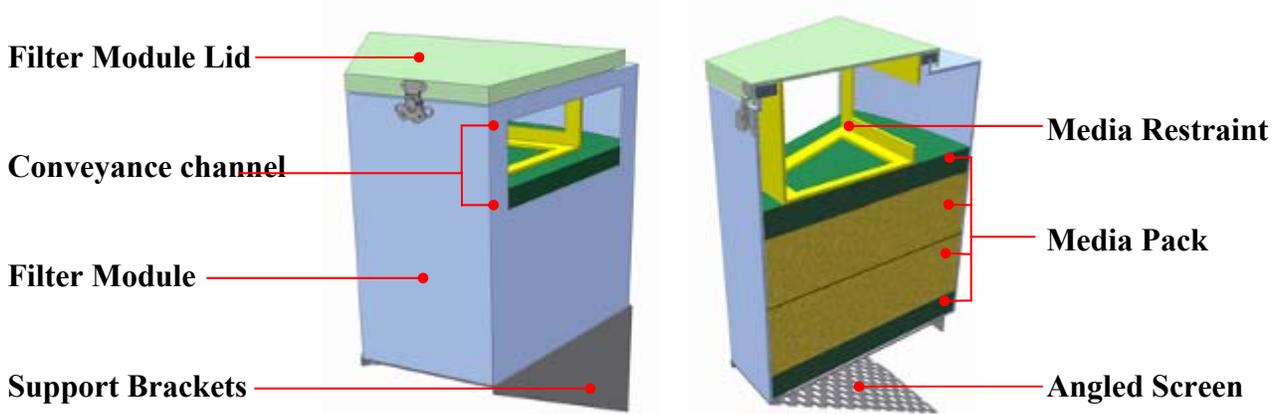


Figure 2-2. Filter module components.

2.2 Hydraulic Flow Path

The Up-Flo™ Filter is self-activating and operates on simple fluid hydraulics. The configuration of the internal components directs the flow in a pre-determined path through the vessel as described below.

2.3 Flow Conditions

2.3.1 Operating Flow Conditions

Challenge water enters the chamber from an inlet pipe or an overhead grate and flows into the sump region where gross debris and coarse grit are removed by settling. Runoff continues to fill the chamber until there is enough driving head to initiate flow through the filter media. At this point, the water flows up through the angled screen into the filter module. In the filter module, water passes up through the filter media and is conveyed to the outlet module via the flow conveyance channel. The flow path through the Up-Flo™ Filter during normal operating conditions is illustrated in Figure 2-3.

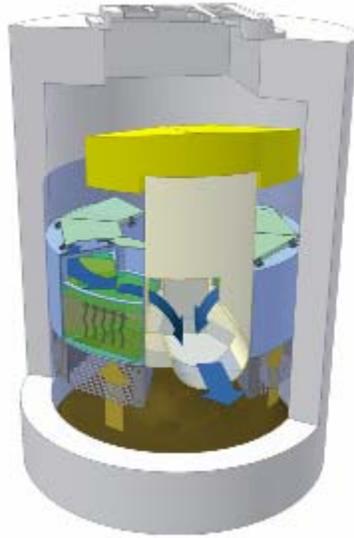


Figure 2-3. Flow path during normal operating conditions.

2.3.2 *Bypass Flow Conditions*

Flows in excess of the filtration capacity are discharged directly to the outlet module by the siphonic bypass. The siphon also serves as a floatables baffle to prevent the escape of buoyant litter and debris. The flow path through the Up-Flo™ Filter during bypass flow conditions is shown below in Figure 2-4.

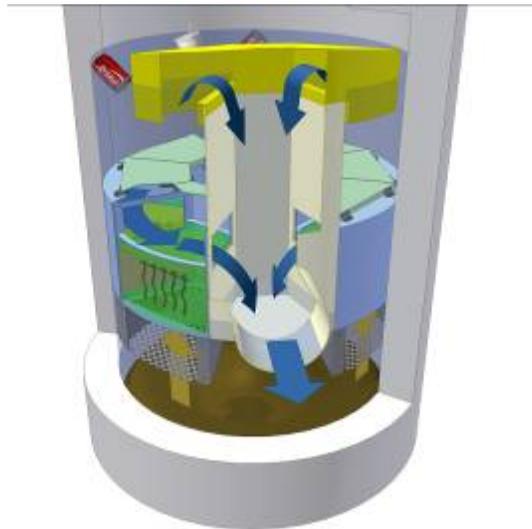


Figure 2-4. Flow path during bypass flow conditions.

2.3.3 Drain Down

Filter media continuously submerged in water can become anoxic, producing an environment that promotes bacterial growth and the release of other harmful leachates. The Up-Flo™ Filter is equipped with a drain-down mechanism to ensure that the filter media sits above the standing water level during no-flow conditions. As flows subside, water slowly drains out of the chamber through drain-down ports located at the base of the outlet module. The drain-down ports are covered with filter fabric to provide treatment to the drain-down flows. The flow path for the drain down mechanism is shown in Figure 2-5.

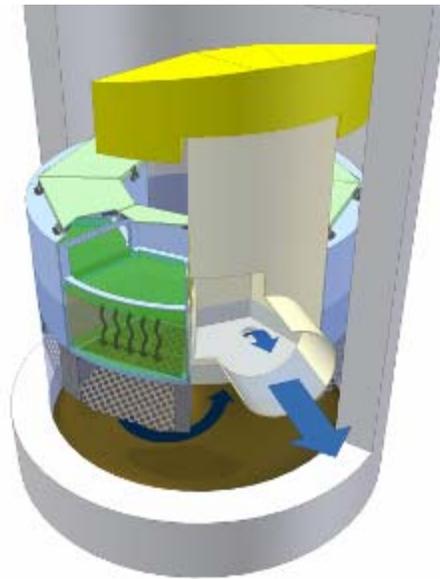


Figure 2-5. Flow path during drain down conditions.

2.4 Sizing and Hydraulic Capacity

The Up-Flo™ Filter is sized to treat the peak treatment flow of a water quality design storm. The peak flow is determined from calculations based on the contributing watershed hydrology and from a design storm magnitude set by the local challenge water management agency. The number of filter modules included in an Up-Flo™ Filter is determined by the peak treatment flow.

The flow rate through each filter module depends on the nature and type of media within the module and the water level in the Up-Flo™ Filter chamber. By adjusting media blends and the height of the water column in the chamber, each filter module can be engineered to have a treatment flow rate of 10 to 25 gpm. The flow rate through each filter module will determine the number of modules needed to treat the peak treatment flow of the storm event.

The Up-Flo™ Filter is equipped with a bypass siphon designed to discharge flows in excess of the treatment flow. When influent flows exceed the filtration capacity, the water level in the

Up-Flo™ Filter chamber rises until it reaches the height of the internal weir of the bypass. Once water starts to flow over the weir, the bypass siphon begins drawing water out of the chamber discharging the excess flows through the outlet module to the outlet pipe.

The height of the bypass can be adjusted to accommodate shallow retrofits or restrictive hydraulic profiles. The standard Up-Flo™ Filter bypasses up to 7 cfs with 2.5 feet of hydraulic drop. A shallow unit, depicted in Figure 2-6, has a bypass capacity of 4 cfs with 1.7 feet of hydraulic drop.

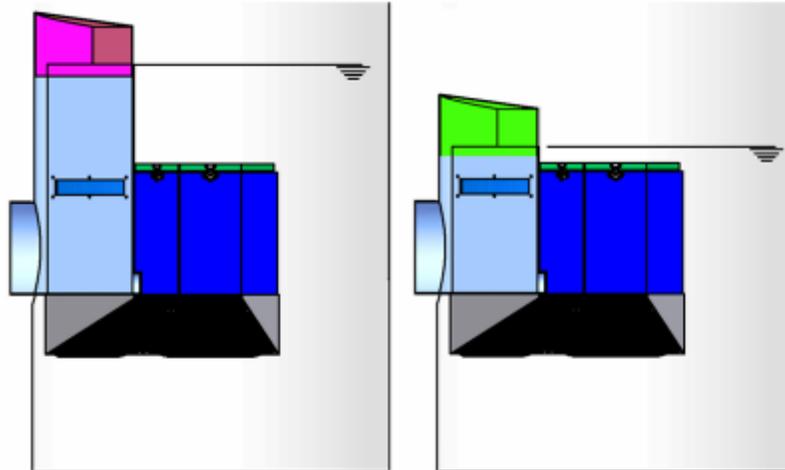


Figure 2-6. Bypass water levels for standard Up-Flo™ Filter (left) and shallow Up-Flo™ Filter.

2.5 Test Unit Specifications and Test Setup Description

The unit to be tested is a full scale, commercially available catch basin system. For the standard catch basin configuration, the Up-Flo™ Filter is comprised of one to six filter modules. In normal business practice, the number of filter modules included in an Up-Flo™ Filter is dependent upon the required peak treatment flow rate. Because the Up-Flo™ Filter is sized on a per-module basis, it is important for modular systems to be characterized on a per-module basis. TSS, phosphorous and hydraulic capacity performance claims will be verified on a one-module Up-Flo™ Filter setup. The two-module Catch Basin Up-Flo™ Filter set up is shown in Figure 2-7, Figure 2-8, and Figure 2-9.

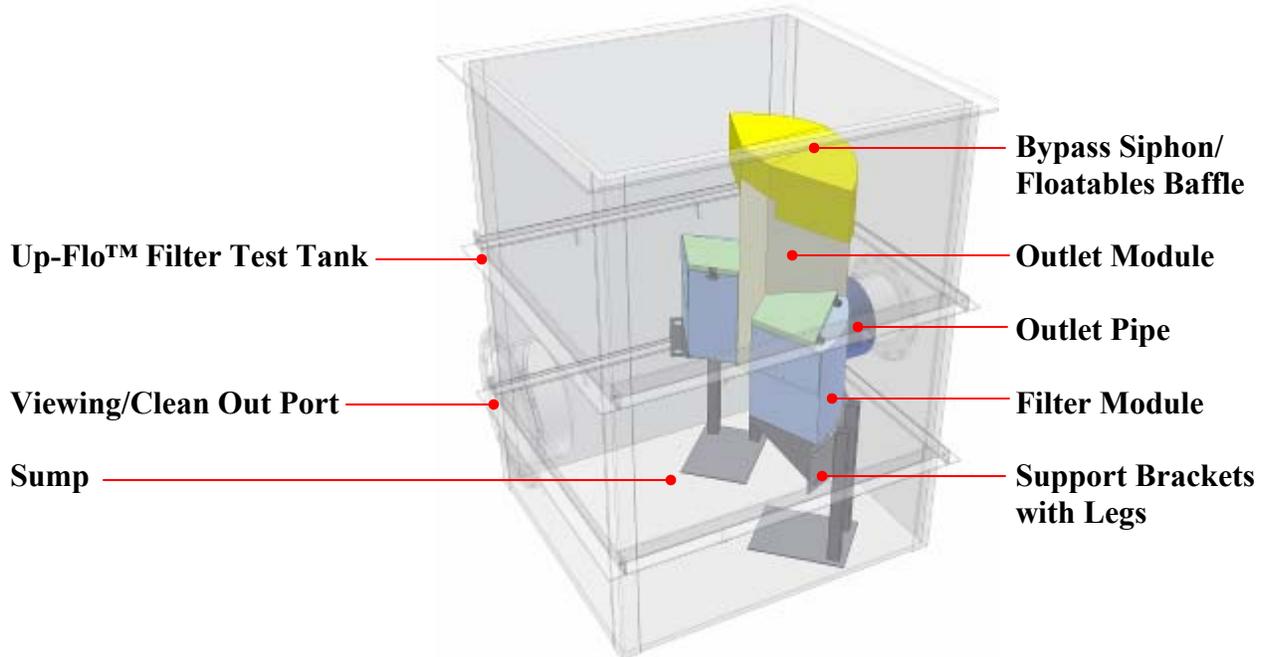


Figure 2-7. Up-Flo™ Filter test unit isometric view.

The test unit has a 24-in. sump depth, a 12-in. outlet, and an 18-in. acrylic viewing port. The height of the bypass is set so that there can be 21 in. of driving head acting on the Up-Flo™ Filter before bypass levels are reached. The test tank will be set up such that inflows pour into the chamber through the open top, replicating a grated-inlet field installation.

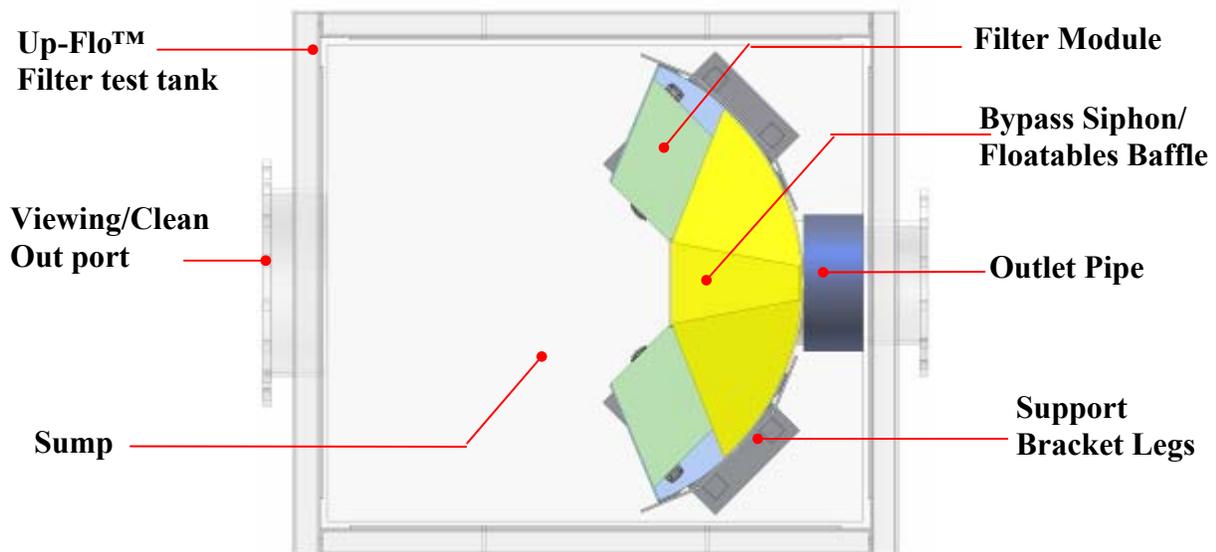


Figure 2-8. Up-Flo™ Filter test unit plan view.

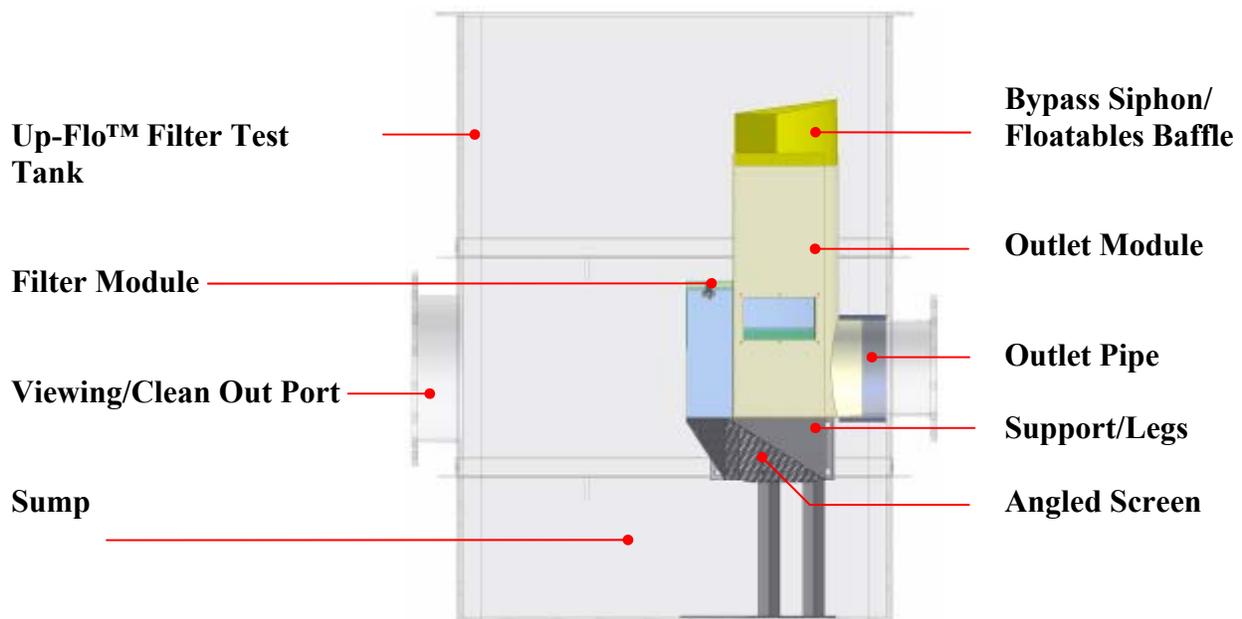


Figure 2-9. Section view of Up-Flo™ Filter test unit.

The tests will be performed at PSH’s Environmental Engineering Program’s Wastewater High-Bay Laboratory. The PSH laboratory is set up to handle testing of this type with physical facilities that includes a water supply up to 50 gpm, tanks, mixers, and pumps to store and feed the synthetic water, and all other associated piping, controls and related equipment. The Up Flo™ Filter is a passive unit that does not require any utility connections to operate. Therefore, there will be no electrical requirements needed for operation of the unit. The laboratory is equipped with water and electrical needs to supply the synthetic challenge water to the unit, operate pumps, mixers, and sampling equipment, etc. However, none of these requirements would be needed in a field application.

The synthetic challenge water described later in this test plan contained simulated challenge water solids and a source of particulate phosphorus. The contaminant concentrations in the synthetic water were similar to those found in challenge water runoff, based on data generated both during the Nationwide Urban Runoff Program (NURP) and the more-recent analysis of outfall data. The solids that accumulated as part of testing were solid waste that required disposal after testing. The solids were tested prior to disposal to ensure they are not regulated materials that require special disposal. In addition, a carbon filter was used to treat the discharge water after the effluent settling tank to ensure that the organic pollutants were removed to acceptable levels prior to discharge.

2.6 Up-Flo™ Filter Capabilities and Claims

2.6.1 System Capability

The Up-Flo™ Filter is a compact treatment-train device that targets the wide range of contaminants typically found in water runoff. Each Up-Flo™ Filter includes a sedimentation sump, coarse screens and polishing filter media. Coarse grit and gross debris is removed by settling in the sump, neutrally buoyant debris is removed by screening, and fine suspended sediment is removed by filtration. The filter media may be customized to target other site-specific pollutants such as metals and organics.

A single filter module was used in this verification program. The filter media installed in the module was Hydro International's CPZ Mix™, which is made up of activated carbon, manganese-coated zeolite and peat. Granular activated carbon is a traditional filter media for targeting organic chemicals, pesticides and herbicides. The manganese-coated zeolite targets TSS, iron, manganese and ammonium in challenge water runoff. The small fraction of peat is highly efficient at removing organics and metals.

Each filter module filled with the CPZ Mix™ has a design flow rate of 20-25 gpm when the water level in the chamber provides 20 in. of driving head. Water is filtered through the filter media until the water level in the chamber falls to zero inches of driving head. When the inflows exceed the filtration capacity, the excess flows discharge through the bypass siphon directly to the outlet module. The bypass is designed to accommodate 7 cfs of excess flows. This high-capacity bypass siphon ensures that head-loss and flow-restrictions due to the filter media will not cause collection system backups and ponding on the surface during events with high flow rates.

Maintenance of the sump and replacement of the filter bags is important for the successful long-term operation of the Up-Flo™ Filter. The flow capacity of the Up-Flo™ Filter will decrease as it accumulates sediments. The filter bags should be replaced once a year (or as needed) to ensure that fine sediment build-up is not allowed to accumulate such that the flow rate of the filter will be significantly reduced. Sediment and gross debris must also be periodically removed from the sump to ensure that accumulated sediment does not block the intake of the filter module.

This test plan was designed to meet the basic protocol requirements and focused on the treatment capability of the unit to remove sediment and particulate phosphorous from synthetic challenge water. The experimental design and sampling and analysis plan presented in the following sections provide details on the test protocol and the constituents targeted for this verification.

2.6.2 Vendor Claims

The Up-Flo™ Filter is designed to incorporate multiple elements of a treatment train into a single, small-footprint device. The Up-Flo™ Filter utilizes settling, screening and filtration to remove gross debris and suspended sediment from challenge water runoff. Specifically, the Up-Flo™ Filter will remove over 80% of fine total suspended solids (TSS) from challenge water runoff, and it will also remove a portion of metals, organics and other pollutants commonly

found sorbed to the surface of suspended sediment particles. Verification of the removals of metals, organics (except that measured as chemical oxygen demand [COD]), and other pollutants was not included as part of the test plan.

Regular maintenance events are necessary to ensure optimal performance of the Up-Flo™ Filter over time. In-field maintenance includes removing floatables, sediment and other pollutants from the sump and changing out the media packs. In-field inspection should occur regularly. In-field media pack replacement should occur once a year or as needed. The in-field maintenance of each Catch Basin Up-Flo™ Filter unit should take a half-hour or less. Maintenance on the Up-Flo™ Filter test unit will occur after each phase of performance testing. The side of the Up-Flo™ Filter test tank is equipped with an 18-in. access port to facilitate sump cleanout (see Figure 3-7). To replace media packs, entry into the test tank is necessary. The tank is spacious enough to provide comfortable access for one maintenance person. Confined space issues did not need to be addressed during this testing since the test tank was open to the atmosphere.

To properly maintain the Up-Flo™ Filter, the steps detailed in the Up-Flo™ Filter Operation & Maintenance (O&M) Manual were followed.

2.7 Performance Measures for the Verification Test

The performance capabilities of the Up-Flo™ Filter were assessed both quantitatively and qualitatively. Sampling and analysis of the influent, effluent, and residues provided data to determine the treatment efficiency of the unit with quantitative data. Recording of visual observations, operational issues and maintenance requirements provided a basis for qualitatively assessing the unit's performance. The test plan, including the Experimental Design, Sampling and Analysis Plan (SAP), and Quality Assurance Project Plan (QAPP), focused on obtaining performance-based data that served as the foundation of the verification report and the verification statement.

2.7.1 Contaminant Selection and Monitoring for Performance

The Up-Flo™ Filter unit is designed to remove solids and solids-associated pollutants, such as particulate-bound phosphorus in runoff. Based on the unit's capabilities a list of targeted contaminants that will be monitored for removal by the unit has been selected. The targeted list is as follows:

Targeted Contaminant List

- Suspended sediment concentration (SSC)
- Total suspended solids (TSS)
- Total phosphorus (TP)

These constituents, in addition COD [as a surrogate for the added organics], were measured in influent and effluent samples in accordance with the experimental design and the SAP. The results provided data for determining the performance capability of the unit to remove targeted contaminants and provide data on the additional and secondary contaminants as well. All of

these data are reported in the verification report as part of the quantitative performance measurements.

2.7.2 System Component Operation and Maintenance Performance

The overall system performance was measured both quantitatively and qualitatively. Quantitative measurements included determination of the range of hydraulic flow conditions that can be handled by the unit. The hydraulic capacity of the unit was determined by measuring the hydraulic flow rate in volume of water treated and flow rate handled. The experimental design included both hydraulic loading tests and loading of contaminants to the unit. The filter media and containment bag combination was stressed to exhaustion and spike loads were charged to the unit at high flow rates. The mass removal of contaminants was determined.

Qualitative measures were assessed by observations of and experience with the unit during the setup and testing phases. Records were maintained on the ease and time of installation, the time and ease of maintenance for cleanout and absorption medium replacement, and other operating observations. The unit is a simple design with no controls, instrumentation, alarms, or other mechanical or electrical devices that will require operation. The unit was monitored for solids or debris buildup, clogging of entry paths, and other related operational issues. The O&M Manual provided by Hydro International was reviewed for its specificity and completeness. These observations, experiences, records and review will be the basis for evaluating the system performance in terms of operation and maintenance.

2.7.3 Quantification of Residuals

Testing the Up-Flo™ Filter created residual material, such as removed contaminants, sediments, and spent filter media. The quantity of residual materials requiring disposal was a factor in performance measurements.

Chapter 3 Verification Testing Procedures

3.1 Testing Objectives

The objective of in-drain treatment system verification testing under the ETV *Source Water Protection Protocol for In-Drain Treatment Technologies* is to evaluate the contaminant removal performance and operational and maintenance performance of commercially available systems.

The objective of this testing was to determine the performance attained by the Hydro International's Up-Flo™ Filter when used to treat synthetic challenge water containing a variety of contaminants, including sediments, hydrocarbons, water-soluble organics and fertilizer. In order to estimate the "life" of the device before maintenance in a rapid period of time, the concentrations of all contaminants except sediment tested were higher than those typically seen in urban stormwater, but lower than those anticipated to be seen in mixes of stormwater and washwater.

The objective was achieved by implementing testing procedures presented in the protocol and test plan (Appendix A). A synthesized challenge water containing sediments, petroleum hydrocarbons, and surfactants was prepared to simulate contaminants at concentrations typically found in a mixture of surface water runoff and other wet-weather flows at a commercial or industrial setting. The treatment system was challenged under a variety of hydraulic loading conditions using the synthetic wastewater. Influent and effluent samples collected from the unit were measured for various contaminants as determined by indicator tests (e.g., COD, TSS, SSC, Particle Size Distribution, and TP). The results were used to calculate removal efficiencies and system capacities, and to determine the system treatment effectiveness. The treatment system was also monitored for operation and maintenance characteristics, including the performance and reliability of the equipment and the level of operator maintenance required.

The experimental design followed the methods and procedures defined in the protocol. The design incorporated all of the elements described in the protocol and included all of the phases of testing prescribed. There were two anticipated deviations or exceptions from the protocol as understood by the TO. These deviations were as follows:

1. The measurement of head loss was not directly applicable due to the design of the Up-Flo™ Filter; and
2. The synthetic challenge water concentrations set to reflect the requested challenge water concentrations, and, since no description of the sediment was provided, the particle size distribution of the sediment was selected based on those required by New Jersey Department of Environmental Protection challenge water device evaluation protocols.

The verification test was a controlled test. The testing was performed on a full-scale unit (containing one filter cartridge) and was set up in the PSH Wastewater Research laboratory. The PSH Wastewater Research laboratory is a physical testing laboratory with space, tanks, piping, utilities, etc., to perform medium scale (10 – 50 gpm) testing of this type. The synthetic challenge used for the testing was made as described later in this section and dosed to the unit as

prescribed in the protocol, with the exceptions noted in this report due to the low concentrations required.

3.2 Test Equipment

The Up-Flo™ Filter unit was placed in a specially designed (vendor-supplied) testing tank that simulated a typical catch basin used in stormwater runoff conveyance systems. The testing rig designed and constructed by PSH personnel controlled influent and effluent flow and constituent feed rates. The rig also provided for collection of influent and effluent liquid samples for laboratory analysis, and observation of performance conditions, such as bypass, in a simple and effective manner.

Figure 3-1 shows the process flow diagram and equipment configuration for the test setup. City water stored in a 1,700 gal holding tank served as the main water feed. Oil-based constituents (OBC) (gasoline, diesel fuel, motor oil, and brake fluid) and water-soluble constituents (WSC) (windshield washer fluid, antifreeze, and surfactants) were stored in two-liter bottles and fed by variable-speed peristaltic pumps into the inlet pipe containing the water. The inlet pipe was a 12-in. PVC plastic pipe that received water from the feed tank and dispensed the water mixture into the Up-Flo™ device. A dry feeder above the channel dispensed the solids mixture into the water stream at controlled rates.

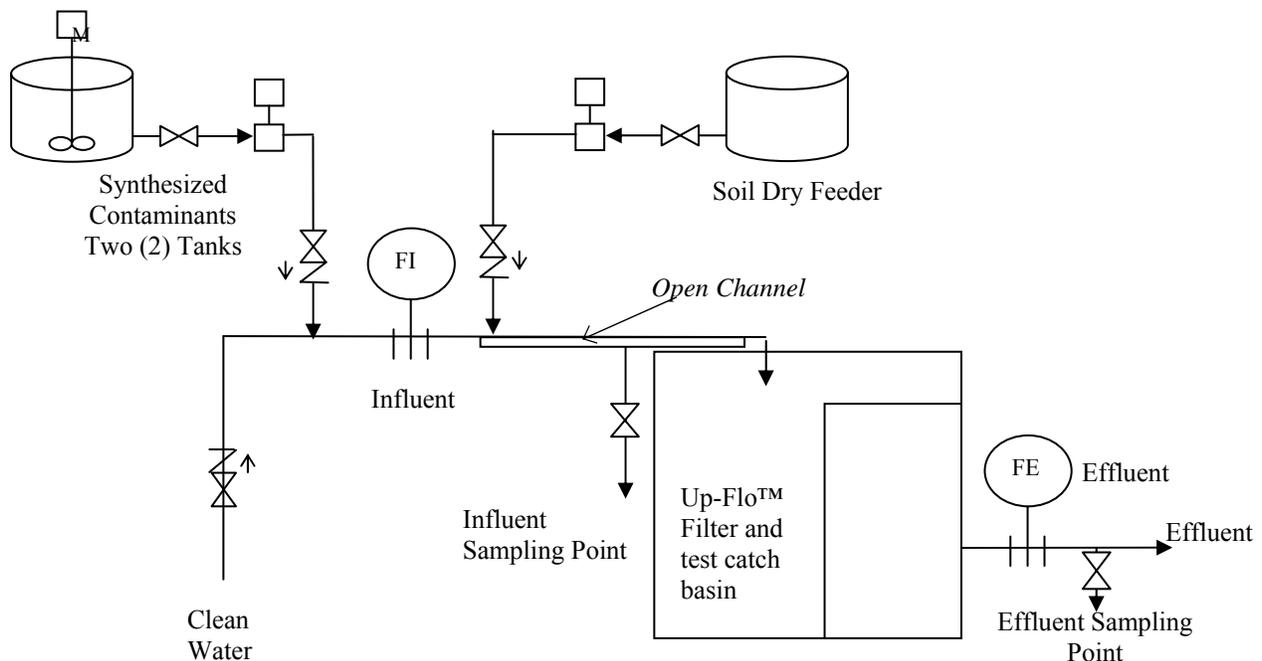


Figure 3-1. Test rig process flow diagram.

The test site was the PSH Environmental Engineering Wastewater Research laboratory in Middletown, Pennsylvania. The physical laboratory was set up to handle medium-range flow testing and full-scale unit testing. The facility had space to set up several large tanks and piping to convey the challenge wastewater to the full-scale test unit. The laboratory setup designed for this verification activity could supply up to 50 gpm of city water as a main feed during the testing. Ample electrical service was available to run all pumps, controllers, samplers, and associated equipment.

The Up-Flo™ Filter unit used for the verification test was that of a full scale commercially available one-module catch basin configuration which would be used in catch basin applications. Influent to the unit was pumped into the same elevation as the grate inlet (relative to the unit) so that flow could move through the system by gravity and the driving head in a manner similar to a field application. Effluent from the unit flowed by siphon out of the side of the test unit in the same manner that the flow would exit the unit in the field.

Figure 3-1 shows the process flow diagram and equipment configuration for the test setup. City water served as the main water feed with a maximum flow rate of up to 50 gpm. A flow control valve controlled the flow. The flow rate of the water was measured using a standard “paddle wheel” style flow meter that showed flow rate (gpm) and totalized the volume processed (gal).

Synthetic challenge water was made by adding pre-mixed and sized solids, with a specific amount of a particulate phosphorus source (ground slow-release fertilizer) to the city water. The solids were mixed in the appropriate ratio using a cement mixer and stored in a bucket near the test device. Periodic samples were collected from the solids dry-feeder (hopper) of the device to ensure that the mixture had not separated during storage. The original intention was to add the solids by slurry, but initial tests in the lab found that the sand could not be kept in suspension even in a stirred sample bottle. Therefore, the hopper was used to feed the solids into the pipe with sufficient mixing area available in the pipe between the solids-addition point and the entry to the device. The sieve size analysis of the selected solids mix, as specified by a New Jersey testing plan, is provided in Table 3-1, and is displayed graphically in Figure 3-1.

Table 3-1. Particle Size Distribution

Description	Particle Size (µm)	Sandy loam (% by mass)
Coarse sand	500 – 1,000	5
Medium sand	250 – 500	5
Fine sand	100 – 250	30
Very fine sand	50 – 100	15
Silt	8 – 50	25
Fine Silt	2 – 8	15
Clay	1 – 2	5

This distribution can be approximated by mixing a pre-sieved concrete plant sand with the Sil-Co-Sil 250 to be purchased from U.S. Silica, Inc. (or one of its distributors). The mix is 42.5% sand and 57.5% Sil-Co-Sil 250.

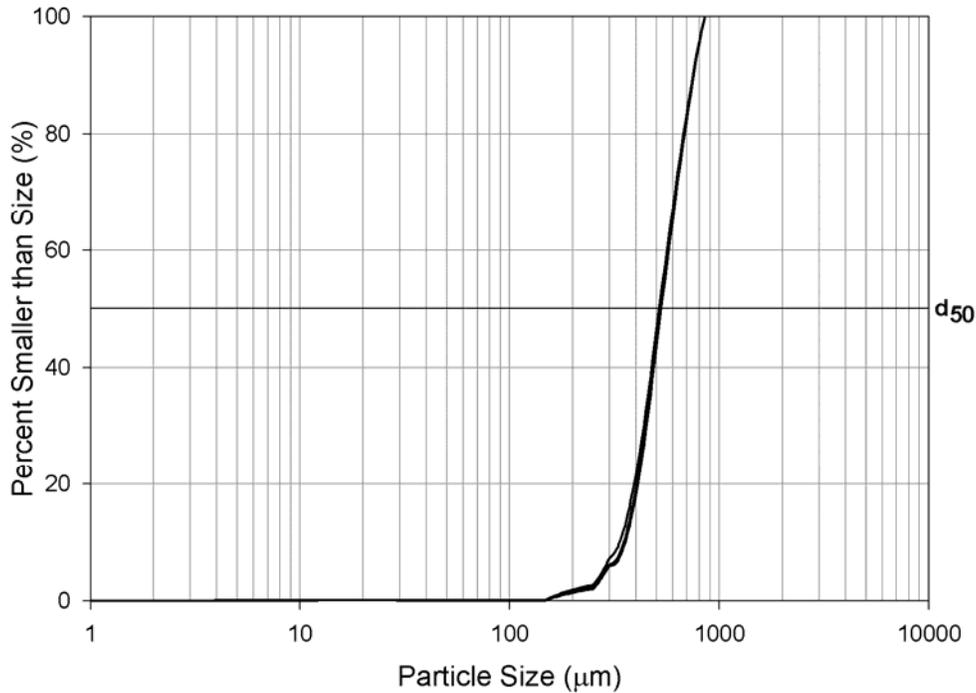


Figure 3-2. Sediment particle size distribution graph.

The original intention was to use Miracle-Gro™ topsoil as the source of particulate phosphorus to generate the required additional phosphorus (above that supplied by the STPP in the organic mixture). Testing at PSH on this topsoil showed that the phosphorus content measured as TP is approximately 0.04 mg TP/g Miracle-Gro™. However, the calculation of the solids mixture requirement was that the topsoil did not have sufficient total phosphorus to be used (the sand would have been eliminated from the mixture entirely). A search for a source of particulate phosphorus resulted in the use of Scott's Starter Slow-Release Lawn Fertilizer. This fertilizer is granular with a coating designed for slow release. The intact particles were too large to use in the solids feed so the fertilizer was ground using a coffee grinder and the phosphorus concentration measured. The testing showed the approximate TP concentration of the Scott's Starter to be 0.3 mg TP/g fertilizer.

All sampling was performed manually for all test sequences. This eliminated the concern regarding the collection of representative solids when using automatic sampling equipment.

The synthetic challenge water entered the treatment unit through the open top of the device grating, flowed through the sump/sediment collection section, and passed over/through the adsorbent materials. The treated water exited through the outlet pipe along the side of the unit. Flow rates were measured both at the beginning and outlet of the system. A sampling port was located in the effluent pipe for collection of manual grab samples. All sampling was performed manually for all test sequences.

Attempts were made to use an automatic flow measuring device to confirm the readings from the flow meter. However, the low flow levels in the effluent pipe that accompanied the unit made the use of the meter impossible. In addition, the TO was concerned about the trapping of solids around the flow meter installation. To compensate for the lack of automatic flow readings in the effluent pipe, manual flow measurements (bucket and stopwatch) were made periodically throughout the testing – typically with every sample collection or every two hours, whichever came first. Head measurements in the tank were taken at every sample collection and flow measurement time.

3.3 Test Phases – Hydraulic Loading

The unit was tested under varying hydraulic load conditions to simulate typical conditions found in wash water applications (i.e., catch basins and drain inlets in streets, parking lots, etc., that contain substantial dry-weather flows or truck-washing facilities) and during challenge water flows. The primary operational characteristics tested included the following:

- Performance under intermittent flow conditions;
- Performance under different hydraulic loadings, including peak flow;
- Performance at different contaminant loadings; and
- Capacity of the unit to contain contaminants.

The testing was done in four phases that included conditions designed to test all of these operating scenarios. The phases described below followed the same phases that are discussed in the protocol.

3.3.1 Phase I -- Performance under Intermittent Flow Conditions

In Phase I the system was operated intermittently to simulate actual in-drain treatment applications during intermittent loadings at flow rates that are typical average flow rates over a period of time. The Up-Flo™ Filter catch basin unit, with one to six filter modules, is designed to treat flow rates of up to approximately 20 gpm per filter module before any water is bypassed through the overflows. A more typical average flow rate at a catch basin or drain inlet is expected to be in the 10-15 gpm range. A flow rate of approximately 11 gpm was used for the Phase I four-to-five day test. The intermittent tests were run for a 40-hr period. During the ON cycle, the unit received flow for 15 min, followed by a 15-min period with no flow. The result was 16 flow periods during eight-hour ON cycle (two 15 min flow periods per hour for 8 hr). The flow was constant during the dosing periods at a flow rate of approximately 11 gpm. Flow rates were recorded throughout the ON-cycle period and the effluent flow rate was recorded periodically during the OFF cycle to determine drain down flows.

Samples of both the influent and the effluent were collected by manual grabs. Samples were only collected when flow is being sent to the unit. Samples for both the solids and phosphorus analysis were collected manually with 500 mL of sample collected every 500 gal (approximately once every 2 hr). Table 5-1 in the Sampling and Analysis Plan Section of the test plan provides a summary of all sampling and analysis schedules for verification test.

Observations included a physical description of the effluent water with respect to color, oil sheen, etc. The unit was observed for any evidence of clogging, change in operating head or head loss, flow patterns, or any evidence of bypass or short-circuiting. These observations are described in Chapter 4. The protocol called for the measurement of head loss as part of the monitoring of flow conditions in the unit. The Up-Flo™ Filter unit, however, is designed to bypass any flow that does not pass through the absorption media. Given that the unit is fed by gravity, is open at the top, and has an overflow capacity greater than the inlet, it is not possible to measure head loss on the influent stream to the unit. An approximation of the depth of water over the filter media in the treatment chamber was monitored by noting whether water was bypassing the treatment media, and reported as an estimate of the head loss through the media. This head loss, however, would only impact the capacity of the unit to treat water and would not impact the concern regarding flooded conditions. Water depth measurements, therefore, were recorded whenever samples and/or flow rates were measured.

The unit has a relatively large capacity (approximately 40 ft³) for holding sediment (settled solids). The challenge water had a target sediment concentration of approximately 300 mg/L. Assuming 100% removal from a flow of 12,000 gal and a 90 lb/ft³ bulk density, the retained sediment would occupy 0.2 ft³. Therefore, sediment cleanout was not anticipated until the Phase I test was completed. At the end of the Phase I period, the unit was inspected to determine the condition of the sediment chamber and the absorbents. Observation of an increase in water depth in the test tank during the test run would indicate whether the media was beginning to blind or plug. If the media and sediment chamber were in good operating condition, the media would be used for the capacity study. If the sediment chamber appeared to be filling quicker than expected or the media was beginning to plug as indicated by water draining through the bypass holes during the low-flow testing, the unit would be cleaned and the media pack will be replaced as described in the O&M Manual.

3.3.2 Phase II – Determination of the Capacity of the Unit

The objective of the Phase II testing was to run the unit to “exhaustion” with respect to the capacity of the absorbent material to remove suspended solids and/or phosphorus. During this phase of testing, the unit was operated under continuous flow conditions for 12 hr/day until the unit plugged with solids or the absorption capacity was exceeded. This was not a continuous test sequence since it would be highly unusual for an in-drain unit to flow at near maximum flow continuously until exhaustion occurred. Therefore, operating on a 12-hr basis was selected since it would most resemble real-world conditions.

The test plan allowed for using the loadings from the Phase I test to contribute to the loadings in Phase II. The total loading from Phase I would then be added to Phase II data to calculate total capacity. The flow rate for this test was set at approximately 16 gpm, which is approximately 80% of the maximum rated flow capacity of 20 gpm.

If the unit capacity had not been exceeded in the first 12 hr run (about 11,500 gal of water), the test plan called for the unit to be operated for a second 12 hr period or until the solids capacity was reached. If after the second 12-hr period indicates exhaustion has not been achieved, then

the unit would be started again and would continue to be dosed on a 12 hr run schedule until the maximum absorption capacity was reached.

Samples were collected on a grab sample basis. Samples from the influent and effluent were collected at the start of the test and after approximately each 10,000 gal of influent flow, and analyzed for the primary constituents (TSS, SSC, TP). Samples were collected on the same schedule until the capacity was achieved.

Flow rates were monitored throughout the test period on a minimum of a once per hour basis. The water depth over the filter media was monitored and recorded. Increasing water elevation in the test tank was an indication that plugging was occurring. At the end of the Phase II test, the unit was cleaned and the media pack was replaced as described in the vendor's O&M Manual.

3.3.3 Phase III – Performance Under Varied Hydraulic and Concentration Conditions

This phase of testing focused on determining the unit's hydraulic capacity and how well it handled spike loads of constituents. Phase III had three distinct parts.

3.3.3.1 Part 1: Hydraulic Capacity with Clean Water

The vendor stated that one filter module has a rated capacity of 20 gpm for treating water. Flows above 20 gpm would be bypassed through the bypass openings in the top of the unit. In order to confirm the rated treatment capacity the unit was challenged with increasing flow rates using clean water in the Part I test.

The test started with a clean unit containing fresh media. Only the clean water line was used for this test. The drain-down ports on the base of the outlet module were plugged prior to testing. Flow started at 10 gpm of fresh water for a period of 15 min. After 15 min, the flow was increased to 15 gpm for a period of 15 min. Flow continued to be increased by an additional 5 gpm (20 gpm, 25 gpm, 30 gpm, etc.) in 15-min increments until flow began through the bypass. The maximum flow rate achieved, before bypass and after bypass occurs, was recorded. Flow increases continued until the maximum available fresh water rate was reached. All flow rates and operating observations were recorded.

Observations of the water elevation at various flows were made so that estimates of media head loss can be made. The overflow was monitored and water height at various bypass flow rates was recorded.

3.3.3.2 Part 2: Hydraulic Throughput with Synthetic Challenge Water

The Part 2 testing followed the same approach as the Part 1 testing except that the synthetic challenge water was used as the influent water. In this part, the chemical feed pumps and hopper were used to add the stock solutions to the fresh water. At each increase in flow rate, the pumps and feeder were increased in rate in ratio to the fresh water feed to maintain a constant concentration of constituents in the synthetic challenge water.

The test was conducted after the Part 1 test and used the same filter media that was used for the Part 1 test. Flow started at 10 gpm for a period of 15 min. After 15 min, the flow was increased to 15 gpm for a period of 15 min. Flow continued to be increased by an additional 5 gpm (20 gpm, 25 gpm, 30 gpm, etc.) in 15-min increments until flow began through the bypass holes. The maximum flow rate achieved before bypass and after bypass begins was recorded in the logbook. After achieving the maximum treated rate, the flow continued to be increased to challenge the bypass system. All flow rates and operating observations were recorded in the logbook along with any physical observations regarding the unit response during the test.

Grab samples of the influent and effluent were collected at each flow rate condition. All samples will be analyzed for the complete list of constituents (solids and phosphorus).

3.3.3.3 Part 3: Impacts of Spike Concentration Loadings

Part 3 was a test series designed to evaluate the impact that spike loadings may have on the unit's ability to remove key constituents. The key constituents for the Up-Flo™ Filter are TSS, SSC, PSD, and TP. The hydraulic loadings were increased following the same protocol as for Part 2.

Using the same unit (no cleanout or media pack) as for Part 2, the test procedure started at a flow rate of approximately 10 gpm. The chemical feed pump rates of the stock solutions and dry feeder were set at a factor of four times higher than used in the previous tests. This increased the concentration of constituents approximately by a factor of four. Grab samples of the influent and effluent were collected at each flow rate condition until the unit flooded or the maximum available feed water capacity was reached. All samples will be analyzed for all constituents of interest. At the end of the Phase III tests, the unit was cleaned and the media pack replaced as described in the vendor's O&M Manual.

3.3.4 Phase IV – Contaminant Capacities at High Hydraulic Throughput

The influence on treatment efficiency of high hydraulic loads on the unit were tested in Phase IV. The Phase IV test was a capacity or "exhaustion test" similar to Phase II, except the unit will be under higher hydraulic loads typical of a very large flow event. The Up-Flo™ Filter unit was somewhat unique in that it treats all of the water that can pass through the treatment chambers and then bypass the remaining water. Thus, at higher flows (above treatment capacity) it will not backup and flood an area around the inlet, but rather will treat a set flow, about 20 gpm/ft² of filter media, and the additional flow will be bypassed to the catch basin outlet and enter the collection system. Under this high flow rate test, the unit was operated above the rated treatment capacity with the bypass flowing and removing the extra flow. The flow rate was set at approximately 32 gpm, which is above the treatment capacity. The test was designed to demonstrate the system's treatment capability when it is operating in bypass mode. The test time period was 12 hr continuous flow per 24-hr day. However, the unit did not end up in bypass. The results are described later in the verification report.

Observation of the flow rates through the treatment unit and the bypass were to be used as the primary indicator that solids capacity has been reached. When flow rates in the treatment section decreased by 25% or more for 30 minutes, capacity was considered to have been reached.

Samples were collected on a grab sample basis. Samples from the influent and effluent were collected at the start of the test. It was anticipated that the flows would be sampled every 10,000 gal of water treated and analyzed for the primary constituents. However, given the nature of the breakthrough pattern and timing seen in Phase II testing, it was determined that higher resolution sampling was required. Samples were collected every 30 min for the first 2 hr of testing and then once per hour after that. Flow rates were monitored throughout the test period on a minimum of a once per hour basis.

3.4 Influent Characterization

3.4.1 Synthetic Challenge Water

The verification test will be performed using synthetic water (Table 3-2) made from a mixture of solids – one of which will provide the particulate phosphorus required by the test plan. The following products will be used to make the synthetic challenge water:

- Regular unleaded gasoline;
- Diesel fuel;
- 10W-30 motor oil;
- Brake fluid;
- Antifreeze (glycol based);
- Vehicle washing detergent (specific chemical addition – see below);
- Windshield washer fluid;
- Sil-Co-Sil 250;
- Slow release phosphorus-supplying fertilizer; and
- Concrete plant sand sieved to a size of all passing through 5,000 µm.

Table 3-2. Revised Synthetic Challenge Water Concentrations

Parameter	Concentration (mg/L)
SSC	300
TSS	300
Total phosphorous (as P)	5-10
COD	100-200

A formula using a mix of the above named products/materials has been made and tested in the laboratory to determine the conformance to these specifications. The synthetic mix that was prepared and tested is shown in Table 3-3. The results of testing the ground fertilizer for phosphorus content is 0.3 mg TP/g Scott’s Lawn Starter Fertilizer. The addition of fertilizer replaced approximately 10% of the sand in the mixture.

Table 3-3. Synthetic Challenge Water Mix Concentrations

Product or Material	Concentration in Water (mg/L)
Regular unleaded gasoline	0.08
Truck diesel fuel	3.9
10W-30 motor oil	19
Brake fluid	0.97
Antifreeze (glycol based)	10
Dodecylbenzenesulfonic acid (LAS)	10
Sodium tripolyphosphate (STPP)	2
Windshield washer fluid	10
Solids Mixture	300

The product concentrations in Table 3-3 represent a deviation in the constituent concentrations identified in the original protocol. The hydrocarbon concentrations specified in the protocol were not achievable in prior testing due to the insolubility of hydrocarbons with water. For this test plan, the VO agreed that the hydrocarbon concentrations could be decreased further (to a targeted concentration range of 10 to 20 mg/L) since the vendor makes no specific claims for hydrocarbon treatment. Since the vendor did request an evaluation of particulate phosphorus removal, a slow-release fertilizer was used to increase phosphorus concentrations to approximately 5 – 10 mg/L (when combined with the STPP required by the VO). The VO, TO, and vendor agreed that the materials that comprise the synthetic challenge water should provide a condition suitable to adequately verify the performance of the Up-Flo™ Filter against the protocol requirements. This mixture was designed to represent a mixture of stormwater runoff and a dry-weather flow/washwater that contains a substantially higher load of detergents and un-emulsified hydrocarbons than is typically seen in urban runoff. The use of this mixture at the higher loadings shortened the testing time required for the Up-Flo™ compared to using a simulated solids mixture and increased the blinding of the media by the OBC and WSC constituents. The concerns raised by this mixture would be likely to be seen in applications with heavy influences of detergents and/or locations with visible free-floating hydrocarbon products.

3.4.2 Stock Solutions

The standard mix determined above (Table 3-3) was used for all of the verification tests. The Sil-Co-Sil, fertilizer, and sand was supplied by the hopper and set to meet the concentration targets in the established mix. The solids were premixed prior to filling the hopper to homogenize the solids feed. The hopper had to be refilled frequently to ensure that the solids did not separate during the test. In addition, the humidity in the laboratory testing required regular maintenance on the hopper to prevent solids “cementing” in the influent line.

The remaining products were mixed into two separate solutions. One solution included the hydrocarbon-based products (gasoline, diesel fuel, motor oil, and brake fluid), while the other solution included the water-soluble products (antifreeze, LAS, STPP, and windshield washer fluid). The two solutions were prepared using the following specifications:

- Hydrocarbon mixture (fed into the water at a rate of 0.03 mL per L of water):
 - 10 grams (g) motor oil
 - 2 g diesel fuel
 - 0.05 g gasoline
 - 0.5 g brake fluid

- Water-soluble mixture (fed into the water at a rate of 0.1 mL per L of water):
 - 10 g windshield washer fluid
 - 10 g antifreeze
 - 10 g LAS
 - 2 g STPP
 - Mixture diluted to 100 mL with tap water

3.4.3 Influent Characterization during the Verification Testing

The influent synthetic challenge water was sampled and analyzed during all of the various test conditions described in Phases I – IV. While the protocol allowed for single daily samples of the influent in several test cases, the approach used in the test plan was to match influent and effluent samples as often as possible for all sampling periods. This was to ensure that the actual influent concentrations would be known for all test conditions.

Because of the large water volumes needed for these tests, it was not practical to make a single large daily batch of synthetic water to supply the entire day's flow. Instead, the system used more concentrated stock solutions that were injected into the fresh water flow in the open channel section.

3.4.4 Solids Characterization during the Verification Testing

Influent and effluent solids were characterized using the Coulter Counter Particle Size Analyzer for particles in the range of 0.6 μm up to 240 μm . Particles above 250 μm were characterized by sieving the samples through a stainless steel sieve with a mesh size of 250 μm . The combination of the Coulter Counter results and the sieve analysis for the large particles allowed for a complete characterization of the influent and effluent particle distribution between 0.6 μm and 5,000 μm . The results for the solids analysis were subdivided into removal for the following particle size ranges:

- 0.6 - 3 μm
- 3 - 12 μm
- 12 - 30 μm
- 30 - 60 μm
- 60 - 120 μm
- 120 - 240 μm
- > 240 μm

3.5 Effluent Characterization

The effluent quality was monitored during all phases of testing except during the fresh water hydraulic test in Phase III, Part 1. The sampling and analysis approach focused frequent sample collection and analysis on the key parameters for evaluating the UpFlo™ Filter unit as described previously. Specific details on the sampling and analysis frequency and parameter list are provided in the SAP section of the test plan and in the previous sections describing the test phases.

3.6 Residue Management

Residues, including sediment in the settling chamber and the absorbent media, were removed from the unit at the end of some Phases of testing as described in Section 4.3. This task included recording the volume of residues/media collected and the wet weight of residues/media collected. These data were used to provide information on typical cleanout volume and weights that can be expected from normal operation.

Solid residues were collected from the sedimentation chamber in the unit after the majority of the water in the unit had been removed using a sump pump. The sediment was removed using a vacuum system (wet/dry shop vacuum) to simulate the typical removal system used in the field (vacuum truck). The content of the shop vacuum reservoir was removed using scoops, spatulas, scrapers, etc. to remove as much material as possible. These solids were measured for wet weight and volume in order to evaluate the amount of solids that can be expected to be generated and cleaned out of the unit on a volume throughput/loading basis. Samples of the solids were also measured for solids content so that a dry weight of solids produced could also be calculated. Three sub samples of the sediment were collected and percent solids measured. The weight of solids collected was used to relate the accumulation rate of solids to total water treated.

One representative sample of the spent filter media and retained sediments was analyzed for COD and TP and for leachate testing following the TCLP procedure. Attempts were made to weigh the filters and obtain masses of residue gathered on the media. However, because of the differences in weights due to moisture content between the new bags (which were not completely dry) and the used bags, this measurement could not be taken accurately.

3.7 Operation and Maintenance Observations

The Up-Flo™ Filter unit was operated by PSH during the test period. The vendor-supplied O&M Manual is presented in Appendix B. Hydro International will also provide consultation on installation and operation of the unit.

Installation of the unit was straight forward as the unit arrived at the PSH lab pre-assembled. Support brackets with legs sit on the base of the test tank. The filter modules were secured onto the support brackets. The outlet module had a pipe stub that fits up to the tank outlet via standard Fernco® coupling. The test tank had an open top.

Laboratory personnel maintained a detailed logbook describing all observations made during the tests. Any unit cleaning, clearing of debris, unclogging of the screens or media, etc. were recorded. Observations were also recorded on the ease of installation, operation, and maintenance. These observations included a qualitative assessment of the degree of difficulty encountered during the cleaning of the unit at the end of each phase and on the ease of replacing the media pack.

Flow rates, volume of water processed, amount of stock solutions pumped from the stock feed tanks, and related operational data for each test run were recorded in the operational log. Any deviations or changes from the prescribed test plan were thoroughly documented. The measurements of residue volumes and weights were recorded after cleaning periods.

Any other observations on the operating condition of the unit or the test system as a whole were recorded for future reference. Observations of changes in effluent quality based visual observations, such as color change, oil sheen, obvious sediment load, etc., were recorded for use during the verification report preparation.

Chapter 4

Verification Testing Results and Discussion

4.1 Synthetic Wastewater Composition

The protocol and test plan set forth a requirement that the TO maintain constituent feed rates in the synthetic wastewater of ± 50 percent of the target feed during the course of testing so that the system would be properly challenged. Prior to beginning the testing, the TO created calibration curves for each pump (water, OBC, WSC) using the appropriate feed mixture. Then the flow rates were set based on the calibration curves. The flow meter calibrations are shown in Figures 4-1, 4-2 and 4-3 for the feed water, WSC and OBC, respectively.

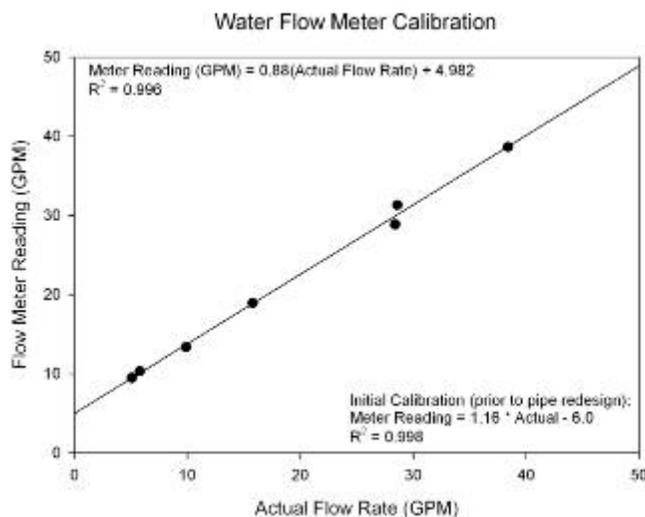


Figure 4-1. Calibration of the flow meter for the feed water.

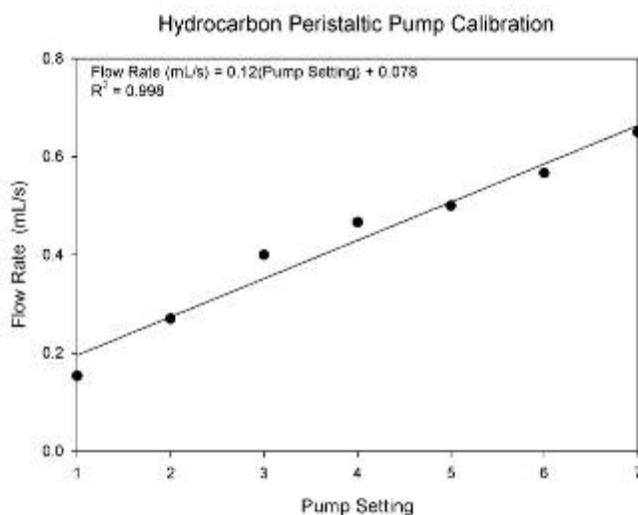


Figure 4-2. Calibration of the hydrocarbon feed peristaltic pump.

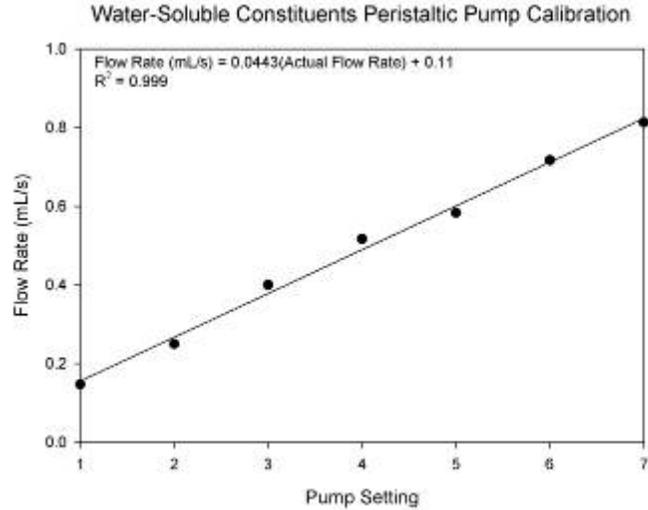


Figure 4-3. Calibration of the WSC peristaltic pump.

Based on the calibration equations, the desired flow readings for the water and the peristaltic pump settings were selected for each flow rate-concentration combination. The following tables for settings were established (Tables 4-1 and 4-2). These were then corresponded to settings on the hopper and the peristaltic pumps.

Table 4-1. Desired Feed Rates at “Normal” Settings (matching the concentrations in the original challenge solution)

Water Flow Rate (gpm)	Solids Feed Rate (mg/sec)	OBC Feed Rate (mL/sec)	WSC Feed Rate (mL/sec)
10	189	0.019	0.063
15	284	0.028	0.095
20	379	0.038	0.13
25	473	0.047	0.16
30	570	0.057	0.19
35	662	0.066	0.22
40	757	0.076	0.25
45	852	0.085	0.28
50	947	0.095	0.32

Table 4-2. Desired Feed Rates at “4X Concentration” Settings.

Water Flow Rate (gpm)	Solids Feed Rate (mg/sec)	OBC Feed Rate (mL/sec)	WSC Feed Rate (mL/sec)
10	757	0.076	0.252
15	1,140	0.114	0.379
20	1,510	0.151	0.505
25	1,890	0.189	0.631
30	2,270	0.227	0.757
35	2,650	0.265	0.883
40	3,030	0.303	1.01
45	3,410	0.341	1.14

Generally, the OBC and WSC feed rate was higher than targeted because of the inherent difficulties posed by the low flows required of the testing. Two different sizes of pump tubing were tried for each measure to better accurately target the desired flow rate range. However, the desired range, especially for the OBC mixture, fell between the two pump tube sizes. The WSC settings were in range but all at the lowest end of the range. For both OBC and WSC, it was decided to proceed with the larger tubing, based on the belief that over-challenging the filter was better than under-challenging it. Part of the desire of the protocol is to evaluate the impact that hydrocarbons and other constituents of washwater (similar to that found in service station and maintenance yard drains) have on blinding of the filter media. Therefore, the use of the larger tubing was warranted in order to not undercut the concentration of the two “fouling” agents.

Two general problems were encountered with the dosing of the solids. The humidity generated in the laboratory due to the water flow created a clogging problem in the solids hopper and removed the option of using the lowest motor settings. The calibration of the hopper therefore was inconsistent and had to be maintained regularly. Physical measurements of the hopper solids being dispensed into the water stream indicated that when the hopper was fully functional, the dispensing was in the desired range. However, the partial clogging was an issue throughout the tests. The second general problem was encountered in all sample collection procedures where the solids mixture contains comparatively large particles and is the question of where to sample in the influent flow stream. For this device, based on initial observations of the flow, the influent was sampled in the stream as the stream “united” entering the device. However, the solids results showed that, although they were not observed un-entrained in the system, the sand particles were falling out of the inlet pipe and were not evenly dispersed in the influent. At the end of the Phase III testing, the sampling location was moved up to the edge of the influent dispensing pipe and near the center bottom of the flow stream. This also has been documented to cause errors of measurement, with a potential bias toward higher solids measurements than actually occurring. This is because the sample is collected along the center flow path which is deemed to be where the larger particles flow. The testing rig, in agreement with prior testing performed under a different verification protocol with a different device, is not equipped to provide adequate mixing of large solids into the water column. The addition of baffles or mixers was considered but was rejected because of the concerns of forming a solids settling location, ensuring that the solids did not end up in the Up-Flo™ Filter.

4.2 Synthetic Wastewater Laboratory Analytical Results

During testing, 60 influent samples were collected during the normal constituent feed conditions (Phase I, Phase II, Phase III Part 2, Phase IV) and analyzed for the various constituents specified in the test plan. Table 4-3 provides a comparison of the mean analytical results for these influent samples versus the analytical results for the synthetic wastewater mix specified in the test plan.

Table 4-3. Synthetic Wastewater Analytical Data Comparison Test Plan Concentration Mean Testing

Constituent	Measured Mean Concentration (mg/L)	Desired Feed Concentration (mg/L)
TSS	132	300
SSC	130	300
TP	44	5 – 10
COD	121	70 – 100

The mean synthetic wastewater data for the primary constituents were measured to be greater than desired for TP, and less than desired for TSS and SSC. They were within the $\pm 50\%$ of the desired concentration for COD. This supports the observations that the test mixture was difficult to dose correctly in a humid environment and when very little of the OBC and WSC were required. The decision was made by the TO to supply a concentration of the OBC and WSC that could be regulated correctly by the pumps. This meant that the flow rate was set for approximately 20 drops per minute at the lower flow rates of testing – not a steady stream, but sufficient to provide a measurable concentration. A review of the data shows that the COVs for all parameters ranged between 0.5 and 1.0. In addition, as discussed earlier in the report, collecting of samples in the “correct location” in the influent stream caused difficulties. A review of the data by phases showed that the influent concentration of TSS and SSC for Phase II (the last phase run) was over 230 mg/L and was within the ± 50 percent guideline of the test plan.

The hopper dosage measurements were within the guideline for the test plan. Therefore, although the mean analytical TSS and SSC concentrations were lower than the 300 mg/L concentration specified in the test plan, the hopper dose measurements suggest that the theoretical test plan concentration was close to the 300 mg/L goal. This also suggests that the analytical samples were biased toward underreporting the actual solids concentration. On the basis of the hopper dosage measurements, the overall objective for sediment loading was met.

The variances between the test plan and mean testing concentrations for the secondary parameters exceeded the $\pm 50\%$ guideline for most parameters, but the vendor makes no claims for the secondary parameters. Therefore, the variation from the targeted concentrations is deemed to have no impact on meeting the testing objectives. However, the potential effects of the increased secondary parameter concentrations on the sediment removal performance is not known.

4.3 Test Phases in the Test Plan

This section summarizes the analytical and flow data for the test phases specified in the test plan (Phases I through IV). The efficiency values reported in this section are a function of the total influent and total effluent concentrations and do not take into account the effects of water bypassing the filter media.

4.3.1 Phase I - Performance under Intermittent Flow Conditions

As described in Section 3.5.1, the Phase I test took place over 40 hr, 8 hr per test day on days 1 and 4 and 12 hr per test day on days 2 and 3, with the flow alternating on and off for 15-min time periods. The influent flow rate was set at 12 gpm throughout the test.

4.3.1.1 Analytical Data

The effect of blinding or clogging of filter media should be evident in the results comparing flow rate through the media to the effluent concentrations. The TSS, SSC, TP and COD analytical data as related to cumulative volumetric loading on the media are summarized in Table 4-4. The test plan required that a minimum of one set of samples be collected each test day. The verification organization collected a total of 26 sets of samples. The increase was to verify whether filter media breakthrough was occurring. Three sets of these samples encountered very low or non-detectable sediment concentrations due to the issues outlined in Section 4.1. For the purposes of verification, these three sample sets were considered testing anomalies and were removed from statistical evaluations. These data are reported in the data set enclosed in Appendix C.

Removal efficiencies for TSS and SSC ranged from 73% to 77%, depending on the analyte and the statistical evaluation, which is slightly below the vendor's 80% performance claim. The VO observed dark particles in the effluent at the beginning of the test phase. These dark particles were likely the result of washing of fine sediments in the media bags. Large negative removal efficiencies were observed, primarily at the beginning of the test phase, which is likely the result of media bags washing out fine particles or bridging in the test rig's sediment dispenser, resulting in low or non-detectable influent sediment concentrations. The TP data showed a mean and median removal efficiency of 13%. The COD analytical data showed a mean and median removal efficiency of 62% and 53%, respectively.

Table 4-4. Phase I Analytical Data Summary

Analyte	Influent Concentration (mg/L)				Effluent Concentration (mg/L)				Removal Efficiency (%) ¹			
	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max	Min
TSS	123	107	435	5	32	29	83	9	74	73	92	-1280
SSC	132	125	480	5	34	29	106	5	74	77	99	-480
TP	40	40	126	0.6	35	35	64	0.6	13	13	91	-533
COD	168	139	523	77	63	65	89	33	62	53	88	5.1

1. Mean and median removal efficiency is a function of mean and median influent and effluent concentrations, and maximum and minimum removal efficiencies are a function of individual paired data points.

A graphical examination of the data was also conducted to illustrate the results discussed above. Figures 4-1, 4-2, 4-3, and 4-4 compare the influent and effluent concentrations for TSS, SSC, TP, and COD, respectively.

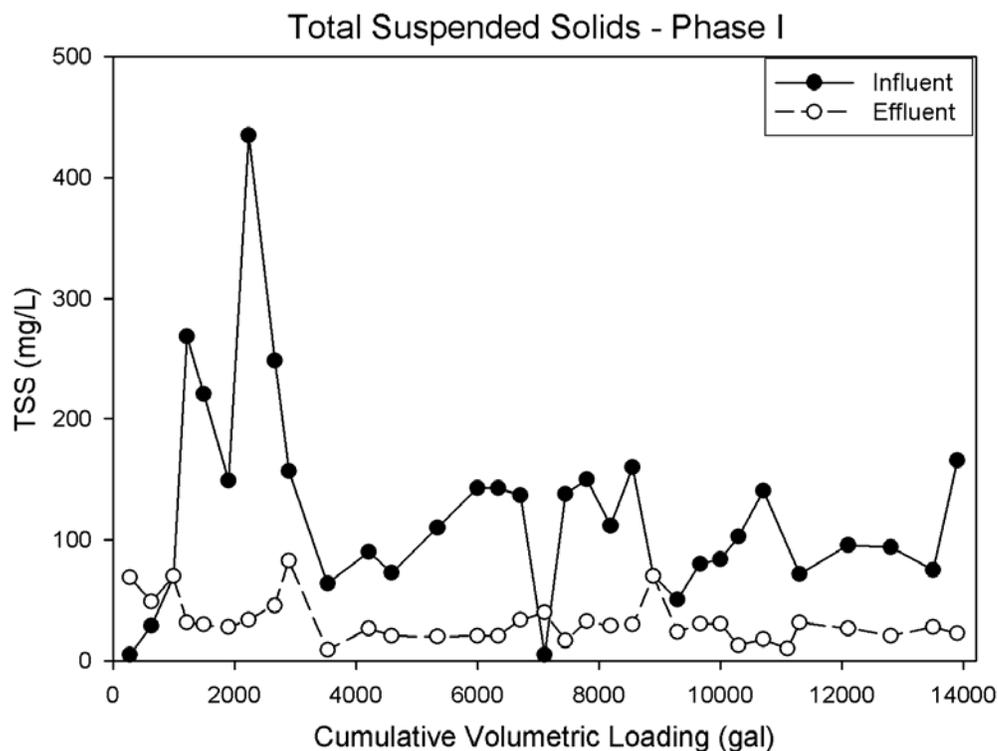


Figure 4-1. Phase I TSS influent and effluent results.

The Up-Flo™ Filter did not exhibit signs of clogging or blinding during the test run. A review of the water depth measurements at each sample time showed that the tank water level remained consistent between 40 and 42 in. No buildup of head was noted in the unit, further indicating that the media capacity had not been exhausted in the Phase I testing.

Particle size distribution analysis was also performed on representative influent samples and on all the effluent samples. Since Phase I was not the chronologically first phase performed, many influent samples had been analyzed prior to this and it was determined that the influent distribution was relatively consistent. Figure 4-5 shows the results of the PSD analysis for Phase I.

Figure 4-5 shows that the influent sample had the largest d_{50} , indicating a reduction in the media particle size in the solution as it passed through the Up-Flo™ Filter. This confirms the predictions of the manufacturer that the Up-Flo™ Filter would be capable of removing the larger particles in the solution. The data show the mean influent d_{50} was 57 μm and the mean effluent d_{50} was 24 μm .

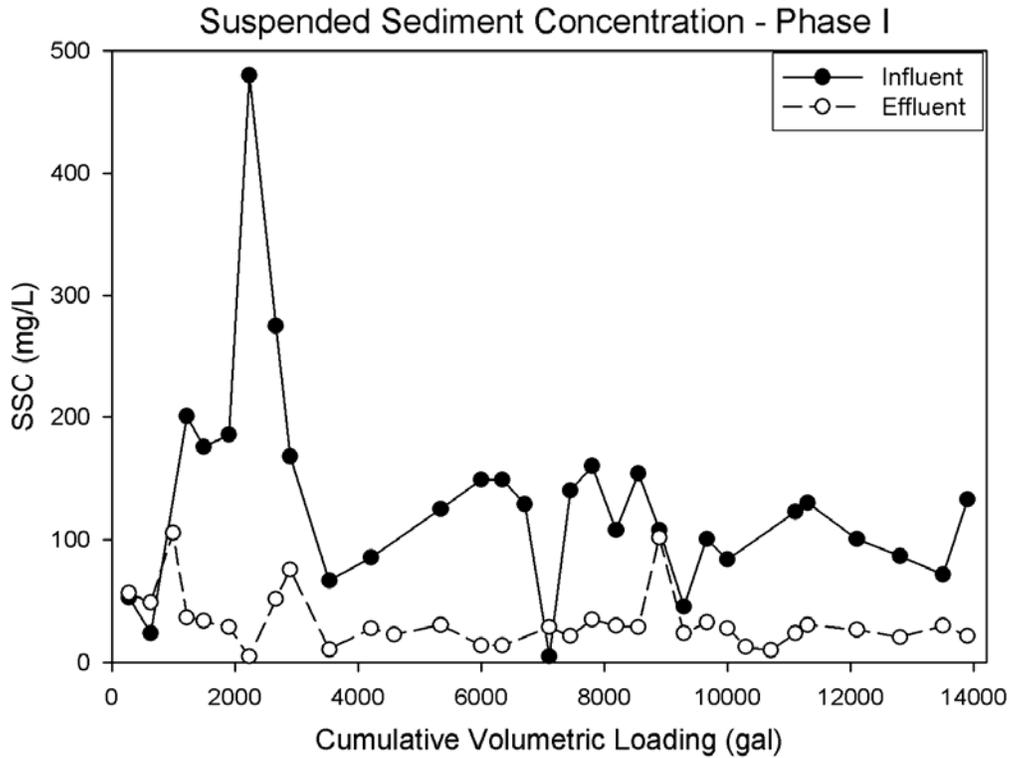


Figure 4-2. Phase I SSC influent and effluent results.

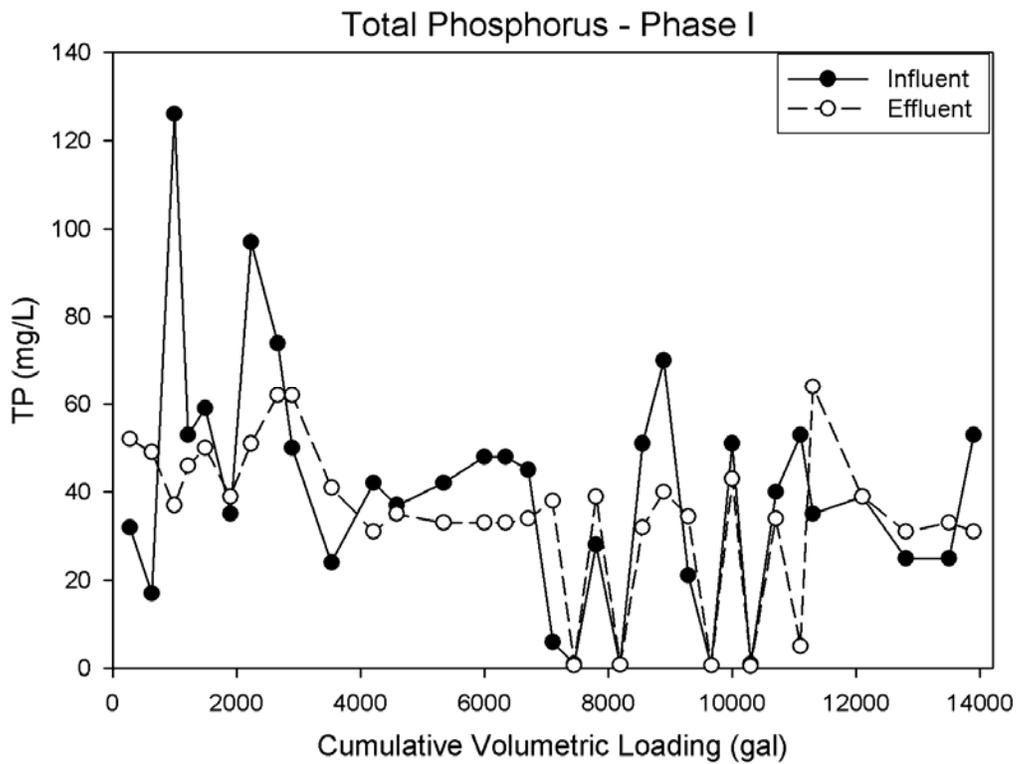


Figure 4-3. Phase I total phosphorus influent and effluent results.

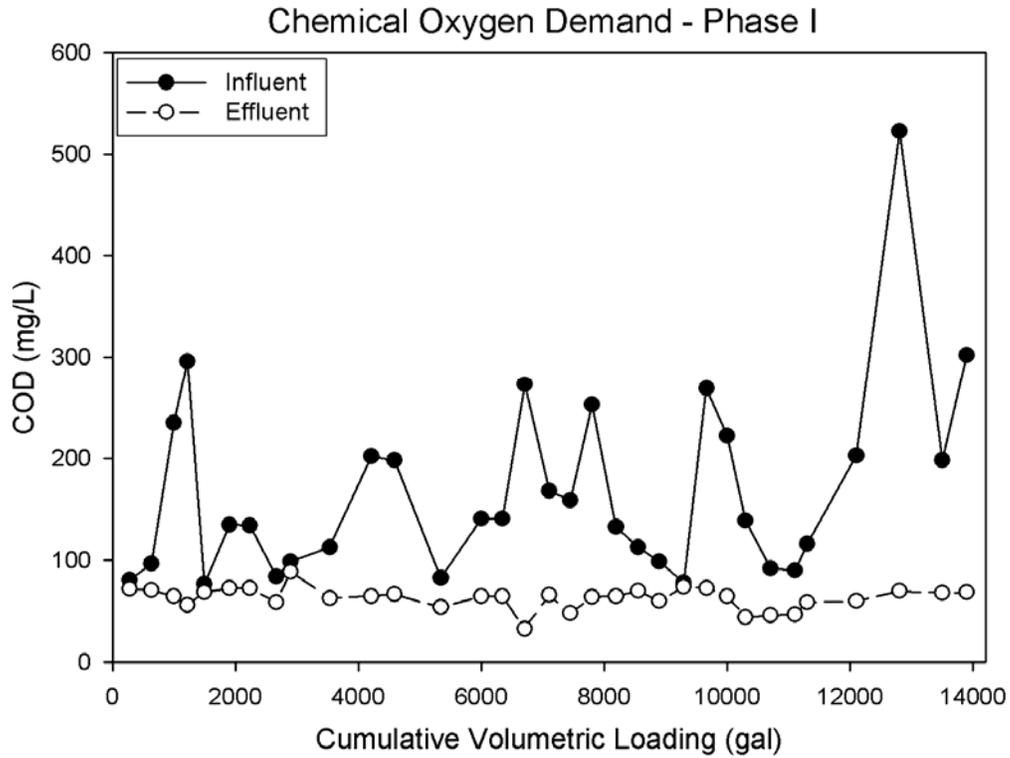


Figure 4-4. Phase I COD influent and effluent results.

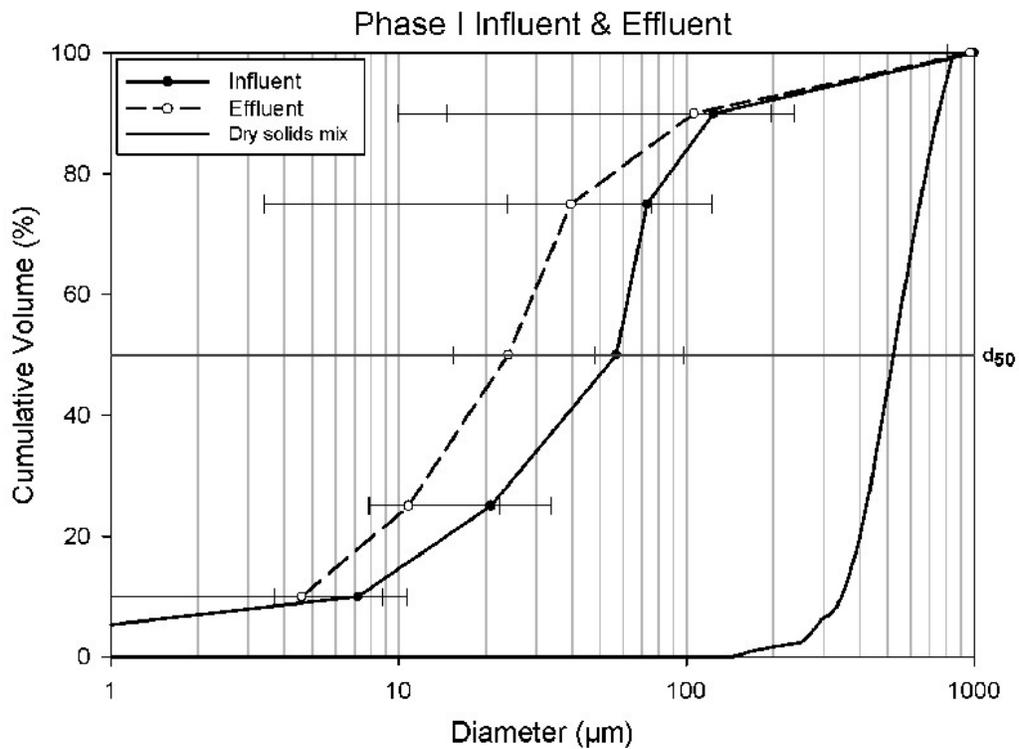


Figure 4-5. Phase I particle size distribution summary.

4.3.2 Phase II – Determination of the Capacity of the Unit

As described in Section 3.5.2, in Phase II the system was run to “exhaustion” with respect to the capacity of the filter media to remove suspended solids or petroleum hydrocarbons. The unit was operated under continuous flow conditions at a constant flow rate of 15 gpm until the unit plugged with solids or the contaminant absorption capacity was exceeded. The test plan specified a flow rate of 16 gpm for this test, based on the vendor’s claims that the system could treat water at a maximum flow rate of approximately 20 gpm.

4.3.2.1 Analytical Data

As specified in the test plan, samples were collected approximately every 10,000 gal and the system was run until breakthrough was noted. Breakthrough was noted by the failure of the media bags to remain in place in the system. The data are summarized in Table 4-5 and are expressed graphically in Figures 4-6 through 4-9.

Table 4-5. Phase II Analytical Summary

	Influent Concentration				Effluent Concentration				Removal Efficiency (%)¹			
	<u>Results (mg/L)</u>				<u>Results (mg/L)</u>							
	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.
TSS	215	164	492	84	60	50	100	30	72	70	82	40
SSC	237	171	555	96	71	64	108	<5	70	63	81	47
TP	89	75	183	47	56	50	81	30	36	33	59	7.1
COD	82	67	134	60	60	62	80	43	27	7.5	53	-3.3

1. Mean and median removal efficiency is a function of mean and median influent and effluent concentrations, and maximum and minimum removal efficiencies are a function of individual paired data points.

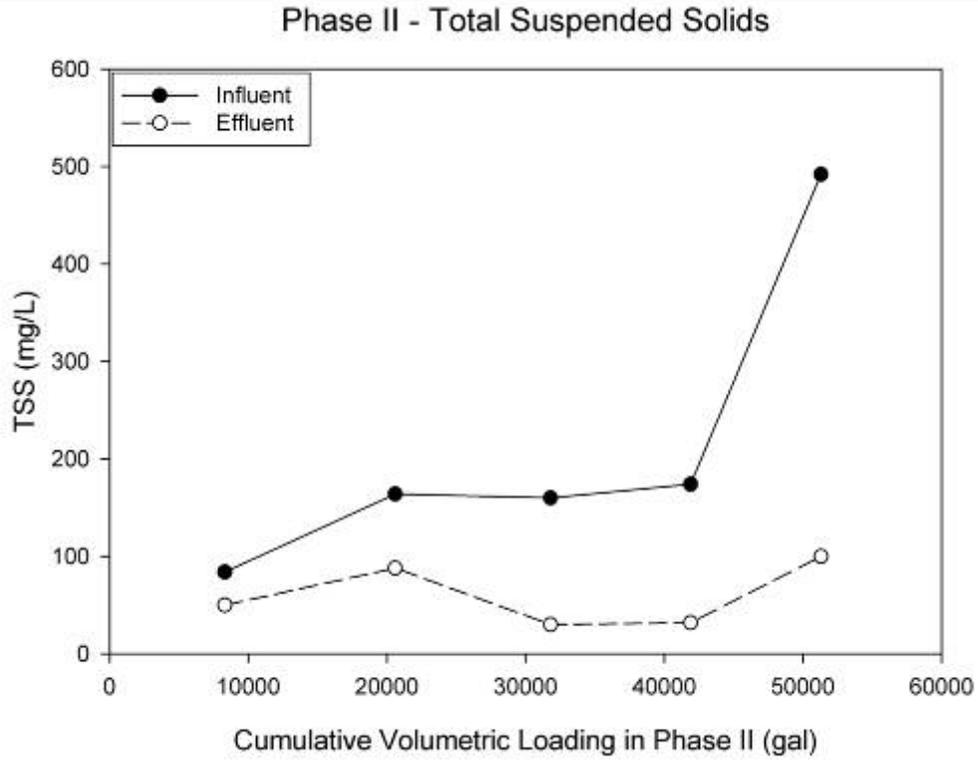


Figure 4-6. Phase II TSS influent and effluent results.

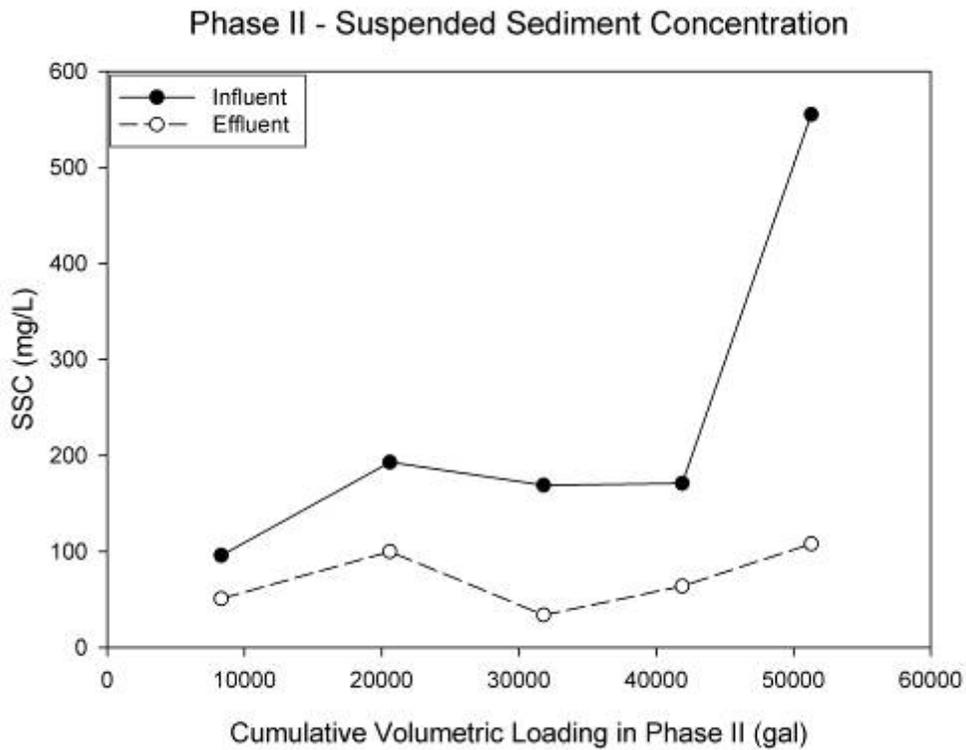


Figure 4-7. Phase II SSC influent and effluent results.

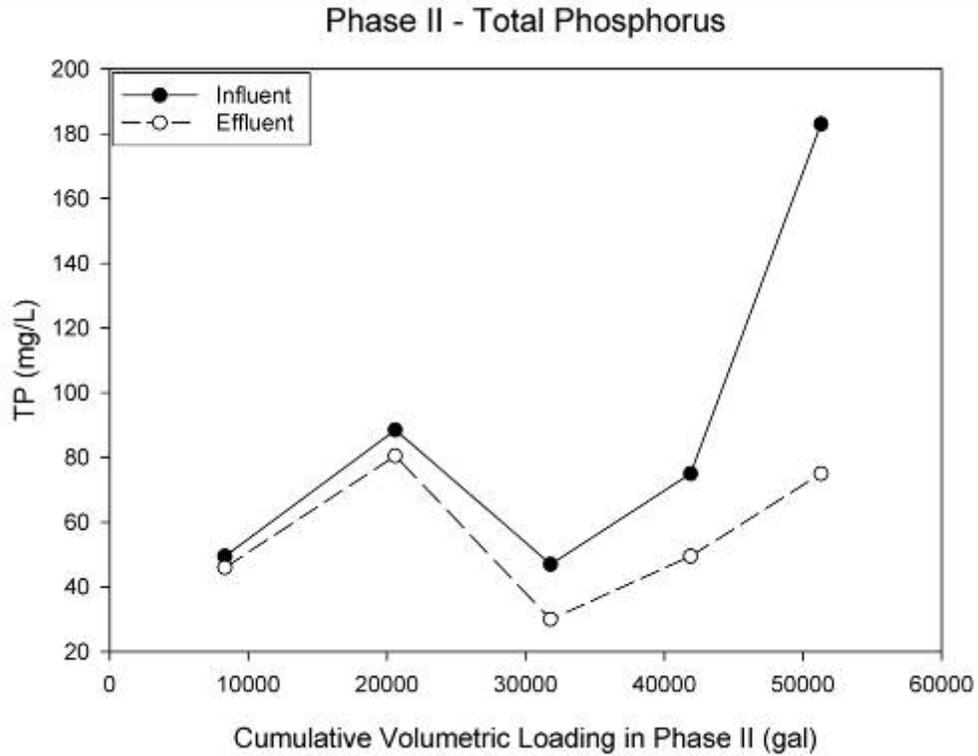


Figure 4-8. Phase II total phosphorus influent and effluent results.

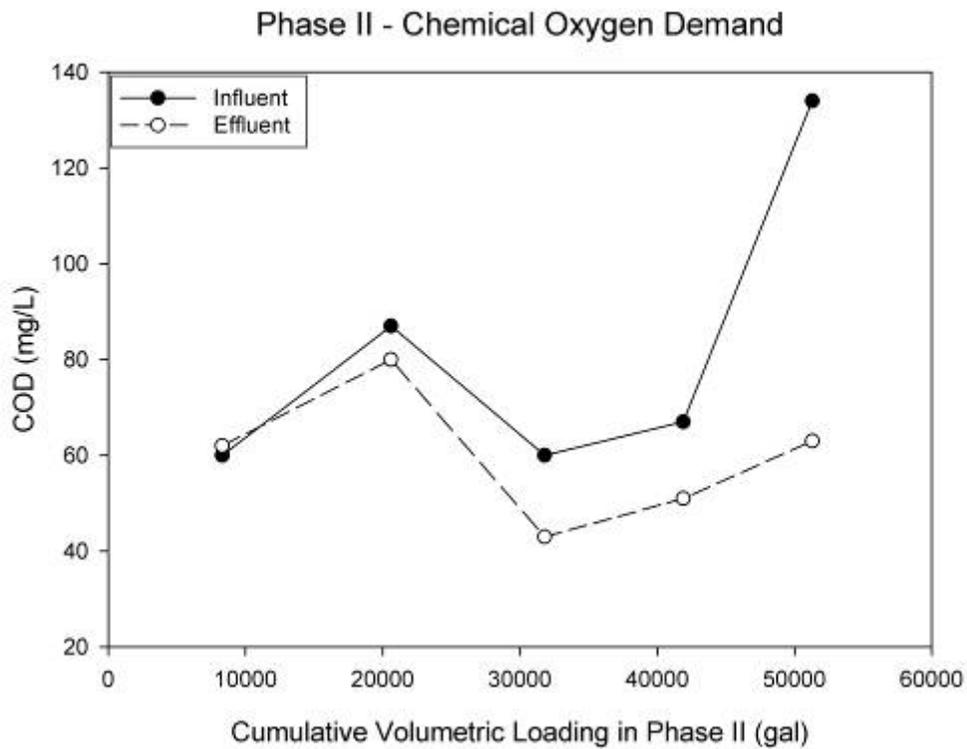


Figure 4-9. Phase II COD influent and effluent results.

In general, the Up-Flo™ Filter was 40% to 82% effective in removing TSS and 47% to 81% efficient in removing SSC from the influent. The TSS and SSC removal efficiencies actually increased over the life of the test. The TP removal efficiencies ranged from 7% to 60% and the COD removals ranged from <0% to 53%, with COD removal efficiencies increasing across the test.

PSD analysis was also performed on the Phase II samples, as shown in Figure 4-10. The mean d_{50} for the influent was 60 μm and the mean effluent d_{50} was 26 μm .

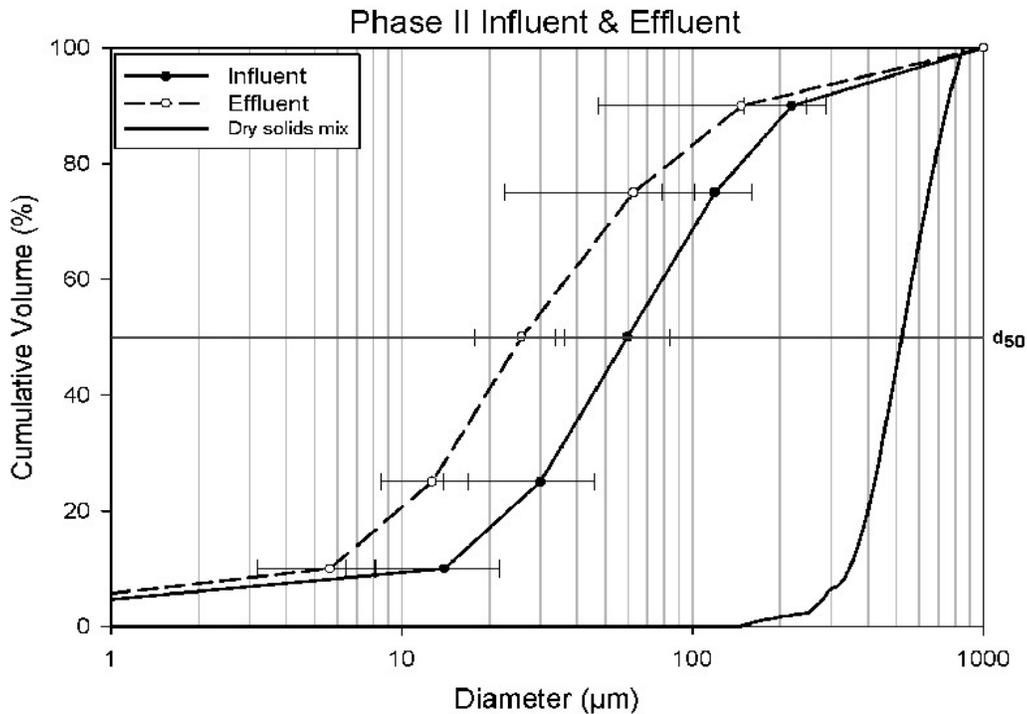


Figure 4-10. Phase II PSD summary.

The Phase II test was stopped when the TO noticed that the Up-Flo™ filter bags had been moved out of place and that substantial solids were appearing the effluent samples compared to previous samples. The mesh retaining the filter bags below the cartridge lid was displaced, allowing water to bypass the filter bags. This breakthrough was noted prior to the water level reaching the designed bypass level.

Because the media bags were not changed between Phases I and II, a full evaluation of the Up-Flo™ Filter requires an evaluation of performance across the entire testing sequence on these bags. Figures 4-11 through 4-14 summarize the media bag behavior across the entire range of testing for TSS, SSC, TP and COD, respectively. Figure 4-15 summarizes the PSD analysis for Phase I and Phase II combined. The mean d_{50} for the influent was 59 μm and the mean effluent d_{50} was 24 μm .

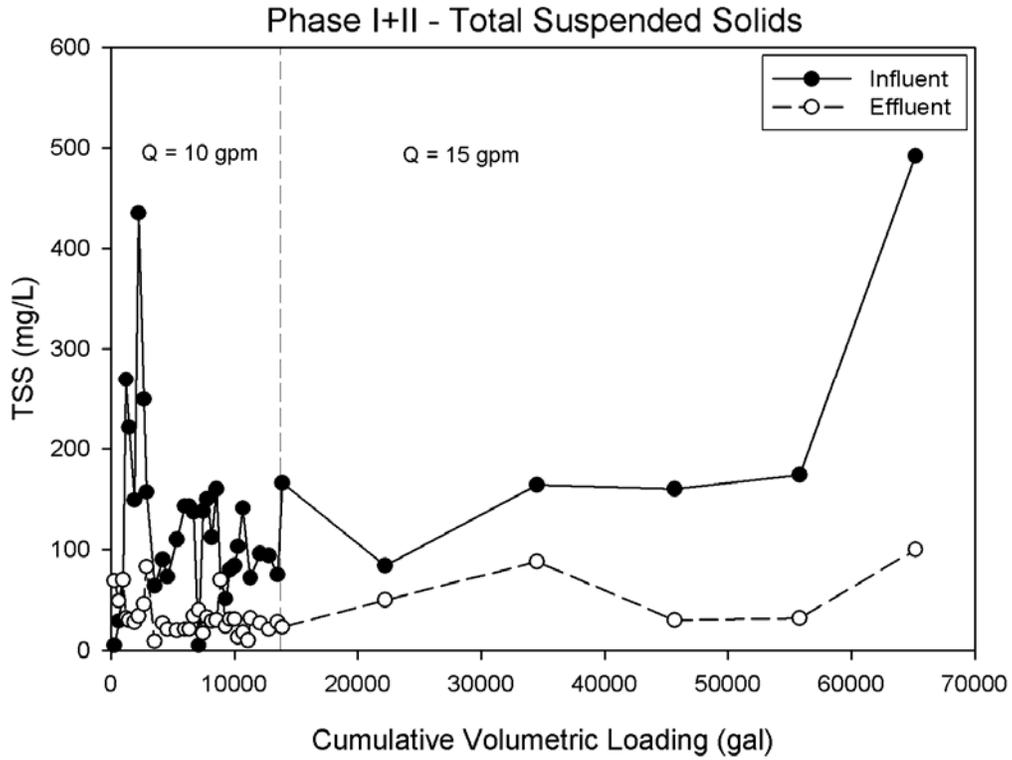


Figure 4-11. Phase I and II TSS cumulative loading results.

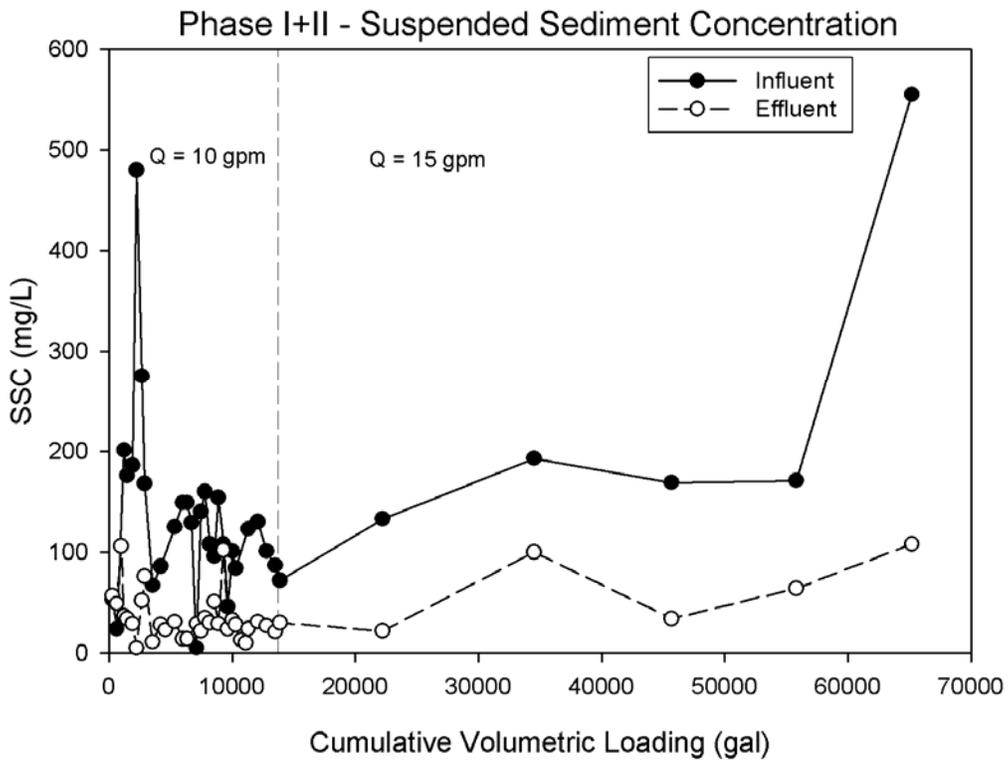


Figure 4-12. Phase I and II SSC cumulative loading results.

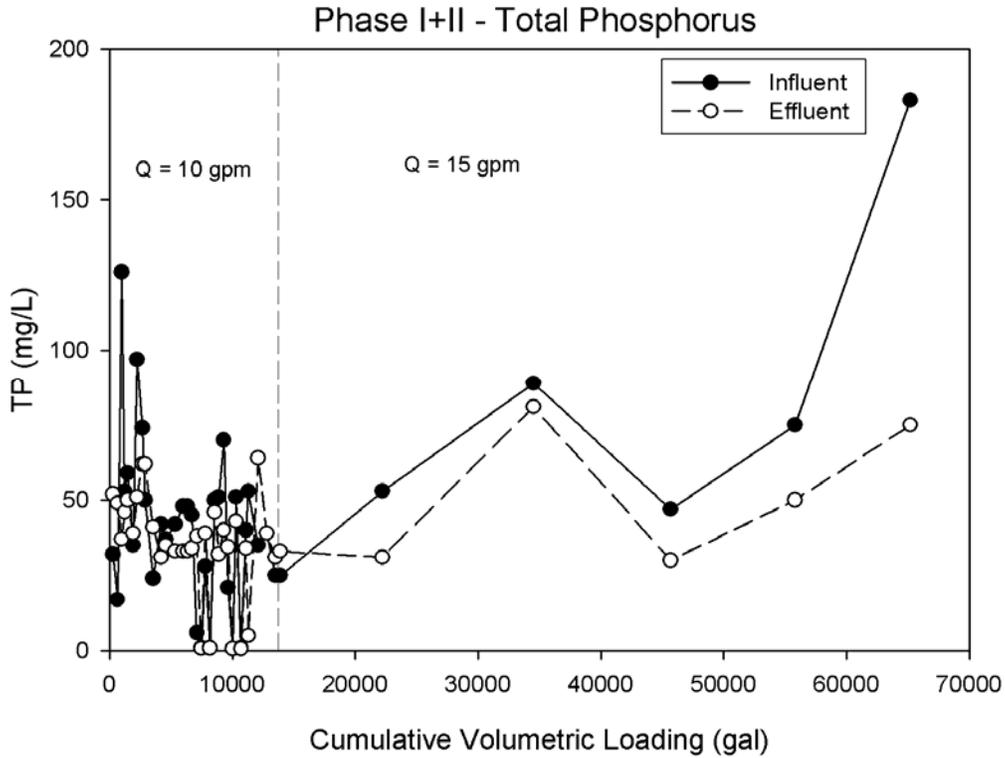


Figure 4-13. Phase I and II total phosphorus cumulative loading results.

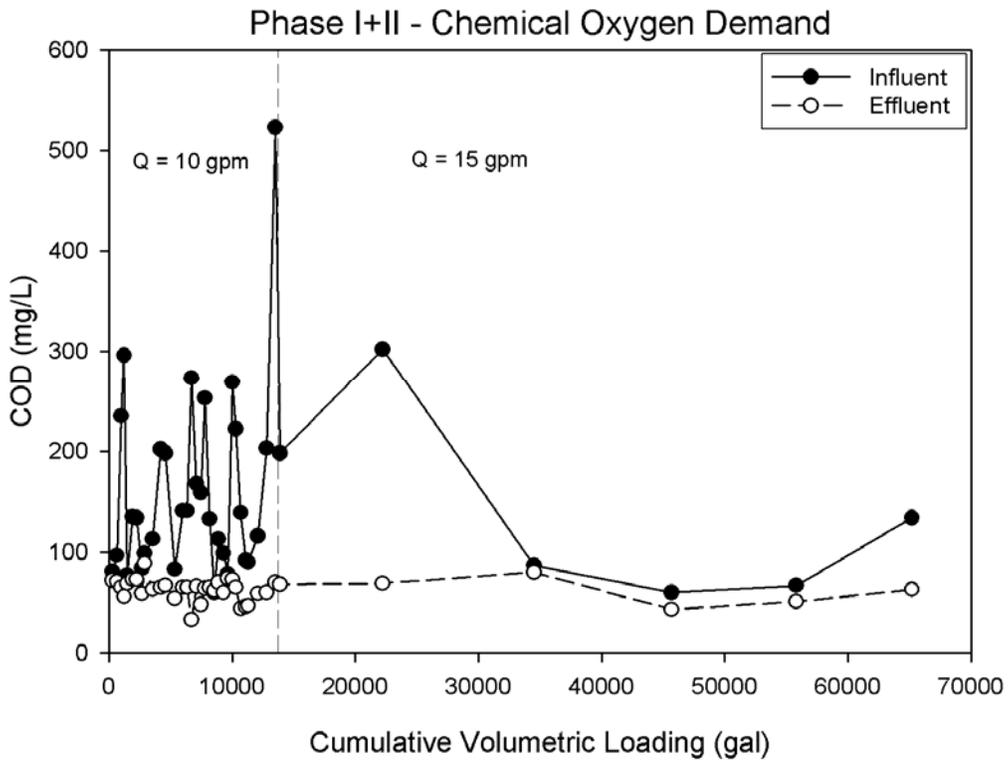


Figure 4-14. Phase I and II COD cumulative loading results.

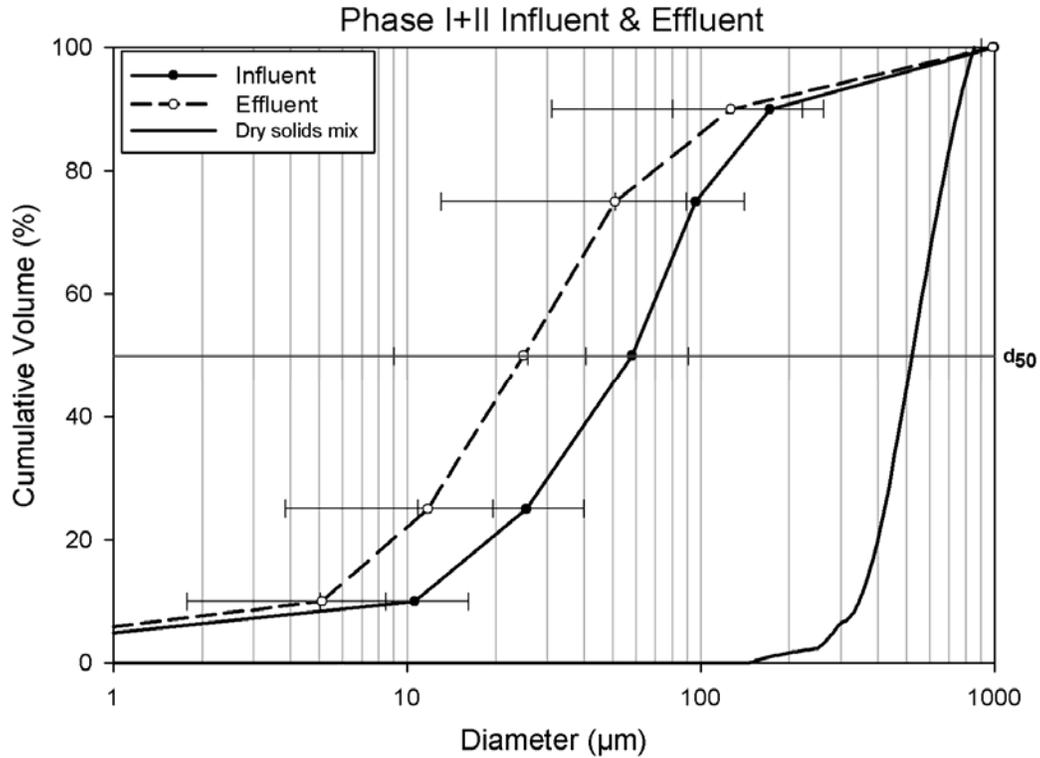


Figure 4-15. Phase I and II PSD summary.

4.3.3 Phase III – Performance under Varied Hydraulic and Concentration Conditions

As described in Section 3.5.3, Phase III testing focused on determining the unit’s hydraulic flow capacity and how well it handles spike loads of constituents. Phase III had three distinct parts:

- Part 1: Hydraulic capacity with clean water;
- Part 2: Hydraulic capacity with synthetic wastewater (regular constituent feed concentrations);
- Part 3: Hydraulic capacity with spiked constituents (four times constituent feed concentrations).

The Phase III tests were performed first because the information gathered in Phase III would help set the flow rates in Phases II and IV.

4.3.3.1 Flow Data

In Phase III Part 1, clean water was used to determine the maximum hydraulic capacity of the system before water bypassed the unit and whether drain backup would occur, resulting in potential flooding of the catch basin. The test started at 10 gpm and ran for a minimum of 15 minutes. The flow rate was then increased at 5 gpm increments, and the test was rerun until bypass occurred. Test Phases III Part 2 and III Part 3 were identical to Phase III Part 1, with the exception that constituents were added to the clean water.

The Phase III-1 data are shown graphically in Figures 4-16, 4-17 and 4-18, representing the relationship between influent and effluent flow rates, between influent flow rate and tank water depth and the drawdown flow rate as a function of water depth. The elevation of the bypass siphon was 60 in. above the tank floor, and served to prevent water depths greater than 60 in. for these flow conditions.

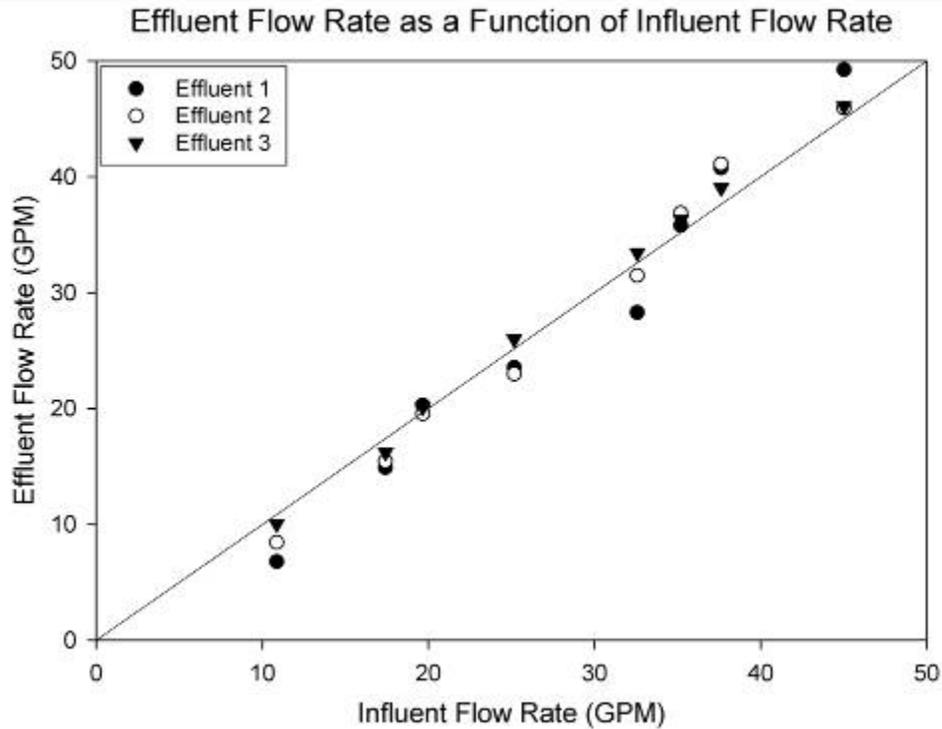


Figure 4-16. Phase III Part 1 relationship between influent and effluent flow rates using clean water.

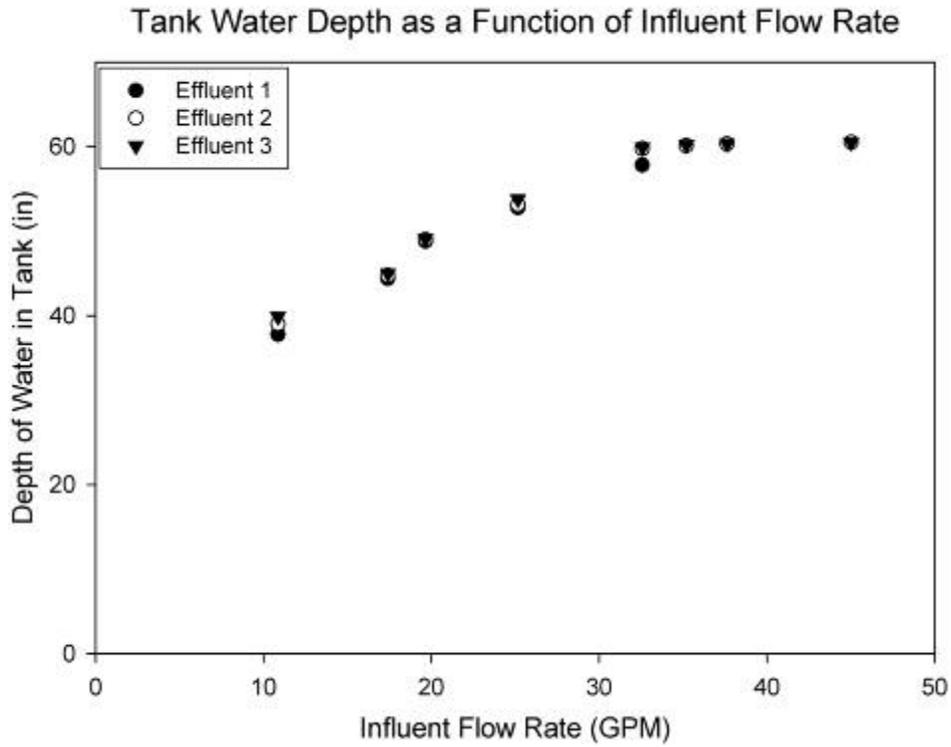


Figure 4-17. Phase III Part 1 tank water depth as a function of influent flow rate.

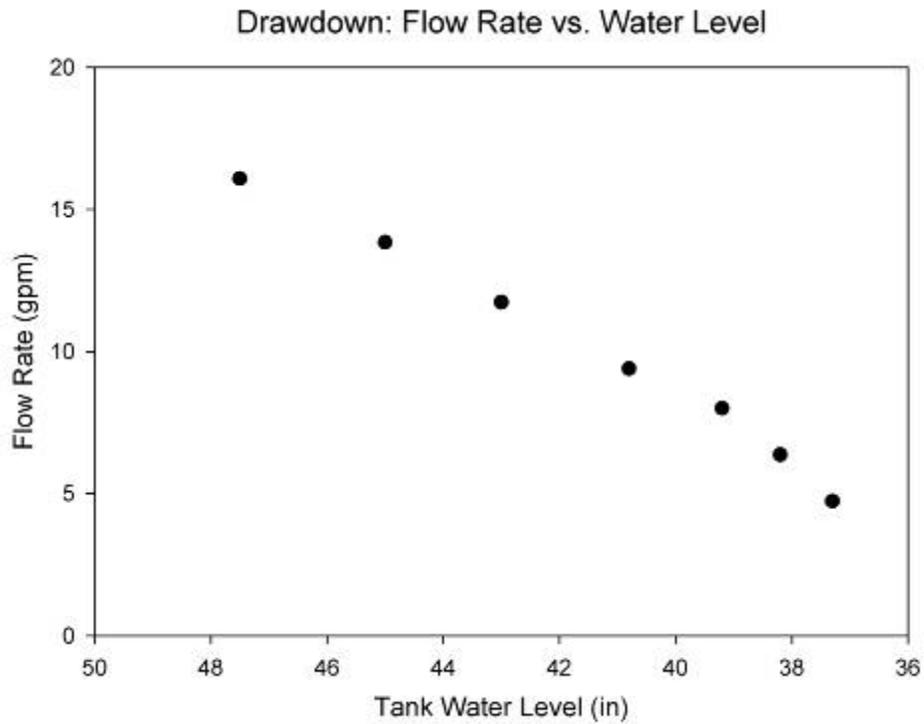


Figure 4-18. Phase III Part 1 drawdown flow rates.

The data show that the influent and effluent flow rates through the system are nearly identical once the flow is greater than approximately 15 gpm. The data also show the Up-Flo™ Filter can operate up to approximately 35 gpm before the bypass level is triggered. The drawdown data showed that the drawdown time for the device was less than one hour and was linearly related (visual assessment only) to the water level in the tank.

The same information was graphed for Phase III Part 2 and Phase III Part 3 (Figures 4-19, 4-20, 4-21, and 4-22, respectively for the relationship between flow rates and between influent flow rate and water depth in the tank. Phase III Part 2 and Phase III Part 3 used the same media bags as in Phase III Part 1.

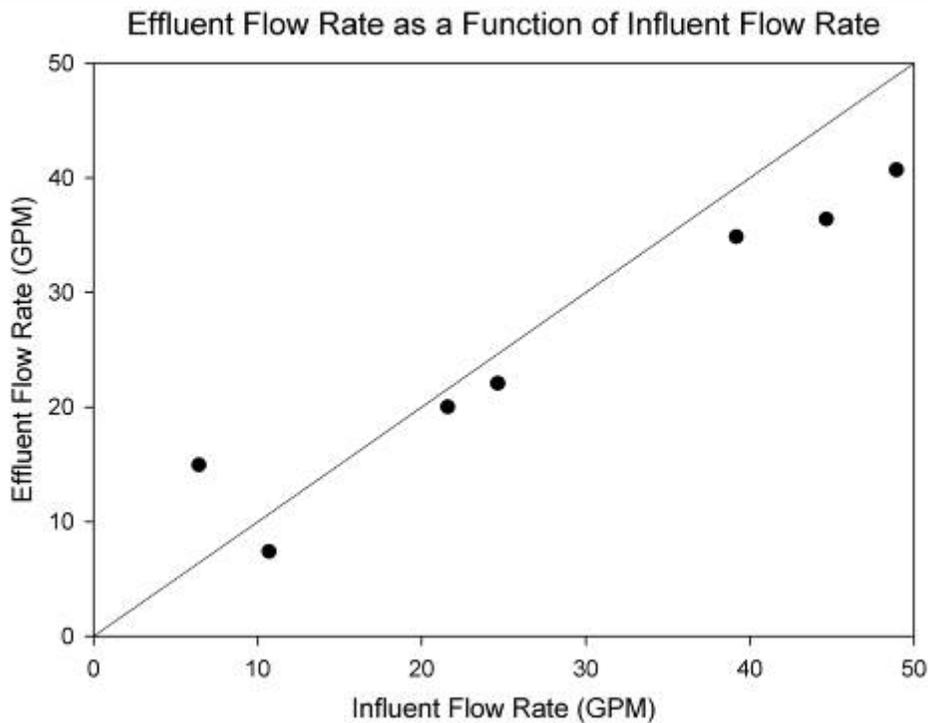


Figure 4-19. Phase III Part 2 relationship between influent and effluent flow rates.

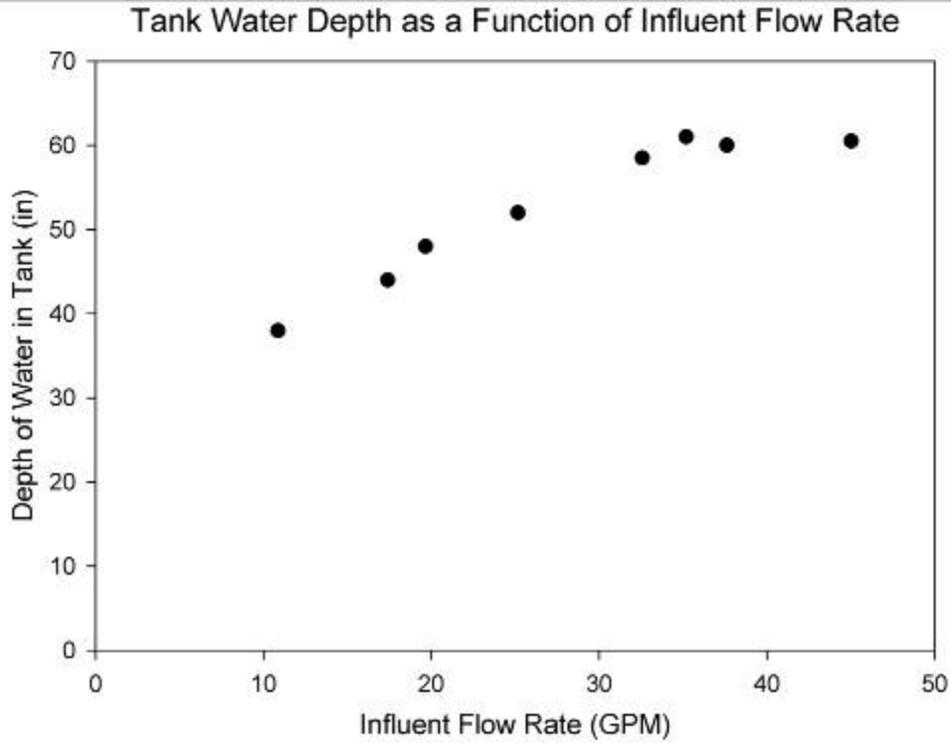


Figure 4-20. Phase III Part 2 tank water depth as a function of influent flow rate.

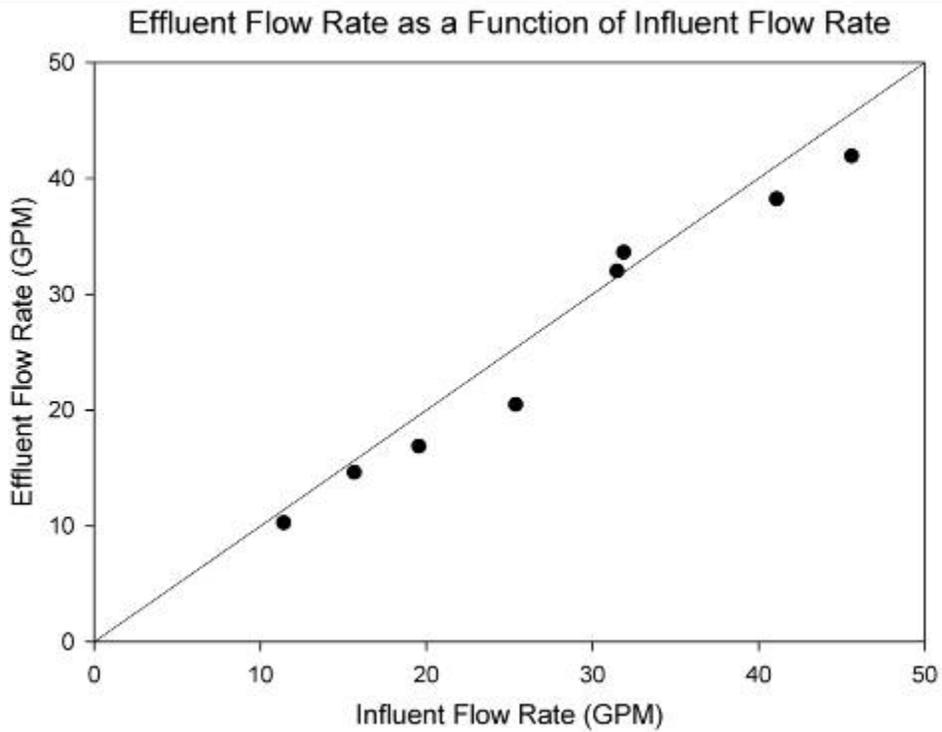


Figure 4-21. Phase III Part 3 relationship between influent and effluent flow rate.

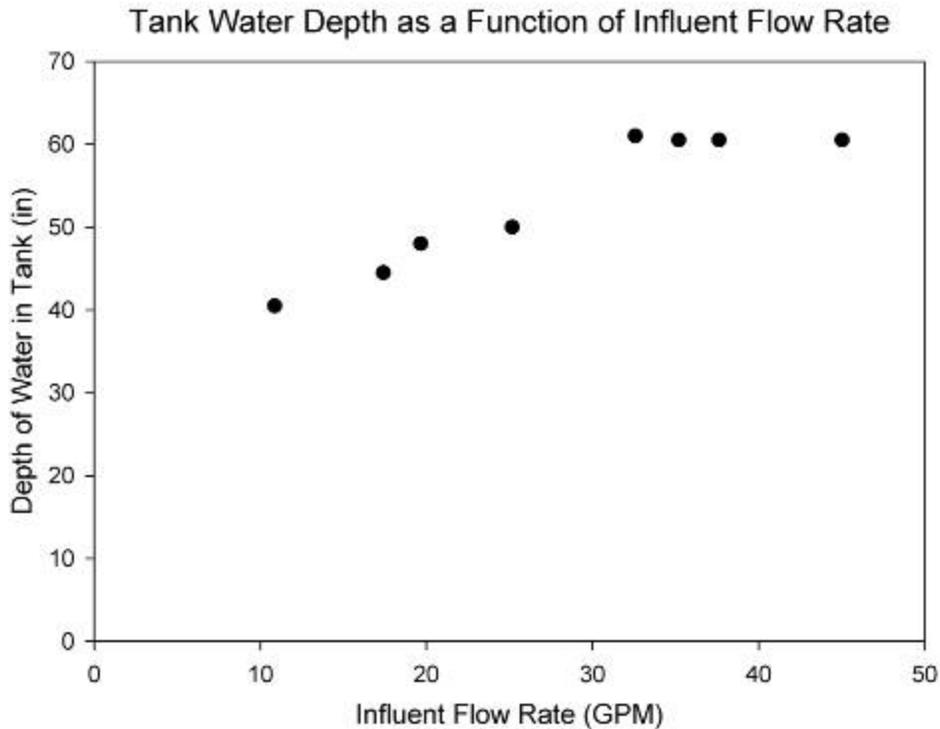


Figure 4-22. Phase III Part 3 tank water depth as a function of influent flow rate.

The results of the flow rates through the media as a function of influent flow rate were compared in Table 4-7 and graphically in Figure 4-23. The results show that, in general, the effluent flow rates were comparable to the influent for all flow rates tested (up to and past the point where the bypass was activated). Hydraulic performance appears to decrease during the 40 gpm and particularly the 45 gpm testing in Phase III Part 3. When Figure 4-22 is evaluated with Table 4-7 and Figure 4-23, it appears that the bypass siphon (with an elevation of 60 in.) was preventing the tank water level from exceeding 60 in., and at influent flows greater than 30 gpm, a portion of the effluent was likely untreated bypass water.

Table 4-6. Phase III Influent and Effluent Flow Summary

Influent Flow Rate (gpm)	Effluent Flow Rate (gpm)		
	Phase III Part 1	Phase III Part 2	Phase III Part 3
10	8.43	7.39	10.3
15	15.5	15.0	14.6
20	20.0	20.0	16.9
25	24.2	22.1	20.5
30	31.1	34.9	32.0
35	36.3	36.4	33.6
40	40.3	40.7	38.2
45	47.1	48.1	41.9

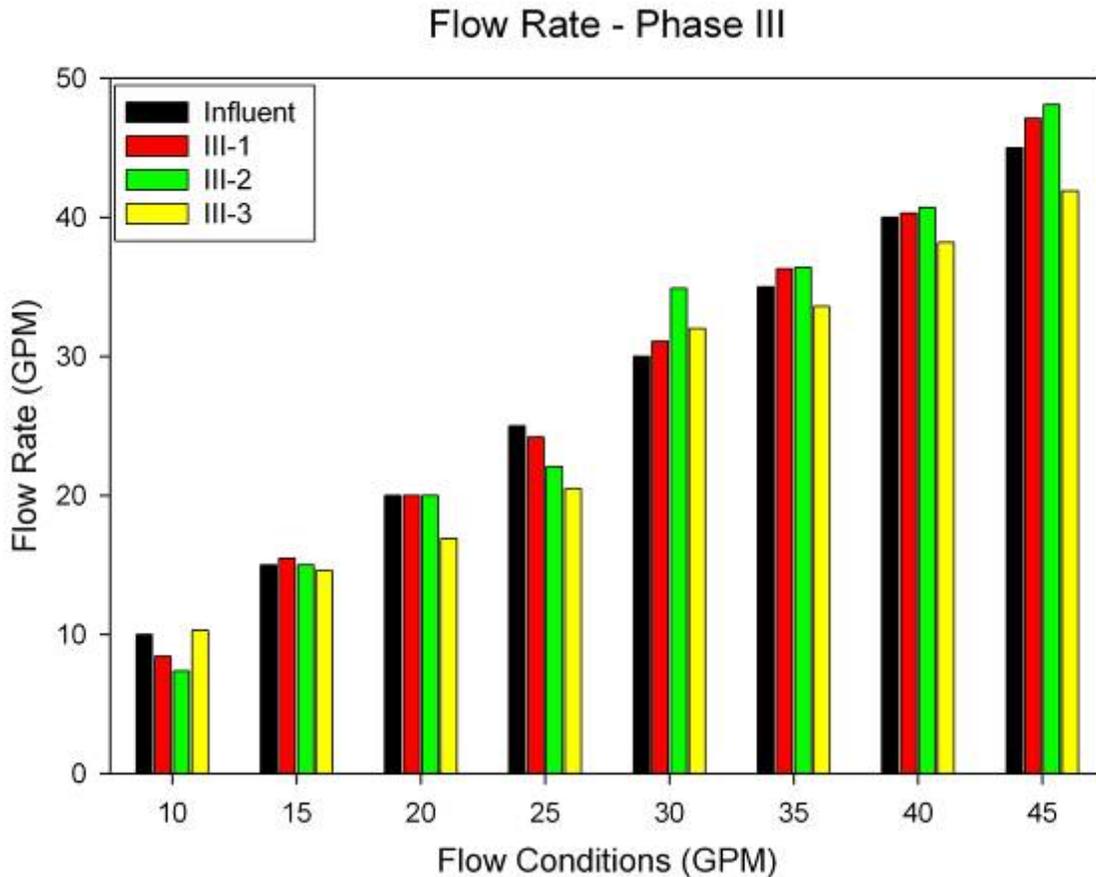


Figure 4-23. Comparison of influent versus effluent flow rates for Phase III hydraulics testing.

4.3.3.2 Analytical Data

Samples were collected during Phase III-2 and Phase III-3 testing at each flow rate condition (10, 15, 20, 25, 30, 35, 40, and 45 gpm). The analytical data are summarized in Tables 4-8 and 4-9. For Phase III-2, the TSS and SSC analytical data showed a reduction starting above 90% and decreasing to 0% at the two highest flow rates (40 and 45 gpm settings, 45 and 50 gpm measured). TP removals ranged from <0% to 65%, while COD removals ranged from <0% to 85%. At the higher challenge concentrations of Phase III-3, performance degradation was noted much sooner for all parameters compared to Phase III-2. The results are shown graphically in Figures 4-24 through 4-27 for Phase III-2 and 4-28 through 4-31 for Phase III-3. The graphics illustrate the much more rapid loss of performance in Phase III-3. This would be expected, since the device would be challenged beyond its design flow capabilities, and a portion of the flows would pass through the bypass mechanism without treatment.

Table 4-7. Phase III Part 2 Analytical Data

Analyte	Influent Flow Rate (gpm)	Influent Conc. (mg/L)	Effluent Conc. (mg/L)	Removal Efficiency (%)
TSS	10.7	140	5	96
	6.43	110	6	95
	21.6	209	<5	>99
	24.6	125	8	94
	39.2	49	3.3	93
	44.7	283	17	94
	48.9	45	26	42
	50.8	45	45	0
SSC	10.7	120	<5	>99
	6.43	215	8.3	96
	21.6	242	3.6	99
	24.6	184	13	93
	39.2	71	7.1	90
	44.7	391	20	95
	48.9	71	32	55
	50.8	49	49	0
TP	10.7	14	79	-464
	6.43	32	54	-69
	21.6	19	61	-221
	24.6	20	13	35
	39.2	13	11	15
	44.7	46	16	65
	48.9	36	33	8.3
	50.8	45	32	29
COD	10.7	35	71	-103
	6.43	30	60	-101
	21.6	41	34	18
	24.6	43	43	1.4
	39.2	286	44	85
	44.7	105	164	-56
	48.9	168	367	-118
	50.8	130	48	63

Table 4-8. Phase III Part 3 Analytical Data

Analyte	Influent Flow Rate (gpm)	Influent Conc. (mg/L)	Effluent Conc. (mg/L)	Percent Efficiency (%)
TSS	11.4	331	13	96
	15.7	253	75	70
	19.5	430	138	68
	25.4	624	269	57
	31.5	314	219	30
	31.9	370	255	31
	41.1	511	511	0
	45.6	575	409	29
SSC	11.4	NA	9.8	NA
	15.7	311	NA	NA
	19.5	396	142	64
	25.4	671	273	59
	31.5	292	340	-16
	31.9	416	320	23
	41.1	415	824	-99
TP	45.6	603	399	34
	11.4	123	60	51
	15.7	150	59	61
	19.5	168	107	36
	25.4	216	162	25
	31.5	79	138	-75
	31.9	132	187	-42
	41.1	197	237	-20
COD	45.6	229	242	-5.7
	11.4	275	27	90
	15.7	363	89	75
	19.5	463	152	67
	25.4	264	190	28
	31.5	151	186	-23
	31.9	377	188	50
	41.1	181	222	-23
45.6	207	198	4.3	

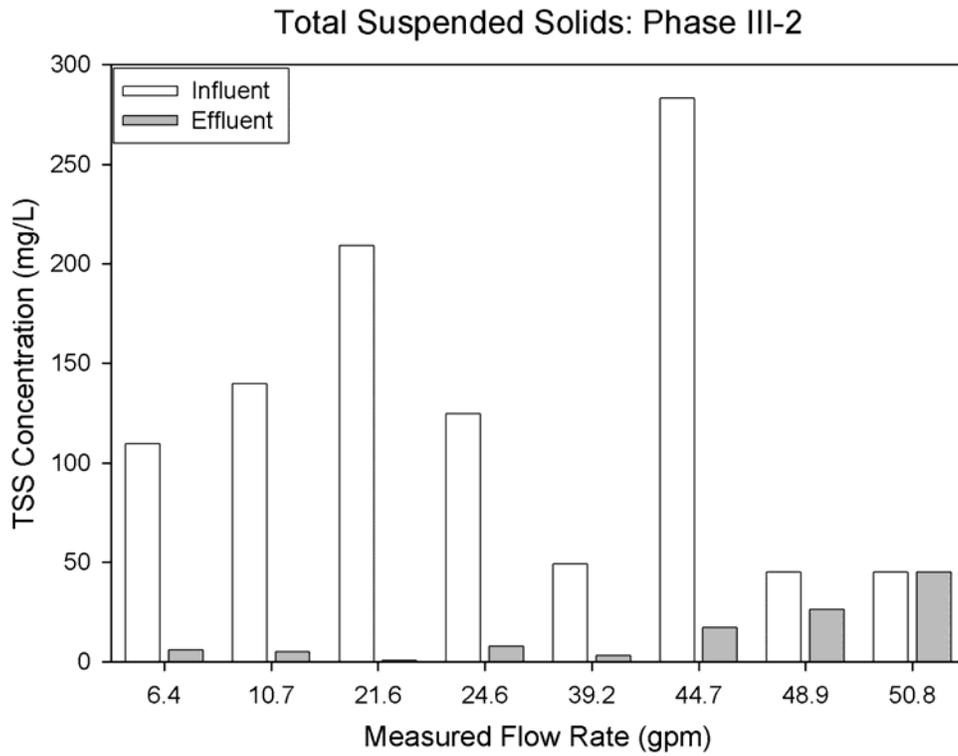


Figure 4-24. Phase III Part 2 TSS influent and effluent results.

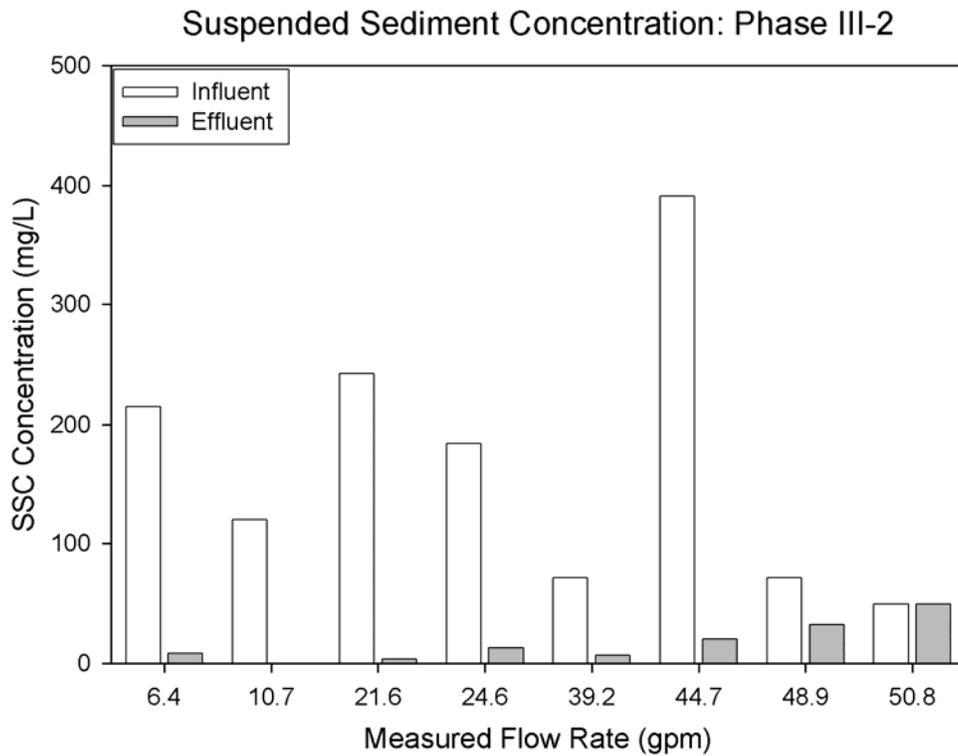


Figure 4-25. Phase III Part 2 SSC influent and effluent results.

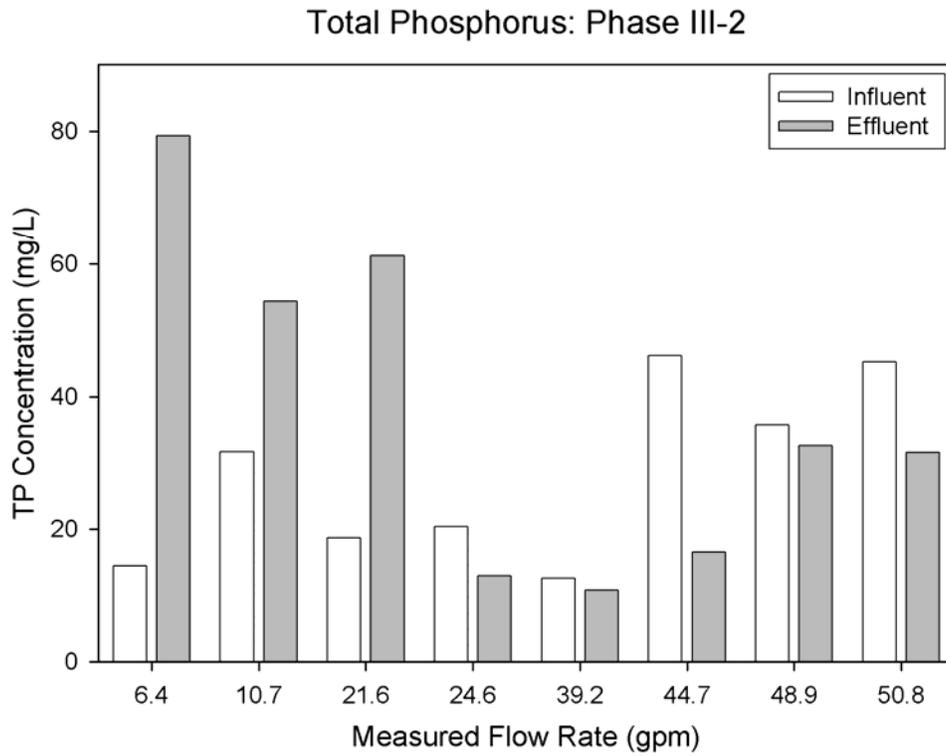


Figure 4-26. Phase III Part 2 total phosphorus influent and effluent results.

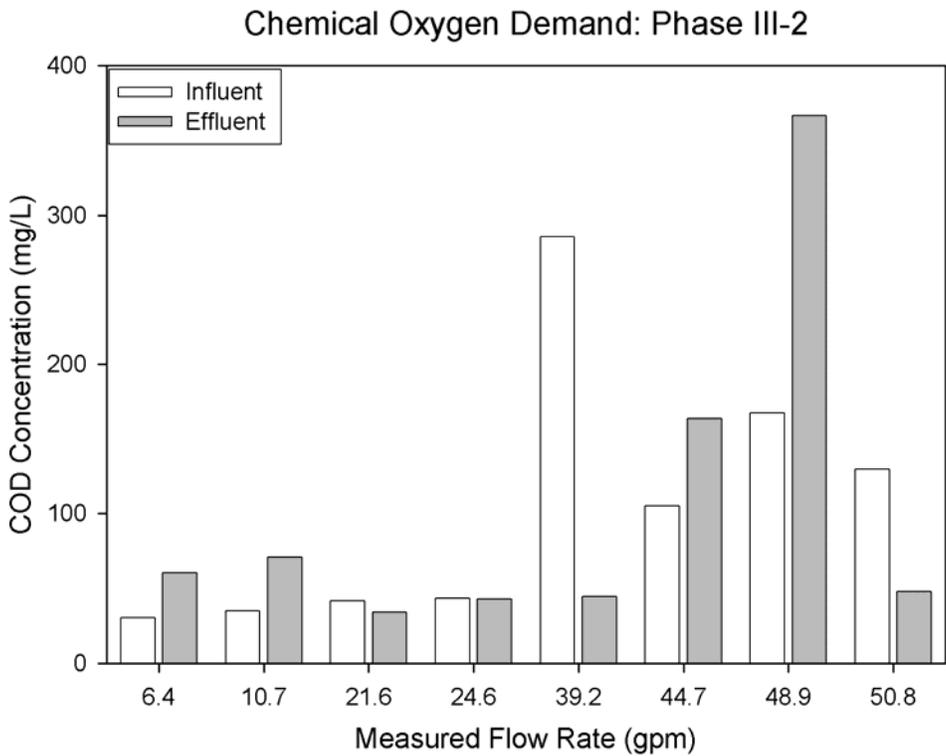


Figure 4-27. Phase III Part 2 COD influent and effluent results.

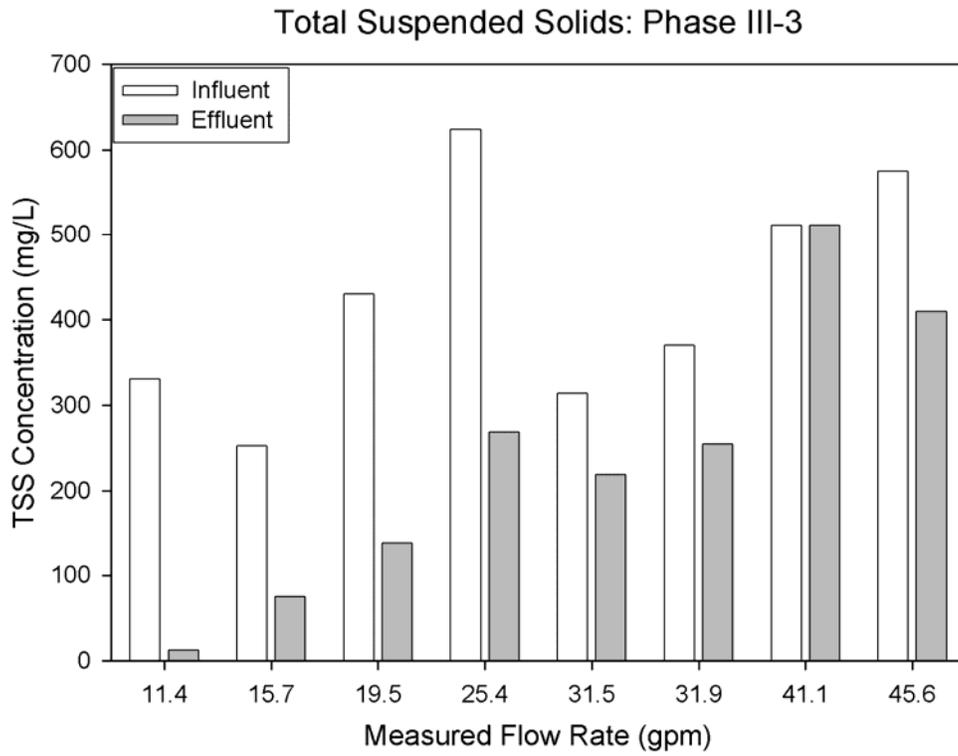


Figure 4-28. Phase III Part 3 TSS influent and effluent results.

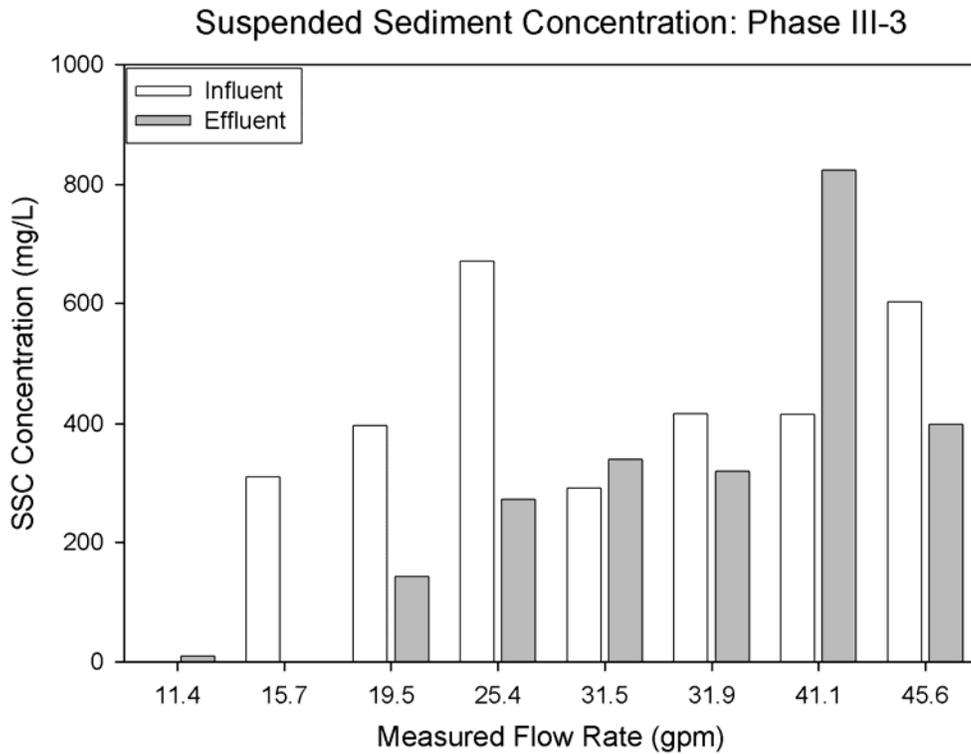


Figure 4-29. Phase III Part 3 SSC influent and effluent results.

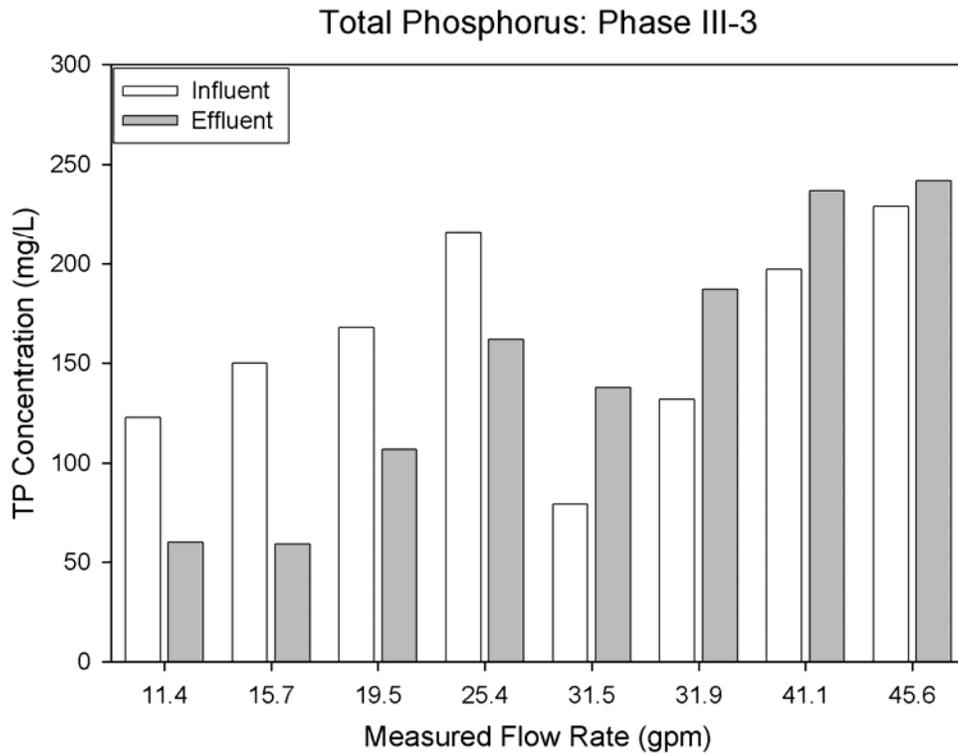


Figure 4-30. Phase III Part 3 total phosphorus influent and effluent results.

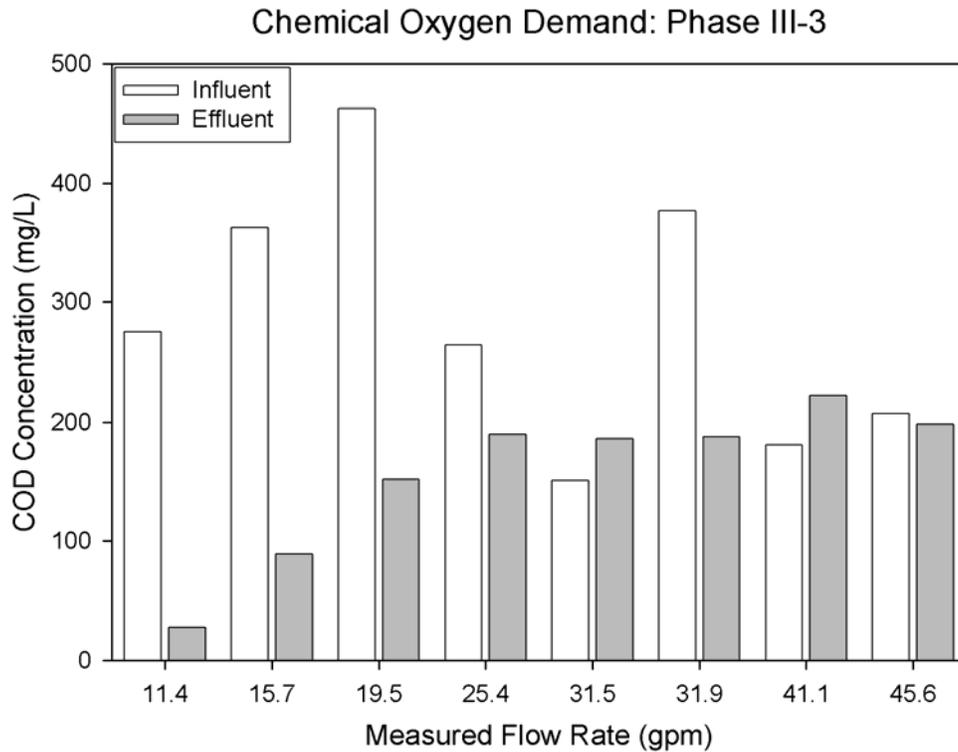


Figure 4-31. Phase III Part 3 COD influent and effluent results.

PSD analysis was also performed for all samples in Phase III. The results are shown graphically in Figures 4-32 and 4-33. For Phase III Part 2, the influent mean d_{50} was 60 μm , while for Phase III Part 3, the mean influent d_{50} was 43 μm . The mean effluent d_{50} for Phase III Part 2 was 11 μm and for Phase III Part 3 was 39 μm . This poorer performance in reducing the d_{50} of the influent was not unexpected given the higher loading entering the filter during Phase III Part 3. This indicates that the Up-Flo™ Filter was capable of removing particulates from the influent during normal operations, and removals are reduced when the filter is challenged, and part of the flow is bypassed, as would be expected.

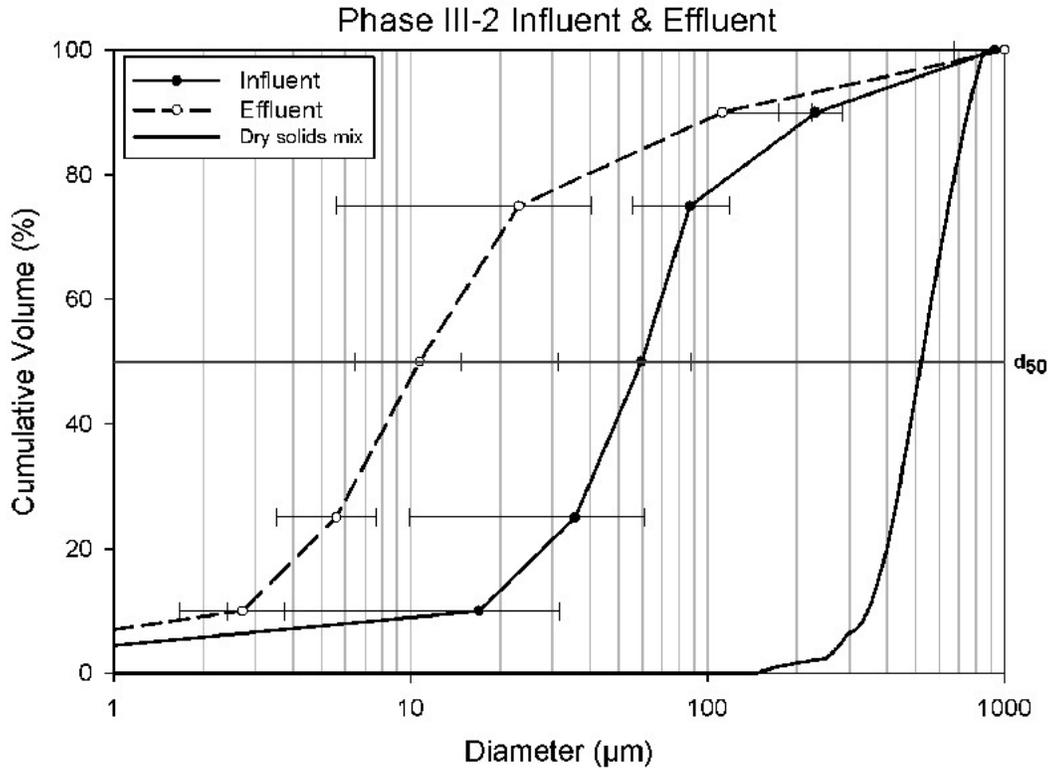


Figure 4-32. Phase III Part 2 PSD summary.

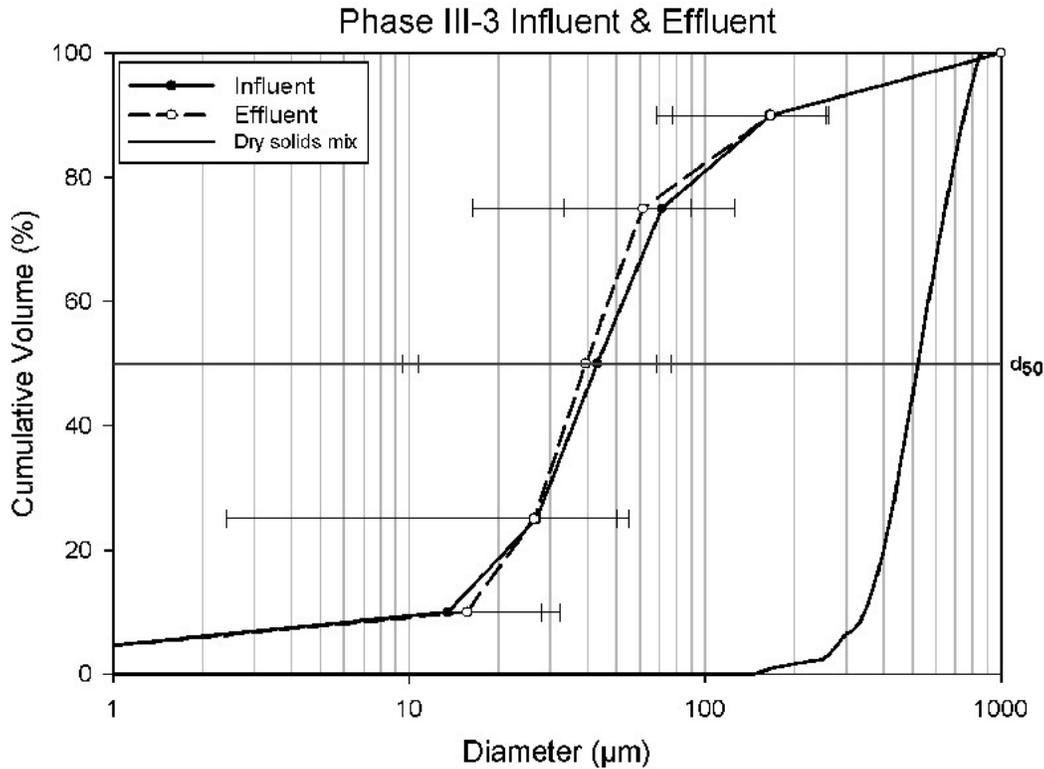


Figure 4-33. Phase III Part 3 PSD summary.

4.3.4 Phase IV– Contaminant Capacities at High Hydraulic Throughput

As described in Section 3.5.4, in Phase IV the system was run to exhaustion (similar to Phase II), except that the unit was under higher hydraulic loads and proportional contaminant loads.

The unit was operated under continuous flow conditions at a constant flow rate of 32 gpm until the unit plugged with solids, or the contaminant absorption capacity was exceeded. The test plan specified a flow rate of 30 gpm, based on the vendor’s claims that the system could treat water at a maximum flow exceeding 20 gpm.

During the first day (approximately two hours into the testing), the TO observed the media bags “broke through” their mesh retainer, causing visible solids in the effluent. New bags were installed and the test rerun the following two days. No samples were analyzed from the first day. The testing under sustained contaminant and flow loading conditions until failure highlighted a failure mode that had not been anticipated by the vendor. Under these conditions, failure occurred through what appeared to be inadequate support of the top flow distribution media, allowing bypassing to occur within the filter module, as opposed to bypassing through the bypass mechanism. Because of the nature of this failure mode, the protocol was modified and additional samples were taken during the first two hours of the rerun.

4.3.4.1 Analytical Data

As described above, samples were collected in accordance with the test plan, plus additional supplemental samples were collected to confirm test observations. A total of 15 sets of samples were collected and analyzed. The results of the testing are summarized in Table 4-10. Visual evidence of breakthrough was noted at 19,800 gallons. Two sets of confirmatory samples were collected and analyzed once failure was observed. As anticipated, the Up-Flo™ Filter performance was more variable than during the earlier runs, even for TSS and SSC. The median removal efficiency for TSS and SSC during Phase IV was 62%, the median TP removal efficiency was less than -8%, and the median COD removal was -42%. Comparison of this data to the Phase I and Phase II data shows that the ability of the Up-Flo™ Filter to remove dissolved and fine particulate pollutants may be compromised by this failure mode, particularly at flow rates 150% above the design flow rate. The data is displayed graphically in Figures 4-34 through 4-37.

Table 4-9. Phase IV Analytical Summary

Analyte	<u>Influent Concentration (mg/L)</u>				<u>Effluent Concentration (mg/L)</u>				<u>Removal Efficiency (%)¹</u>			
	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max	Min
TSS	131	95	480	<5	45	36	113	6.5	65	62	95	-1,640
SSC	121	102	389	<5	46	39	129	7.3	62	62	93	-1,420
TP	42	36	163	0.9	39	39	80	3	7	-8	81	-4,680
COD	66	59	180	18	107	84	370	42	-63	-42	41	-1,960

1. Mean and median removal efficiency is a function of mean and median influent and effluent concentrations, and maximum and minimum removal efficiencies are a function of individual paired data points.

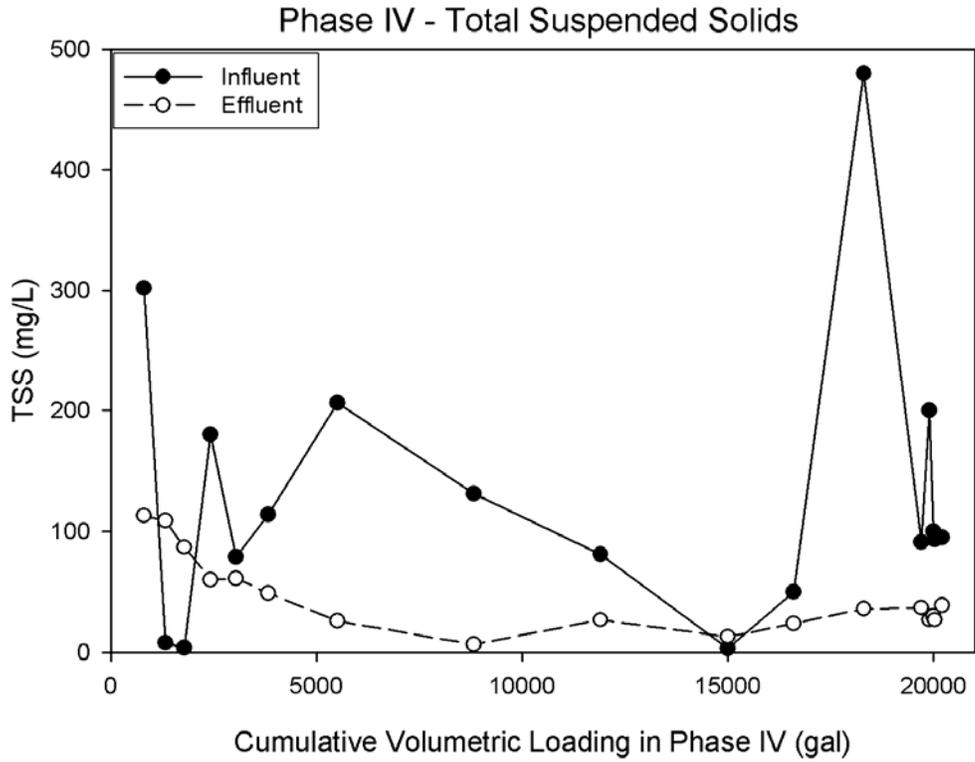


Figure 4-34. Phase IV TSS influent and effluent cumulative loading results.

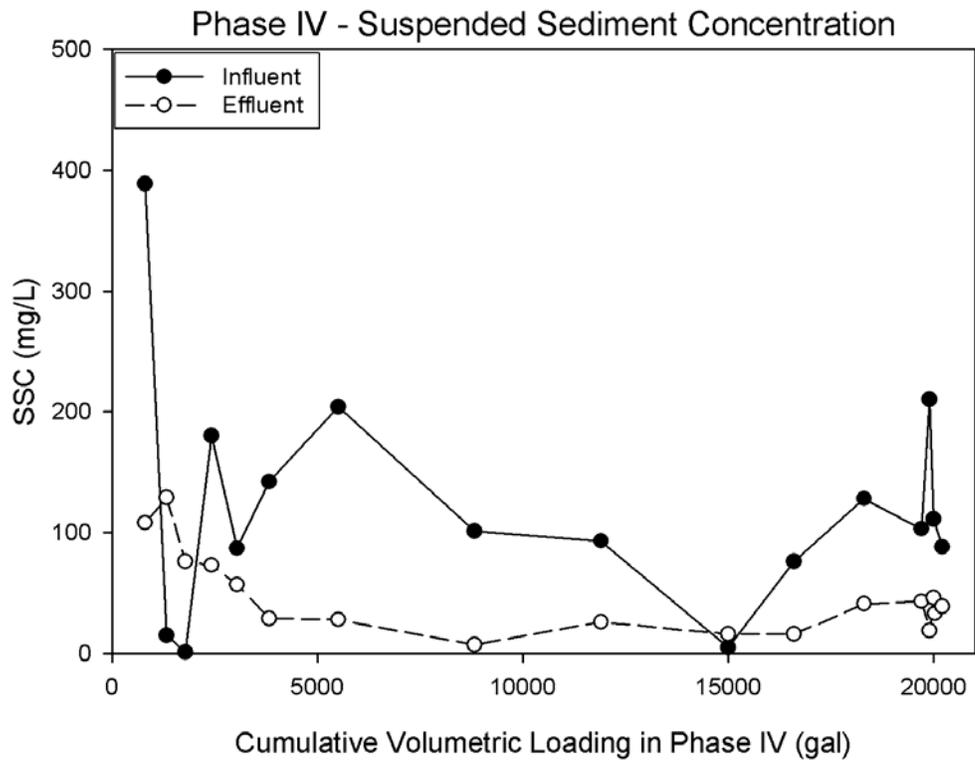


Figure 4-35. Phase IV SSC influent and effluent cumulative loading results.

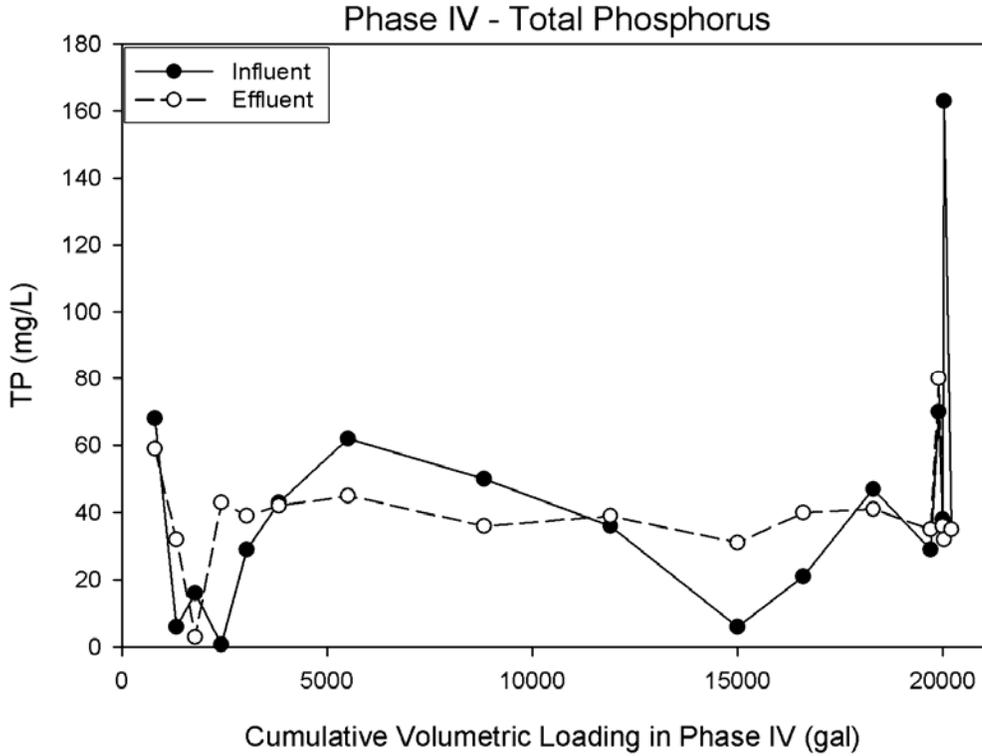


Figure 4-36. Phase IV total phosphorus influent and effluent cumulative loading results.

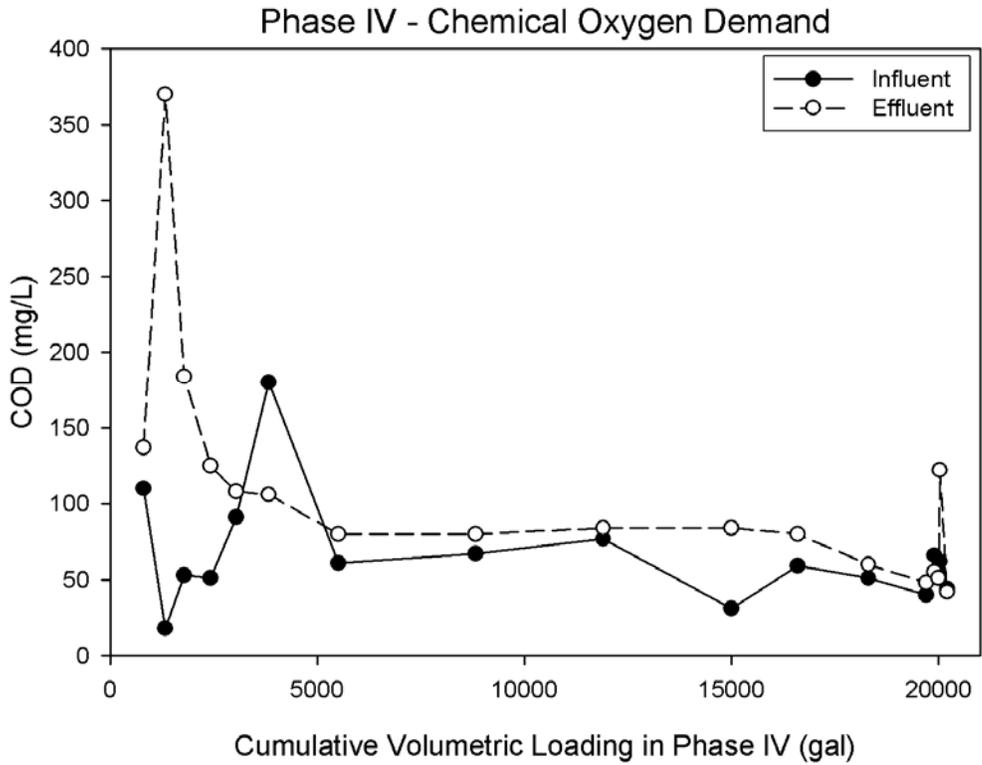


Figure 4-37. Phase IV COD influent and effluent cumulative loading results.

The PSD analysis for Phase IV (Figure 4-38) shows that the Up-Flo™ Filter was not as effective at reducing the influent d_{50} during its operation at high hydraulic loadings. This is likely due to the breakthrough of the filter bags and holder seen during this phase. The operation of the filter was halted when the bag breakthrough was noticed visually, but it likely occurred to a slight extent prior to its being visible in the operation.

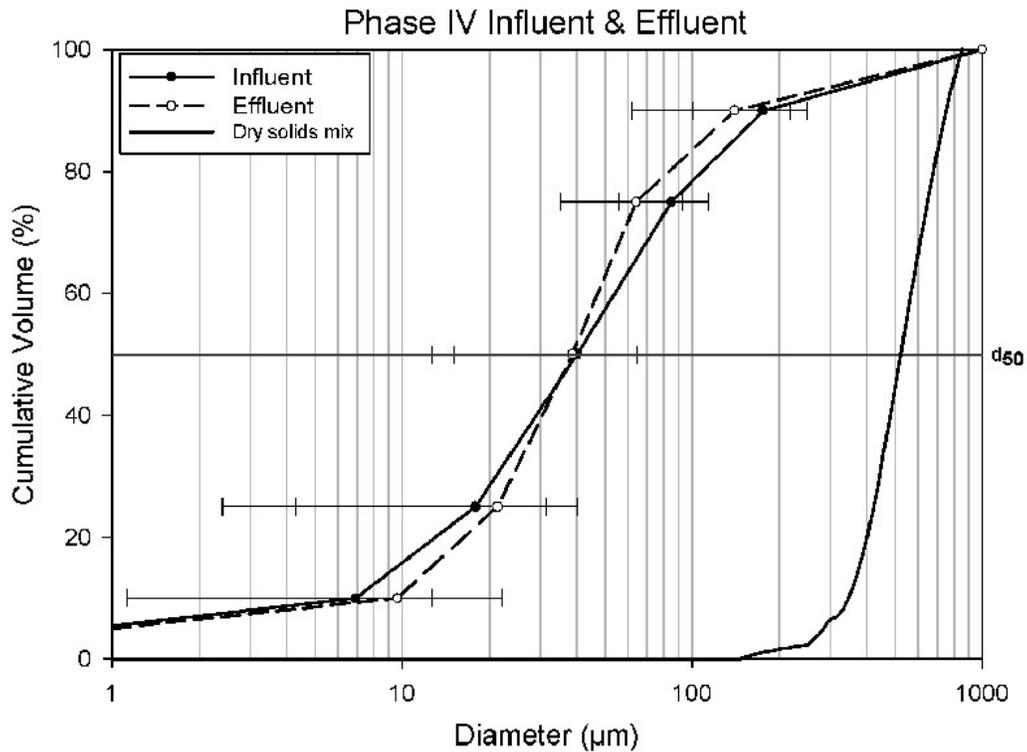


Figure 4-38. Phase IV particle size distribution analysis.

4.4 Phases I-IV Data Summary and Discussion

The flow and analytical data in the four test phases provided the following general observations:

- The Up-Flo™ Filter was capable of removing sediments from the influent water. TSS and SSC removals were variable, resulting primarily from variable influent concentrations with effluent concentrations remaining fairly consistent. The mean removal efficiencies during typical operating conditions were slightly less than 80%, and in some circumstances were as high as 90% to 95%. Performance was poorer when the hydraulic flows or pollutant loadings were higher.
- Particle size distribution analysis confirmed these results, with poorer removals (or no removal) occurring during the test phases with sustained high hydraulic flows or pollutant loadings.

- Total phosphorus removals ranged from negative to approximately 60%. COD removals also ranged from negative to greater than 85%. In general, filter performance improved as the filter aged, up to the point where failure began.
- The failure mechanism noted by the TO was not the one anticipated by the vendor. The vendor indicated that the Up-Flo™ Filter would fail by having the filter bags clog, forcing a build up of water in the tank, which would eventually reach the bypass and flow out through the bypass. Instead, the TO noticed (at the ends of Phases II and IV) that the water built up in the tank to a specific level, indicating that the filter was clogging. However, prior to activation of the bypass, the pressure on the bags apparently built up to a level sufficient to move the bags and mesh supports in the filter module. This uplifting of the bags provided an opening large enough (at one corner) to allow water to flow freely past the bags. This failure was noted in two ways: (1) the edges of the bags were noted above the effluent opening of the cartridge container, and (2) the water level suddenly dropped noticeably after the slow buildup to the bypass level.

In general, the Up-Flo™ Filter was capable of removing solids consistent with claims made by the vendor, at the concentrations used during testing. It is anticipated that the results of this series of tests could be adjusted to calculate loadings throughout the filter's life and used to develop design curves that can be used to predict behavior when challenged by lower TP and hydrocarbon concentrations. What is unknown (from a performance prediction standpoint) is what effect the higher hydrocarbon loadings had on blinding the filter bags. This data is not easily translated without additional work at different hydrocarbon loadings, where the effect of hydrocarbon loading on filter life can be evaluated.

4.4.1 Installation and Operation & Maintenance Findings

The TO performed O&M on the system as outlined in the vendor's written O&M procedures between test phases and as necessary during testing. O&M procedures and observations focused on:

- Ease of installation;
- Weight of filter media bags, before and after testing;
- Clarity of written O&M procedures;
- Ease and time needed to clean unit and replace filter media; and
- Characteristics of waste materials.

4.4.1.1 Installation

To evaluate the ease of installation of the Up-Flo™ Filter, the TO installed the system in the test rig supplied by the vendor in accordance with the vendor's instructions for use in a catch basin. In general, the TO found the installation instructions were clear and the procedures were simple to follow.

4.4.1.2 Filter Media Bags

The TO was unable to observe differences in the sizes and dry weights of the filter media bags from phase to phase since the bags were shipped slightly damp. Therefore, obtaining a point of comparison was impossible. According to the vendor, the net weight of the carbon-based filter bags is approximately 50 lb. Two bags of the CPZ media were installed in the unit between phases (chronologically, new filter bags were installed after Phases III, II and IV). Because of the height of the test unit compared to the location of the filter cartridge, it was difficult to lift the heavy filter bags in and out, especially one-to-two days after use when they were still nearly soaked (although not dripping to a measurable extent). The TO was concerned that the straps used to lift the bags in and out of the cartridge and the device would not hold up during installation and removal. These concerns were unfounded. The bags stayed intact until they were sliced open to observe the depth of penetration of the pollutants into the filter media.

4.4.1.3 General O&M/System Cleanout

System cleanout consisted of pumping down the water to the sediment level, taking care not to disturb the sediment. One person entered the device and one person remained outside to hand in materials as needed. The replacement of the bags consisted of opening the module lid, removing the top layer of mesh, the two bags and the bottom layer of mesh. The interior of the filter module was wiped down with a paper towel and tap water to remove grit trapped along the edges. The sediment was cleaned out between phases using a wet/dry shop vacuum. Once the filter module was visually clean, new mesh and filter bags were installed as outlined in the O&M manual with care taken to fit the bags to the edges of the filter module and to fit the top mesh below the mesh sill of the filter module. The typical O&M session took between 30 and 45 min with approximately half of the time devoted to pumping down the water in the tank.

4.4.1.4 Waste Material Characterization

Waste material characterization focused on two primary areas: physical and chemical. Physical characterization determined the mass and volume of waste material generated during a cleanout session, while chemical characterization determined hazardous characteristics important in waste disposal considerations.

As waste materials were generated, representative composite samples of the recovered sediments were submitted for analysis for sediment COD and sediment phosphorus. Three samples from different sections of the sump were collected and analyzed. The results were as listed in Table 4-11. The hopper solids were also tested and the solids' concentration was >0.0875 g TP/g solid. The statistical analysis showed less than 20% deviation among the hopper solids samples indicating that the contaminants of concern were well-distributed across the hopper solids. While there are no waste disposal regulations that specifically address these pollutants, the results indicate that the sump is capable of trapping particulate pollutants and that further testing may be required if the influent water contains one or particular contaminants of concern, such as metals (which were not included in the scope of this project).

Table 4-10. Characterization of Material Captured in Up-Flo™ Filter Sump

Sample Number	COD (g COD/g waste)	TP (g TP/g waste)
1	0.070	0.016
2	0.10	0.022
3	0.087	0.017
Average	0.086	0.018
Standard Deviation	0.015	0.0034
COV	0.18	0.19

4.5 Summary of Findings

A newly maintained Up-Flo™ System, operating in the design range, is capable of reducing sediment concentrations in this test wastewater in a range of 50% to 90%, as measured by TSS and SSC. Hydrocarbon removals, as measured by COD analyses, were highly variable and ranged from negative to >85%. TP removals were in the same range as the COD removals. The TO observed the following regarding the removals of TP and COD. The filter performance was optimum during the middle of the filter run (after the filter had ‘aged’ and before breakthrough began). Filtration performance was best when the filter was operating on an intermittent schedule and at the design flow rates or below. This is in agreement with filter treatment theory.

An Up-Flo™ with new filter media can accept a hydraulic flow of up to approximately 35 to 40 gpm, without bypassing, depending on the concentration of contaminants in the wastewater. The maximum treated flow decreases as the filter media trap contaminants, preventing water from flowing through the filter bags. The activation of the bypass was only observed during the testing across the operational flow rates (Phase III) testing. A different failure mechanism (where the pressure on the bags was sufficient to dislodge the bags and open a flow path through the cartridge) was observed in Phases II and IV. This failure mechanism was new to the vendor, who indicated that this failure mechanism had not been noted before in the vendor’s laboratory. The TO supposes that this may be due to the different test mixtures used in the vendor’s laboratory compared to the TO, who was following the test plan. The test plan had a mixture that was much closer to washwater than stormwater.

In addition to hydrocarbon and phosphorus treatment, the Up-Flo™ system was also capable of reducing suspended solids concentrations in the treated effluent. Sediment removal efficiency was measured three ways:

1. the TSS and SSC analytical methods;
2. theoretical methods (measuring the mass of solids fed into the synthetic wastewater by the test rig); and
3. particle size distribution comparison of influent and effluent.

An important consideration in determining overall system efficiency is the propensity of contaminants to plug the filter media, resulting in untreated wastewater bypassing the filter media. When the Up-Flo™ Filter failed in the method described by the vendor, it was simple to

verify visually. The water in the tank built up to the bypass level. This would be easy to observe in the field also if the storm inlet is covered by a grate. The failure due to the shifting of the bags and mesh will not be visible in normal applications. It was visible here because the effluent flowed directly into the treatment basin prior to discharge to the TO's sewer system.

Filter media blinding, which is a function of the influent flow rate and pollutant loading, did not occur immediately, even at the high flow rate and high influent concentration conditions. However, as can be seen in the data for Phases III (high concentration) and Phase IV (high sustained flow rate) when compared to the Phase I+II results, treatment efficiency is decreased across the run and the run is shortened. Because of the elevated concentrations of detergents and because of the behavior of the sediments as flocs, the TO can only predict that performance in the field would be extended compared to that in the laboratory. The length of that extended performance is unknown because of the manner in which the blinding occurred, with an oily slime appearing on the media face and oil particles plus detergent creating rings around the test tank. The results of these tests are more directly applicable to the performance of an Up-Flo™ Filter at hotspots where substantial vehicular maintenance and washing could be expected.

O&M procedures are relatively simple and can be completed in approximately 30-45 min.

Chapter 5

Quality Assurance/Quality Control

The test plan included a QAPP with critical measurements identified and several QA/QC objectives established. The verification test procedures and data collection followed the QAPP, and summary results are reported in this section. The full laboratory QA/QC results and supporting documentation are presented in Appendix C.

5.1 Audits

The VO conducted one audit of the PSH Environmental Engineering Laboratory at the start of the verification test. The audit found that the field and laboratory procedures were generally being followed, and that the overall approaches being used were in accordance with the established QAPP. Recommendations for changes or improvements were made, and the responsible parties responded quickly to these recommendations.

5.2 Precision

Throughout the verification test, the laboratory performed laboratory duplicates or matrix spike/matrix spike duplicates to monitor laboratory precision. Field duplicates were collected to monitor the overall precision of the sample collection and laboratory analyses. The test plan data quality objectives for precision were based on laboratory precision for the analyses. The test plan did not set field precision targets, as it was recognized that precision impacted by sampling and constituent mixtures would be highly constituent- and equipment-dependent.

The relative percent difference (RPD) recorded from the sample analyses was calculated to evaluate precision. RPD is calculated using the following formula:

$$\%RPD = \frac{x_1 - x_2}{x} \times 100\% \quad (5-1)$$

where:

x_1 = Concentration of compound in sample

x_2 = Concentration of compound in duplicate

x = Mean value of x_1 and x_2

5.2.1 Field and Laboratory Precision Measurements

The laboratory performed precision analyses in two methods: laboratory standard measurements and analysis of field replicates. Triplicate analyses for all samples collected during Phase III (the first phase chronologically) for TSS, SSC, COD, and TP were performed. These field samples were individual bottles collected after the system had sufficient time to stabilize.

For the laboratory, the required analytical tolerance limits are 10% for all analytes used in this test plan. The samples all fell within this tolerance, with the exception of TSS, which was within the 30% tolerance seen for prior TSS sampling. Several papers have been written addressing the

limitations and relationship between TSS and SSC, including one under review by Dr. Clark, the principal investigator (PI) on this project. The data from the PSH laboratory where the TSS results are 70% to 80% of the SSC values for the same samples is in agreement with that seen by other researchers working with stormwater samples. The statistical analysis of the data contained in that paper (based on 215 sample pairs) showed that there was no statistical difference between the TSS and SSC results, indicating that the variability seen between samples is sufficiently large to drown out the differences between the analytical methods. This is particularly true when influent samples were analyzed (and not as true for effluent samples). These results are due to the larger particles that are in the influent samples (and not in the effluent). The TSS sampling methods are not easily able to sample particles larger than 100 to 200 μm .

For COD and TP, the field replicates are not in the 0% to 25% COV range deemed tolerable by the test plan. The reason for this difference is the non-continuous distribution of TP and COD in the influent. In order to obtain the dosing required by the test plan, only periodic dosing (adding periodic drops of solution, rather than a continuous stream) was required of the OBC and WBC solutions. The solids dosing was more consistent, although problems were noted with dosing due to clogging of the solids hopper and distribution system occasionally. This resulted in the installation of a technician at the solids' hopper to monitor the dosing of the system.

The field precision results are summarized in Tables 5-1. All of the data are presented in the Appendices to this report. These samples are based on triplicate influent samples collected during Phase III Part 2.

Table 5-1. Replicate Laboratory Sample RPD Summary

Analyte	Number of Samples	Mean (mg/L)	Standard Deviation	COV
TSS	24	109	67	0.61
SSC	24	168	115	0.69
TP	8	56	46	0.82
COD	8	71	50	0.71

All of the TOC laboratory data was within the established precision limits, although this analysis may not have provided a true result for the samples, as discussed in this Section 5.5.

While the results were not always within the limits established by the test plan, the procedures were reviewed regularly and standards analyzed. These standards' results showed that laboratory procedures, calibrations, and data were found to be in accordance with the published methods and good laboratory practice.

The design of the sampling program anticipated that precision might be low for some of the constituents due to the nature of the water being tested. The sampling plan included collection of several aliquots over time to make composite samples. The data evaluation also was based on mean data collected over a large volume of flow and long time periods. This approach was used to help mitigate minute-by-minute changes that might occur in the water, particularly in the influent water. Also, the careful monitoring of the total volume of water used and the total mass

of constituents fed to the system provided a basis for calculating influent concentration. The sampling techniques and laboratory procedures were carefully reviewed before and during the test. The procedures used were in accordance with best sampling practice, and the laboratory methods and procedures were found to be performed in accordance with the published methods.

5.3 Accuracy

Method accuracy was determined and monitored using a combination of matrix spikes and laboratory control samples (known concentration in blank water) depending on the method. Recovery of the spiked analytes was calculated and monitored during the verification test. Accuracy was in control throughout the verification test. Table 5-2 shows a summary of the laboratory control sample recovery data.

Table 5-2. Laboratory Control Sample Data Summary

Analyte	Actual (mg/L)	Measured (mg/L)	COV	Deviation from Standard Concentration
TSS	150	159	0.08	6%
SSC	350	344	0.002	2%
TP (as P)	2.00	2.25	0.05	13%
COD	300	294		5%

All the samples were within the quality control limits, with the exception of one COD sample (151 mg/L) which was much lower than the allowed limits. This does not raise a concern, because all other COD standard samples were well within their limits. Samples associated with the COD standard were spot-checked the next day to ensure that the problem was in the standard only. This was confirmed when the sample analytical results were similar from Day 1 to Day 2 and the standard was measured at the desired level.

The balance used for TSS and SSC analysis was calibrated routinely with weights that were National Institute of Standards and Technology (NIST) traceable. Calibration records were maintained by the laboratory and inspected during the on site audits. The temperature of the drying oven was also monitored using a thermometer that was calibrated with a NIST-traceable thermometer. Pipettes and graduated cylinders had their calibrations confirmed using the analytical balance and deionized water.

5.4 Representativeness

The testing procedures were designed to ensure that representative samples were collected of both influent and effluent wastewater. Supervisor oversight and audits provided assurance that procedures were being followed. As discussed earlier, the challenge in sampling wastewater is obtaining representative samples. The data indicated that while individual sample variability might occur, the long-term trend in the data was representative of the concentrations in the wastewater, and redundant methods of evaluating key constituent loadings in the wastewater

were used to compensate for the variability of the laboratory data. In addition, the results and shape of the effluent curves were compared to known filter theory to evaluate abnormalities. For example, while the models were not fitted to this data, it is well known that filter flow rate can be modeled by a power equation with suspended solids loading or time as the independent variable. This occurred in this case to the extent seen in prior laboratory work by the TO with up-flow filters. In addition, the graphs of pollutant behavior over filter life showed the traditional breakthrough curves, where filter performance was variable at the start of the run, optimal performance was obtained after the filter aged slightly and the pollutant removals decreased as the filter neared breakthrough.

The laboratories used standard analytical methods and written standard operating procedures for each method to provide a consistent approach to all analyses. Sample handling, storage, and analytical methodology were reviewed during the on-site and internal audits to verify that standard procedures were being followed. The use of standard methodology, supported by proper quality control information and audits, ensured that the analytical data were representative of the actual wastewater conditions.

5.5 Completeness

The test plan set a series of goals for completeness. During the startup and verification testing, flow data were collected for each day at a minimum of once per two hours for Phases II, IV, and V, and once per active flow setting for Phases I and III. The flow records are 100% complete.

No scheduled analyses had to be omitted from the testing program. Less than seven TSS or SSC samples were not sieved prior to analysis. In all cases but two, either the TSS or SSC sieved was performed and while the protocol called for using the TSS only data to adjust the particle size distribution for the mass above 250 μm , in those cases where the TSS sieve data was missing, the SSC unsieved and sieved comparison was used. For those two instances where no sieve data was available, the samples were not included in the particle size distribution analysis presented here. Given the number of samples collected (which exceeded the requirements of the test plan for all phases but Phase II), these missing samples were not considered sufficiently important to rerun the testing phase. Sufficient data was available to document the performance of the device. This results in less than five omitted data points from a more than 200 data points per analytical parameter, resulting in greater than 99% completeness, which exceeds the 80% completeness goal for this program.

While COD was used as a surrogate organic measurement in the protocol to measure the capture of hydrocarbons, the free product (un-emulsified hydrocarbons) in the device and in the flow stream affected the repeatability of the tests even from aliquots drawn from the same sample bottle. All samples collected for COD were analyzed, resulting in 100 percent completeness, giving a reasonable indication of the bounds of performance of the Up-Flo™ Filter. Similar variability was seen with the TP measurements because of the small additions of the WBC which contained the bulk of the dissolved phosphorus. All samples were analyzed, resulting in 100% completeness and allowing for the bounds of performance to be evaluated.

Chapter 6 Vendor Supplemental Testing

The vendor requested that supplemental testing be conducted on the Up-Flo[®] Filter after they reviewed the test data and results derived from the ETV testing. They expressed concerns that the filter media breakthrough in the filter module was something they had not seen in testing at their facility or in field applications. This test was conducted to examine whether the filter module design should be modified to reduce the ability of the filter media to move within the module coupled with whether the synthetic challenge water created a challenge that was beyond the design considerations of the device and not indicative of real-world situations.

6.1 Up-Flo[®] Filter Modifications

The filter modules were redesigned to improve support and restraint and prevent the media bags from shifting and potentially displacing vertically, observed during the original phase of testing. The number of latches attaching the filter module lid was increased from one to three. Additionally, the media restraint was redesigned by increasing the width of each structural side. Figure 6-1 shows the Up-Flo[®] Filter module and Figure 6-2 shows the modifications made to the module to improve the support on the filter media.

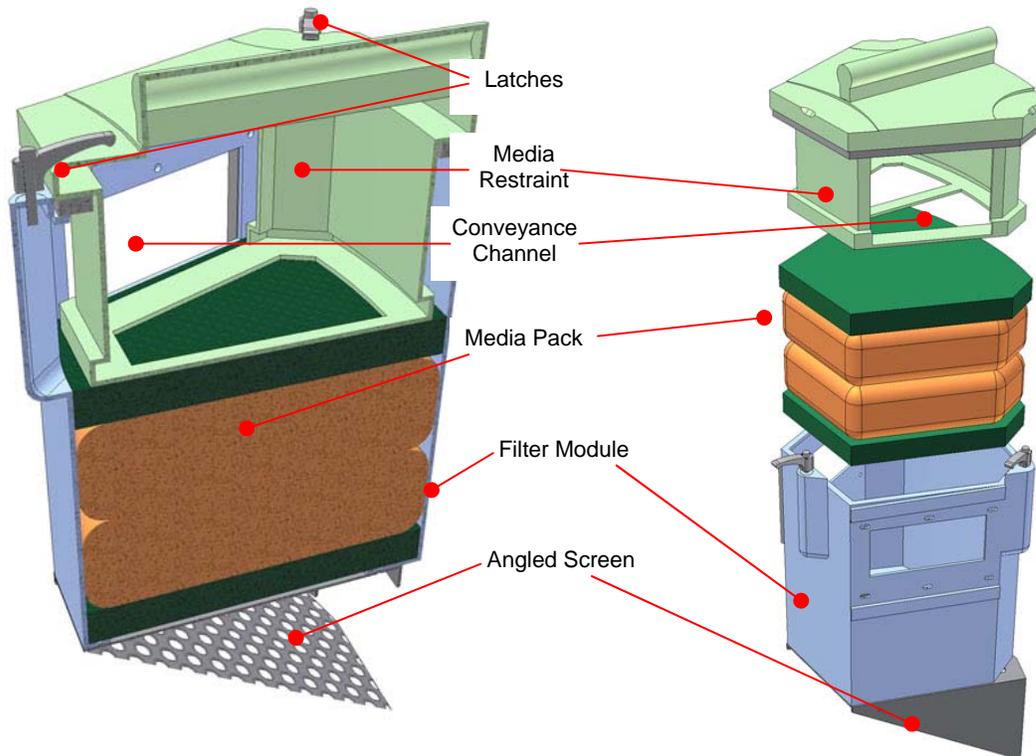


Figure 6-1. Modifications to Up-Flo[®] Filter module.

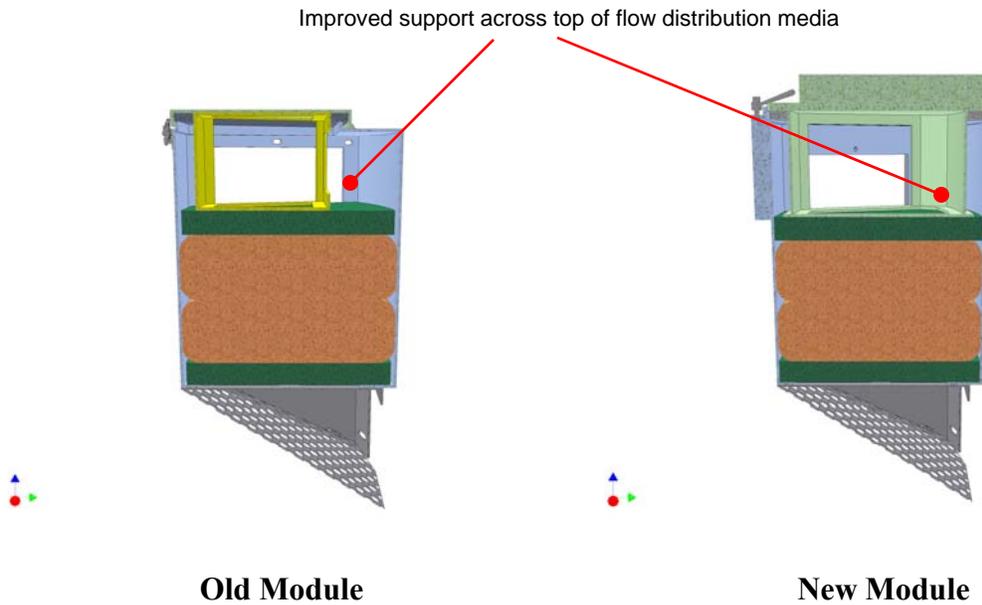


Figure 6-2. Modifications to Up-Flo[®] Filter module showing improved support details.

6.2 Test Procedure Modifications

The testing procedures were modified, including modifications to the synthetic challenge water, elimination of COD as an analyte based on the changes to the synthetic challenge water, and omission of the Phase III and Phase IV tests. These modifications are outlined in greater detail in this section.

6.2.1 Synthetic Challenge Water

The verification test was performed using synthetic water (Table 6-1) made from a mixture of solids – one of which provided the particulate phosphorus required by the test plan. The following products were used to make the synthetic challenge water:

- Sil-Co-Sil[®] 250;
- Slow release phosphorus-supplying fertilizer; and
- Concrete plant sand sieved to a size of all passing through 5,000 μm .

Table 6-1. Modified Synthetic Challenge Water Concentrations

Parameter	Concentration (mg/L)
SSC	300
TSS	300
Total phosphorous (as P)	3
Reactive phosphorus (as P)	1

A formula using a mix of the above named products/materials was made and tested in the laboratory to determine the conformance to these specifications. The result of testing the ground fertilizer for phosphorus content is 0.3 mg TP/g Scott's Lawn Starter Fertilizer. The amount of fertilizer used was decreased from the amount used during the initial testing because phosphorus recovery during initial testing was found to be greater than the target concentration. This higher concentration may have been from the combination of the slow-release property of the fertilizer and the grinding of the pellets into smaller particles, thus releasing more phosphorus because of the increased surface area that comes into contact with water. For the supplemental testing, the fertilizer replaced approximately 1% of the sand in the mixture to decrease the phosphorus concentration to the target concentration.

The other constituents added to the synthetic challenge water in the initial testing (gasoline, diesel fuel, motor oil, brake fluid, antifreeze, detergents, and windshield washer fluid) were removed. Observations during the initial testing indicated that the synthetic challenge water including the hydrocarbon constituents mixed with the solids to form a viscous substance that was atypical of stormwater and could prematurely blind the filter media.

6.2.2 Analytical Methods

Constituent analysis for this testing included reactive and total phosphorus (RP and TP, respectively), and solids (PSD, TSS, and SSC). COD was not analyzed because the hydrocarbon mixture was removed from the synthetic challenge water.

Influent and effluent solids were characterized using wet sieve analysis on samples for particles less than 20 μm to above 250 μm . Samples were sieved through stainless steel sieves with mesh sizes of 20 μm , 38 μm , 63 μm , 106 μm , and 250 μm . This wet sieve analysis allowed a complete characterization of the influent and effluent particle distribution from less than 20 μm to 5,000 μm . The results for the solids analysis were subdivided into removal for the following particle size ranges:

- <20 μm
- 20-38 μm
- 38-63 μm
- 63-106 μm
- 106- 250 μm
- >250 μm

6.3 Synthetic Challenge Water Laboratory Analytical Results

During testing, 46 influent samples were collected during the normal constituent feed conditions (Phase I, Phase II) and analyzed for the various constituents specified in the test plan. Table 6-2 provides a comparison of the mean analytical results for these influent samples versus the analytical results for the synthetic challenge water mix specified in the test plan.

Table 6-2. Synthetic Challenge Water Analytical Data Comparison to Desired Feed Concentration

Constituent	Measured Mean Concentration (mg/L)	Desired Feed Concentration (mg/L)
TSS	101	300
SSC	299	300
TP	1.26	3
RP	0.73	1

The mean synthetic challenge water data for the primary constituents were measured to be approximately half of the desired target concentration for TP, approximately 75% of the targeted RP concentration, approximately one-third the concentration for TSS, and 99% for SSC. A review of the data shows that the COVs for all parameters ranged between 0 and 1.0. To confirm reliability of the sampling and to assess the repeatability of the testing with new personnel, testing was performed again to ensure that the sampling met the required criteria for efficient solids capture. The differences in solids analysis procedure resulted in capturing almost all solids by the SSC method but only approximately one-third by the TSS methodology¹.

The hopper dosage measurements are consistent with the biases reported for TSS concentrations, which typically underreport the total sediment concentration in the sample, especially for sediment with a specific gravity greater than 1 and a d_{50} greater than approximately 75 μm .² Although the mean analytical TSS concentrations were lower than the 300 mg/L target concentration goal, the hopper dose measurements suggest that the theoretical test plan concentration was close to the 300 mg/L goal.

6.4 Test Results

This section summarizes the analytical data, flow data, and observations for the test phases conducted during the supplemental testing. The efficiency values reported in this section are a function of the total influent and total effluent concentrations.

6.4.1 Phase I - Performance under Intermittent Flow Conditions

The TSS, SSC, TP, and RP analytical data as related to cumulative volumetric loading on the media are summarized in Table 6-3. The test plan required that a minimum of one set of samples be collected each test day, however, the TO collected samples twice per day. The testing organization collected a total of 20 sets of samples. The increase was to verify whether filter media breakthrough was occurring.

¹ An in-depth discussion of solids recovery using the TSS and SSC analytical methods can be found in: Clark, S.E. and Siu, C.Y.S. "Measuring Solids Concentration in Stormwater Runoff: Comparison of Analytical Methods." *Environmental Science & Technology*. 2008, Vol. 42, No. 2, pp. 511-516.

² Ibid.

Table 6-3. Phase I Analytical Data Summary

Analyte	Influent Concentration (mg/L)				Effluent Concentration (mg/L)				Removal Efficiency (%) ¹			
	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.
TSS	85	75	243	15	41	37	68	24	52	51	81	-133
SSC	288	247	775	85	42	37	79	20	86	85	95	32
TP (as P)	1.32	1.19	2.55	0.58	1.50	1.42	2.27	1.12	-14	-19	40	-291
RP (as P)	0.73	0.66	1.61	0.38	0.92	0.86	1.37	0.60	-25	-30	37	-234

1. Mean and median removal efficiency is a function of mean and median influent and effluent concentrations, and maximum and minimum removal efficiencies are a function of individual paired data points.

The median removal efficiency for TSS was 51%, while the median removal efficiency for SSC was 85%. The mean and median influent SSC concentration was approximately four times higher than the mean and median TSS concentrations; and the median TSS and SSC effluent concentrations were nearly identical. The difference in sediment removal efficiencies can be explained by the particle size distribution of the synthetic challenge water and the differences in the analytical methods. The TSS analytical method requires the analyst to shake the sample and collect an aliquot using a pipette, while the SSC analytical method utilizes the entire sample. Therefore, the SSC analytical method is perceived as a more effective method to quantify the full spectrum of solids including the coarser fractions of particles which may fall out of suspension and finer fractions of particles which will tend to stay in suspension, and as a result, generally yields higher removal efficiencies than results based on TSS. The Up-Flo[®] Filter was generally not effective in treating total phosphorus or reactive phosphorus as presented in the form utilized in the synthetic challenge water.

A graphical examination of the data also was conducted to illustrate the results discussed above. Figures 6-3, 6-4, 6-5, and 6-6 compare the influent and effluent concentrations for TSS, SSC, TP, and RP, respectively. Figure 6-7 shows the tank water levels for each test day.

The Phase I testing was conducted with new filter media bags installed in the Up-Flo[®] Filter. The Up-Flo[®] Filter did not exhibit signs of clogging or blinding during the test run. A review of the water depth measurements at each sample time showed that the tank water level remained consistent between 38 and 42 in. No buildup of head was noted in the unit, further indicating that the media capacity had not been exhausted in the Phase I testing.

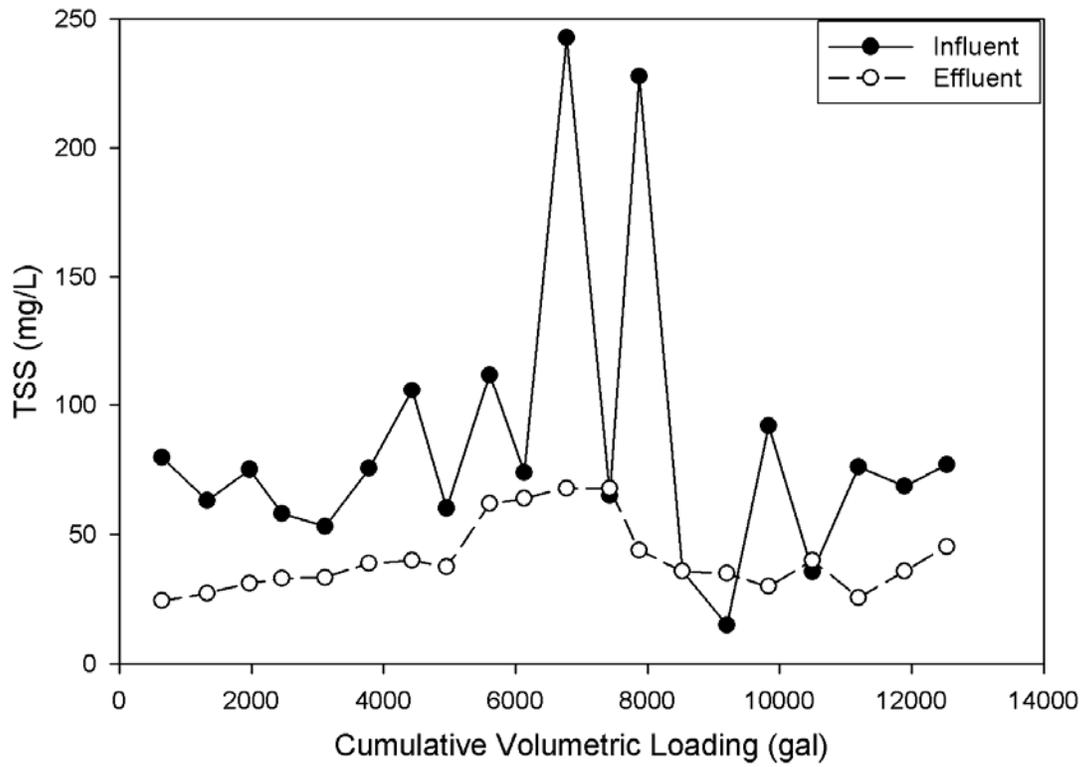


Figure 6-3. Phase I TSS influent and effluent results.

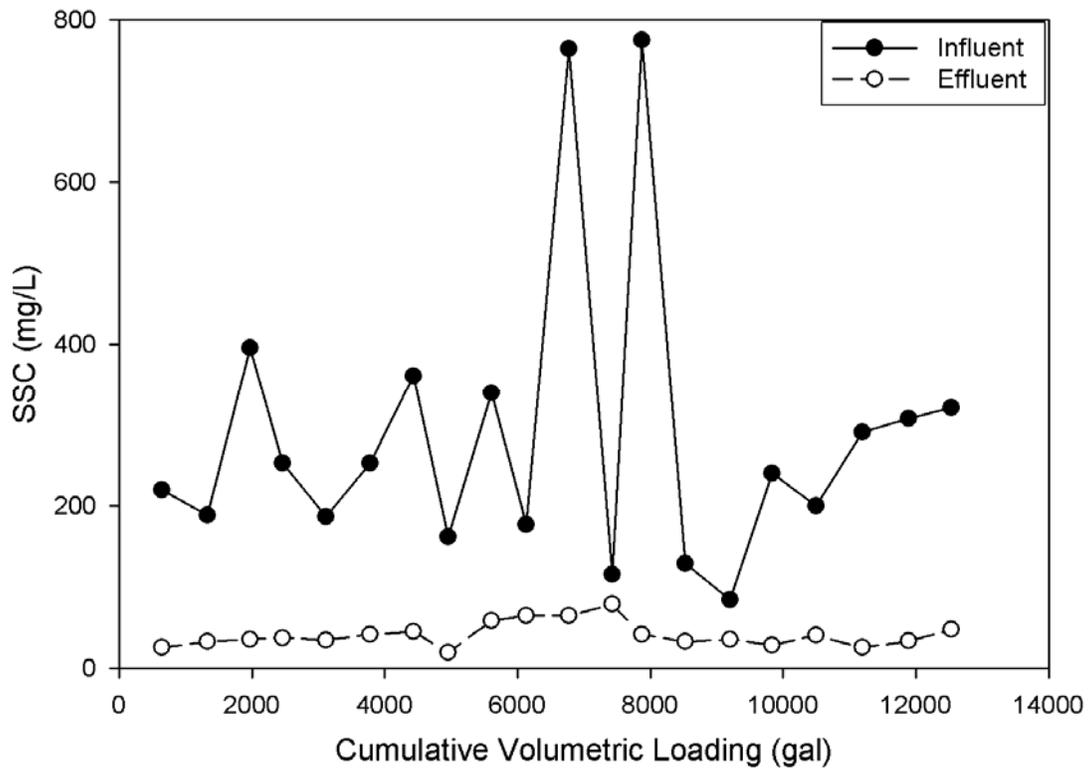


Figure 6-4. Phase I SSC influent and effluent results.

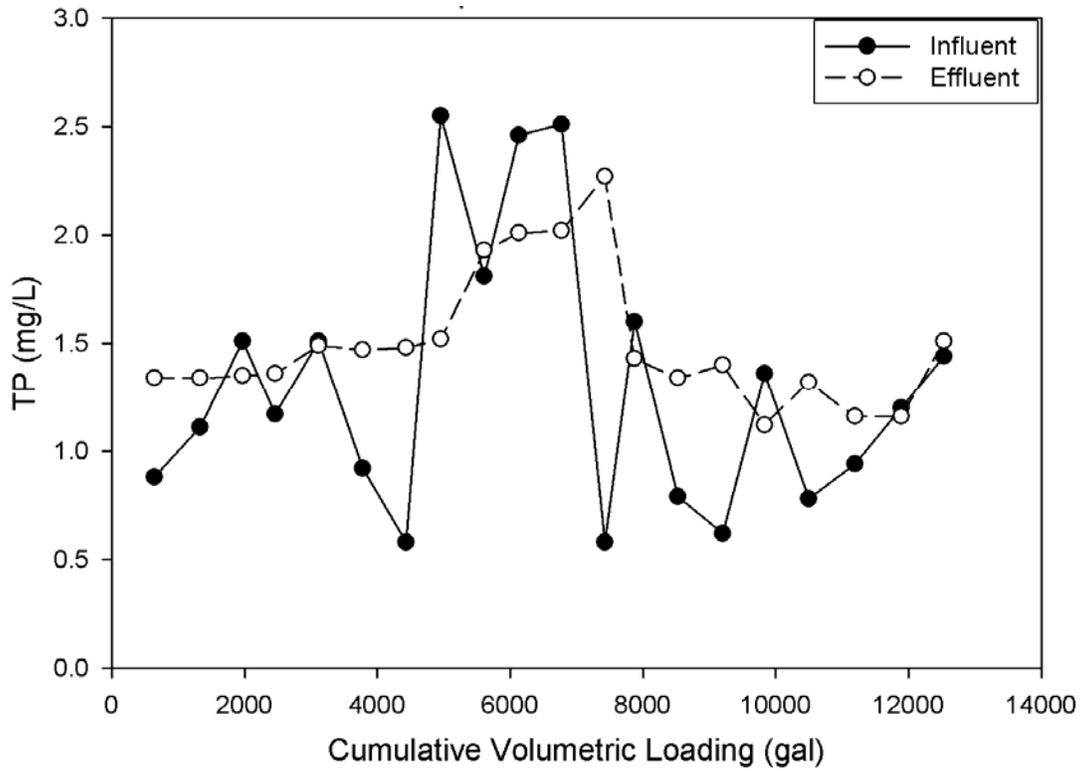


Figure 6-5. Phase I TP influent and effluent results.

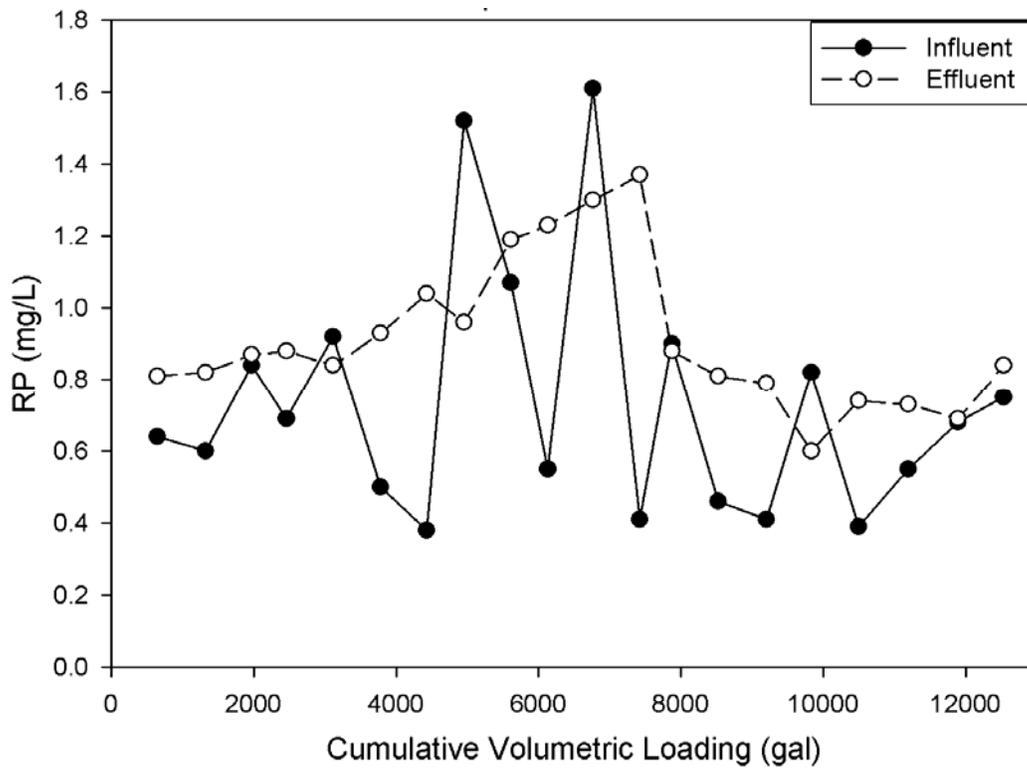


Figure 6-6. Phase I RP influent and effluent results.

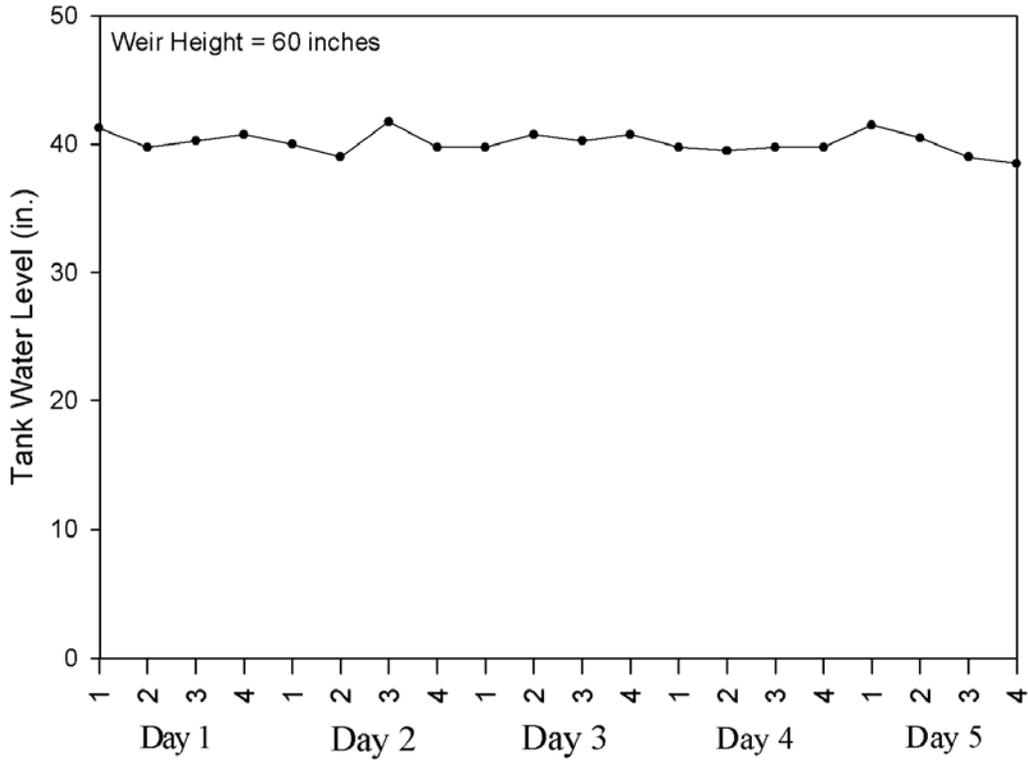


Figure 6-7. Phase I tank water level.

Particle size distribution analysis was also performed on all influent and effluent samples. Figure 6-8 shows the results of the PSD analysis for Phase I. The mean influent d_{50} was 306 μm and the mean effluent d_{50} was 13 μm , indicating a reduction in the particle size in the challenge water as it passed through the Up-Flo[®] Filter. This confirmed the predictions of the manufacturer that the Up-Flo[®] Filter would be capable of removing a high proportion of the particulates in the challenge water.

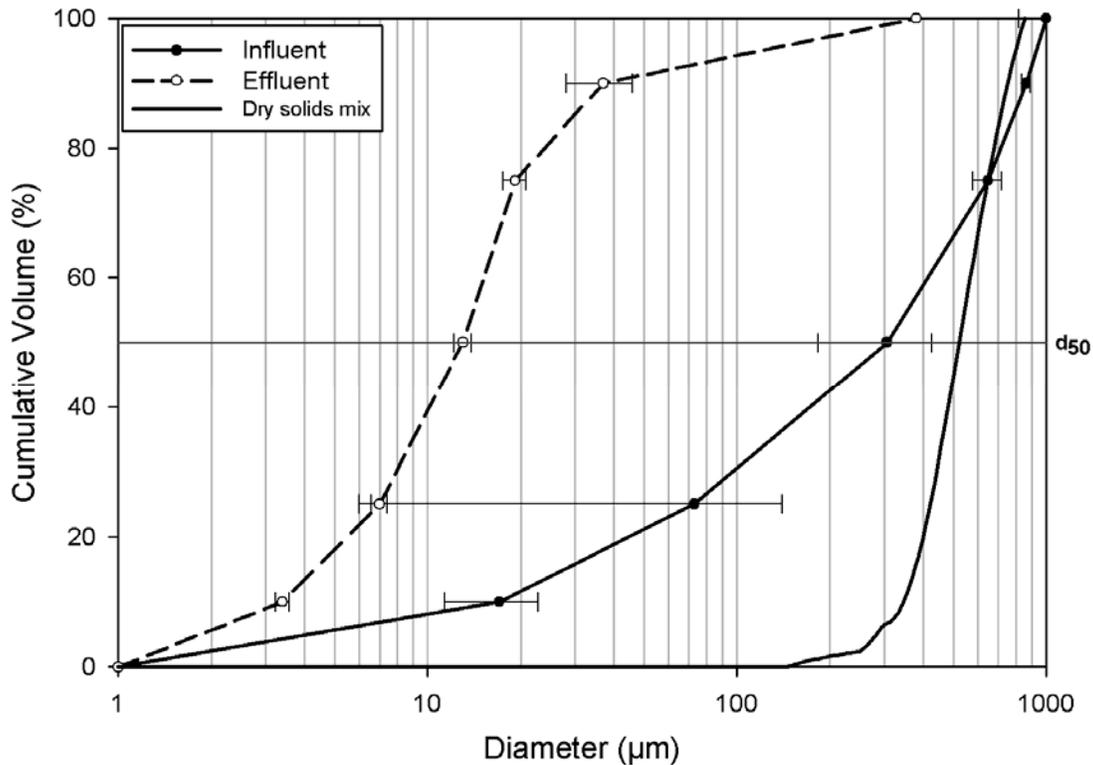


Figure 6-8. Phase I influent and effluent PSD summary.

6.4.2 Phase II – Determination of the Capacity of the Unit

Upon inspection of the filter media bags after Phase I testing, the bags were found to be covered with sediment. The TO shared this information with the vendor, who requested that the Up-Flo[®] Filter be equipped with new filter media bags prior to the start of the next test phase. Since each phase began with new filter media bags, with the exception noted previously, Phase I and II data were not combined during the supplemental testing.

The data are summarized in Table 6-4 and are expressed graphically in Figures 6-9 through 6-12. The median SSC removal efficiency was 77%, while the median TSS removal efficiency was 41%. Similar to Phase I, the median influent SSC concentration was approximately three times higher than the median influent TSS concentration, yet the median effluent TSS and SSC concentrations were nearly identical. The Phase II data also show that the Up-Flo[®] Filter was not effective at treating total or reactive phosphorus as presented in the form utilized in the synthetic challenge water.

Figure 6-13 shows the water levels during each day of testing. At the beginning of the test, the water level in the sump would rise to around the elevation of the bypass weir (60 in.). As the testing progressed, the TO observed that the water level in the sump would take progressively longer to reach the bypass weir elevation. On Day 14, after three consecutive days of the water level in the tank failing to reach the bypass weir elevation, the TO concluded that the Up-Flo[®]

Filter had reached a point where maintenance would be required to restore original operating conditions, so the Phase II test was considered finished.

Analytical data results for the final three days of testing did not demonstrate an increase in contaminant concentrations in the effluent, which could be anticipated if the filter mechanism was breached and flows were exiting the Up-Flo® Filter without filtration. Figures 6-9 through 6-12 do not show a dramatic change in the effluent contaminant concentrations at the end of the test. The TO concluded that, there was a change in conditions in the filter modules sufficient to relieve the pressure in the filter modules and to decrease the head in the tank, but this change did not result in contaminant concentration increase in the effluent.

Table 6-4. Phase II Analytical Data Summary

Analyte	Influent Concentration Results (mg/L)				Effluent Concentration Results (mg/L)				Removal Efficiency (%) ¹			
	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.
TSS	110	99	309	43	59	58	87	30	47	41	83	-14
SSC	307	289	845	109	64	65	101	33	79	77	93	41
TP (as P)	1.26	1.28	2.24	0.40	1.30	1.25	2.53	0.51	-3.6	2.3	46	-78
RP (as P)	0.73	0.69	1.61	0.23	0.75	0.71	1.38	0.27	-3.5	-2.2	67	-100

1. Mean and median removal efficiency is a function of mean and median influent and effluent concentrations, and maximum and minimum removal efficiencies are a function of individual paired data points.

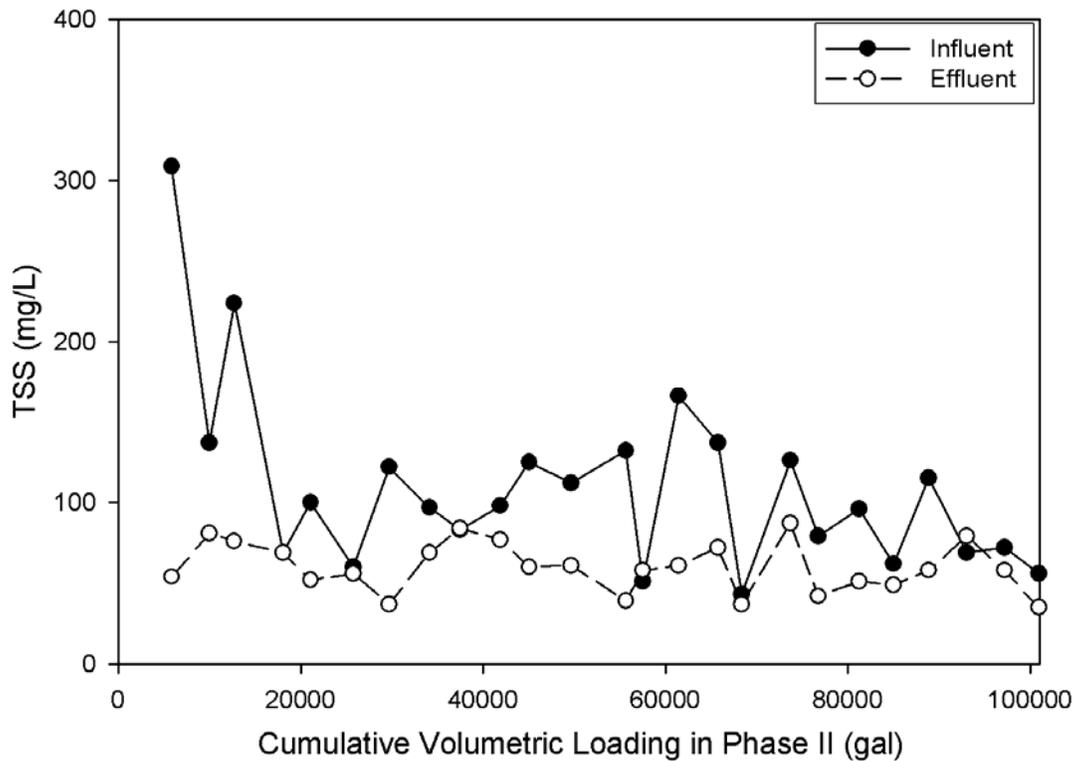


Figure 6-9. Phase II TSS influent and effluent results.

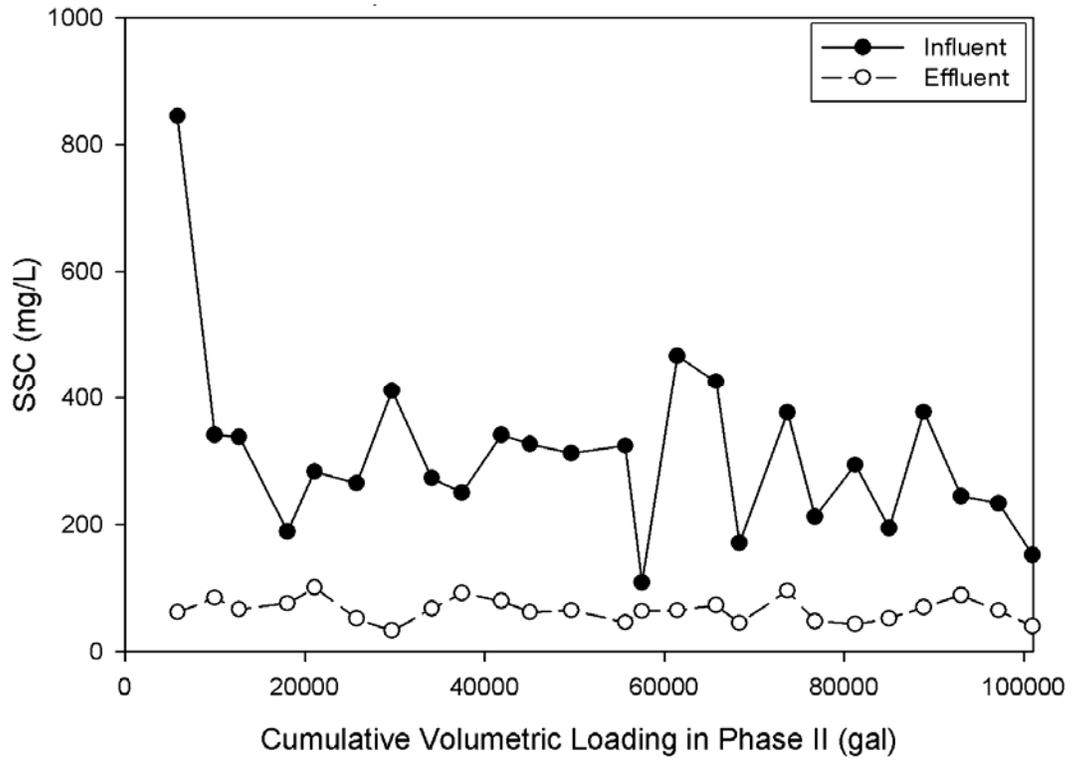


Figure 6-10. Phase II SSC influent and effluent results.

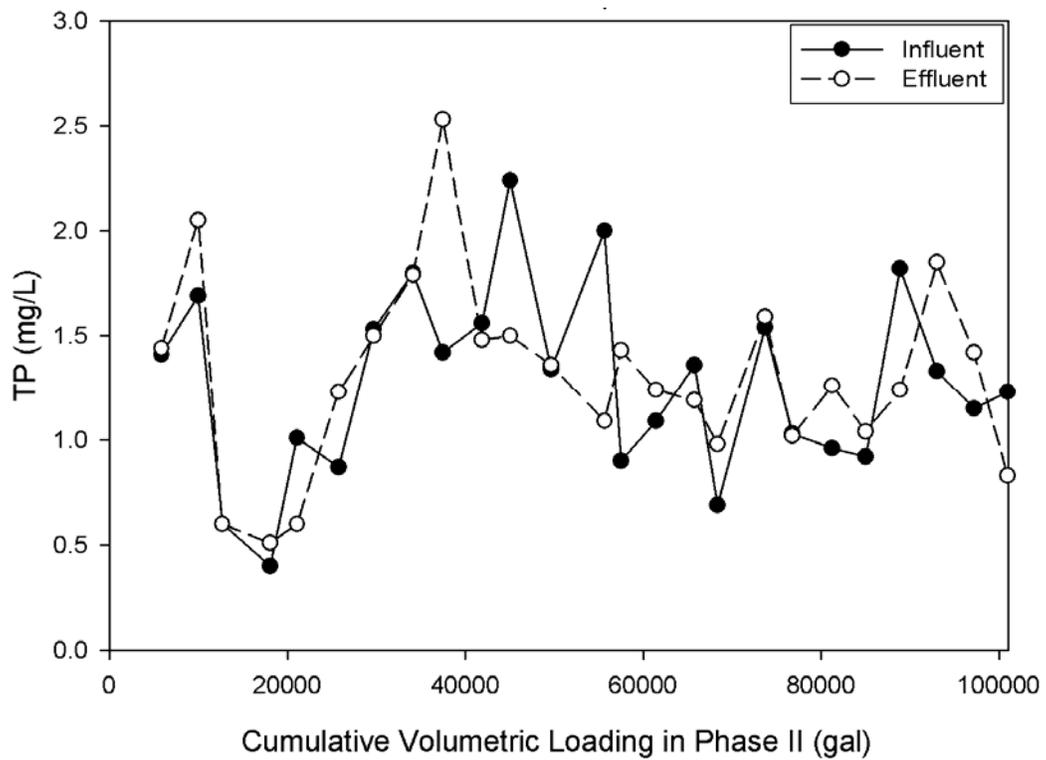


Figure 6-11. Phase II TP influent and effluent results.

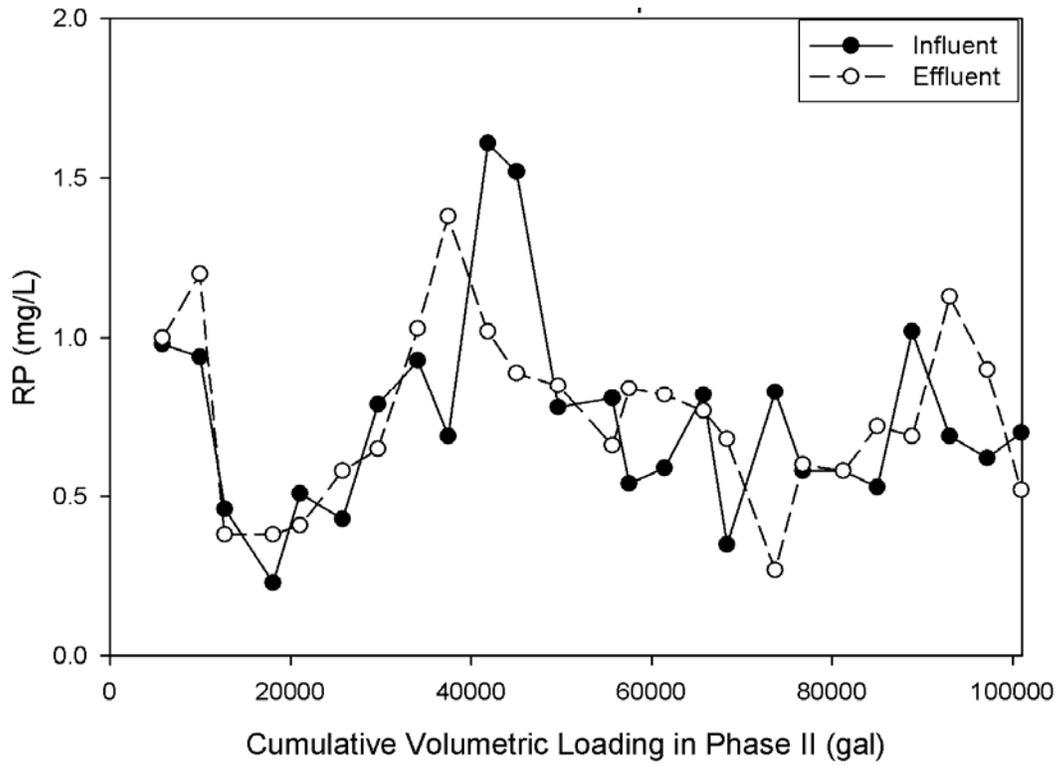


Figure 6-12. Phase II RP influent and effluent results.

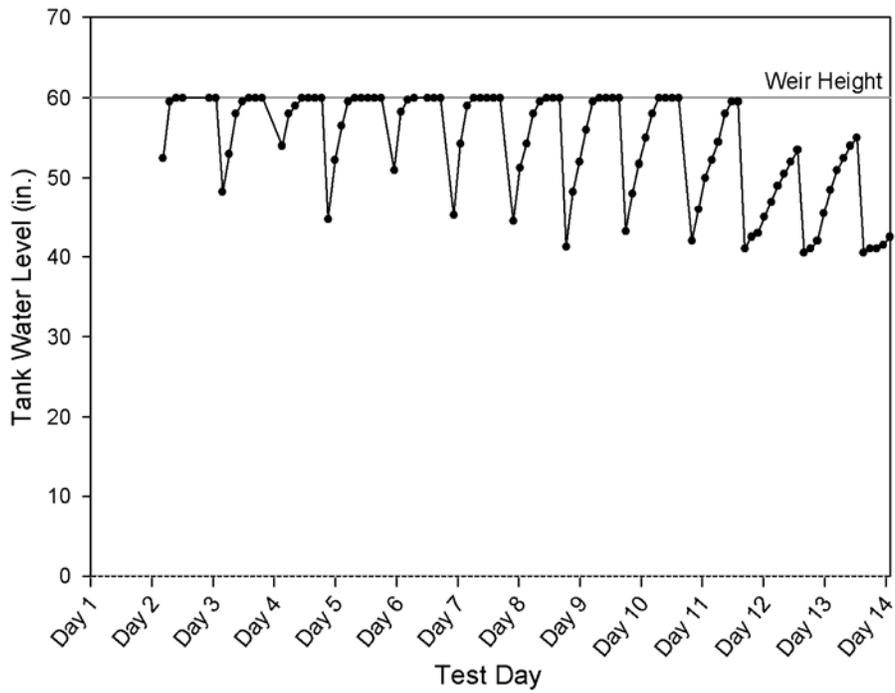


Figure 6-13. Phase II tank water level.

PSD analysis also was performed on the Phase II samples, as shown in Figure 6-13. The mean d_{50} for the influent was 156 μm and the mean effluent d_{50} was 16 μm . This confirmed the manufacturer's claims that the Up-Flo[®] Filter would be capable of removing a high proportion of the particulates in the solution.

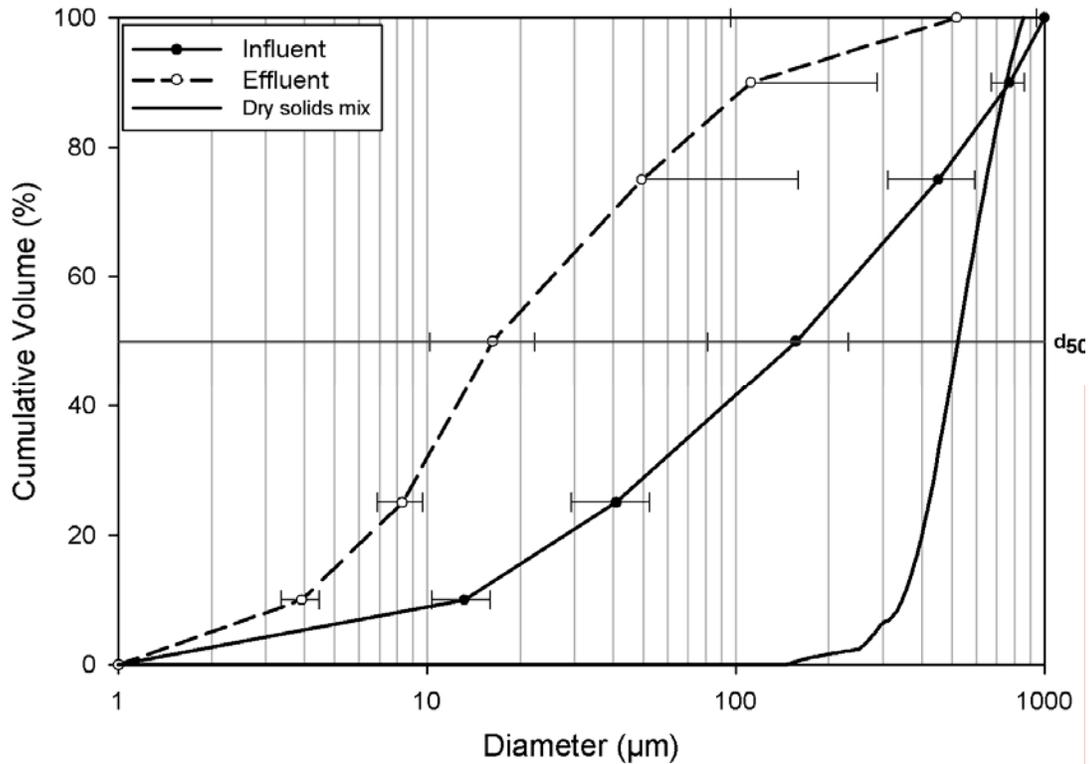
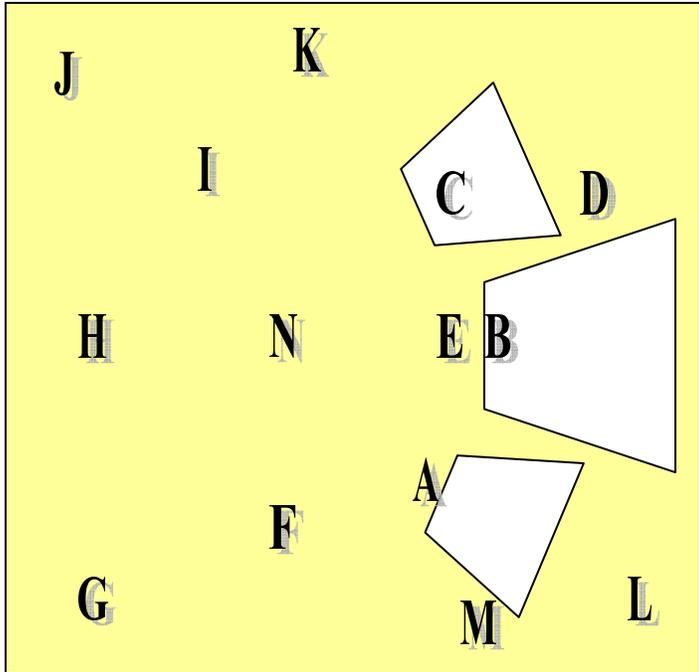


Figure 6-14. Phase II influent and effluent particle size distribution summary.

6.5 Sediment Retained in Sump

Figure 6-15 shows the depth of sedimentation in different areas in the sump after running both Phases I and II. The letters on the figure correlate to grab sample locations. The greatest sediment depth occurred near the filter modules. The water stream exited the influent pipe in this general area. As a result, the larger particles most likely settled out of solution beneath the filter modules.

Figure 6-16 presents the sieve analysis of the three sampled locations within the sump. The distribution of the hopper solids is given also for comparison. The heavier solids in the mixture tend to settle out near the inlet outflow area. The grade of the solids appears to become finer (based on these samples) the further away from initial point of entry into the tank (around Location E).



Sample Location	Depth (in.)
A	4.9
B	4.0
C	2.5
D	4.4
E	2.8
F	2.0
G	1.1
H	1.3
I	0.8
J	1.0
K	1.4
L	1.3
M	1.5
N	1.5

Figure 6-15. Depth of sedimentation in sump.

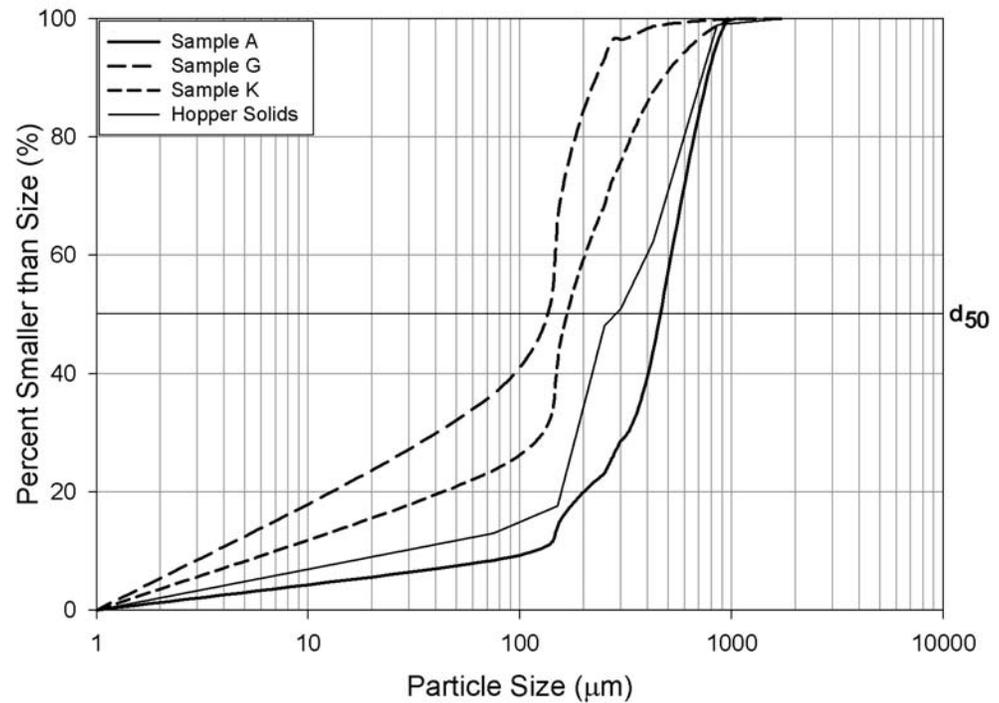


Figure 6-16. Sump particle size distribution analysis results.

Based on the data shown in Figure 6-14, the mass of solids in the sump after the running of Phases I and II was estimated to be 85.3 kg. The total sum of loads for both phases was approximately 104 kg. This indicates that the device retained approximately 82% of the total solids loading in the sump. The concentration of phosphorus retained in the sump was estimated to be 31.3 mg PO₄³⁻ per gram of solids, or a total phosphorus mass of 3.5 kg PO₄³⁻, which represents approximately 3% of the total solids loading. The increase of the phosphorus loading from approximately 1% in the influent to 3% in the sump is likely attributable to the affinity of phosphorus to be retained in sediments.

6.6 Test Summary and Discussion

The flow and analytical data result in the following general observations:

- The Up-Flo[®] Filter was capable of removing sediments from the influent. Removal efficiencies for SSC were near 80% and were near 50% for TSS. The difference between the TSS and SSC removal efficiencies are attributable to the TSS analytical procedure quantifying only the finer fraction of sediment as opposed to the SSC analytical procedure which quantifies a full spectrum of coarse and fine sediment. Most of the sediments removed from the flows were retained within the sump.
- Particle size distribution analysis showed that the Up-Flo[®] Filter removed a high proportion of the particulate sediments. The influent d₅₀ ranged from approximately 100 µm to 300 µm, and the effluent d₅₀ was approximately 15 µm.
- The Up-Flo[®] Filter was generally not effective at removing total or reactive phosphorus as presented in the form utilized in the synthetic challenge water during this phase of testing.
- The Up-Flo[®] Filter is designed so that flows exceeding the filtration capacity discharge to the bypass weir. It is anticipated that clogging of the filter bags over time would decrease the filtration capacity, which would result in the water elevation and head increasing in the tank. Flows reaching the bypass module elevation would pass through the weir in the bypass module without undergoing filtration. Based on this supplemental testing and the original ETV study, the TO observed that as the filter media ripens, conditions within the filter modules change, resulting in an increase in the capacity of the flow through the filter modules and a decrease in the driving head, instead of filter clogging decreasing the flow through the filter module. This observation is demonstrated graphically in Figure 6-12.
- The vendor's redesign of the media restraint and the latching mechanisms of the lid of the filter module prior to the supplemental testing aimed to decrease the ability of the filter media bags to shift within the filter module and let flows pass between the filter media and the filter module walls. The latches were able to keep the filter bags encased within the filter module. As the filter media ripens, it appears that conditions within the filter modules change, allowing for an increase in the flow capacity through the filter module.

- The decrease in the driving head due to the apparent increase in the flow capacity through the filter modules as the filter media ripened did not coincide with an increase in effluent analytical concentrations, as might be expected if the flows were bypassing the filter media. Effluent concentrations toward the end of the Phase II test, when the tank water level did not reach the weir elevation, were consistent with the effluent concentrations observed at the beginning of testing.

Glossary

Accuracy - a measure of the closeness of an individual measurement or the mean of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Commissioning – the installation of the in-drain removal technology and start-up of the technology using test site wastewater.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a qualitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope, and procedures for the study. A protocol shall be used for reference during vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final effluent, that are retained by or discharged from the technology.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Source Water Protection Stakeholder Advisory Group -a group of individuals consisting of any or all of the following: buyers and users of in-drain removal and other technologies, developers and vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals with expertise and knowledge of in-drain treatment technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and Test Plans.

Vendor – a business that assembles or sells in-drain treatment equipment.

Verification – to establish evidence on the performance of in-drain treatment technologies under specific conditions, following a predetermined study protocol(s) and test plan(s).

Verification Organization – an organization qualified by EPA to verify environmental technologies and to issue verification statements and verification reports.

Verification Report – a written document containing all raw and analyzed data, all quality assurance/quality control (QA/QC) data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The test plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report reviewed and approved and signed by EPA and NSF.

Verification Test Plan – a written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of in-drain treatment technology. At a minimum, the test plan shall include detailed instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and QA/QC requirements relevant to the technology and application.

Appendices

- A Test Plan**
- B UpFlo™ Filter O&M Manual**
- C Analytical Data**