NJCAT TECHNOLOGY VERIFICATION

UP-FLO® FILTER

Hydro International

January 2015

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1. Introduction

1.1 New Jersey Corporation for Advance Technology (NJCAT) Program

NJCAT is a not-for-profit corporation to promote in New Jersey the retention and growth of technology-based businesses in emerging fields such as environmental and energy technologies. NJCAT provides innovators with the regulatory, commercial, technological and financial assistance required to bring their ideas to market successfully. Specifically, NJCAT functions to:

- Advance policy strategies and regulatory mechanisms to promote technology commercialization;
- Identify, evaluate, and recommend specific technologies for which the regulatory and commercialization process should be facilitated;
- Facilitate funding and commercial relationships/alliances to bring new technologies to market and new business to the state; and
- Assist in the identification of markets and applications for commercialized technologies.

The technology verification program specifically encourages collaboration between vendors and users of technology. Through this program, teams of academic and business professionals are formed to implement a comprehensive evaluation of vendor specific performance claims. Thus, suppliers have the competitive edge of an independent third party confirmation of claims.

Pursuant to N.J.S.A. 13:1D-134 et seq. (Energy and Environmental Technology Verification Program) the New Jersey Department of Environmental Protection (NJDEP) and NJCAT have established a Performance Partnership Agreement (PPA) whereby NJCAT performs the technology verification review and NJDEP certifies that the technology meets the regulatory intent and that there is a net beneficial environmental effect of the technology. In addition, NJDEP/NJCAT work in conjunction to develop expedited or more efficient timeframes for review and decision-making of permits or approvals associated with the verified/certified technology.

The PPA also requires that:

- The NJDEP shall enter into reciprocal environmental technology agreements concerning the evaluation and verification protocols with the United States Environmental Protection Agency, other local required or national environmental agencies, entities or groups in other states and New Jersey for the purpose of encouraging and permitting the reciprocal acceptance of technology data and information concerning the evaluation and verification of energy and environmental technologies; and

- The NJDEP shall work closely with the State Treasurer to include in State bid specifications, as deemed appropriate by the State Treasurer, any technology verified under the Energy and Environment Technology Verification Program.

1.2 Interim Certification

Hydro International (H.I.L. Technologies, Inc. dba Hydro International) manufactures the Up-Flo® Filter, a patented stormwater Best Management Practice (BMP) used to treat stormwater runoff via sedimentation, screening and media filtration. NJCAT Verification for the laboratory testing of the Up-Flo® Filter was achieved in November 2008. In December 2009, the Up-Flo® Filter was granted Conditional Interim Certification (CIC) from the New Jersey Department of Environmental Protection (NJDEP). To achieve NJDEP Final Certification of the Up-Flo® Filter, a field performance evaluation was conducted in accordance with the Quality Assurance Project Plan (QAPP) approved by NJCAT in July 2012. This field monitoring program was conducted according to the "Protocol for Total Suspended Solids Removal Based on Field Testing: Amendments to TARP Protocol Dated August 5, 2009, Revised December 15, 2009". The results of the field monitoring program are contained within this verification report.

1.3 Applicant Profile

Hydro International, founded in 1980 in the United Kingdom, was formed to promote hydrodynamic vortex separators and vortex flow controls around the world. Today the company provides a wide range of innovative technologies to the wastewater, stormwater and combined sewer overflow sectors of the water industry. The company is headquartered in Clevedon, England and has been publicly listed on the Alternative Investment Market of the London Stock Exchange since 2005. In 2005, Hydro International acquired UK-based wastewater product supplier Vexamus, Inc. and in 2008, Hydro acquired the US-based wastewater grit solutions provider, Eutek Systems, LLC.

Hydro International has state-of-the-art laboratory facilities located in Clevedon, England and Portland, Maine, where research and product engineers conduct development and verification programs to evaluate new and existing products. Hydro currently has 130 employees in the United Kingdom, United States and Middle East. Its office locations include:

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94 Hutchins Drive
Portland, Maine 04102
Tel: +1 (207) 756-6200

<u>US Wastewater</u>
2925 NW Aloclek Drive, Suite 140
Hillsboro, OR 97124
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<u>Headquarters and UK Stormwater</u>
Shearwater House
Clevedon Hall Estate
Victoria Road, Clevedon BS21 7RD
Tel: +44 (0) 1275 878371

<u>UK Wastewater</u>
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1.4 Key Contacts

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1.5 Roles and Responsibilities

Consultant Project Manager: Cai Yezhao, Graduate Research Assistant, University of Alabama

- Coordinate field testing with Hydro International, field operations team, and analytical laboratory
- Collect flow, rainfall, and water quality data at test site
- Document sample collection procedures, Chain of Custody (COC) and QA/QC
- Track Quality Assurance (QA) including preliminary review of field and lab data
- Maintain records & data management systems
- Perform long-term maintenance of equipment
- Oversee preparation of test reports
- Provide additional testing recommendations, if needed

Vendor Project Manager: Lisa Lemont, Hydro International

- Serve as liaison between Vendor, Consultant, and NJCAT, as necessary
- Coordinate testing protocols with Consultant and contract laboratory
- Assist with changes/improvements to test program, as necessary
- Perform detailed analysis of test report
- Prepare Quarterly Performance Summary (QPS) reports
- Prepare Treatment Evaluation Report (TER) and field testing conclusions and compare these with Up-Flo Filter performance claims

Quality Assurance Manager: Kwabena Osei, Hydro International

- Review QAPP
- Verify that sampling, monitoring, and analysis are being performed at the testing site in accordance with the QAPP requirements to assure QA objectives are being met
- Recommend changes to improve QC procedures as necessary
- Perform detailed analysis of sampling data
- Validate data to verify that the monitoring was conducted in accordance with the approved protocol and QAPP

Technical Advisor: Prof. Robert Andoh, Chief Technology Officer, Hydro International

- Provide technical oversight and advice
- Perform review and quality checks on analyses and reporting

Third Party Independent Observer: Jonathon Bonner, CFM Group, Inc.

- Be familiar with QAPP requirements
- For a minimum of ten storm events, witness the sampling performed by the Consultant, including set-up of monitoring equipment at the site in preparation for upcoming storm events, collection of samples and storm data following the storm event and preparing monitoring equipment for future storm events.
- Observe inspections and maintenance performed on monitoring equipment and verify that the information is properly documented in field logs.

Academic Advisor: Robert Pitt, Ph.D., P.E., BCEE, D.WRE, Cudworth Professor of Urban Water Systems Dept. of Civil, Construction, and Environmental Engineering, University of Alabama

- Oversee the Consultant Project Manager
- Oversee the preparation of test reports
- Provide testing recommendations, if needed

In the interest of full disclosure, Robert Pitt is one of three inventors listed on the Up-Flo® Filter Patent (US Patent No.7005060 B2) and one of the founders of Stormtrain LLC, the original patent assignee. Hydro International Plc purchased the rights to the patent in 2005. Although Dr. Pitt supervised the Graduate Research Assistant who managed this field testing project, Dr. Pitt was not personally involved in the sampling or analysis of the field monitoring data. Hydro International contracted with the University of Alabama to fund the monitoring program. Contract funds were used to cover the cost of supplies, analysis and tuition and associated costs for the Graduate Research Assistant. No contract funds covered in whole or in part Dr. Pitt's salary or stipend(s) from the University of Alabama. No payments were made from Hydro International directly to Dr. Pitt for his role in this field monitoring program.

2. The Up-Flo® Filter

The Up-Flo® Filter is a passive stormwater filtration system designed to remove 80% of Total Suspended Solids (TSS) from stormwater runoff at a water quality flow rate of 25 gpm per Filter Module (22 gpm/ft^2 given a Filter Module surface area of 1.1 ft^2). The Up-Flo® Filter can be retrofitted into an existing storm drain manhole or supplied as a complete system housed in a 4-ft diameter manhole or precast vault. The vaulted systems are designed to house multiple platforms each having one to six Filter Modules. It is designed with a treatment train concept that incorporates gravitational separation of floating and settling materials, screening, and filtration of stormwater flows. A filtered drain down prevents media from remaining saturated after storm events and becoming anaerobic. Inspection and maintenance is necessary to maintain the design filtration rate. A siphon-activated bypass conveys flows larger than the design filtration rate for on-line installations (**Figure 1**).

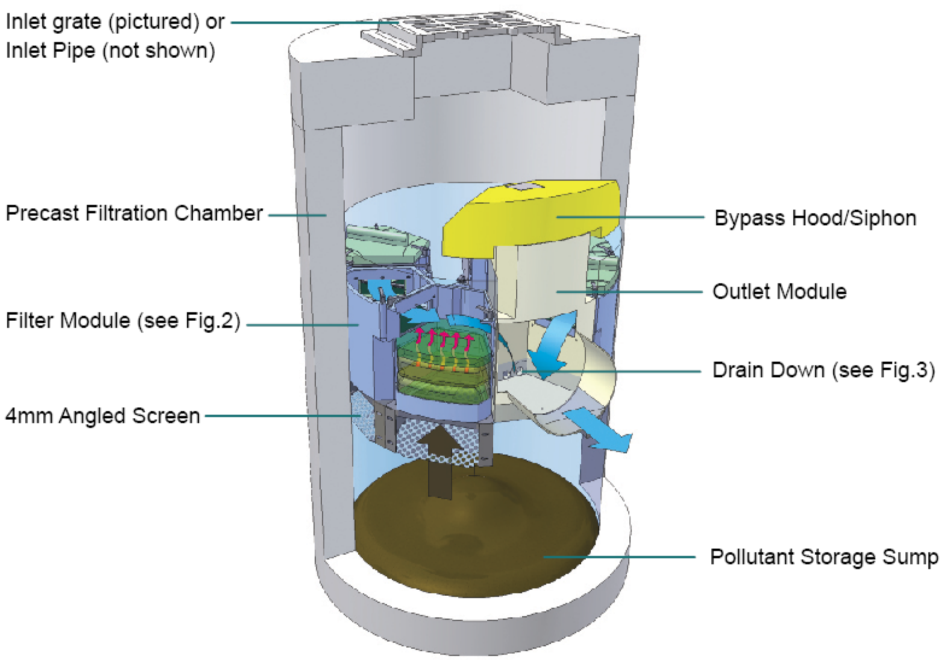

Figure 1 Components of the Up-Flo® Filter

Operation of the Up-Flo® Filter is initiated during a rainfall event when stormwater is conveyed into the chamber from a surface inlet or directly from the drainage system's pipe network. As flow enters the chamber, internal components act as baffles to slow down flows and encourage gross debris and sediment to settle into the sump and floating debris to rise to the surface. Depending on the runoff rate entering the chamber, a water column builds above the top of the media until it reaches the Bypass Weir elevation. This water column provides the driving head to convey flow upward through an Angled Screen and Media Pack into a Conveyance Slot where filtered flow is discharged into the Outlet Module. The Media Pack is 9.5-inch thick and includes a bottom 0.75-inch thick layer of Flow Distribution Media, two media bags each with a 4-inch depth of filtration media, and a top 0.75-inch thick layer of Flow Distribution Media (**Figure 2**). A wide range of media types can be can be used in the Filter Modules including CPZ™ (Carbon, Peat, and Manganese Coated Zeolite), CPS™ (Carbon, Peat, Sand) and Hydro Filter Sand, or HFS™ (**Figure 2 inset**).

The Flow Distribution Media is a polyethylene fiber web filtration media used to support the Media Bags and evenly disperse the flow across the entire surface of the media. The Angled Screens are designed to minimize the chance of ragging and blinding as they are situated below the Filter Modules, sheltering them from the direct path of the influent. The angle is designed to release any pollutants that may temporarily lodge on the screens once flow subsides and drain down initiates.

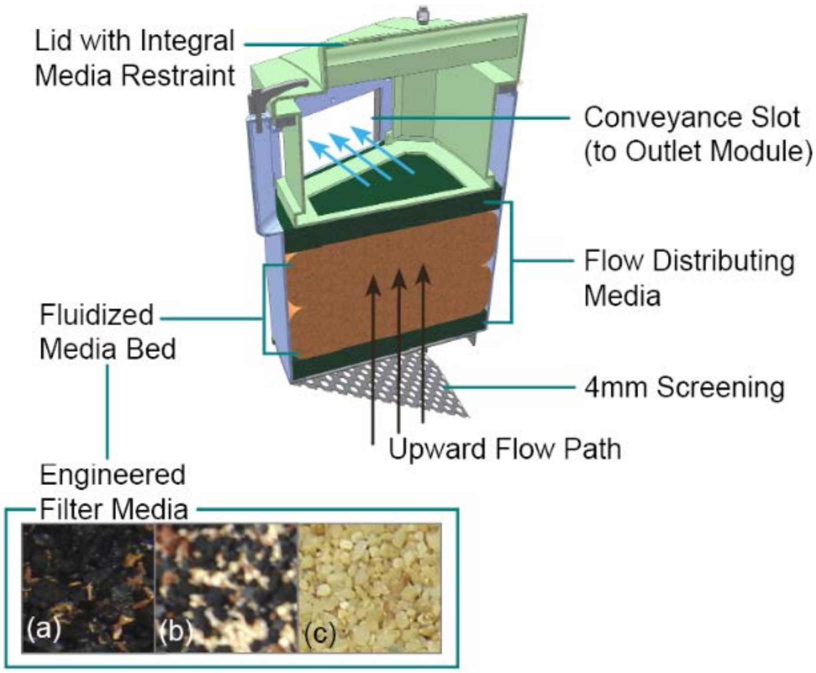

Figure 2 Filter Module Components Containing Media Bags of (a) CPZ™ Mix, (b) CPS™ Mix, or (c) HFS™ Media

The driving head or water column above the top of the Media Bags imposes an upward pressure on the media, causing the media particles to become suspended in an upward-flowing column of water. The extent of media movement, however, is limited by the constraining volume of the Media Bags. The movement of the filter media allows pollutants to be trapped throughout the entire depth of the media bed, rather than just the first few inches, thus increasing the length of filter runs. High hydraulic loading rates are maintained without compromising effluent control by restraining the media within the Media Packs.

Treated flow exits the Filter Module(s) into the Outlet Module via a conveyance channel located above the media. Flow in excess of the design filtration capacity discharges over the Bypass Weir. The Outlet Module has a hood to act as a Floatables Baffle preventing the escape of buoyant debris and trash during bypass. It also siphons excess flows into the outlet once the air in the outlet chute is displaced, increasing the maximum discharge rate for extreme events. After a storm event, the water column drops to the top of the Media Bags at which point there is no longer any head to drive flow.

The Up-Flo® Filter employs a patented drain down (**Figure 3**) that allows the water level in the chamber to drop below the filter media between storm events to prevent the media from becoming anaerobic. The drain down assembly includes three drain-down ports at the base of the Outlet Module. During the drain-down mode of operation, a light backwashing effect occurs, washing captured pollutants off the surface of the filter bag to help prevent blinding and prolong media life. By draining the water out of the media, the weight of the Media Bags is reduced for easier removal during maintenance operations.

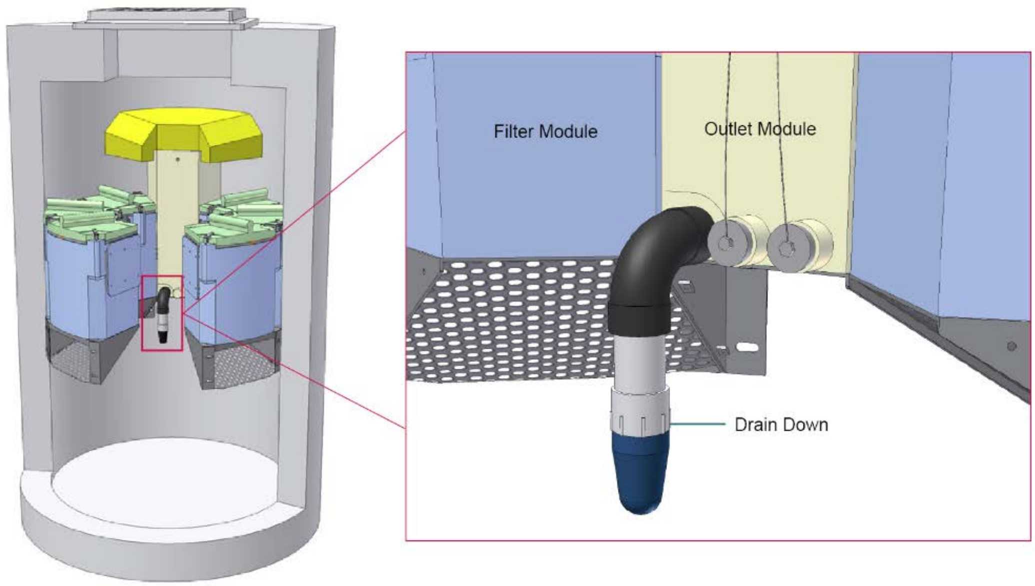

Figure 3 Outlet Module with Three Drain-Down Ports

A standard Up-Flo® Filter comes equipped with one drain down filter attached to one of the three drain-down ports, while the other two ports are capped by plugs with pull chains. The pull-chains are attached near the top of the Outlet Module so that maintenance personnel can easily pull the plugs to drain standing water from the filter chamber in the event that the drain down filter becomes clogged and can no longer drain the water from to the base of the Filter Modules. Additional drain down filters can be used in lieu of one or both plugs to accommodate sites with moderate to high base flows.

3. Technology System Evaluation: Project Plan

3.1 Introduction

The primary goal of this field verification project was to evaluate performance of the Up-Flo® Filter based on performance goals specified in the TARP program requirements, including NJDEP's Amendments to the TARP Protocol dated August 5, 2009 Revised December 5, 2009. To meet this goal:

- Influent and effluent stormwater pollutant concentrations were evaluated for the Up-Flo® Filter using flow-weighted composite sampling;
- Bypass frequency, duration, and volume in relation to design expectations were evaluated. Effluent samples were composites consisting of both treated and bypassed flow; and

- The maintenance schedule required for proper functioning of the Up-Flo® Filter was quantified.

The experimental design for this project involved the continuous monitoring of discharge from the outlet pipe of a 6-module 4-ft diameter Up-Flo® Filter designed to treat up to 25 gpm per Filter Module.

Hydro International contracted the Civil, Construction and Environmental Engineering (CCEE) Department of the University of Alabama (UA) College of Engineering to act as the independent consultant to execute the field monitoring program. Environmental Engineering Master's Degree Candidate Cai Yezhao was Project Manager on behalf of the University of Alabama. CFM Group, a civil and environmental engineering consulting firm based in Tuscaloosa, Alabama, acted as the independent observer. Monitoring conducted according to the Up-Flo® Filter Quality Assurance Project Plan (QAPP) approved by NJCAT began in May 2012 and finished in March 2013.

3.2 Site and System Description

Bama Belle Riverwalk Test Site

In the fall of 2007, the City of Tuscaloosa Alabama, installed an Up-Flo® Filter at the Tuscaloosa Bama Belle Riverwalk parking area, a city-owned facility located on the bank of the Black Warrior River (**Figures 4 and 5**). The Black Warrior River, a tributary of the Tombigbee River, is approximately 178 miles long and drains an area of 6,275 square miles. The Up-Flo® Filter was installed at the site to serve as a research facility for the nearby University of Alabama. The university researchers opted to install a standard 4-ft diameter model equipped with six Filter Modules treating site runoff rates of approximately 25 gpm per Filter Module with CPZ filter media, for a total Treatment Flow Rate of 150 gpm (see detailed drawing in **Appendix A**).

Figure 4 Up-Flo® Filter

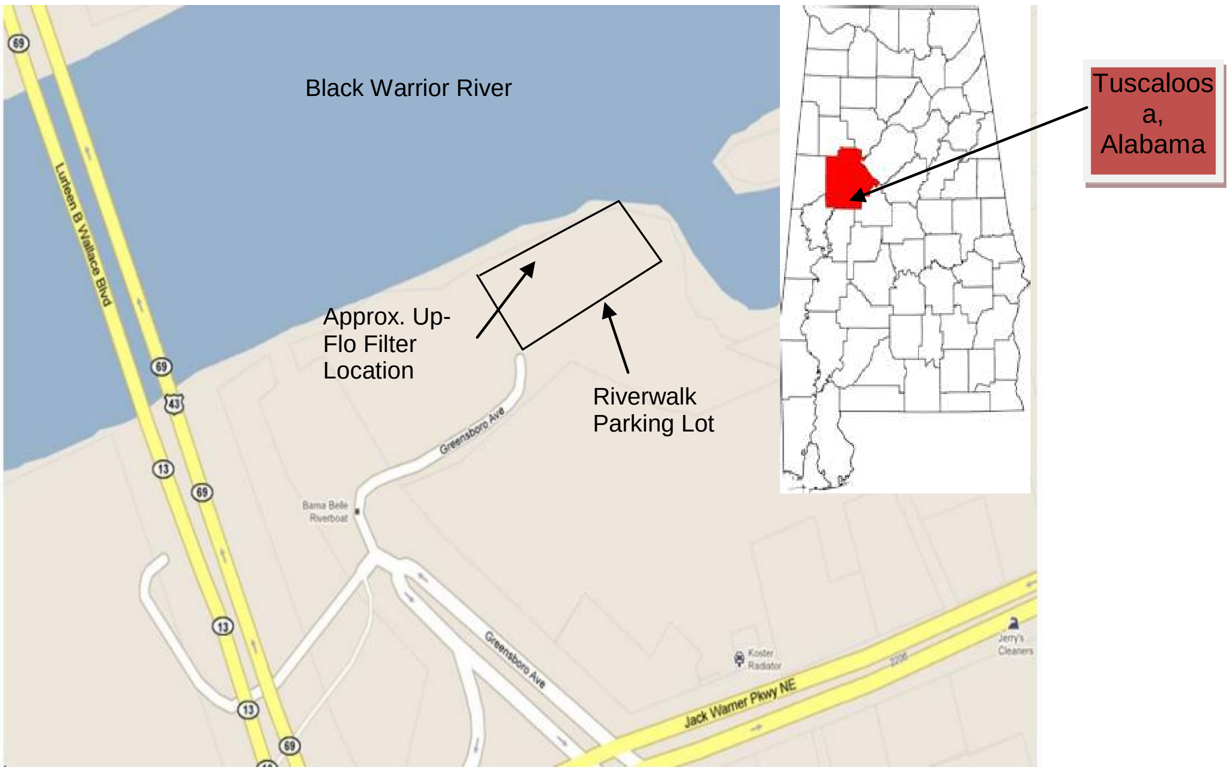

Figure 5 Map of the Bama Belle Test Site

The total site acreage is approximately 0.9 acre, of which about 68% is impervious. **Table 1** shows the land uses within the drainage area.

Table 1 Land Use of the Drainage Area Comprising the Bama Belle Test Site

Land Use	Area		Fraction of Site's Land Use
	(ft^2)	(acre)	%
Parking Space	11,800	0.27	30.6
Other Paved	1,300	0.03	3.4
Sidewalks	2,100	0.05	5.4
Driveways	10,990	0.25	28. 5
Green Space	12,400	0.29	32.1
Total	38,590	0.89	

The Up-Flo® Filter receives surface runoff from the parking lot, driveways, sidewalks, and small landscaped areas (**Figure 6**). Effluent from the Up-Flo® Filter flows approximately 30 feet via a discharge pipe into the Black Warrior River. The main pollutants within the drainage area are associated with vehicular activity, erosion from the landscaped areas, and park activities. The City of Tuscaloosa infrequently cleans the site road and parking lot areas. There are no other stormwater control practices within the drainage area.

Figure 6 Aerial Photograph Showing Drainage Area and Up-Flo® Filter Inlet Location

Up-Flo® Filter Sizing

The “Protocol for Total Suspended Solids Removal Based on Field Testing: Amendments to TARP Protocol Dated August 5, 2009, Revised December 15, 2009” requires that the stormwater treatment device be sized using the methodology outlined in Chapter 5 of the New Jersey Stormwater Best Management Practices Manual (NJDEP, 2004).

Using the New Jersey rainfall intensity, i = 3.2 in/hr, and a site area of 0.89 acre with an assumed C_v = 0.73 (0.60 acres impervious and 0.29 acres pervious), the water quality flow rate, Q, is found to be 942 gpm:

$$Q = C_v ia = (0.73) * (3.2 \text{ in/hr}) * (0.89 \text{ acre}) = 2.1 \text{ cfs } (942 \text{ gpm})$$

A 38-module Up-Flo® Filter would be required to treat 100% of 942 gpm.

When the Up-Flo® Filter was being installed in 2007, a 6-module Up-Flo® Filter with an MTFR of 150 gpm was selected because hydrologic modeling results showed that a 6-module system would treat 90% of the site’s annual runoff. To model the site, Dr. Robert Pitt, Professor of Civil Engineering at the University of Alabama (http://rpitt.eng.ua.edu/index.shtml) produced a series of conservative preliminary calculations using the Wisconsin Source Loading and Management Model (WinSLAMM) to determine the distribution of flows that could be expected for several sets of conditions at the Tuscaloosa site. Although WinSLAMM contained more than 50 years of rainfall data for Tuscaloosa, the model was based rainfall data from January through September of 1999. The entire historical rainfall record contained over a million cells of data, which exceeded the computational capacity of Excel 2007, which was used to create a Flow Rate vs. Percentage of Annual Flow chart. The nine month period from 1999 was determined to be statistically representative of the historical rainfall conditions in Tuscaloosa.

Figure 7 is a sizing plot for one-acre paved parking or storage areas for Tuscaloosa, AL. Although the curve was generated for a 100% impervious site, this methodology can be applied to the Bama Belle site, which is approximately 70% impervious. The actual ratio of runoff volume to rain volume (Rv) at the test site was found from hydrological monitoring to be about 1.0, indicating that almost all of the rainfall occurred as runoff. Therefore using curves for 100% impervious is appropriate. Additionally, using Rv=1 provides a conservative calculation of the peak flow rate that requires treatment.

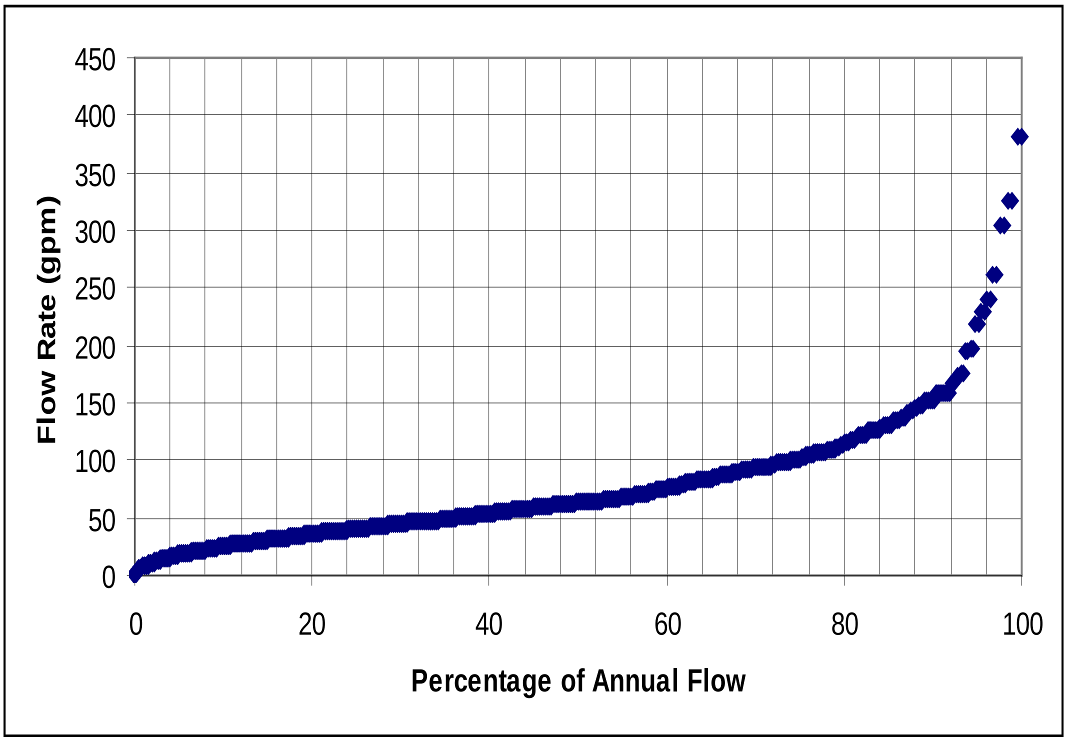

Figure 7 Percentage of Annual Flows at Tuscaloosa 0.89-ac Test Site (Pitt & Khambhammettu, 2006)

Figure 7 shows the annual runoff distributions calculated using WinSLAMM. These plots were made using calculated flows every six minutes, corresponding to the expected time of concentration (TOC) limitations. The plot shows the calculated percentage of the annual flows that would be treated by the Up-Flo® Filter at different treatment flow rates. Since the annual pollutant load removal of the Up-Flo® Filter is directly dependent on the amount of the annual runoff that is treated by the unit, this information can be used to size the Up-Flo® Filter. **Figure 7** shows that by sizing the Up-Flo® Filter to treat 150 gpm for a one-acre site, approximately 90% of annual runoff would be treated.

Although the 6-module Up-Flo® Filter was undersized according to the NJDEP sizing method, it was deemed adequate for the monitoring program because approximately 90% of the annual flow would be treated. The sizing calculation suggests that the Bama Belle installation would be stressed beyond what would be a typical design in New Jersey, and therefore performance results from the test site would be conservative when applied to the New Jersey performance standard.

3.3 Sampling Design and Test Equipment

Field monitoring for this program was conducted in accordance with the QAPP developed by Hydro International in consultation with the UA CCEE Department and NJCAT. Sampling was set up and conducted in accordance with "Protocol for Total Suspended Solids Removal Based on Field Testing: Amendments to TARP Protocol Dated August 5, 2009, Revised December 15, 2009" (NJDEP, 2009) and the TARP Tier II Protocol (TARP, 2003).

Hydrological, water quality, and sediment data were collected in order to verify performance of the Up-Flo® Filter. Sampling took place during actual storm events, which covered a wide range of rainfall intensities that occurred between May 31, 2012 and March 30, 2013. Automatic water quality sampling and flow monitoring equipment at the Up-Flo® Filter's inlet and outlet collected flow-weighted composite samples to evaluate TSS and SSC removal efficiency and other water quality parameters on an average annual basis for both treated flow and treated/bypassed flow. Additional hydrologic and sediment monitoring was conducted over the duration of events. The monitoring equipment setup is shown in **Figure 8**.

Figure 8 Location of Monitoring Equipment at Bama Belle Site

For hydrological monitoring, two ISCO 4250 area-velocity flow sensors were used to continuously monitor the water level in the influent sump and the flow rate in the effluent pipe. The rain depth and intensity were monitored continuously by an ISCO 674 tipping bucket rain gage installed on the top of the monitoring station. This rain gage's main function is as a trigger for the monitoring samplers, instead of accurately representing rainfall information, as there are several trees closer to the monitoring station than desired for the best rainfall monitoring. The selection of events to monitor is based on weather prediction information for Tuscaloosa, AL from www.weather.com (Cai et al., 2013).

The two ISCO 6712 automatic water samplers (with 15L composite HDPE sample containers) were remotely programmed in anticipation of the storm events based on the weather forecast and type of storm event (small, moderate, or large) predicted (**Figure 9**). During water quality monitoring, the runoff samples were simultaneously collected at both influent and effluent locations in small plastic trays where the water is cascading directly onto the sampler intakes, reducing problems associated with stratified flows. Sampling was initiated when the rain gage registers 2 tips, or 0.02 inches of rain within 30 minutes. Both samplers obtain flow-proportional subsamples simultaneously from the influent and effluent, based on pre-programmed sample pacing that is adjusted by reliable weather forecast services, as noted above.

Figure 9 Two ISCO 6712 Automatic Water Samplers

Table 2 shows the automatic sampler programming for different sized storm events. This programming design fulfills the protocol sampling requirements and obtains the needed sample volumes for the laboratory analyses.

Table 2 Automatic Sampler Programming for Various Rain Events (Cai et. al, 2013).

	Small Rain Event	Moderate Rain Event	Large Rain Event
Precipitation (in)	0.1 - 0.5	0.4 - 2	1.5 - 8
Duration (hr)	2 - 6	4 - 20	> 15
Runoff Volume (gal)	1,440 - 7,190	4,310 - 28,800	21,600 - 115,000
Average Rain Intensity (in/hr)	0.05 - 0.08	0.08 - 0.1	0.19 - 0.33
Average Runoff Rate (GPM)	46 - 76	68 - 91	171 - 304
Programmed Subsample Volume (mL)	250	250	250
Runoff Volume per Subsample (gal / L)	120 / 32	480 / 130	2,000 / 530
Estimated Number of Subsamples	12 - 60	12 - 60	11 - 58
Sample Volume per Event (L)	3.0 - 15	3.0 - 15	2.7 - 14
Filling Percentage of 15 L Capacity (%)	20 - 100	20 - 100	18 - 96
Subsample Collection Rate (min. for each sub-sample)	6 - 10	20	25 - 45

As shown, the programmed subsample volume for all three setups is always 250 mL, with the only sampler change being the amount of flow associated with each subsample. Also, the minimum number of subsamples expected is 11 and the subsample collection rate enables subsamples to be collected every several minutes at the shortest interval.

The ISCO samplers require an interval of about 1.5 minutes to collect each subsample, considering the required time for the initial back flush of the sample line, sample collection, and the final back flushing of the sample line (Burton and Pitt, 2001). The moderate-sized rain program was routinely used, unless an unusually large or small rain was expected.

Additionally, continuous water quality monitoring was conducted using two YSI 6600 water quality sondes for turbidity, conductivity, and temperature (the storage and use conditions are too harsh for reliable use of the DO, pH, and ORP sonde probes without excessive maintenance). As shown in **Figure 10**, both sondes are installed and secured before each monitored rain in the cleaned plastic trays at the inlet and outlet sampling locations. Each measurement is taken every 5 minutes, setting the data resolution as high as possible to detect variability's in stormwater quality during the events.

Figure 10 Influent (at left) and Effluent (at right) Sampling Trays

New media bags were installed in March 2012. Monitoring took place over the following year to evaluate the performance over time and verify the typical maintenance cycle of the Up-Flo® Filter. Sediment accumulation in the sump and filter media was evaluated to demonstrate Up-Flo® Filter performance and maintenance requirements. Equipment set-up, sample collection and data collection was performed by the UA Project Manager, who also conducted sample analysis at the UA laboratory. The independent observer witnessed the UA Project Manager's collection and analyses of 10 samples.

3.4 Test Methods and Procedures

Field Sampling Procedures for Storm Events

Water quality samples from the influent and effluent flows were collected by two programmable, automated Model 6700 ISCO Portable Samplers. Individual influent and effluent samples were composited into one influent collection container and one effluent collection container per storm event. Samples were packed in ice and transported to the analytical laboratory as soon as practical once the rain had ended. As noted above, sample collection and subsequent laboratory analysis at the University of Alabama was independently witnessed for 10 of the 30 storm events. At the UA lab, the composite container was thoroughly mixed and the entire contents poured into a USGS/Dekaport cone splitter to create subsamples. Subsamples from all storm events were sent to Stillbrook Environmental Testing Laboratory, an independent, state-certified laboratory located in Fairfield, AL, and analyzed for Total Suspended Solids (TSS) and Suspended Sediment Concentration (SSC).

Following sample collection, clean composite bottles were placed in the sampler and the used bottles were brought back to the UA laboratory for analysis and decontamination. All sampling equipment was decontaminated prior to use. Decontamination procedures consisted of scrubbing the composite bottles with Liqui-Nox and rinsing with deionized water prior to use.

Continuous Monitoring Procedures

After the samples were retrieved, the inlet sampling tray was emptied into the filter sump and the influent probe moved into a perforated pipe in the filter sump to continuously measure water quality between events in the standing water.

Stormwater exiting the manhole structure was also monitored on a continuous basis for flow and several secondary constituents (pH and temperature). Water level in the Up-Flo® Filter was continuously monitored by a pressure transducer

Analysis Methods for Primary Constituents

The primary constituents analyzed were Suspended Sediment Concentration (SSC), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and Particle Size Distribution (PSD). Both TSS (APHA Standard Method 2540 D) and SSC (ASTM Method D3977) test methods were used during verification testing to establish the TSS and SSC removal efficiency. Influent and effluent samples from all events were analyzed for VSS and PSD. The methods used to analyze water quality samples for the primary constituents are shown in **Table 3**. The process used followed the flow chart shown in **Figure 11**.

Table 3 Analytical Methods for Primary Constituents

Constituent	Method	Reporting Limit/Resolution	Units
Total Suspended Solids (TSS)	SM 2540 D	1	mg/L
Particle Size Distribution (PSD)	See Note 1	--	--
Suspended Sediment Concentration (SSC)	ASTM D3977-97	1	mg/L
Volatile Suspended Solids (VSS)	SM 2540E	1	Mg/L

[1] Wet sieving was used to calculate the particle size distribution of particles greater than 250 µm. The Coulter Counter (Model 3) was used to measure the particle size distribution of particles from 3 µm to 250 µm. A 0.45 µm filter was used to measure the concentration of particles in the 0.45 µm to 3 µm range.

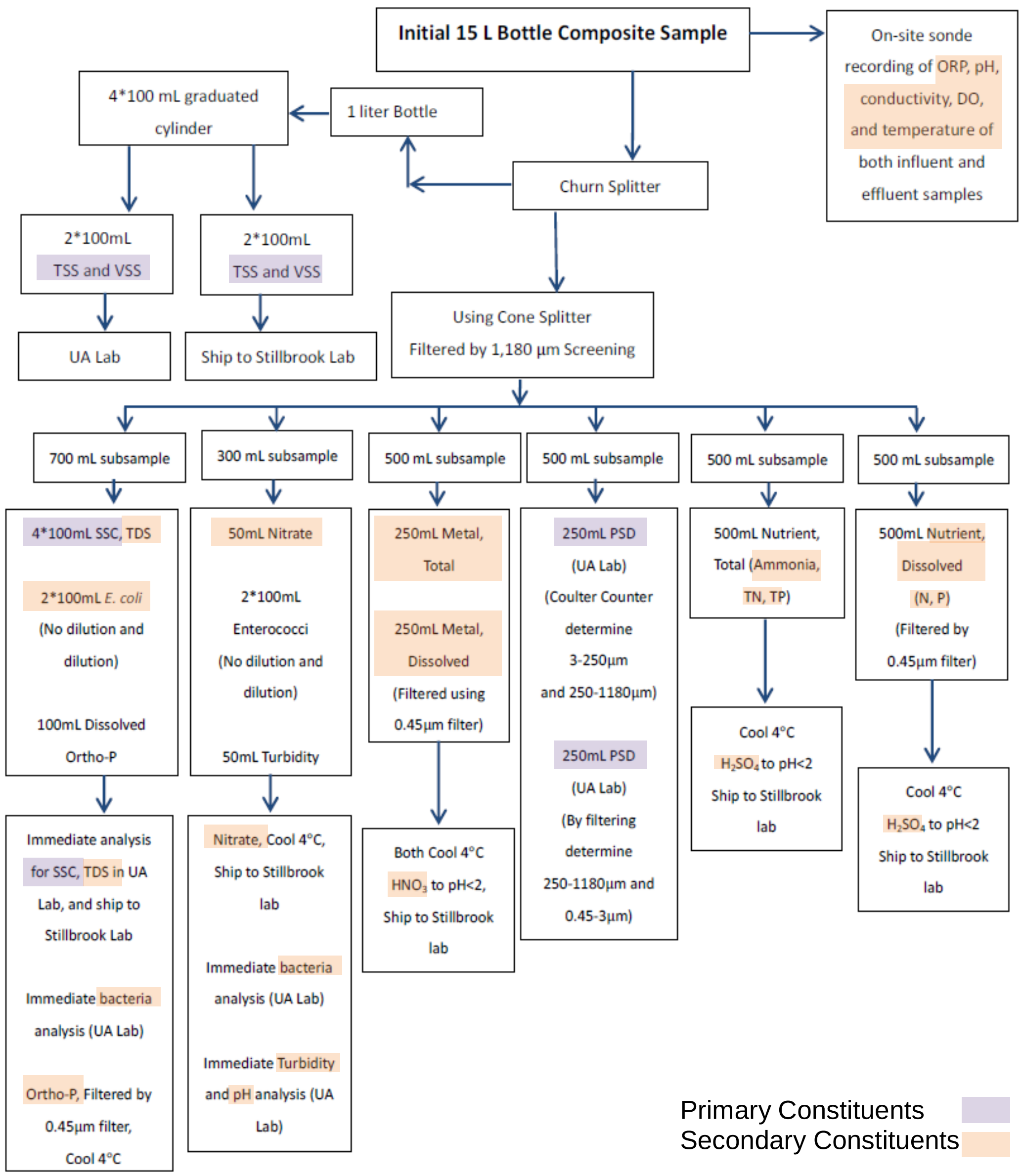

Figure 11 Analysis Process at the University of Alabama Laboratory

Samples were also analyzed for secondary constituents including Temperature, pH, Oxidation Reduction Potential (ORP), Dissolved Oxygen (DO), Turbidity, Total Phosphorus, Total Soluble Phosphorus, Soluble Reactive Phosphorus, Total/Dissolved Nitrogen, Ammonia, Nitrate, Total Dissolved Metals, E. Coli and Enterococci. The analysis results for the aforementioned secondary constituents will not be discussed as part of this verification report as they are not part of the TARP Tier II protocol and NJDEP Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol Dated August 5, 2009 Revised December 15, 2009.

Pollutant Accumulation Monitoring

Pollutant accumulation monitoring included measuring the sediment accumulation rate in the Up-Flo® Filter to demonstrate facility performance over time and to generate data for maintenance requirements. Pollutant accumulation monitoring included:

- Determination of sump sediment depth
- Sump sediment collection and analysis
- Mass, nature and type of sediment in Media Bags
- Other pollutants of concern were analyzed but are not presented in this report as they are outside of the scope of the TARP Tier II protocol and NJDEP Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol Dated August 5, 2009 Revised December 15, 2009.

At the beginning of the testing period, the Up-Flo® Filter sump was cleaned of all sediment and debris. Sediment samples were collected from the sump of the Up-Flo® Filter at the end of the monitoring program. These samples were collected from three separate areas of the sump by extending a wide mouth bottle to the bottom of the sump and compositing. Sump sediments were analyzed for particle size distribution (PSD) and other secondary constituents such as Total Metals.

Accumulation of sediment in the filtration media was determined by weighing the Media Bags before installation, and drying and weighing the Media Bags at the conclusion of the monitoring program after a full year maintenance cycle.

The solids loading rate in the filtration media was calculated by weighing the Media Bags and dividing the weights by the correlating interval of time since they were installed. The total weight of the bags (after drying) was measured to determine the loading rate of the material captured in the media bags. Results are discussed in Section 4.4 System Maintenance and Mass Loading Calculation.

3.5 Precipitation Measurements

Rainfall intensity and depth were measured using a standard tipping bucket rain gauge. The total rain depths were checked after each event by recording the totalizing rain gauge located at the side of the tipping bucket. The rain gauge triggered the automatic sampler and was not intended to be an accurate indication of the actual rainfall conditions. Since the rain gauge had to be located near moderately sized trees that posed potential interference with rain measurements, a second, smaller totalizing rain gauge was used for verification and rainfall reporting purposes. A third tipping bucket rain gauge, located on the roof of the University of Alabama Civil Engineering building 1.75 miles away, was also used to compare rainfall depth to the site rain gauges; results from the second and third totalizing rain gauges compared favorably. The rain gauges were routinely checked for debris and cleaned as necessary.

3.6 Flow Measurements

Flow rate was monitored on a continuous basis utilizing an ISCO 2150 Area Velocity Meter, which measures velocity (to calculate flow rate) and water level at the Up-Flo® Filter outlet. Due to the configuration of the installation, the influent flow could not be directly monitored. The effluent area-velocity meter was calibrated based on known influent flow rates during pumped river water tests conducted prior to the start of the field monitoring program. The effluent area velocity meter reading is therefore taken to accurately represent the influent flow conditions.

Additionally, a pressure transducer was installed in the Up-Flo® Filter chamber and continuously monitored water level during each storm event. It was also used to calculate the bypassing flow level.

3.7 Stormwater Data Collection Requirements

A number of criteria must be met for an event to be considered a "qualifying" event as per the New Jersey Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol (NJDEP, 2009) protocol requirements:

1) Inter-event time since prior rain must exceed 12 hours
2) The allowable rainfall depth must be greater than or equal to 0.1" but less than 3".
3) The maximum allowable 15-minute rainfall intensity must not exceed 5" per hour
4) The number of samples taken during the storm shall be 10 or more and a minimum of 70% of a storm's total runoff volume must be included in the sampling
5) The minimum allowable storm duration is 1 hour. Storms lasting less than 1 hour are allowed if 6 or more subsamples are taken.
6) The arithmetic average influent concentration must not exceed 100 mg/L, with no singular storm event's concentration exceeding 300 mg/L; the arithmetic average influent PSD d_{50} must not exceed 100 microns, with no singular storm event's d_{50} exceeding 200 micron.

For the total set of storms to qualify:

1) The cumulative precipitation depth must equal 15 or more inches
2) The peak treatment flow of at least 3 of the sampled storms must be greater than 75% of the MTFR

4. Technology System Performance

4.1 Hydrology Results

Hydrology

The monitoring period ran from March 2012 and March 2013. The first sampled storm was May 31, 2012. The final storm was March 30, 2013. A summary of all events is shown in **Table 4**.

Table 4 Summary of Storms Monitored for 1-Year Period

Storm Event	Storm Date	Storm Duration	Total Precipitation	Independent Witness Present for Sample Collection/Analysis[1]	Comments
		(hr)	(in)	(Y/N)	
1	31 May 2012	16.87	0.27	N	
2	10 June 2012	15.25	0.60	N	
3	11 July 2012	9.17	0.29	N	
4	12 July 2012	5.75	0.28	Y	
5	21 July 2012	13.07	1.78	Y	
6	3 August 2012	4.75	0.18	N	
7	4 August 2012	0.67	0.75	Y	
8	13 August 2012	2.22	1.01	Y	
9	1 September 2012	3.58	0.70	N	
10	3 September 2012	5.62	0.41	N	
11	30 September 2012	35.68	1.83	Y	
12	14 October 2012	3.13	1.01	Y	
13	18 October 2012	2.40	1.17	Y	
14	27 November 2012	1.90	0.32	N	
15	4 December 2012	8.85	0.59	Y	
16	8 December 2012	0.72	0.09	N	Non-qualifying due to total rainfall depth.
17	10 December 2012	8.50	2.24	N	
18	16 December 2012	10.00	1.20	N	
19	28 December 2012	12.55	0.73	N	
20	1 January 2013	16.80	1.30	N	
21	13 January 2013	53.50	2.15	N	
22	30 January 2013	15.22	1.59	N	
23	10 February 2013	64.68	2.44	N	
24	21 February 2013	35.88	2.29	N	
25	25 February 2013	9.50	0.31	N	
26	5 March 2013	1.87	0.23	N	
27	11 March 2013	11.20	2.32	Y	
28	22 March 2013	23.52	0.41	N	
29	23 March 2013	7.68	0.89	N	
30	30 March 2013	22.78	0.78	N	
	Total	**423.31**	**30.16**		

[1] The independent observer witnessed 10 sample collections and analyses. Nine of these were actual storm events as indicated in Table 4. One was from a field blank QA/QC check conducted on June 28, 2012.

Storm 16 was non-qualifying for failing to meet the qualifying requirements of a minimum 0.1 inch of rainfall depth as specified by the Protocol for Total Suspended Solids Removed Based on Field Testing Amendments to TARP Protocol (NJDEP, 2009).

Data Collection for Qualifying Storms

Table 5 summarizes the stormwater data collected for the 29 qualifying storms. The total volume summed to 30.07 inches of rainfall. Per the protocol, the minimum inter-event period was greater than 12 hours for each sampled storm; flow weighted composite samples covered 87.6% - 100% of total storm flow; the number of influent/effluent samples collected ranged from 11 to 110 for the qualifying events; and no peak 15-minute rainfall intensity exceeded 5 in/hr.

Table 5 Summary of Stormwater Data Collected for the 29 Qualifying Storm Events

Storm Event	Storm Date	Storm Duration	Total Precipitation	Inter-Event Time since prior rain	Maximum 15-Min Rainfall Intensity	Samples Coverage of Total Storm Flow	
		(hr)	(in)	(hr)	(in/hr)	No. Samples	(%)
1	31 May 2012	16.9	0.27	220.0	0.28	12	100.0
2	10 June 2012	15.3	0.60	246.4	1.64	16	90.3
3	11 July 2012	9.2	0.29	20.6	0.32	36	96.8
4	12 July 2012	5.8	0.28	18.9	0.16	42	98.2
5	21 July 2012	13.1	1.78	64.5	3.56	75	99.5
6	3 August 2012	4.8	0.18	84.3	0.48	15	92.8
7	4 August 2012	0.67	0.75	26.9	2.16	35	100.0
8	13 August 2012	2.2	1.01	154.9	2.52	42	97.9
9	1 September 2012	3.6	0.70	52.1	1.12	21	96.1
10	3 September 2012	5.6	0.41	36.3	0.64	16	93.2
11	30 September 2012	35.7	1.83	631.8	0.48	74	96.9
12	14 October 2012	3.1	1.01	357.6	2.20	78	98.3
13	18 October 2012	2.4	1.17	74.9	1.88	35	93.9
14	27 November 2012	1.9	0.32	355.0	0.28	18	96.0
15	4 December 2012	8.9	0.59	175.8	1.04	21	94.9
16	8 December 2012	Non-qualifying Event					
17	10 December 2012	8.50	2.24	40.8	2.04	98	98.0
18	16 December 2012	10.0	1.20	143.2	0.40	13	87.6
19	28 December 2012	12.6	0.73	64.0	0.24	32	91.6
20	1 January 2013	16.8	1.30	74.9	0.32	57	98.1
21	13 January 2013	53.5	2.15	27.67	1.36	92	96.2
22	30 January 2013	15.2	1.59	99.1	1.72	57	96.9
23	10 February 2013	64.7	2.44	79.1	1.04	109	96.8
24	21 February 2013	35.9	2.29	56.6	0.56	110	98.4
25	25 February 2013	9.5	0.31	64.4	0.24	11	90.4
26	5 March 2013	1.9	0.23	175.4	0.88	19	93.1
27	11 March 2013	11.2	2.32	132.0	0.96	110	98.8
28	22 March 2013	23.5	0.41	87.3	0.68	21	91.3
29	23 March 2013	7.7	0.89	12.3	1.16	41	94.2
30	30 March 2013	22.8	0.78	156.7	1.08	22	96.1
	Total	**422.59**	**30.07**				

Flow measurements for the 29 qualifying storms are summarized in **Table 6**.

Table 6 Flow Measurements for the 29 Qualifying Storm Events

Storm Event	Storm Date	Storm Volume (gal)	Runoff Rate, Q (gpm) Q_{25}	Q_{50}	Q_{75}	Peak (100%)	Peak as % of MTFR	Flow Bypassed (gal)	(%)
1	31 May 2012	3,267	14	28	42	68	45%	0	0
2	10 June 2012	8,240	30	65	150	962	641%	2054	25
3	11 July 2012	4,464	27	55	70	83	55%	0	0
4	12 July 2012	5,062	20	34	52	77	51%	0	0
5	21 July 2012	30,906	35	120	450	1009	673%	14,993	49
6	3 August 2012	2,065	11	25	60	128	85%	13	1
7	4 August 2012	11,535	55	140	200	850	567%	5,518	48
8	13 August 2012	20,903	40	175	300	1023	682%	10,571	51
9	1 September 2012	10,402	58	105	210	390	260%	2,507	24
10	3 September 2012	8,509	26	50	85	239	159%	315	4
11	30 September 2012	39,335	38	80	125	206	137%	3	0
12	14 October 2012	20,062	31	70	260	784	523%	9,686	48
13	18 October 2012	17,650	27	130	275	299	199%	7,320	41
14	27 November 2012	8,510	49	75	100	134	89%	0	0
15	4 December 2012	10,693	26	54	210	273	182%	2,824	26
16	8 December 2012	Non-qualifying Event							
17	10 December 2012	47,830	58	100	160	325	217%	4,988	10
18	16 December 2012	27,550	35	68	120	166	111%	433	2
19	28 December 2012	16,242	24	47	75	112	75%	0	0
20	1 January 2013	28,886	28	53	90	130	87%	4,511	16
21	13 January 2013	52,199	35	75	140	332	221%	13,613	26
22	30 January 2013	28,721	33	75	200	297	198%	14,429	50
23	10 February 2013	61,131	33	73	120	290	193%	14,552	24
24	21 February 2013	54,490	50	105	160	353	235%	16,145	30
25	25 February 2013	6,432	17	34	55	98	65%	1,341	21
26	5 March 2013	2,492	14	52	140	217	145%	1,485	60
27	11 March 2013	53,629	53	105	150	299	199%	33,803	63
28	22 March 2013	7,129	15	37	82	265	177%	2,627	37
29	23 March 2013	20,583	33	70	167	299	199%	9,364	45
30	30 March 2013	13,978	14	56	95	340	227%	4,602	33
	Average		**32**	**74**	**150**	**346**	**231%**		
	Total	**622,895**						**177,697**	**29%**

The total runoff volume of the 29 qualifying storms was 622,895 gallons. The Up-Flo® filtered 445,198 gallons (71.5% of the total flow), and 28.5% was bypassed. A pressure transducer installed in the Up-Flo® Filter chamber was used to determine when the water level in the chamber exceeded the bypass level. The bypass volume was calculated by subtracting the filter flow volume from the volume of total flow discharged during bypass. Effluent subsamples taken when no bypass flows were present were combined with effluent subsamples taken during bypass into a single composited effluent sample for each storm event.

The Up-Flo® Filter was stressed beyond 100% of its MTFR of 150 gpm during 21 of the 29 qualifying storms, with 25 of the events stressing it beyond 75% of its MTFR. Peak runoff rates ranged from 68 gpm to 1,023 gpm with an average peak of 346 gpm, or 231% of the MTFR of 150 gpm.

Table 6 shows that the Up-Flo® Filter filtered >70% of the flow from these 29 qualifying storm events. In Section 3.2 Site and System Description, it was shown that the 6-module Up-Flo® Filter was expected to filter 90% of the annual runoff at the test site. More flow appears to have been bypassed for two reasons. First, the Up-Flo® Filter showed a ≥10% drop in its MTFR during Storm 20. Due to the lag between a monitoring event and the availability of a full storm report, this drop in flow rate was not noticed throughout January and February until subsequent storms had already been sampled. After January 1, the Up-Flo® Filter flow rate appears to have dropped significantly, bypassing 111,961 gal (37%) of the total flow from Storms 21 – 30 (300,784 gal). When considering Storms 1 – 20, before the Up-Flo® Filter experienced a drop in filtration rate, it filtered 80% (256,375 gal) of the total qualifying storm flow (322,111 gal).

Secondly, not every storm from March 1, 2012 to March 31, 2013 was monitored, as the automated samplers were not pre-programmed when very small storms were predicted because they were unlikely to meet the protocol's required minimum value for rainfall depth. The runoff from these smaller storm events were still treated by the Up-Flo® Filter even though monitoring and sampling did not occur.

When considering the total rain events between March 1, 2012 and January 1, 2013 (when occlusion caused the Up-Flo® Filter treatment flow rate to drop below 10% of its MTFR), the rain gauge record from the roof of the civil engineering building on the UA campus recorded 30.16 inches of precipitation. The total runoff for the 30.16 inches of precipitation depth can be estimated using a linear relationship between rainfall depth and runoff:

$$Q_{30.16\text{-in}} = (322{,}111 \text{ gal} * 30.16") / 16.66 \text{ in}$$
$$Q_{30.16\text{-in}} = 583{,}125 \text{ gal}$$

Assuming that no runoff from these smaller, unmonitored storms generated flows greater than 100% of the Up-Flo Filter MTFR, it is estimated that the total bypassed flow for the Up-Flo® Filter before it reached >10% occlusion was approximately 11%:

Estimated % Flow Bypassed Before 10% Occlusion = 65,736 gal/ 583,125 gal **= 11.3%**

This is in line with the predictions made by the WinSLAMM sizing model previously presented in Section 3.2 Up-Flo® Filter Sizing.

Further, it should be noted that these unmonitored storms will also have captured sediment, adding additional sediment accumulation to the sump to that from the monitored storms (See Section 4.4).

4.2 Data Quality

Laboratory analysis for Total Suspended Solids (TSS) and Suspended Sediment Concentrations (SSC) were conducted at both the University of Alabama laboratory and Stillbrook Environmental Testing Laboratory. The results from the two laboratories were significantly different. As discussed in **Appendix B** Data Quality Assessment, the University of Alabama's laboratory's analyses were used for the Up-Flo® Filter's performance assessment.

4.3 Test Results

SSC and Particle Size Distribution

During the site pre-characterization process, 20 storm events were monitored for pollutant concentrations and PSD from July 2010 to April 2011. The results of the pre-characterization, which were presented in the QAPP, showed influent TSS concentrations in the 23 to 115 mg/L range with an average concentration of 63 mg/L and an SSC d_{50} = 63 micron. The TARP field protocol requires that that the arithmetic average influent concentration not exceed 100 mg/L, with no singular storm event's influent concentration exceeding 300 mg/L, and that the arithmetic average influent d_{50} not exceed 100 microns, with no singular storm event's d_{50} exceeding 200 micron. The site pre-characterization data supported the conclusion that this would be a suitable site for field testing. However, during the 2012-2013 monitoring period the average SSC concentrations was determined to be higher and the d_{50} was shown to be coarser than what was observed during the pre-characterization. This required a more in-depth analysis of the data as discussed below.

As shown in **Table 5**, 14 of the 29 storms between May 31, 2012 and March 31, 2013 had peak 15-minute rainfall intensities greater than 1 inch/hr. The runoff from these intense rains generated enough energy to mobilize a considerable concentration of particles with a wide particle size range. Furthermore, it was observed that destabilization of landscaping on the site provided additional explanation of the high concentrations and coarse particle sizes. Large fire ant mounds materialized in the immediate vicinity of the Up-Flo® Filter inlet grate between Storms 21 and 22. The long, intense winter rains from late January through March caused destabilization and erosion of the ant mounds (**Figure 12**), which caused an extended period of excessively high loading or coarse solids that was observed from Storms 22 to Storm 30. These storm event SSC concentrations and PSDs are shown in **Table 7**.

Figure 12 Eroded Ant Hills Adjacent to the Filter Inlet

The average influent SSC concentration for the first 19 qualifying storms was 228 mg/L, which is typical of stormwater runoff from high-use sites. **Table 7** shows that when considering all 29 qualifying events, the average influent SSC concentration increases to 804 mg/L and the flow-weighted average influent concentration increases to 1381 mg/L. A similar pattern was seen with the TSS concentrations presented later in **Table 8**. It was determined that only the fraction of particulate matter <273µm in diameter would be used as the basis of performance verification in order to comply with the concentration and particle size requirements set forth by the protocol, New Jersey Protocol for Total Suspended Solids Removal Based on Field Testing Amendments to TARP Protocol (NJDEP, 2009). These results will be presented and discussed in Section 4.3 Test Results, **Table 10.**

The measured SSC is typically different and coarser than the measured TSS (Gray et al., 2000). In **Appendix B** Data Quality Assessment: *TSS Blind Samples,* results of the blind TSS QA/QC checks showed that the University of Alabama laboratory was reporting TSS that correlated closely to the SSC albeit at lower concentrations as would be expected as TSS measures sub-samples that are likely to be devoid of the coarser solids fractions.

Table 7 SSC Event Particle Size Distributions for 29 Qualifying Events

Storm Event	Storm Date	SSC Influent				SSC Effluent				SSC Removal
		Conc. (mg/L)	d_{10} (µm)	d_{50} (µm)	d_{90} (µm)	Conc. (mg/L)	d_{10} (µm)	d_{50} (µm)	d_{90} (µm)	(%)
1	May 31, 2012	101	9	65	1080	22	5	27	900	78%
2	June 10, 2012	80	8	268	>1180	12	6	59	>1180	85%
3	July 11, 2012	120	10	47	830	12	14	61	830	90%
4	July 12, 2012	34	15	56	1000	4	5	25	300	88%
5	July 21, 2012	2297	260	1029	>1180	40	13	43	700	98%
6	August 3, 2012	116	15	52	>1180	54	13	28	1000	53%
7	August 4, 2012	133	14	210	>1180	57	15	350	1000	57%
8	August 13, 2012	93	8	467	1180	16	12	25	1180	83%
9	September 1, 2012	304	13	661	>1180	22	4	61	>1180	93%
10	September 3, 2012	290	60	878	>1180	13	13	406	>1180	96%
11	September 30, 2012	23	13	49	1000	6	5	24	800	74%
12	October 14, 2012	83	15	585	>1180	16	6	50	380	81%
13	October 18, 2012	85	16	411	>1180	38	14	60	>1180	55%
14	November 27, 2012	86	6	672	>1180	11	13	25	850	87%
15	December 4, 2012	239	33	696	>1180	27	12	27	850	89%
16	December 8, 2012	Non-qualifying Event								
17	December 10, 2012	34	11	67	1000	16	13	28	700	53%
18	December 16, 2012	99	145	891	>1180	7	13	528	1180	93%
19	December 28, 2012	88	15	528	>1180	6	4	22	400	93%
20	January 1, 2013	29	14	412	1080	3	13	23	420	90%
21	January 13, 2013	401	24	892	>1180	27	6	30	750	93%
22	30 January 2013	2655	277	920	>1180	47	13	23	550	98%
23	10 February 2013	1864	275	869	>1180	29	10	24	600	98%
24	21 February 2013	6231	284	881	>1180	35	12	71	>1180	99%
25	25 February 2013	524	36	872	>1180	8	13	66	>1180	98%
26	5 March 2013	495	24	901	>1180	68	7	52	>1180	86%
27	11 March 2013	2386	306	1175	>1180	30	6	44	>1180	99%
28	22 March 2013	302	15	711	>1180	42	4	32	>1180	86%
29	23 March 2013	3243	327	>1180	>1180	41	6	48	>1180	99%
30	30 March 2013	879	30	1003	>1180	51	12	50	>1180	94%
All 29 Qualifying Storms										
29 Storm EMC		804				26	29 Storms - EMC Removal			97%
29 Storm Flow Wtd EMC		1381				25	Flow Wtd. Mass Removal			98%

Total Suspended Solids - % Removal

A summary of removal efficiency results for measured TSS is shown in **Table 8**. Although the average peak runoff rate was 346 gpm (231% of the MTFR) for the 29 qualifying storms, the average EMC TSS removal rate was 86% with an annualized flow-weighted removal rate of 89%, at an average influent concentration of 166 mg/L and an average effluent concentration of

23 mg/L. When considering only the six non-bypassing events the average effluent concentration was 10 mg/L.

Table 8 TSS Event Mean Concentrations (EMCs) and Removal Rates.

Storm Event	Date	Storm Vol (gal)	EMC Influent TSS (mg/L)	EMC Effluent TSS (mg/L)	Percent % Removal	Pounds TSS IN	Pounds TSS OUT
1	May 31, 2012	3,267	124	27	78%	3.4	0.7
2	June 10, 2012	8,240	69	9	87%	4.7	0.6
3	July 11, 2012	4,464	119	12	90%	4.4	0.4
4	July 12, 2012	5,062	31	3	90%	1.3	0.1
5	July 21, 2012	30,906	571	41	93%	147.3	10.6
6	August 3, 2012	2,065	116	54	53%	2.0	0.9
7	August 4, 2012	11,535	126	55	56%	12.1	5.3
8	August 13, 2012	20,903	93	14	85%	16.2	2.4
9	September 1, 2012	10,402	162	10	94%	14.1	0.9
10	September 3, 2012	8,509	156	11	93%	11.1	0.8
11	September 30, 2012	39,335	21	4	81%	6.9	1.3
12	October 14, 2012	20,062	47	19	60%	7.9	3.2
13	October 18, 2012	17,650	62	34	45%	9.1	5.0
14	November 27, 2012	8,510	59	10	83%	4.2	0.7
15	December 4, 2012	10,693	124	27	78%	11.1	2.4
16	December 8, 2012	Non-qualifying Event					
17	December 10, 2012	47,830	22	13	41%	8.8	5.2
18	December 16, 2012	27,550	50	4	92%	11.5	0.9
19	December 28, 2012	16,242	34	5	85%	4.6	0.7
20	January 1, 2013	28,886	11	3	73%	2.7	0.7
21	January 13, 2013	52199	79	23	71%	34.4	10.0
22	30 January 2013	28721	313	40	87%	75.0	9.6
23	10 February 2013	61131	354	25	93%	180.6	12.8
24	21 February 2013	54490	478	29	94%	217.4	13.2
25	25 February 2013	6432	210	4	98%	11.3	0.2
26	5 March 2013	2492	197	56	72%	4.1	1.2
27	11 March 2013	53629	245	28	89%	109.7	12.5
28	22 March 2013	7129	197	43	78%	11.7	2.6
29	23 March 2013	20583	369	26	93%	63.4	4.5
30	30 March 2013	13978	389	46	88%	45.4	5.4
Summary of 29 Qualifying Events							
	Average EMC TSS (mg/L)		166	23	86%		
	Total Storm Volume (gal)	622,895		TSS Mass (lb)		1036.1	114.8
	Flow Weighted TSS Removal Efficiency						89%

"Particulate Matter <273µm" – Particle Size Distribution and % Removal

In this study, influent and effluent SSC samples were sieved prior to analysis in order to determine the suspended sediment concentrations within specific particle size ranges. TSS samples were not analyzed for particle size distribution. It would be expected that the particle size distribution of TSS would be similar to the particle size distribution of SSC for storms where suspended sediment concentrations are low and the d_{50} of suspended sediment was less than 50 micron (Gray et al., 2000). With an arithmetic average suspended sediment influent concentration >800 mg/L and an influent d_{50} >400 micron, it cannot be assumed that the particle size distribution of the SSC also represented the particle size distribution of the TSS.

Since the protocol requires that that the arithmetic average influent concentration not exceed 100 mg/L, with no singular storm event's influent concentration exceeding 300 mg/L, and that the arithmetic average influent d_{50} not exceed 100 microns, with no singular storm event's d_{50} exceeding 200 micron, additional review of the data was conducted to ensure that the removal efficiency reported was for stormwater that met the protocol requirements.

The removal efficiency of each storm event was determined using just the fraction of particulate matter less than 273µm. A cut-point of 273 micron was found to be the largest particle size which resulted in each storm complying with the protocol's influent d_{50} requirements (**Figure 13**, below**)** and concentration requirements (presented later in **Table 10**).

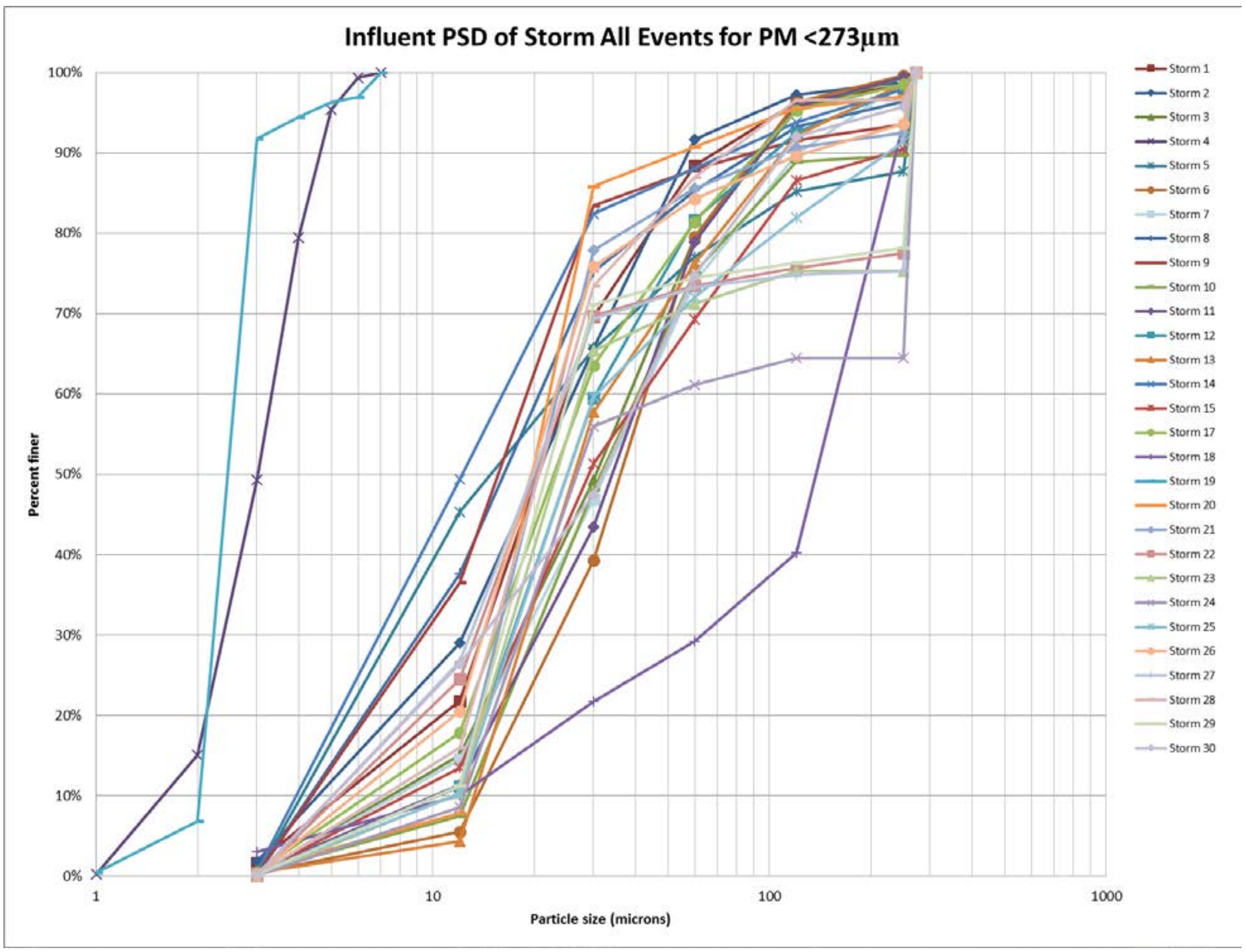

Figure 13 Particle Size Distributions for Each Storm Event Considering Only PM <273µm

The resulting influent d_{50}'s ranged from 12 to 144 microns with an average d_{50} of 29 microns, and effluent d_{50}'s ranged from 12 to 34 microns with an average of 23 microns (**Table 9**).

Table 9 D50's for Influent and Effluent Considering Only PM <273µm

Event	Influent d50	Effluent d50
	Microns	Microns
May 31, 2012	23	20
June 10, 2012	22	25
July 11, 2012	31	31
July 12, 2012	29	21
July 21, 2012	16	29
August 3, 2012	38	23
August 4, 2012	33	28
August 13, 2012	18	21
September 1, 2012	17	12
September 3, 2012	32	27
September 30, 2012	36	17
October 14, 2012	26	34
October 18, 2012	27	27
November 27, 2012	12	22
December 4, 2012	29	23
December 10, 2012	25	24
December 16, 2012	144	19
December 28, 2012	21	17
January 1, 2013	22	21
January 13, 2013	22	24
January 30, 2013	22	21
February 10, 2013	25	21
February 21, 2013	28	29
February 25, 2013	26	20
March 5, 2013	22	22
March 11, 2013	22	22
March 22, 2013	23	17
March 23, 2013	24	25
March 30, 2013	33	29
Average	**29**	**23**

The average influent and effluent particle size distributions of all PM <273µm are shown in **Figure 14**. The average effluent PSD is shown to be significantly finer than the average influent

PSD, with 84% of the material being less than 120 micron in the influent, and 85% of the material being less than 60 micron in the effluent. The average influent d_{50} was 29 microns and the average effluent d_{50} was 23 microns. Because the particle size distribution when considering only PM<273µm is shown to be very fine, it is considered a suitable proxy for evaluating the removal of TSS in line with the particle size and concentration guidelines of the NJDEP protocol.

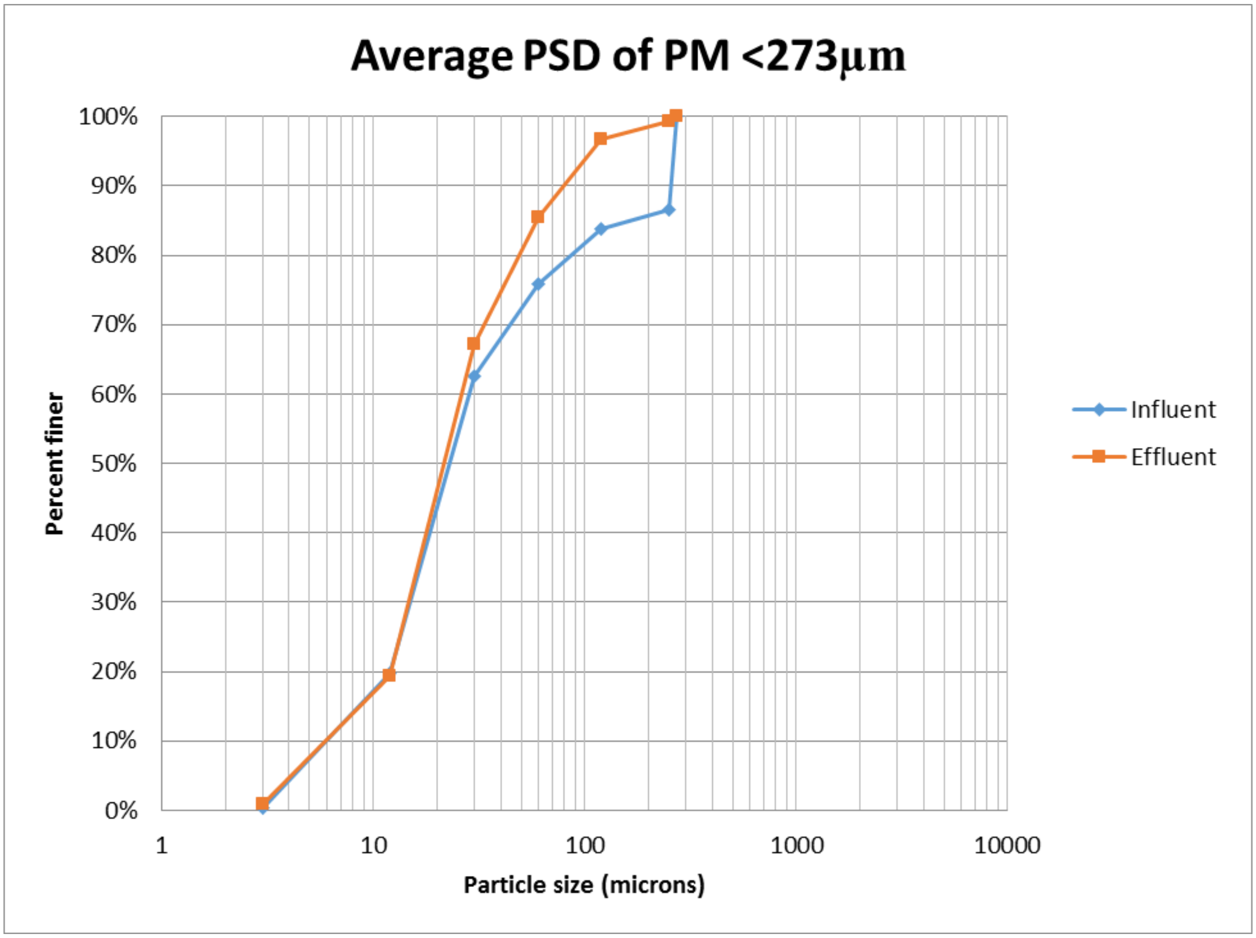

Figure 14 Average Particle Size Distribution of all PM (<273µm) for 29 Qualifying Storms

A summary of removal efficiency results for PM <273µm is shown in **Table 10**. The average influent concentration was 81 mg/L and the average effluent concentration was 18 mg/L, giving an average EMC removal rate of 78%. For the six storms with no bypass (Storms 1, 3, 4, 11, 14 and 19) the average influent concentration was 41 mg/L and the average effluent concentration was 7 mg/L, giving an average EMC removal rate of 83%. The annualized flow-weighted removal rate was 81%, with 417.4 lb of material being captured from 512.4 lb of material in the influent.

Table 10 Event Mean Concentrations (EMCs) and Removal Rates for PM <273µm

Storm Event	Date	Storm Vol (gal)	EMC Influent PM <273µm (mg/L)	EMC Effluent PM <273µm (mg/L)	Percent Removal (%)	Pounds PM <273µm IN	Pounds PM >273µm OUT
1	May 31, 2012	3,267	56	15	73%	1.53	0.41
2	June 10, 2012	8,240	40	7	83%	2.75	0.48
3	July 11, 2012	4,464	90	7	92%	3.35	0.26
4	July 12, 2012	5,062	19	3	84%	0.80	0.13
5	July 21, 2012	30,906	228	32	86%	58.81	8.25
6	August 3, 2012	2,065	84	40	52%	1.45	0.69
7	August 4, 2012	11,535	68	21	69%	6.55	2.02
8	August 13, 2012	20,903	36	13	64%	6.28	2.27
9	September 1, 2012	10,402	73	14	81%	6.34	1.22
10	September 3, 2012	8,509	39	6	85%	2.77	0.43
11	September 30, 2012	39,335	17	4	76%	5.58	1.31
12	October 14, 2012	20,062	34	10	71%	5.69	1.67
13	October 18, 2012	17,650	39	24	38%	5.74	3.54
14	November 27, 2012	8,510	32	8	75%	2.27	0.57
15	December 4, 2012	10,693	43	21	51%	3.84	1.87
16	December 8, 2012	Non-qualifying Event					
17	December 10, 2012	47,830	20	12	40%	7.98	4.79
18	December 16, 2012	27,550	18	2	89%	4.14	0.46
19	December 28, 2012	16,242	33	5	85%	4.47	0.68
20	January 1, 2013	28,886	12	2	83%	2.89	0.48
21	January 13, 2013	52199	67	22	67%	29.19	9.58
22	30 January 2013	28721	181	40	78%	43.38	9.59
23	10 February 2013	61131	126	25	80%	64.28	12.75
24	21 February 2013	54490	299	23	92%	135.97	10.46
25	25 February 2013	6432	81	4	95%	4.35	0.21
26	5 March 2013	2492	79	42	47%	1.64	0.87
27	11 March 2013	53629	111	20	82%	49.68	8.95
28	22 March 2013	7129	91	32	65%	5.41	1.90
29	23 March 2013	20583	137	28	80%	23.53	4.81
30	30 March 2013	13978	186	37	80%	21.70	4.32
Summary of 29 Qualifying Events							
	Average EMC SSC (<273µm) (mg/L)		81	18	78%		
	Total Storm Volume (gal)	622,895		PM (<273µm) Mass (lb)		512.4	95.0
	Annual (Flow Weighted) PM (<273µm) Removal Efficiency						81%

Influent concentrations spanned a wide range, from 12 mg/L to 299 mg/L; the range of effluent concentrations was narrower, from 2 mg/L to 42 mg/L (**Figure 15**).

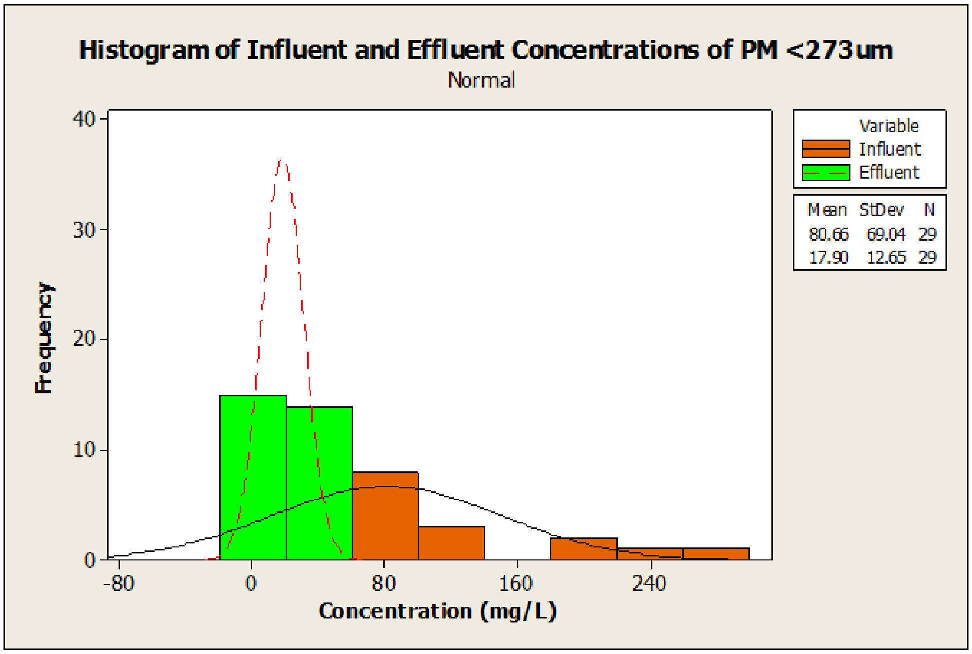

Figure 15 Influent and Effluent SSC Concentrations of SSC <273 Microns

The observed average EMC removal rate removal was 78%, which was skewed lower by a few storms with low percent removals. The median event removal rate was higher, at 80%. The removal efficiencies for all events were normally distributed to a 95% confidence interval, with only Storm 17's 40% removal rate shown to be an outlier (**Figure 16**).

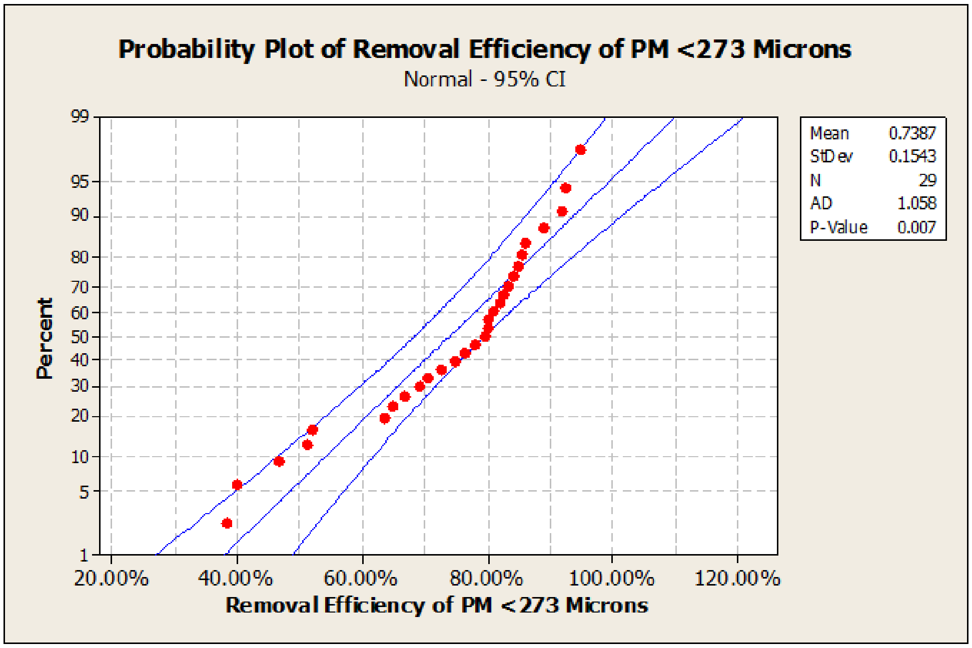

Figure 16 Probability Plot of the Event Removal Efficiencies for the 29 Qualifying Storms (showing a Median Removal Efficiency of 80%)

Headloss

The median and peak driving heads over the Up-Flo® Filter outlet pipe invert are tabulated in **Table 11**. As would be expected, there is a notable difference in average median driving head measurements before and after Storm 19 when the Up-Flo® Filter media reached >10% occlusion. The overall average median head was 12.6 inches. Up through Storm 19, the average median head was significantly lower at 6.3 inches. The average median head of Storms 20 – 30 was significantly higher at 22.8 inches.

Table 11 Event Based Driving Heads over Outlet Invert Level

Storm Event	Date	Median head over Outlet invert (in)	Median head over Outlet invert (mm)	Peak head over Outlet invert (in)	Peak head over Outlet invert (mm)
1	May 31, 2012	10.38	26.4	29.46	74.8
2	June 10, 2012	9.82	24.9	52.45	133.2
3	July 11, 2012	6.86	17.4	29.4	74.7
4	July 12, 2012	4.15	10.5	22.63	57.5
5	July 21, 2012	3.67	9.3	58.62	148.9
6	August 3, 2012	6.69	17.0	30.69	78.0
7	August 4, 2012	7.29	18.5	55.29	140.4
8	August 13, 2012	4.06	10.3	56.44	56.4
9	September 1, 2012	4.49	11.4	56.11	56.1
10	September 3, 2012	4.19	10.6	38.07	38.1
11	September 30, 2012	6.89	17.5	30.11	30.1
12	October 14, 2012	5.21	13.2	57.83	57.8
13	October 18, 2012	5.51	14.0	58.44	58.4
14	November 27, 2012	3.55	9.0	29.77	29.8
15	December 4, 2012	5.25	13.3	54.92	54.9
16	December 8, 2012	Non-Qualifying Event			
17	December 10, 2012	12.47	31.7	57.41	57.4
18	December 16, 2012	4.13	10.5	32.83	32.8
19	December 28, 2012	9.16	23.3	29.58	29.6
20	January 1, 2013	16.5	41.9	42.51	42.5
21	January 13, 2013	19.49	49.5	102.97	103.0
22	30 January 2013	16.52	42.0	98.77	98.8
23	10 February 2013	32.87	83.5	162.45	162.5
24	21 February 2013	27.66	70.3	129.29	129.3
25	25 February 2013	21.11	53.6	75.77	75.8
26	5 March 2013	20.75	52.7	125.51	125.5
27	11 March 2013	46.59	118.3	119.41	119.4
28	22 March 2013	13.9	35.3	110.57	110.6
29	23 March 2013	17.72	45.0	118.13	118.1
30	30 March 2013	18.22	46.3	110.29	110.3
	Mean	12.6	32.0	68.1	173.0
	Median	9.2	23.3	56.4	143.4

4.4 System Maintenance and Mass Loading Assessment

Maintenance

The Up-Flo® Filter was visually inspected from the surface after each storm event when storm samples were collected. The twentieth storm event, which took place January 1, 2013, was the first storm event that the filter showed a 10+% drop in maximum treatment flow rate due to possible media occlusion (**See Appendix C Storm C-20**) after a cumulative influent load of 792.9 lbs (presented later in Table 13). The mass loading calculations in the NJDEP Filtration Protocol are based on the premise that 1 acre of impervious surface annually generates 200 lbs of particulate matter. Applying that same premise to the Bama Belle site, which had 0.6 acres of impervious surface, a typical annual sediment load from an equivalent site in New Jersey would generate 120 lbs of particulate matter. As the Up-Flo® Filter showed a 10% drop in MTFR after a cumulative load of 792.9 lbs, it is calculated that this 6-module system would operate for 6.6 years prior to occlusion at an equivalent site (0.6 impervious acres) in New Jersey.

The storm reports took approximately 4 weeks to prepare so the drop in flow rate during Storm 20 was not noted until February. Monitoring was continued with the expectation that the media would recharge due to the backwashing design of the Up-Flo® drain down process. However, a significant amount of site erosion that took place during February and March storms contributed an abnormally high solids loading. After the February 25 event many storms fell in quick succession so storms continued to be monitored concurrently with preparation of the Storm 25 storm report. Upon completion of the storm report, it was shown that the Up-Flo® Filter flow rate dropped from 135 gallons per minute during Storm 24 to 65 gallons per minute during Storm 25. At this point, it appeared unlikely that the filter would reclaim any of its high filtration rate due to the media being spent and requiring a change out.

The Protocol for Total Suspended Solids Removed Based on Field Testing Amendments to TARP Protocol requires maintenance to be carried out when the treatment flow rate drops below 90% of its MTFR. Accordingly, final maintenance was scheduled and then carried out on April 14, 2013. Due to logistical constraints, a full clean-out of the Up-Flo® sump was not possible. The final depth of sediment in the sump was measured to be 10 inches. The filter media bags were removed from the Filter Modules. The contents were allowed to air dry for 6 weeks and then weighed and analyzed for PSD.

The final maintenance results are summarized in **Table 12**. No further storm monitoring was conducted following the thirtieth (30^{th}) storm event on March 30, 2013.

Table 12 Final Maintenance Summary

Parameter	Measurement
Measured Sediment Depth	10 inches
Measured Difference in Media Bag Weight	25 lbs
Weighted Average Specific Gravity of Sump Material	2.31 g/cc
Percent Volatile Solids	34.36%

Mass Loading

The Up-Flo® Filter experienced significant hydraulic and pollutant loadings over the course of the monitoring period. The Up-Flo® Filter showed a 10% drop in flow rate sometime during Storm 20. Nevertheless, the Up-Flo® Filter performance continued to be robust, maintaining good levels of effluent TSS control for storms 21 – 30 when there was an increased incidence of bypass due to media occlusion and a significant uptick in influent concentrations due to the destabilization and erosion of site landscaping. Between Storms 1 – 19, 294,975 gallons of monitored runoff passed through the Up-Flo® Filter. The total particulate matter load for the first 19 monitored storms was 792.9 lbs, of which 746.2 were captured (**Table 13**).

Table 13 Summary of Mass Loading to Up-Flo® Filter Prior to >10% Reduction in MTFR

Storm Event	Storm Date	Storm Volume	Particulate Loading			
		(gal)	Influent SSC (mg/L)	Total Mass In (mg)	Total Mass Out (mg)	Total Mass Captured (mg)
1	31 May 2012	3,267	101	1249061	272073	976988
2	10 June 2012	8,240	80	2495344	374302	2121042
3	11 July 2012	4,464	120	2027770	202777	1824993
4	12 July 2012	5,062	34	651500	76647	574853
5	21 July 2012	30,906	2,297	268730494	4679678	264050816
6	3 August 2012	2,065	116	906757	422111	484646
7	4 August 2012	11,535	133	5807408	2488889	3318519
8	13 August 2012	20,903	93	7358761	1266023	6092738
9	1 September 2012	10,402	304	11970260	866269	11103991
10	3 September 2012	8,509	290	9340921	418731	8922190
11	30 September 2012	39,335	23	3424681	893395	2531286
12	14 October 2012	20,062	83	6303264	1215087	5088177
13	18 October 2012	17,650	85	5679065	2538876	3140189
14	27 November 2012	8,510	86	2770391	354352	2416039
15	4 December 2012	10,693	239	9674101	1092890	8581211
16	8 December 2012	1,750	26	172236	46371	125865
17	10 December 2012	47,830	34	6155913	2896900	3259013
18	16 December 2012	27,550	99	10324522	730017	9594505
19	28 December 2012	16,242	88	5410474	368896	5041578
	Total	**294,975**		**360,452,923**	**21,204,284**	**339,248,639**
			Total (Kg)	**360.4**	**21.2**	**339.2**
			Total (lb)	**792.9**	**46.7**	**746.2**

The NJDEP Filtration Protocol provides the following formula for calculating the maximum allowable inflow drainage for a filter as:

Maximum Inflow Drainage Area (ac) = Weight of TSS Before 10% Loss in MTFR (lbs) / 200 lbs per Acre of Impervious Drainage Area Annually

Using 792.9 lbs of material for the 6-module Up-Flo® Filter Module (132 lbs per Filter Module), the Maximum Inflow Drainage Area per Filter Module is 0.66 acres as per the calculation below:

Max. Inflow Area (ac) = 792.9 lbs / (200 lbs per ac x 6 Up-Flo® Filter Modules used) **= 0.66 acres per Up-Flo® Filter Module**

The manual measurement of sediment in the sump support the mass of 792.9 lbs calculated above. After Storm 19, a depth of 6” of sediment was manually measured in the sump. With an average measured specific gravity of 2.31 g/cc for the sump material, 6” of material would correspond to approximately 900 lbs of sediment. Since not all storms were monitored during this period (May 31- December 28), it would be expected that the sediment captured (in sump and filters) would be greater than the 746.2 lbs shown in **Table 13** and consequently the sediment run-off mass likewise higher than 792.9 lbs. Hence it is concluded that attributing 792.9 lbs of run-off sediment for maximum inflow area determination is conservative.

5. Performance Verification

Between March of 2012 and March 2013, a 6-module Up-Flo® Filter with CPZ filter media, sized for an MTFR of 150 gpm, or 25 gpm per filter module (22.7 gpm/ft^2 given a Filter Module surface area of 1.1 ft^2), was monitored during 30 storm events. Twenty-nine (29) of these storms were determined to meet the storm data collection requirements as per New Jersey Tier II Stormwater Test Requirements – Amendments to TARP Tier II Protocol (NJDEP, 2009).

The filter, installed in 2007 for research purpose, had been sized based on WinSLAMM simulations where the goal was to treat 90% of the annual runoff amount with 10% bypass. Compared to the NJDEP guidelines for stormwater BMP sizing, which calculates a recommended size of 38 modules for this site, the 6-module Up-Flo® Filter was undersized. As a result, twenty-five (25) of the 29 qualifying storm events had a maximum runoff rate that equaled or exceeded 75% of the MTFR. The total runoff for the 29 qualifying events was 622,895 gallons, with approximately 29% of the flow bypassing without filtration. However, it is noted that the performance monitoring at the effluent was based on blended samples comprised of flow-proportionate fractions of filtered flow and bypassed flow. Therefore, the greater bypass amounts likely reduced the pollutant removal performance reported. If an Up-Flo® Filter sized in accordance with NJDEP guidelines for stormwater BMPS had been installed at the site, the bypass would have been less and one would expect that the overall removal performance would have been greater.

The Up-Flo® Filter demonstrated an annual flow-weighted TSS removal efficiency of 89% and an annual flow-weighted SSC removal efficiency of 98% during the field test. However, TSS and SSC concentrations and particle size distributions were outside the ranges specified by the New Jersey Tier II Stormwater Test Requirements. Therefore the performance when considering only particulate matter with a d_{100} of <273µm was assessed to verify compliance with the protocol. When considering only particulate matter with a d_{100} of <273µm and an average d_{50} of 29µm, the annual flow-weighted removal of the Up-Flo® Filter was 81% and the average EMC removal was 78%.

Hydro International's Up-Flo® Filter stormwater treatment units with CPZ filter media and sized for an MTFR of 0.056 cfs (25 gpm) per filter module has demonstrated an 80% TSS Removal Rate. This equates to an MTFR of 0.336 cfs (150 gpm) for a 6-module filter unit.

Before 10% filter occlusion, the mass load to the Up-Flo® Filter system was at least 793 lbs of sediment, which corresponds to 6.6 years' worth of sediment at an equivalent site in New Jersey (0.6 impervious acres) and a **New Jersey maximum inflow drainage area of 0.66 acres per Up-Flo® Filter module.**

6. Net Environmental Benefit

The Up-Flo® Filter system requires no input of raw material, has no moving parts and therefore uses no water or energy other than that provided by stormwater runoff. For the 30 storm events monitored during the 12-month monitoring period the mass of materials captured and retained by the Up-Flo® Filter system would otherwise have been released to the environment.

7. References

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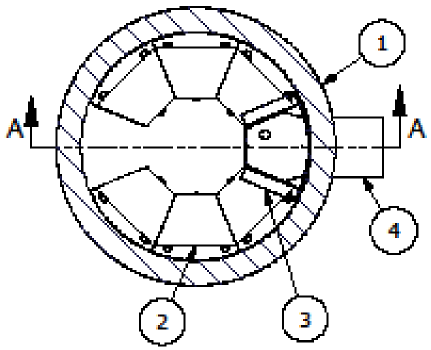
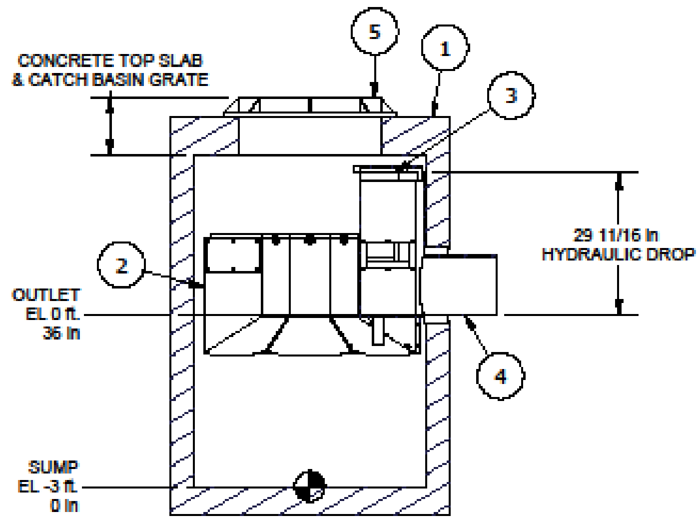
APPENDIX A

4-FT DIAMETER UP-FLO® FILTER SPECIFICATIONS





SECTION A-A

Parts List

ITEM	QTY	SIZE	DESCRIPTION
1	1	48 in	CONCRETE MANHOLE
2	6		FILTER MODULE
3	1		SIPHONIC BYPASS AND FLOATABLES BAFFLE
4	1	12 in	OUTLET MODULE AND PIPE STUB
5	2	30 in	FRAME AND COVER

EQUIPMENT PERFORMANCE
The stormwater filtration system shall adhere to the parameters listed below:
Minimum Performance Criteria: 80% removal of Sil-Co-Sil 106 at the peak treatment flow.
Bypass Capacity: 2244 gpm (141.58 l/s)
Minimum Sump Storage Capacity: 29.3 cu. ft. (0.83 cu. m.)
Minimum Floatables Storage Capacity: 39.3 cu. ft. (1.11 cu. m.)
Minimum Oil Storage Capacity: 50 gal. (189 liters)

OUTLET PIPE STUB SIZE INFORMATION
Outside Diameter: 12 1/2" OD
Concrete Penetration: Pipe Boot (by Hydro)
Hook-up: Fernco-type coupling (by others)

Notes

REVISION HISTORY

REV	BY	DATE	DESCRIPTION
	JF	8/22/06	FIRST ISSUE
A	JF	9/12/06	DRIVING HEAD
B	JF	9/14/06	DRIVING HEAD
C	RC	10/23/13	Low Flo Bypass

Date	Scale
8/22/2006	3/8"=1'-0"

Drawn	Checked	Approved
JBF		

Title

4-FT DIAMETER
UP-FLO FILTER

University of Alabama Test Site
Tuscaloosa, AL

Hydro International ™

94 Hutchins Drive
Portland, Maine 04102
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Email: hiltech@hil-tech.com

CAD Ref: GA1
Project No. 2006-551
Drawing No. GA1 Rev. B

APPENDIX B

DATA QUALITY ASSESSMENT

Data Quality Assessment

Field Blanks

Field blanks were collected to evaluate whether contamination was introduced during field sampling activities. Two rounds of field blanks were conducted. Field blanks were collected by passing deionized water through the automatic sampler. The first field blank was collected at the beginning of the study to allow results at the earliest possible time in the monitoring schedule to make adjustments if necessary. The second field blank was taken in the fall of 2012. The blank samples were delivered to the laboratories as "blinds" and processed and analyzed in the same manner as event samples. The field blanks collected did not find any indication of sampling or analytical contamination.

Duplicates

Field duplicates were used to assess variability attributable to collection, handling, shipping, storage and/or laboratory handling and analysis. Three rounds of field duplicates were conducted at the beginning, middle and end of the monitoring period. Duplicates for composite sampling were obtained by splitting a composite sample of adequate volume into two separate samples. The duplicate samples were processed, delivered to the laboratory and analyzed in the same manner as the regular samples. Results from the duplicates did not indicate a high level of variability within the UA and Stillbrook laboratories.

Blind Samples

Significant differences in SSC and TSS measurements between the UA and Stillbrook laboratories were however noted by the tenth storm event. To understand the differences, two sets of blind QC samples were analyzed to test the accuracy of each laboratory's analytical methods under blind concentrations of SSC and TSS. The blind QC samples were analyzed by both laboratories using the same methods as the field event samples. The measured concentrations were used to calculate error compared to the actual concentration. Results may be higher or lower than the actual concentration if interferences or inaccuracies are present during the sample processing or analysis.

UA Quality Control Tables for TSS

For each storm event, the UA laboratory measured the influent and effluent concentrations four separate times. The influent and effluent were measured twice using SM 2540D with a Whatman® 934-AH™ 1.5µm Glass Microfiber Filter as previously discussed in **Table 3**. The two TSS measurements for each influent and effluent sample were then averaged. The average was reported as the measured concentration for each storm event. For quality control, the influent and effluent were also measured twice by SM 2540D with a Millipore 0.45µm Membrane Filter. The two influent measurements and two effluent measurements were then averaged and reported in a Quality Control table. These quality control measurements are reported on the individual storm reports found in **Appendix C**.

SSC Blind Samples

Two blind samples prepared by ERA, a certified reference materials provider based out of Golden, Colorado were submitted to both UA and Stillbrook laboratories for analysis using the SSC analytical method in accordance with the procedures discussed in Section 3.4. The UA laboratory split the sample with the cone splitter to replicate how storm samples are handled. The UA laboratory's measured SSC values ranged from 29.00 to 30.84 mg/L, with an overall average of 30.10 mg/L and a standard deviation of 0.69 mg/L, and a coefficient of variation of 0.023. The subsample volume was also indicated for verifying the splitting variability of the cone splitter. The Stillbrook laboratory analyzed the whole sample without splitting it into replicates and reported a single measurement of 32 mg/L. The values measured by both laboratories had a very small difference compared to the certified concentration value, demonstrating excellent recovery and reliability of the laboratory analytical method and procedures used, particularly for the relatively low constituent concentration (**Table B-1**). ERA did not report the particle size distribution of the particulates in the blind sample, but qualitative observation indicated it was a very fine blend.

Table B-1: July, 2012 Blind QC Sample SSC Analysis Results

	UA Laboratory					Stillbrook Laboratory
Sample Replicate #	1	2	3	4	5	1
Subsample Volume (mL)	107	110	100	106	105	Not reported
Subsample Conc. (mg/L)	30.84	30.00	29.00	30.19	30.48	32
Average Conc. (mg/L)	30.10					32
Certified Value[1] (mg/L)	31.9					31.9
Analytical Verification[2] (mg/L)	30.9					32
Percent Recover (%)	96.9					100.3

1 The Certified Values are the actual "made-to" concentrations confirmed by ERA analytical verification.

2 The Analytical Verification data include the mean value, percent recovery and number of data points reported by the laboratories in ERA's Proficiency Testing study compared to the Certified Values. In addition, where NIST Standard Reference Materials (SRMs) are available, each analyte has been analytically traced to the NIST SRM listed.

The results of the ERA blind sample suggest that both laboratories could accurately measure SSC concentrations when the particles are very fine and the concentration is relatively low. However, the blind sample was not able to confirm the accuracy of both laboratories when using the SSC analysis method to measure higher concentrations of coarser blends, similar to the concentration and particle size distribution of solids in the storm event influent samples.

TSS Blind Samples

In order to further evaluate the ability of the laboratories to assess higher TSS concentrations and medium to coarser solids fractions, two separate silica sand gradation blends were used by the Hydro International R&D Department to create four separate blind samples with concentrations ranging from 45 mg/L to 170 mg/L.

Samples A and B contained a finer gradation of silica with an approximate d_{50} of 45 microns. Blind samples C and D contained a coarser gradation with a d_{50} of approximately 90 microns (**Figure B-1**). The analytical method was in accordance with the TSS test method (Standard Method APHA 2540 D). The results for the set of blind TSS QC samples are shown in **Table B-2**.

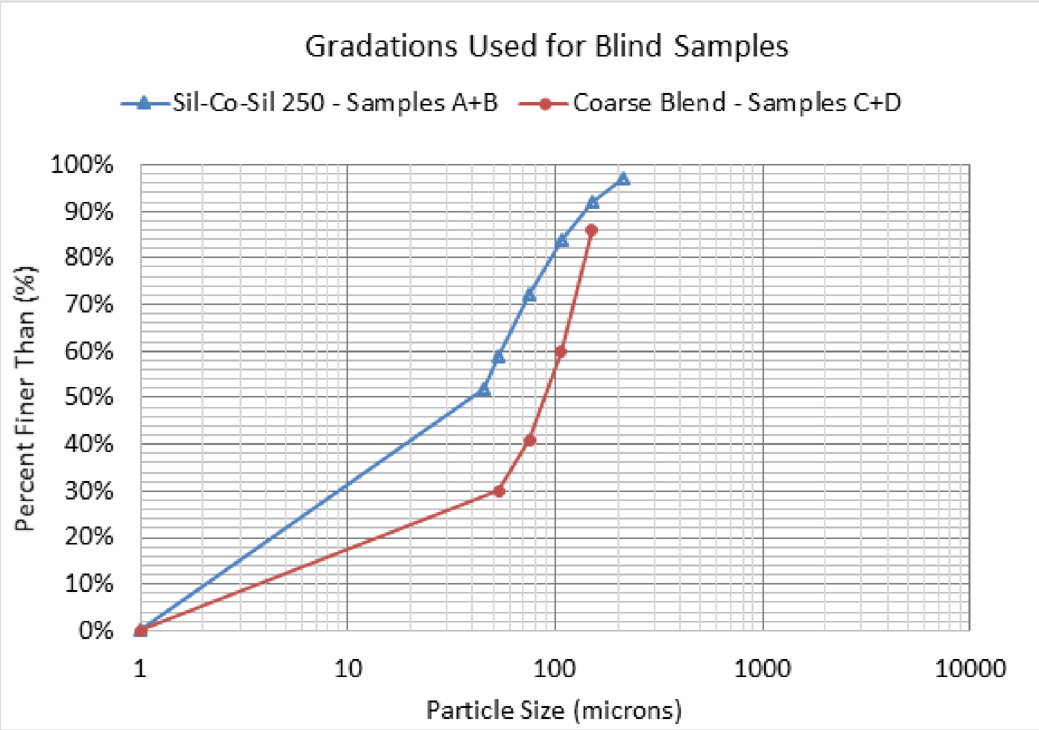


Figure B-1 Particle Size Distribution of the TSS Blind Samples

Table B-2: November, 2012 Blind QC Samples TSS Analyses Results (blind samples prepared by Hydro International)

Sample #	Test Sand Used	Actual Conc. (mg/L)	Stillbrook Lab Results (mg/L)	Stillbrook Lab Recovery	UA Lab Results (mg/L)	UA Lab Recovery
A	SCS 250	60	45	75%	53.5	89%
B	SCS 250	140	79	56%	121.5	87%
	Average Accuracy			66%		88%
	Precision			±10%		±1%
	Implied Maximum TSS Particle Size Capture Range			49 to 80 µm		123 to 134 µm
C	SCS 250/F-100 blend	45	31	69%	28.5	63%
D	SCS 250/F-100 blend	170	60	35%	100	59%
	Average Accuracy			52%		61%
	Precision			±17%		±2%
	Implied Maximum TSS Particle Size Capture Range			63 to 121 µm		105 to 111 µm
	Overall Recovery Average			59%		75%

As shown, the overall recovery from both laboratories varied from 35% to 89%. The recovery measurements for the samples with finer particles were higher than the recovery measurements for the samples with the coarser blend, as would be expected for TSS analytical methods. Since these test mixtures were made using coarse ground silica, the TSS testing methods would not be expected to be able to accurately determine the SSC values that have large particles beyond the range of the TSS test method.

The results indicate that the UA laboratory produces TSS measurements with a higher level of recovery and greater precision than the Stillbrook laboratory. **Figure B-2** is a plot of measured TSS concentrations as a function of the known SSC concentrations. The UA data shows a higher TSS yield and a better coefficient of determination (R^2 of 0.81) compared with the Stillbrook data which shows a significantly lower yield and poorer coefficient of determination (R^2 of 0.25).

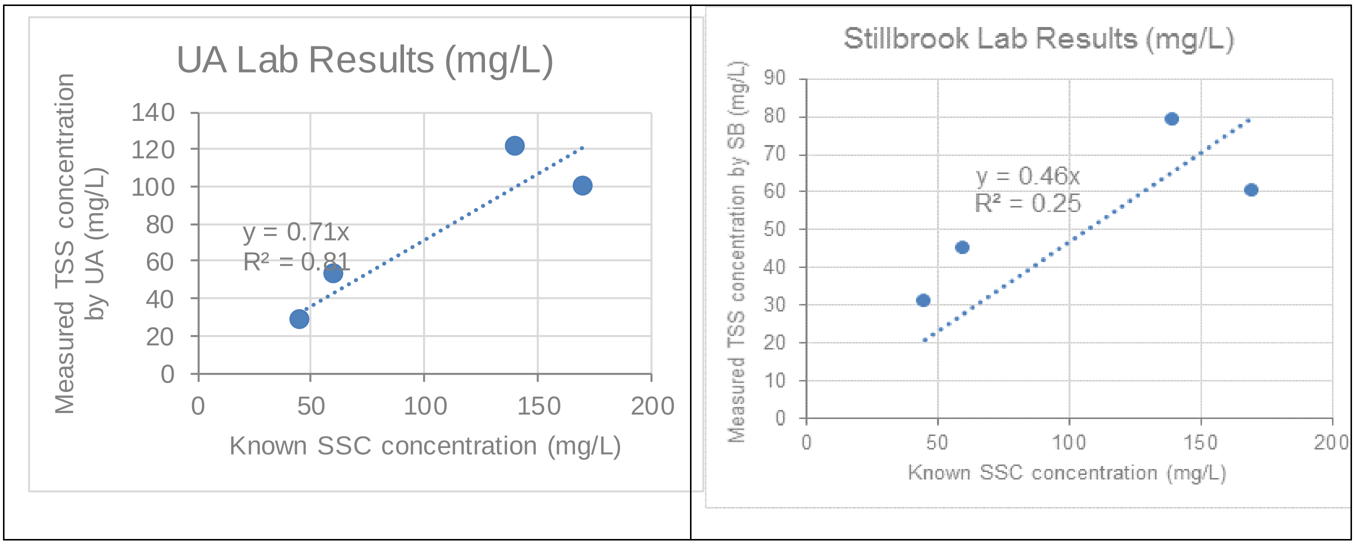


Figure B-2 Comparison of Known SSC Concentrations and Measured TSS Concentrations

Figure B-3 is a plot of the measured TSS concentrations as measured at the UA laboratory compared to the measured TSS concentrations as measured at the Stillbrook laboratory. The correlation between these two sets of data is good, which suggests that they have similar trends as would be expected. However, it is clear that the recovery of the two laboratories was significantly different. Stillbrook reported TSS concentrations that were significantly less than the UA-reported TSS concentrations, particularly for the higher solids concentrations. Additionally, the Stillbrook method had a large negative intercept indicating a potential bias or a calibration error.

The blind QC SSC analysis showed that both laboratories' SSC analytical methods indicated good recoveries with no significant errors. However, as noted, the initial sets of blind QA samples did not have appreciable amounts of the larger particles typical of stormwater runoff. As was clearly demonstrated in the QC TSS analysis, potential laboratory discrepancies arise when samples having large particles and/or larger concentrations are measured using TSS analytical methods. This has been reported by a number of researchers (Clark & Pitt, 2008; Sansalone & Kim, 2008).

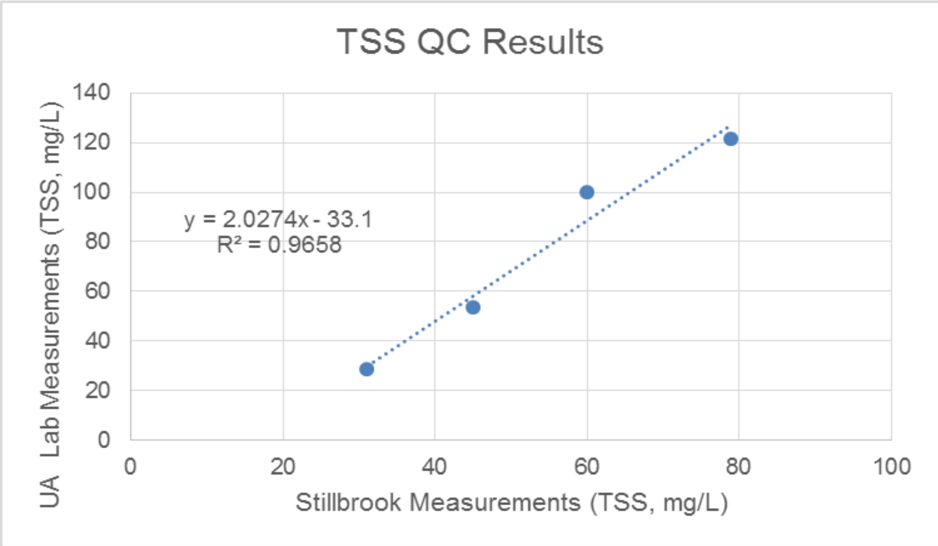


Figure B-3 TSS Measurement Comparison of Blind Samples for the Two Laboratories

TSS Analysis Differences between UA and Stillbrook Laboratories

The Stillbrook laboratory analyzed one influent sub-sample and one effluent sub-sample per storm event. Although some discrepancy between UA and Stillbrook's TSS measurements was expected, the correlation between UA and Stillbrook's TSS measurements was lower than anticipated. As was seen with the blind QC TSS samples, the full influent TSS measured by UA was generally twice the value of Stillbrook's measured TSS (**Figure B-4**). The correlation of effluent TSS measurements was better than influent measurements, which may be due to lack of recovery of larger particles in the influent by Stillbrook, as was shown in the QA/QC blind results presented in **Table B-2**.

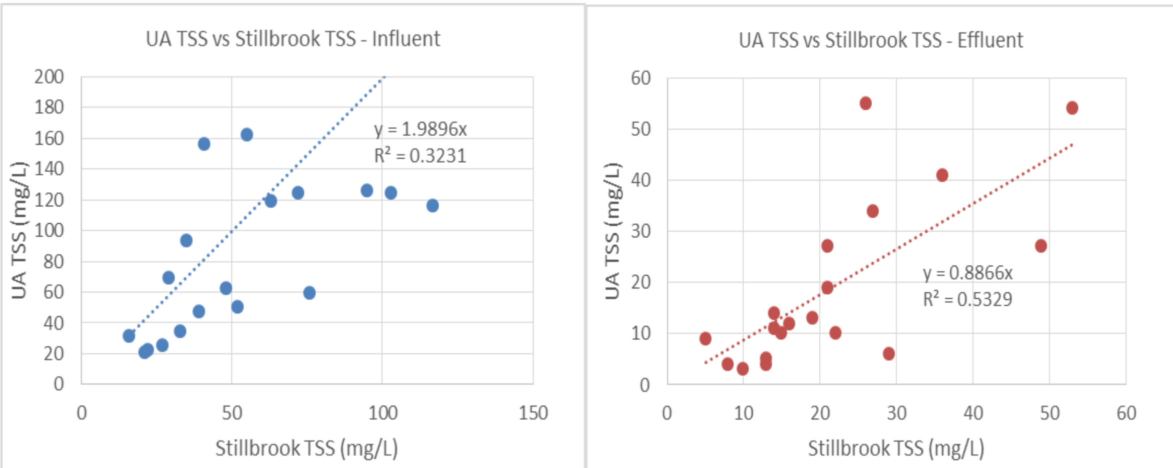


Figure B-4 Influent (left) and Effluent (right) TSS values Measured by UA and Stillbrook

Figure B-5 and **Figure B-6** compare the measured influent and effluent TSS and SSC between the UA and Stillbrook laboratories. (Note: The UA analysis comparison is plotted on a log-log scale to be able to represent the wide range of concentrations measured.) The red dotted line represents when TSS and SSC are equal (i.e. TSS is 100% of SSC). Due to the wide particle size distribution and expected error inherent in the analysis, TSS:SSC = 1 is theoretical and since SSC should be greater than TSS all data points should be above the red line. This is true for almost all UA data points but true for only a few Stillbrook data points, where a significant number lie below the red line. This is particularly more pronounced for the influent concentrations where a wider range of solids including larger particulates are to be anticipated. The plot clearly shows a significant proportion of the Stillbrook TSS concentrations exceeding SSC concentrations which suggests non-representative sub-sampling.

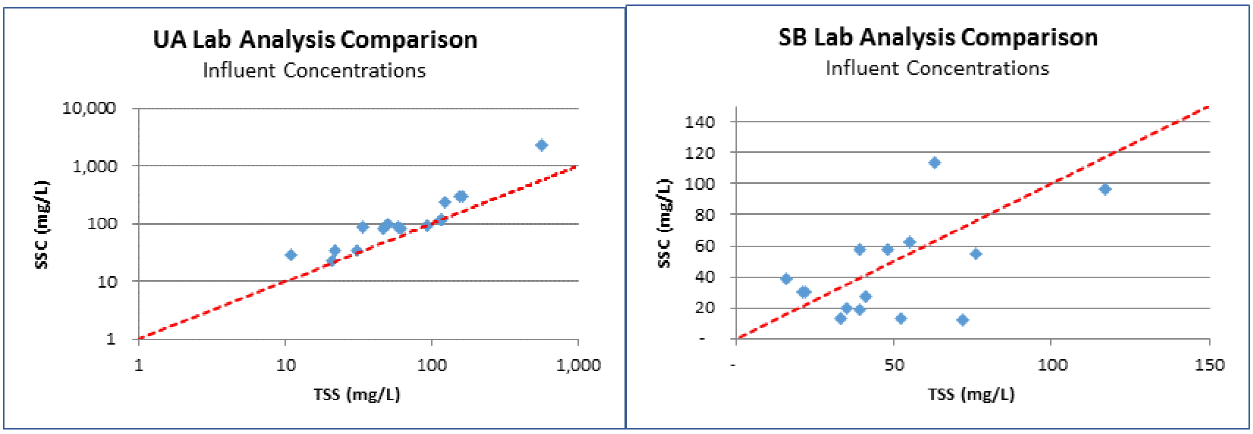


Figure B-5 Laboratory Comparison: Measured Influent SSC with Measured Influent TSS

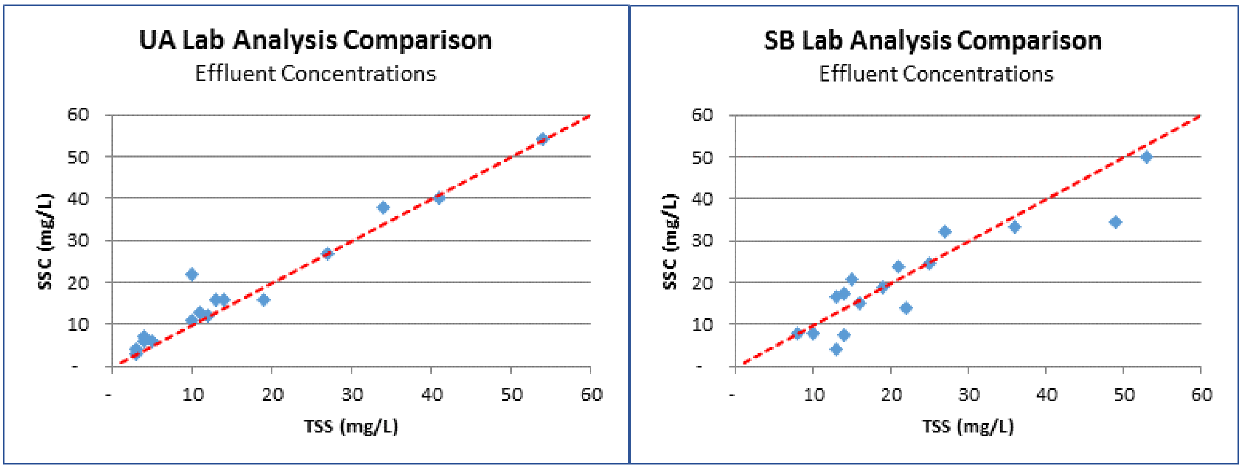


Figure B-6 Laboratory Comparison: Measured Effluent SSC with Measured Effluent TSS

Comparison plots for effluent solids show an improvement for Stillbrook, which is to be expected given that effluent samples are likely to contain fewer large particulates

The plots for measured TSS and SSC removal efficiencies for each laboratory are shown in **Figure B-7**. Both the correlation between TSS and SSC efficiency and the slope (TSS:SSC=1) are reasonable for UA data, indicating that the UA TSS analysis is more accurate even with the wide range of particle sizes. Conversely, the efficiency data for Stillbrook shows poor correlation and several negative points indicating the SSC effluent concentrations are higher than influent concentrations while the TSS effluent concentrations are lower than the corresponding influent concentrations. This raises serious concerns regarding the accuracy and usefulness of the Stillbrook laboratory data.

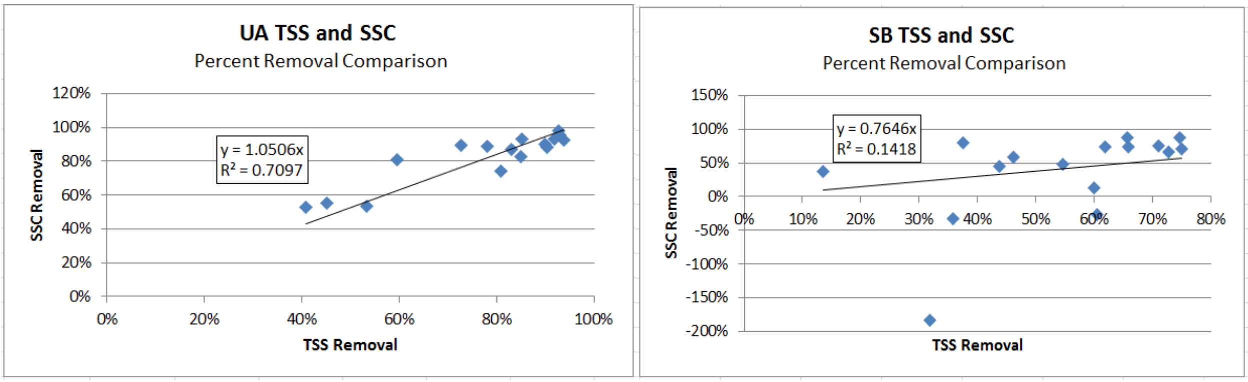


Figure B-7 Laboratory Comparison: TSS and SSC Percent Removal Efficiencies

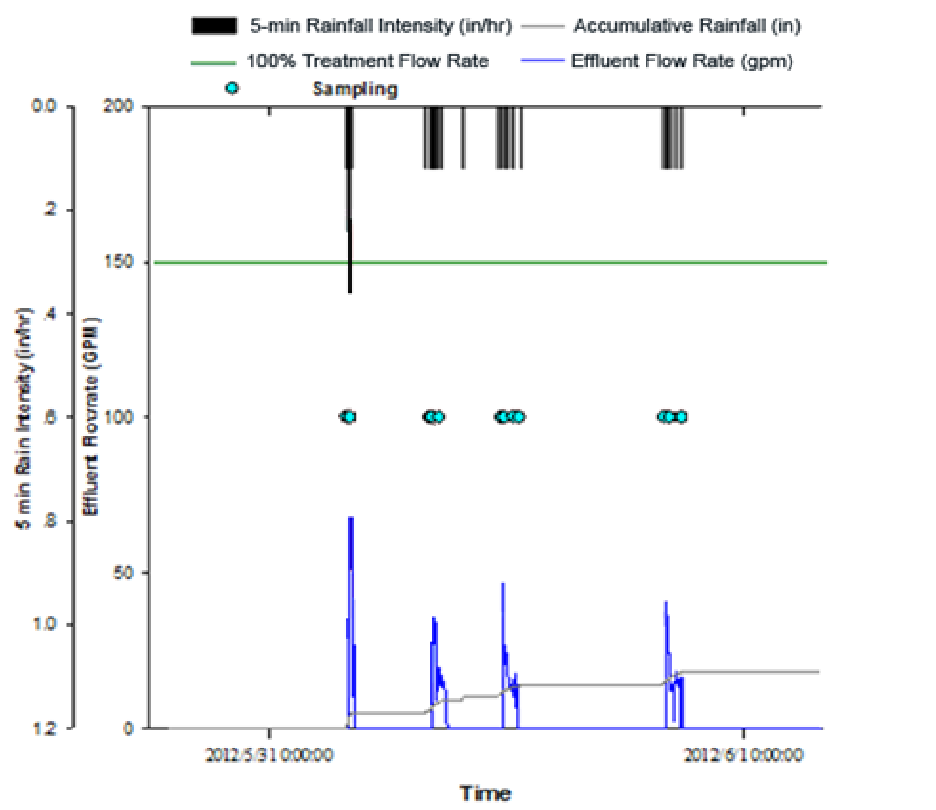
Because the UA and Stillbrook laboratory's measurements for the same storm were significantly different, using both Stillbrook and UA's data would not accurately represent the true influent and effluent concentrations of the storm event. It was decided that only the UA measurements would be used for the purposes of the performance analysis because the UA laboratory had several QA/QC advantages over Stillbrook and produced scientifically defensible data:

1. As indicated in **Table 4**, the CFM Group independent observer witnessed UA collect and analyze 10 sets of samples, 8 of which were from qualified storm events, whereas the Stillbrook SSC laboratory had no independent observer.
2. UA's SSC concentrations are mostly greater than their corresponding measured TSS concentrations for individual storm events as would be expected. However, Stillbrook's measured TSS is often larger than their corresponding measured SSC, including for the effluent concentrations where the PSD range is narrower.
3. Stillbrook reported negative SSC percent removal efficiency but positive TSS percent removal efficiency for several storm events.
4. The TSS measurement that UA reported for each influent and effluent sample was based on analyzing two samples with a Whatman® 934-AH™ Glass 1.5 µm Microfiber Filter. The two measurements were then averaged. The average value was reported as the UA TSS measurement.
5. The UA TSS data had two other QC checks in that TSS was measured twice by a 0.45 micron Millipore Membrane Filter and logged in a QA/QC table. The average of the two measured values is reported in the individual storm reports in **Appendix C**.
6. The UA laboratory outperformed Stillbrook in the TSS blind QC sample analysis, as previously noted.
7. The UA laboratory has a long history analyzing stormwater samples for TSS and SSC. The Stillbrook laboratory had no history analyzing SSC before the third storm of the monitoring program. Although Stillbrook has a history analyzing TSS, their experience was specific to analyzing wastewater effluent samples, which tend to contain finer particulates and smaller concentrations overall than stormwater samples.

APPENDIX C

INDIVIDUAL STORM REPORTS

Appendix C-1	6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	May 31, 2012		
Hydrology			
Total Outflow (gal):	3267	Total Precipitation (inch):	0.27
Peak Rain Intensity (in/hr): 5 min: 0.36	15-min: 0.28	Rain Duration (hours):	16.87
Peak Runoff Rate (gal/min):	68	Inter-Event Time since prior rain (hours)	219.97
Peak Runoff Rate (% of Design Flow Rate):	45%	Number of Subsamples in event:	12
Bypassed flow volume (gal):	0	Samples Coverage of total storm flow (%)	100



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	101	9	65	1,080	22	5	28	900	78.2
TSS (measured)[3]	124	N/A	N/A	N/A	27	N/A	N/A	N/A	78.2
PM <273µm[4]	56	5	23	70	15	3	20	60	73.2

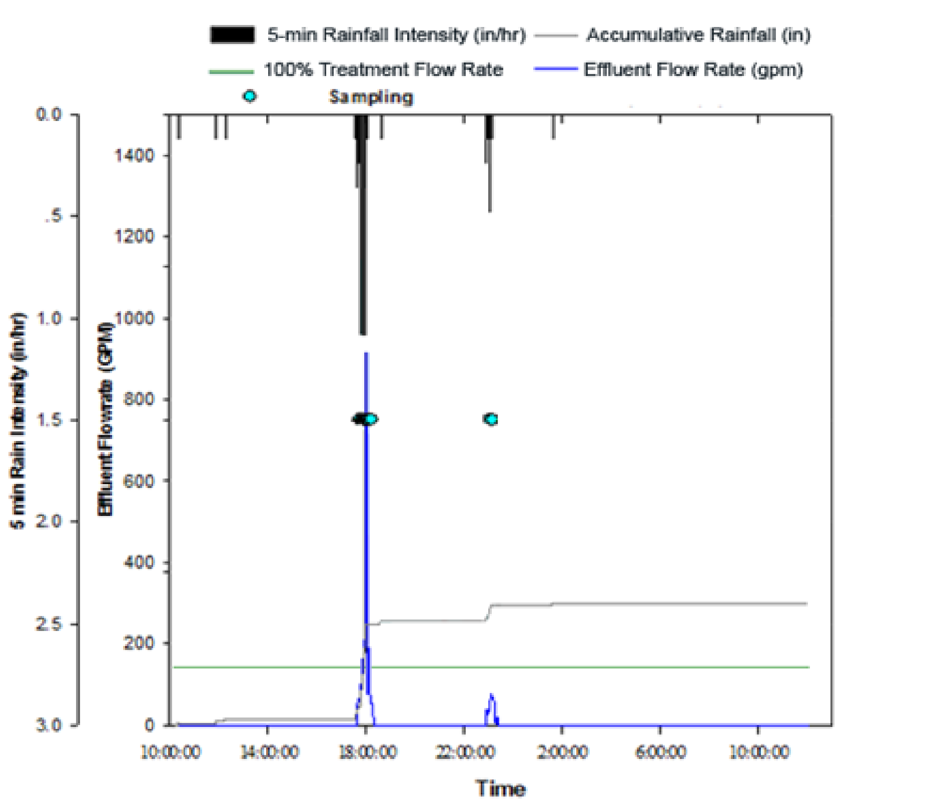
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-2		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		June 10, 2012		
Hydrology				
Total Outflow (gal):		8240	Total Precipitation (inch):	0.60
Peak Rain Intensity (in/hr):	5-min: 2.64	15-min: 1.64	Rain Duration (hours):	15.25
Peak Runoff Rate (gal/min):		962	Inter-Event Time since prior rain (hours)	246.37
Peak Runoff Rate (% of Design Flow Rate):		641%	Number of Subsamples in event:	16
Bypassed flow volume (gal):		2,054	Samples Coverage of total storm flow (%)	90.28



Analytical Data

Constituent	Influent Conc. (mg/L)	Influent d10 (µm)	Influent d50 (µm)	Influent d90 (µm)	Effluent[1] Conc. (mg/L)	Effluent[1] d10 (µm)	Effluent[1] d50 (µm)	Effluent[1] d90 (µm)	% Reduction
SSC (measured)[2]	80	8	268	>1180	12	6	59	>1180	85.0
TSS (measured)[3]	69	N/A	N/A	N/A	9	N/A	N/A	N/A	87.0
PM <273µm[4]	40	5	22	58	7	5	25	90	82.5

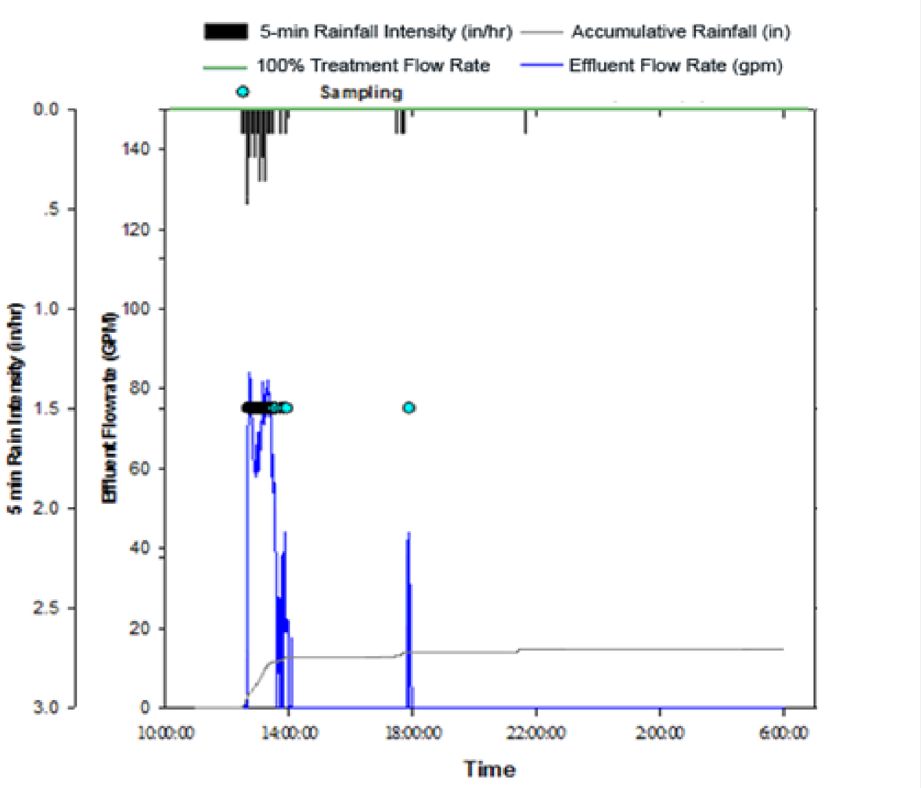
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-3		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		July 11, 2012		
Hydrology				
Total Outflow (gal):		4464	Total Precipitation (inch):	0.29
Peak Rain Intensity (in/hr):	5-min: 0.48	15-min: 0.32	Rain Duration (hours):	9.17
Peak Runoff Rate (gal/min):		83	Inter-Event Time since prior rain (hours)	20.63
Peak Runoff Rate (% of Design Flow Rate):		55%	Number of Subsamples in event:	36
Bypassed flow volume (gal):		0	Samples Coverage of total storm flow (%)	96.84



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	120	10	47	830	12	14	61	830	90.0
TSS (measured)[3]	119	N/A	N/A	N/A	12	N/A	N/A	N/A	89.9
PM <273µm[4]	90	7	31	95	7	12	31	85	92.2

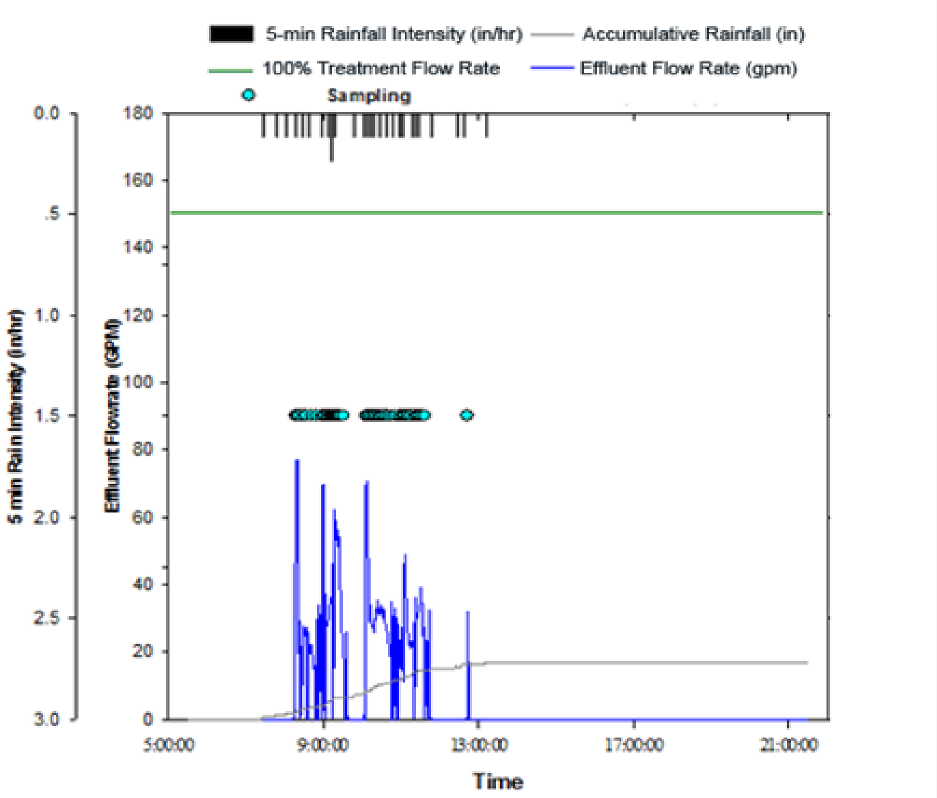
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-4		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		July 12, 2012		
Hydrology				
Total Outflow (gal):		5062	Total Precipitation (inch):	0.28
Peak Rain Intensity (in/hr):	5-min: 0.24	15-min: 0.16	Rain Duration (hours):	5.75
Peak Runoff Rate (gal/min):		77	Inter-Event Time since prior rain (hours)	18.93
Peak Runoff Rate (% of Design Flow Rate):		51.3%	Number of Subsamples in event:	42
Bypassed flow volume (gal):		0	Samples Coverage of total storm flow (%)	98.24



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	34	15	56	1000	4	5	25	300	88.2
TSS (measured)[3]	31	N/A	N/A	N/A	3	N/A	N/A	N/A	90.3
PM <273µm[4]	19	13	29	55	3	5	21	70	84.2

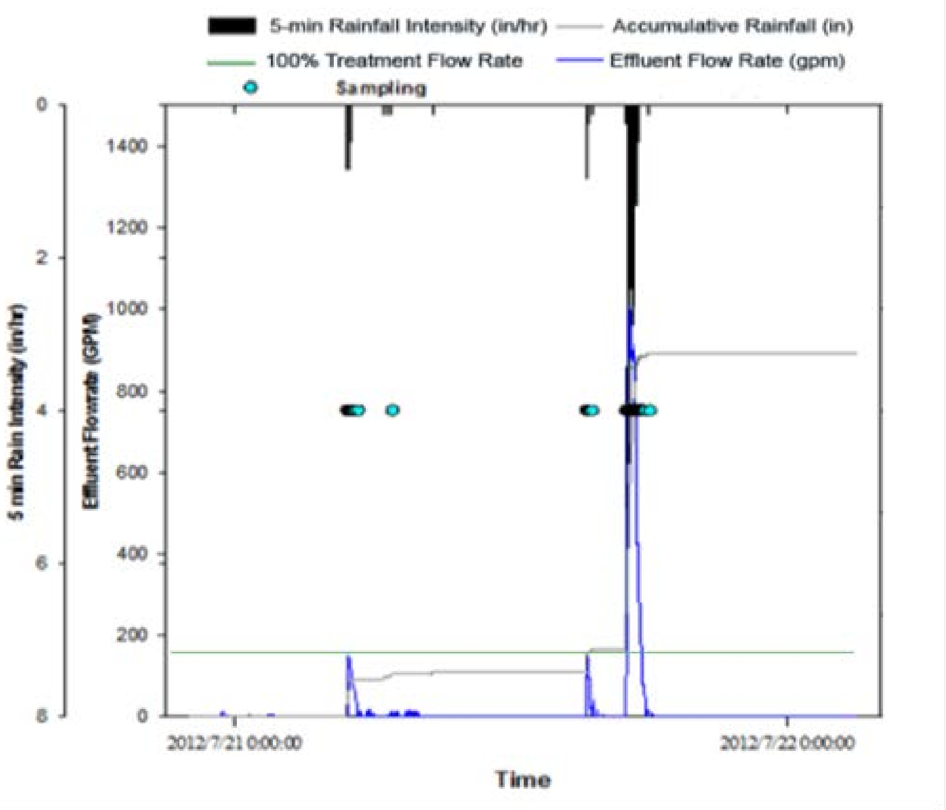
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-5		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		July 21, 2012		
Hydrology				
Total Outflow (gal):		30,906	Total Precipitation (inch):	1.78
Peak Rain Intensity (in/hr):	5-min: 4.68	15-min: 3.56	Rain Duration (hours):	13.07
Peak Runoff Rate (gal/min):		1009	Inter-Event Time since prior rain (hours)	64.48
Peak Runoff Rate (% of Design Flow Rate):		673%	Number of Subsamples in event:	75
Bypassed flow volume (gal):		14,993	Samples Coverage of total storm flow (%)	99.54



Analytical Data

Constituent	Influent Conc. (mg/L)	Influent d10 (µm)	Influent d50 (µm)	Influent d90 (µm)	Effluent[1] Conc. (mg/L)	Effluent[1] d10 (µm)	Effluent[1] d50 (µm)	Effluent[1] d90 (µm)	% Reduction
SSC (measured)[2]	2297	260	1029	>1180	40	13	43	700	98.3
TSS (measured)[3]	571	N/A	N/A	N/A	41	N/A	N/A	N/A	92.8
PM <273µm[4]	228	4	16	260	32	12	29	115	86.0

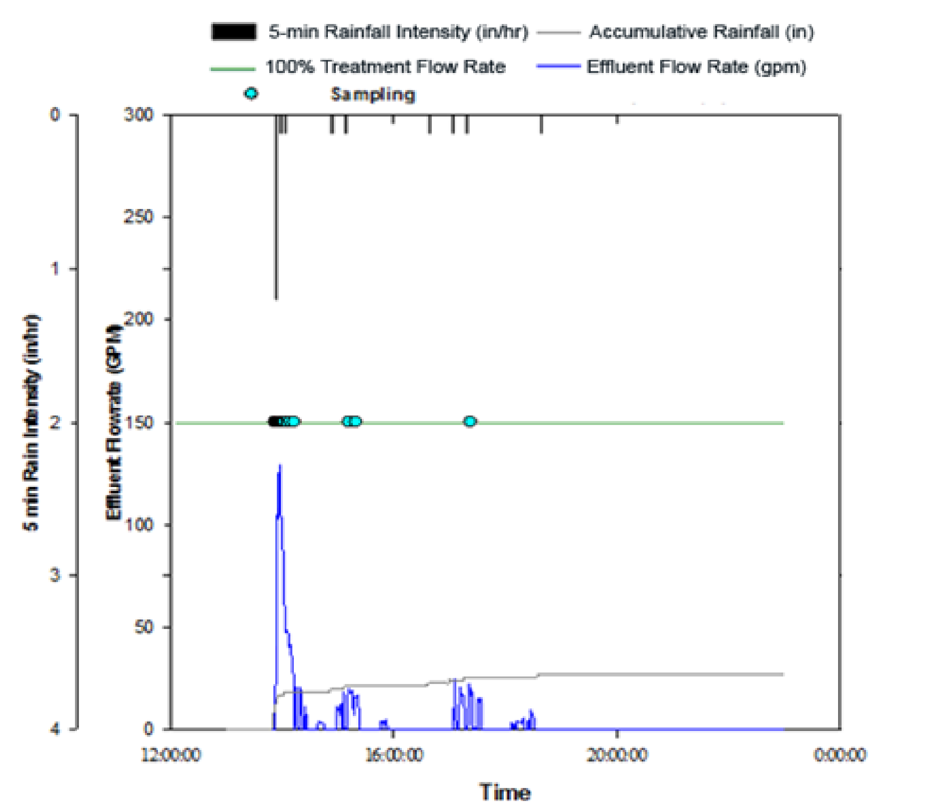
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-6		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		August 3, 2012		
Hydrology				
Total Outflow (gal):		2065	Total Precipitation (inch):	0.18
Peak Rain Intensity (in/hr):	5-min: 1.21	15-min: 0.48	Rain Duration (hours):	4.75
Peak Runoff Rate (gal/min):		128	Inter-Event Time since prior rain (hours)	84.25
Peak Runoff Rate (% of Design Flow Rate):		85%	Number of Subsamples in event:	15
Bypassed flow volume (gal):		13	Samples Coverage of total storm flow (%)	92.78



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	116	15	52	>1180	54	13	28	1000	53.4
TSS (measured)[3]	116	N/A	N/A	N/A	54	N/A	N/A	N/A	53.4
PM <273µm[4]	84	14	38	90	40	12	23	50	52.4

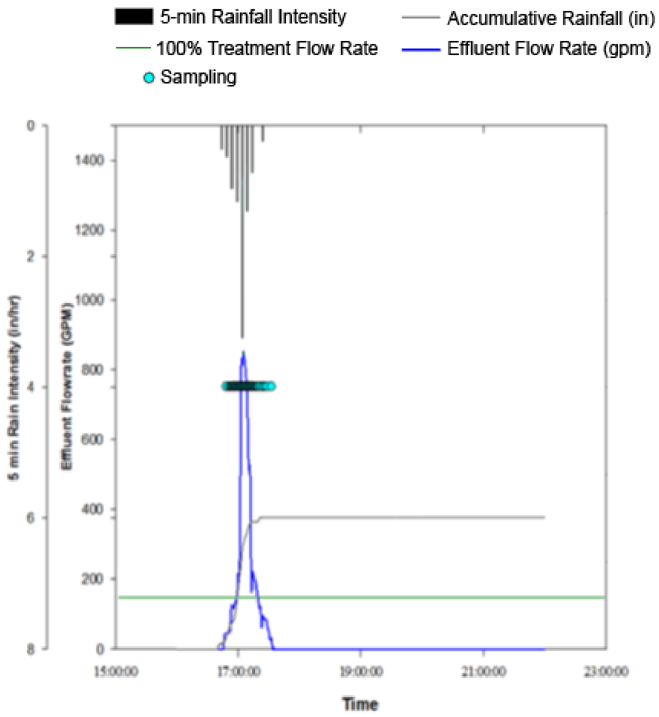
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-7		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		August 4, 2012		
Hydrology				
Total Outflow (gal):		11535	Total Precipitation (inch):	0.75
Peak Rain Intensity (in/hr):	5-min: 3.24	15-min: 2.16	Rain Duration (hours):	0.67
Peak Runoff Rate (gal/min):		850	Inter-Event Time since prior rain (hours)	26.85
Peak Runoff Rate (% of Design Flow Rate):		567%	Number of Subsamples in event:	35
Bypassed flow volume (gal):		5,518	Samples Coverage of total storm flow (%)	100



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	133	14	210	>1180	57	15	350	1000	57.1
TSS (measured)[3]	126	N/A	N/A	N/A	55	N/A	N/A	N/A	56.3
PM <273µm[4]	68	8	33	120	21	8	28	160	69.1

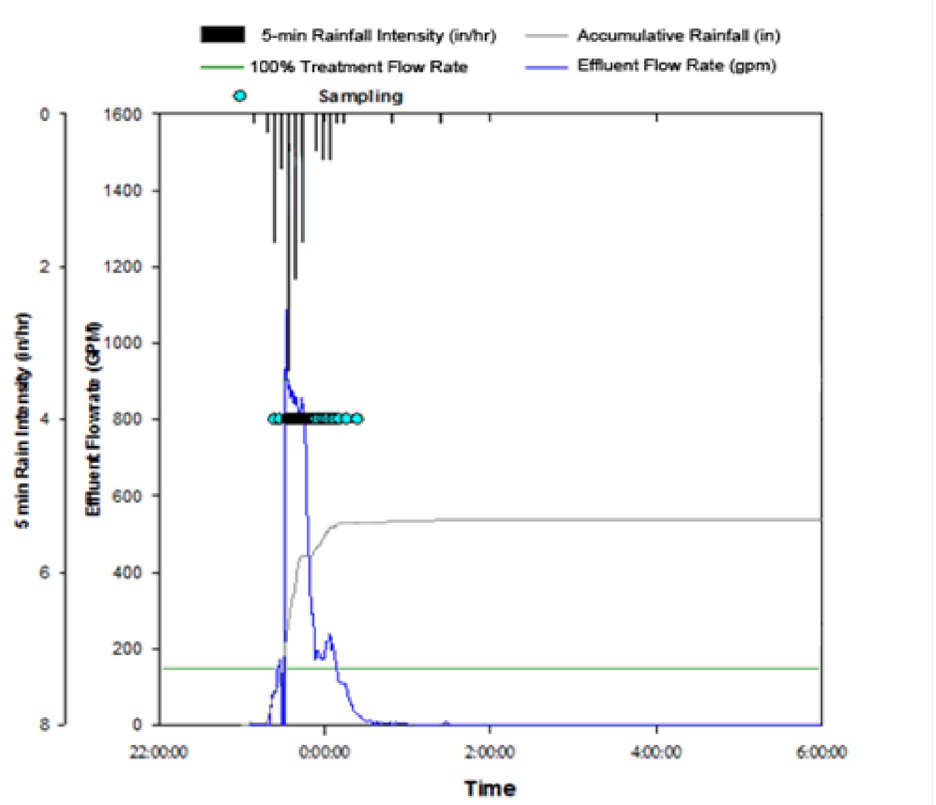
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-8		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		August 13, 2012		
Hydrology				
Total Outflow (gal):		20903	Total Precipitation (inch):	1.01
Peak Rain Intensity (in/hr):	5-min: 3.36	15-min: 2.52	Rain Duration (hours):	2.22
Peak Runoff Rate (gal/min):		1023	Inter-Event Time since prior rain (hours)	154.85
Peak Runoff Rate (% of Design Flow Rate):		682%	Number of Subsamples in event:	42
Bypassed flow volume (gal):		10,571	Samples Coverage of total storm flow (%)	97.87



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	93	8	467	1180	16	12	25	1180	82.8
TSS (measured)[3]	93	N/A	N/A	N/A	14	N/A	N/A	N/A	84.9
PM <273µm[4]	36	5	18	90	13	9	21	37	63.9

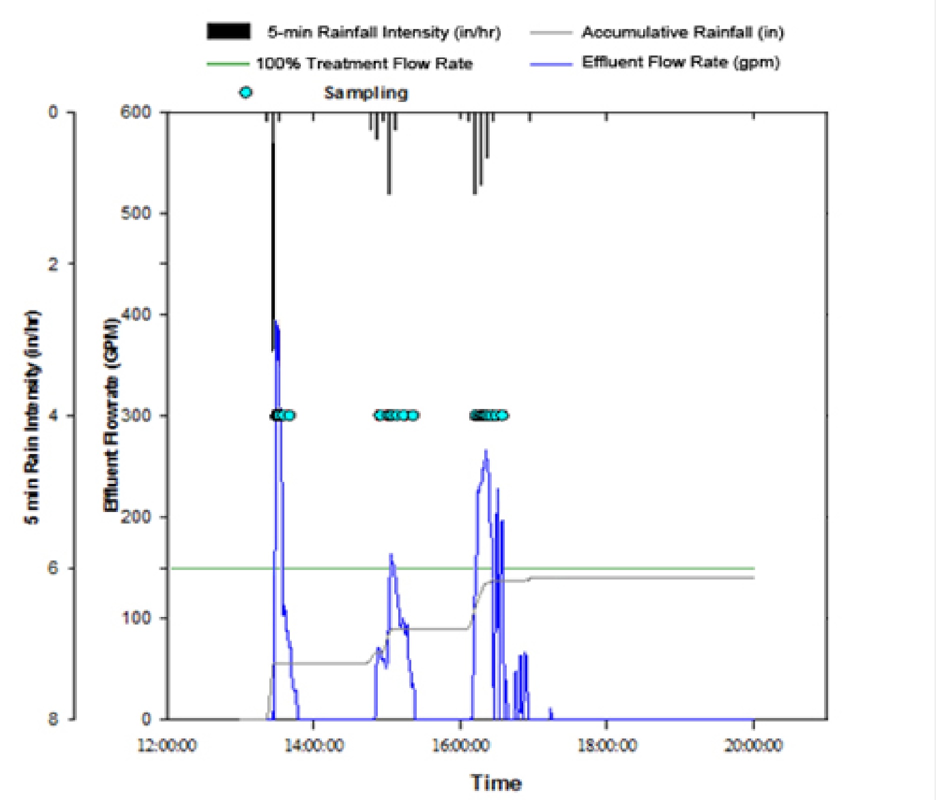
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-9		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		September 1, 2012		
Hydrology				
Total Outflow (gal):		10402	Total Precipitation (inch):	0.70
Peak Rain Intensity (in/hr):	5-min: 3.12	15-min: 1.12	Rain Duration (hours):	3.58
Peak Runoff Rate (gal/min):		390	Inter-Event Time since prior rain (hours)	52.07
Peak Runoff Rate (% of Design Flow Rate):		260%	Number of Subsamples in event:	21
Bypassed flow volume (gal):		2507	Samples Coverage of total storm flow (%)	96.09



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	304	13	661	>1180	22	4	61	>1180	92.8
TSS (measured)[3]	162	N/A	N/A	N/A	10	N/A	N/A	N/A	93.8
PM <273µm[4]	73	5	17	90	14	4	12	90	80.8

[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

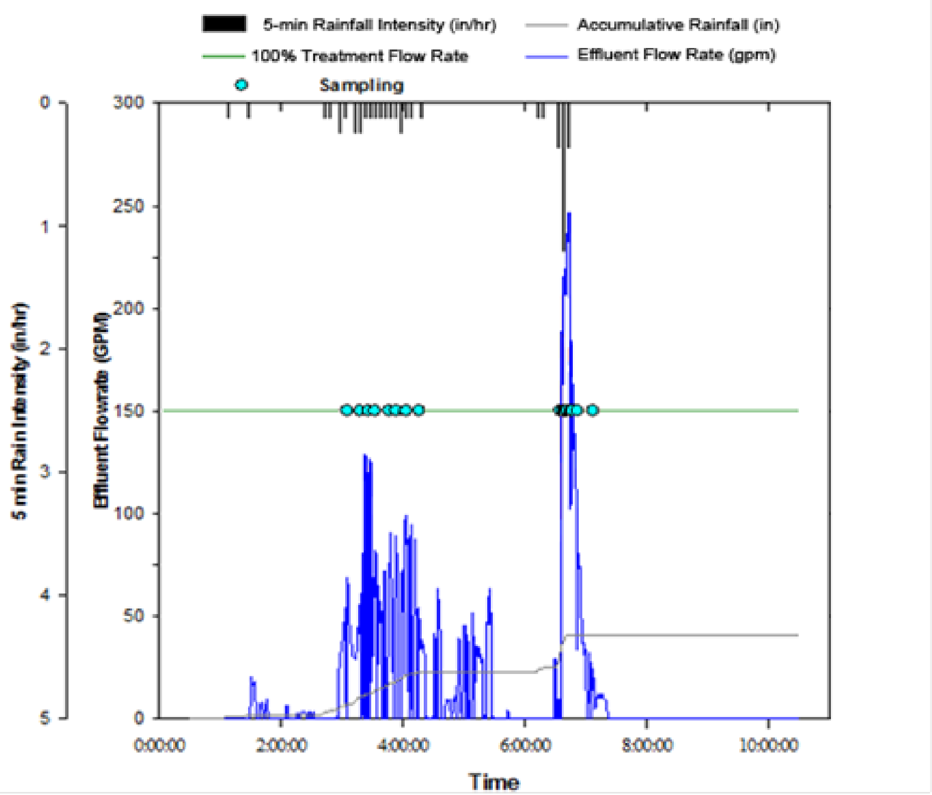
[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-10	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	September 3, 2012		

Hydrology			
Total Outflow (gal):	8509	Total Precipitation (inch):	0.41
Peak Rain Intensity (in/hr): 5-min: 1.20	15-min: 0.64	Rain Duration (hours):	5.62
Peak Runoff Rate (gal/min):	239	Inter-Event Time since prior rain (hours)	36.3
Peak Runoff Rate (% of Design Flow Rate):	159%	Number of Subsamples in event:	16
Bypassed flow volume (gal):	315	Samples Coverage of total storm flow (%)	93.23



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	290	60	878	>1180	13	13	406	>1180	95.5
TSS (measured)[3]	156	N/A	N/A	N/A	11	N/A	N/A	N/A	92.9
PM <273µm[4]	39	13	32	250	6	6	27	100	84.6

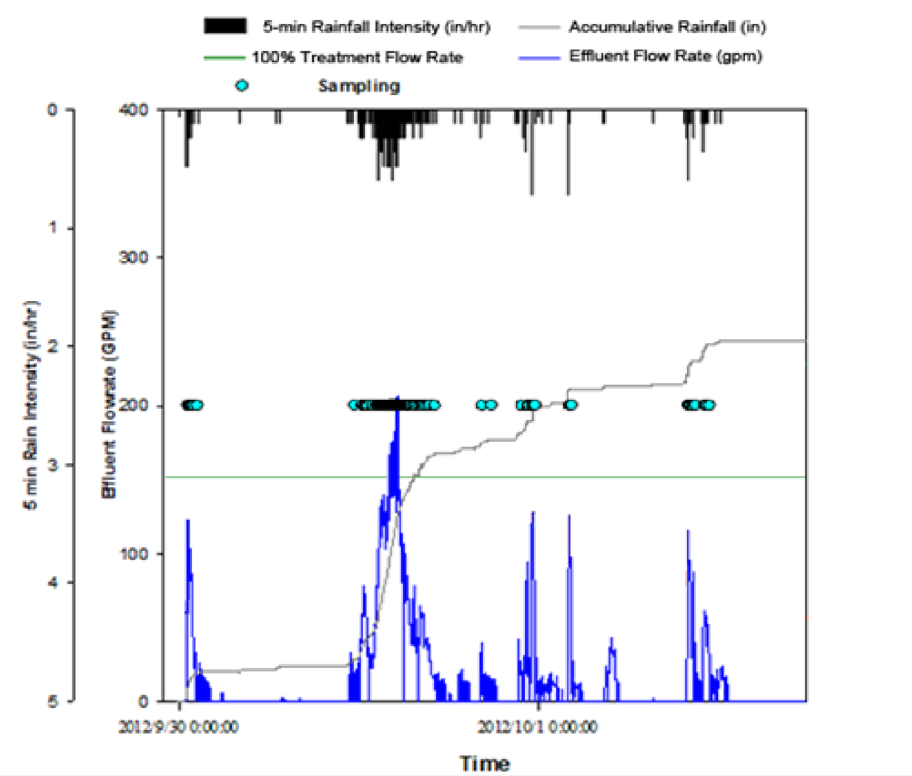
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-11		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		September 30, 2012		
Hydrology				
Total Outflow (gal):		39335	Total Precipitation (inch):	1.83
Peak Rain Intensity (in/hr):	5-min: 0.72	15-min: 0.48	Rain Duration (hours):	35.68
Peak Runoff Rate (gal/min):		206	Inter-Event Time since prior rain (hours)	631.77
Peak Runoff Rate (% of Design Flow Rate):		137%	Number of Subsamples in event:	74
Bypassed flow volume (gal):		3	Samples Coverage of total storm flow (%)	96.87



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	23	13	49	1000	6	5	24	800	73.9
TSS (measured)[3]	21	N/A	N/A	N/A	4	N/A	N/A	N/A	81.0
PM <273µm [4]	17	10	36	100	4	4	17	58	76.5

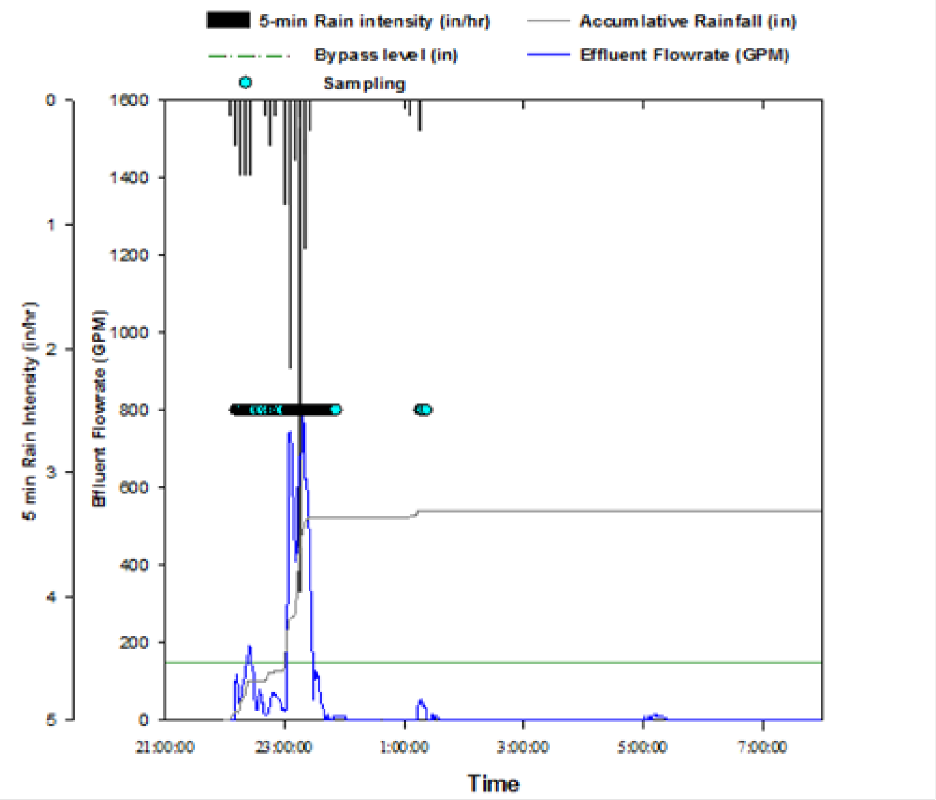
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-12		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		October 14, 2012		
Hydrology				
Total Outflow (gal):		20062	Total Precipitation (inch):	1.01
Peak Rain Intensity (in/hr):	5-min-3.96	15-min: 2.20	Rain Duration (hours):	3.13
Peak Runoff Rate (gal/min):		784	Inter-Event Time since prior rain (hours)	357.62
Peak Runoff Rate (% of Design Flow Rate):		523%	Number of Subsamples in event:	78
Bypassed flow volume (gal):		9686	Samples Coverage of total storm flow (%)	98.27



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	83	15	585	>1180	16	6	50	380	80.7
TSS (measured)[3]	47	N/A	N/A	N/A	19	N/A	N/A	N/A	59.6
PM <273µm[4]	34	10	26	100	10	5	34	100	70.6

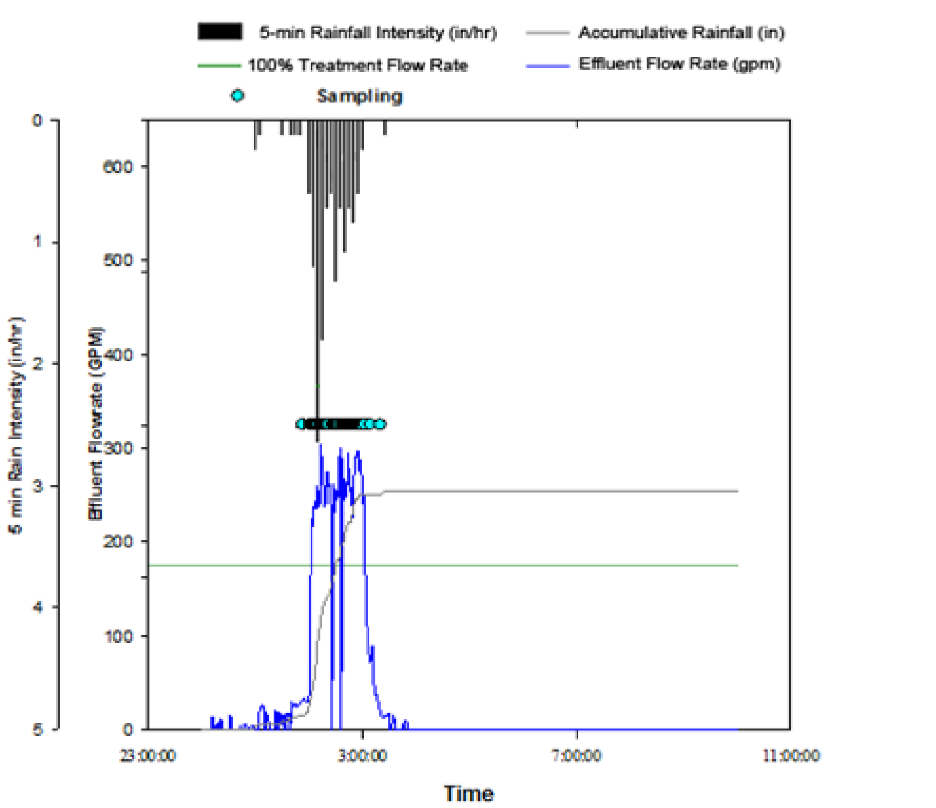
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-13		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		October 18, 2012		
Hydrology				
Total Outflow (gal):		17650	Total Precipitation (inch):	1.17
Peak Rain Intensity (in/hr):	5-min: 2.64	15-min: 1.88	Rain Duration (hours):	2.40
Peak Runoff Rate (gal/min):		299	Inter-Event Time since prior rain (hours)	74.88
Peak Runoff Rate (% of Design Flow Rate):		199%	Number of Subsamples in event:	35
Bypassed flow volume (gal):		7,320	Samples Coverage of total storm flow (%)	93.88



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	85	16	411	>1180	38	14	60	>1180	55.3
TSS (measured)[3]	62	N/A	N/A	N/A	34	N/A	N/A	N/A	45.2
PM <273µm[4]	39	13	27	110	24	13	27	100	38.5

[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

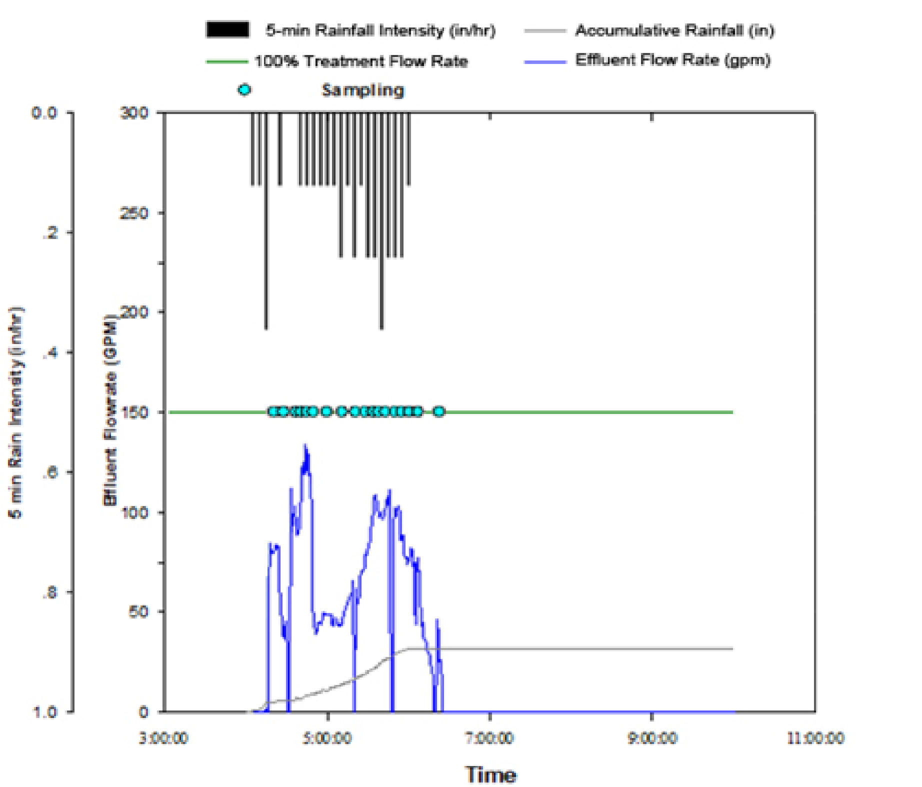
[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-14	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	November 27, 2012		

Hydrology				
Total Outflow (gal):		8510	Total Precipitation (inch):	0.32
Peak Rain Intensity (in/hr):	5-min: 0.36	15-min: 0.28	Rain Duration (hours):	1.90
Peak Runoff Rate (gal/min):		134	Inter-Event Time since prior rain (hours)	355.0
Peak Runoff Rate (% of Design Flow Rate):		89%	Number of Subsamples in event:	18
Bypassed flow volume (gal):		0	Samples Coverage of total storm flow (%)	96.03



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	86	6	672	>1180	11	13	25	850	87.2
TSS (measured)[3]	59	N/A	N/A	N/A	10	N/A	N/A	N/A	83.1
PM <273µm [4]	32	4	12	80	8	12	22	50	75.0

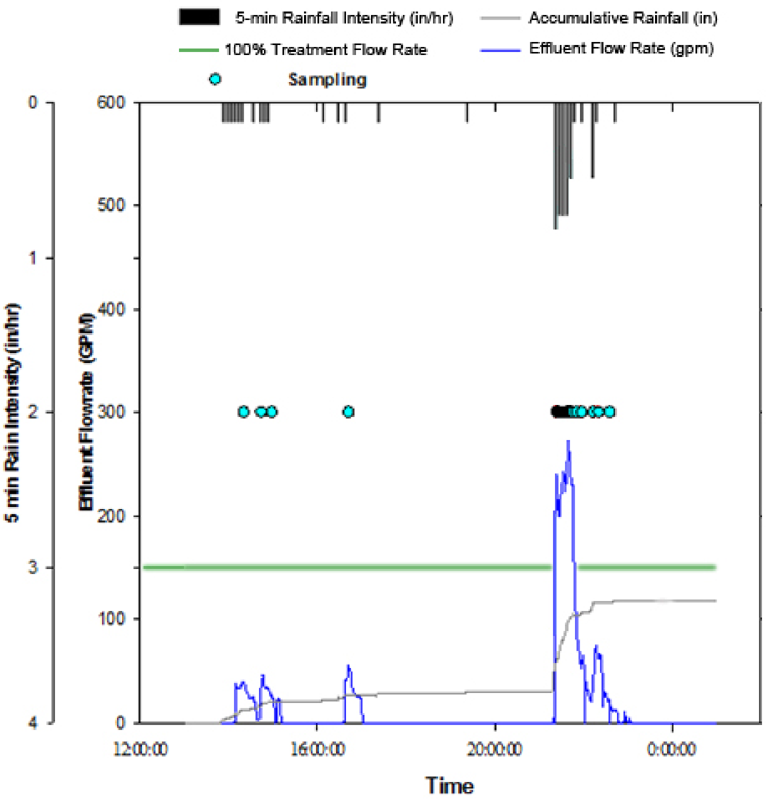
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-15		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		December 4, 2012		
Hydrology				
Total Outflow (gal):		10693	Total Precipitation (inch):	0.59
Peak Rain Intensity (in/hr):	5-min: 1.68	15-min: 1.04	Rain Duration (hours):	8.85
Peak Runoff Rate (gal/min):		273	Inter-Event Time since prior rain (hours)	175.8
Peak Runoff Rate (% of Design Flow Rate):		182%	Number of Subsamples in event:	21
Bypassed flow volume (gal):		2,824	Samples Coverage of total storm flow (%)	94.90



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	239	33	696	>1180	27	12	27	850	88.7
TSS (SM 2540D)[3]	124	N/A	N/A	N/A	27	N/A	N/A	N/A	78.2
PM <273µm [4]	43	8	29	250	21	10	23	65	51.2

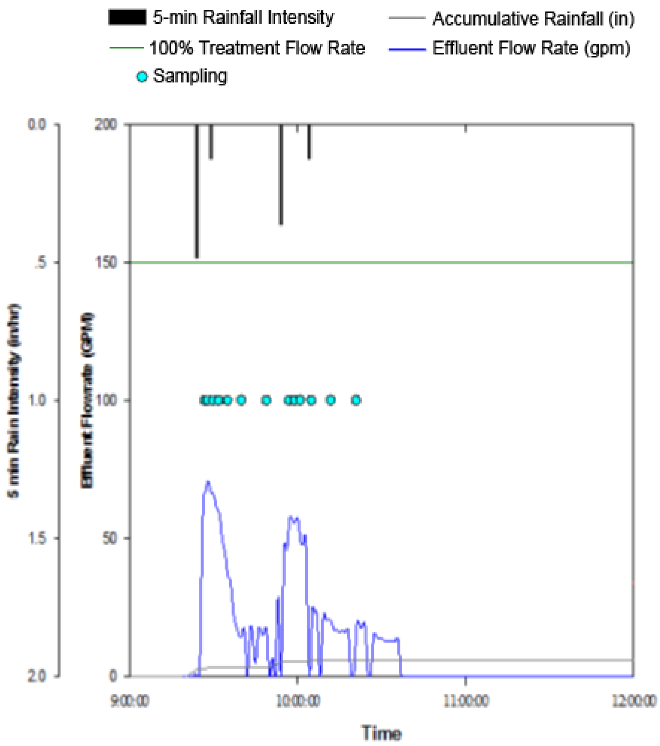
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-16		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		December 8, 2012		
Hydrology				
Total Outflow (gal):		1750	Total Precipitation (inch):	0.09
Peak Rain Intensity (in/hr):	5-min: 0.48	15-min: 0.20	Rain Duration (hours):	0.72
Peak Runoff Rate (**gal**/min):		71	Inter-Event Time since prior rain (hours)	82.7
Peak Runoff Rate (% of Design Flow Rate):		47%	Number of Subsamples in event:	13
Bypassed flow volume (gal):		0	Samples Coverage of total storm flow (%)	86.00



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	26	12	25	700	7	12	310	900	73.1
TSS (measured)[3]	26	N/A	N/A	N/A	6	N/A	N/A	N/A	76.9
PM <273µm[4]	20	13	22	55	3	1	20	31	85.0

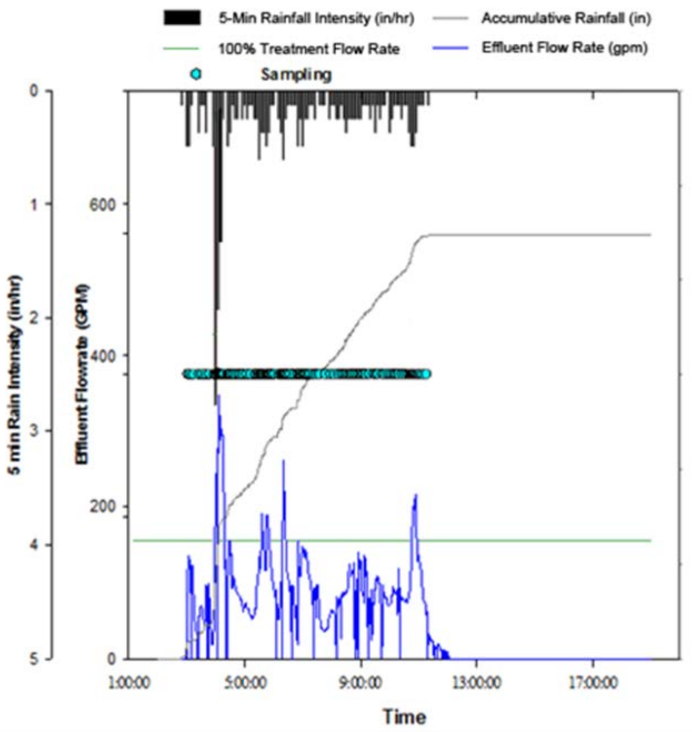
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-17	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm		
Site Name:	Bama Belle Parking Deck			
Location:	N(33°12'50") W(87°34'17")			
Date	December 10, 2012			
Hydrology				
Total Outflow (gal):		47830	Total Precipitation (inch):	2.24
Peak Rain Intensity (in/hr):	5-min: 2.76	15-min: 2.04	Rain Duration (hours):	8.50
Peak Runoff Rate (gal/min):		325	Inter-Event Time since prior rain (hours)	40.8
Peak Runoff Rate (% of Design Flow Rate):		217%	Number of Subsamples in event:	98
Bypassed flow volume (gal):		4,988	Samples Coverage of total storm flow (%)	97.98



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	34	11	67	1000	16	13	28	700	52.9
TSS (measured)[3]	22	N/A	N/A	N/A	13	N/A	N/A	N/A	40.9
PM <273µm [4]	20	6	25	90	12	12	24	50	40.0

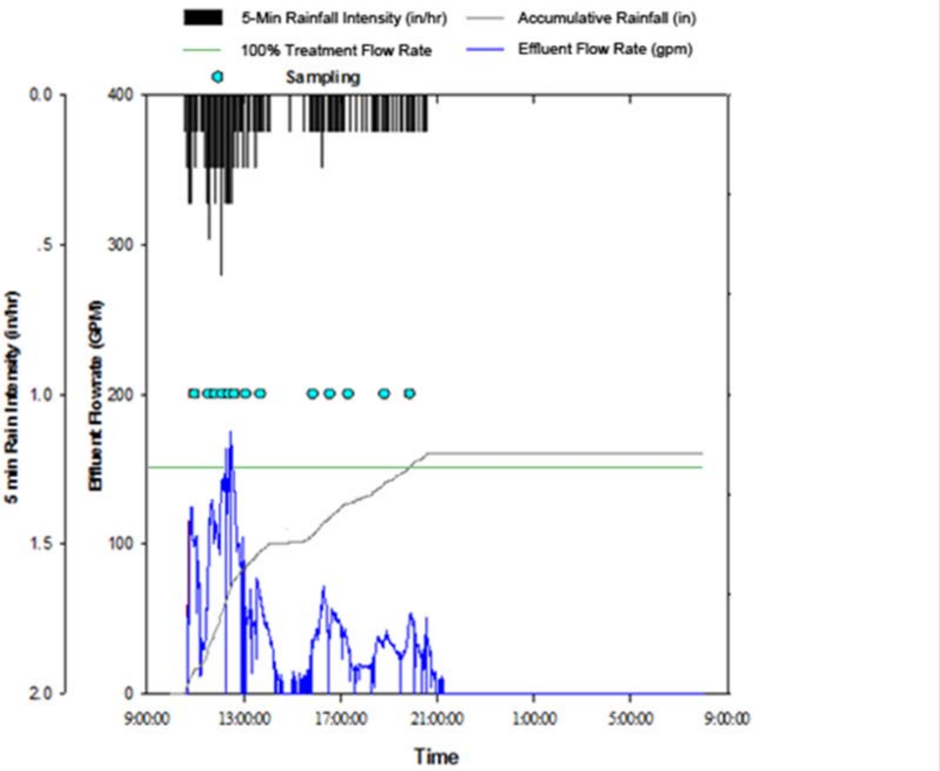
[1] Effluent samples were composites of filtered and non -filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977 -97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273 µm.

Appendix C-18	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	December 16, 2012		
Hydrology			
Total Outflow (gal):	27550	Total Precipitation (inch):	1.20
Peak Rain Intensity (in/hr): 5-min: 0.60	15-min: 0.40	Rain Duration (hours):	10.00
Peak Runoff Rate (gal/min):	166	Inter-Event Time since prior rain (hours)	143.2
Peak Runoff Rate (% of Design Flow Rate):	111%	Number of Subsamples in event:	13
Bypassed flow volume (gal):	433	Samples Coverage of total storm flow (%)	87.63



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	99	145	891	>1180	7	13	528	1180	92.9
TSS (measured)[3]	50	N/A	N/A	N/A	4	N/A	N/A	N/A	92.0
PM <273µm [4]	18	12	144	240	2	2	19	30	88.9

[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

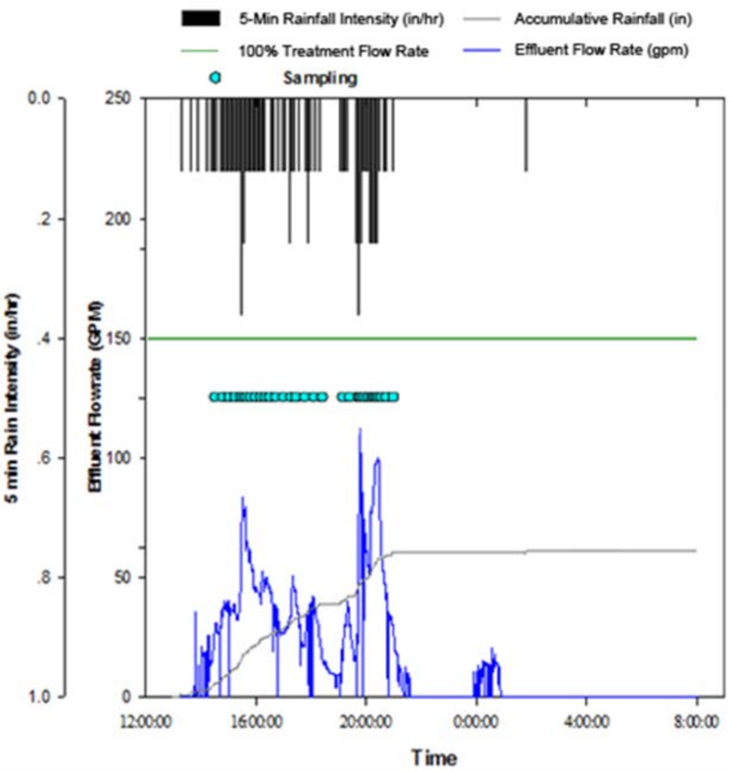
[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-19	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	December 28, 2012		

Hydrology			
Total Outflow (gal):	16242	Total Precipitation (inch):	0.73
Peak Rain Intensity (in/hr): 5-min: 0.36	15-min: 0.24	Rain Duration (hours):	12.55
Peak Runoff Rate (gal/min):	112	Inter-Event Time since prior rain (hours)	64.03
Peak Runoff Rate (% of Design Flow Rate):	74%	Number of Subsamples in event:	32
Bypassed flow volume (gal):	0	Samples Coverage of total storm flow (%)	91.62



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	88	15	528	>1180	6	4	22	400	93.2
TSS (measured)[3]	34	N/A	N/A	N/A	5	N/A	N/A	N/A	85.3
PM <273µm [4]	33	13	21	29	5	4	17	59	84.8

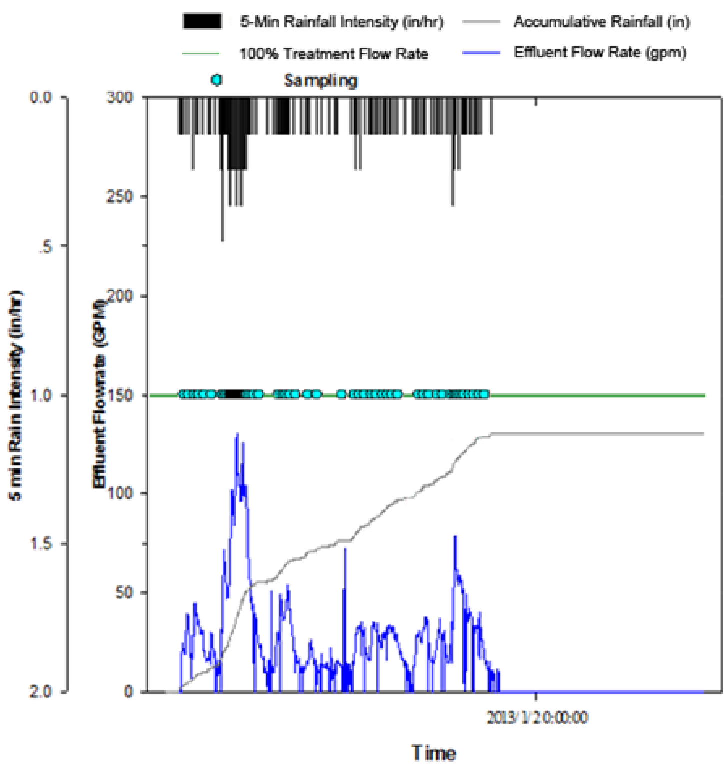
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-20		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		January 1, 2013		
Hydrology				
Total Outflow (gal):		28886	Total Precipitation (inch):	1.30
Peak Rain Intensity (in/hr):	5-min: 0.48	15-min: 0.32	Rain Duration (hours):	16.8
Peak Runoff Rate (gal/min):		130	Inter-Event Time since prior rain (hours)	74.92
Peak Runoff Rate (% of Design Flow Rate):		87%	Number of Subsamples in event:	57
Bypassed flow volume (gal):		4,511	Samples Coverage of total storm flow (%)	98.13



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	29	14	412	1080	3	13	23	420	89.7
TSS (measured)[3]	11	N/A	N/A	N/A	3	N/A	N/A	N/A	72.7
PM <273µm [4]	12	12	22	55	2	12	21	28	83.3

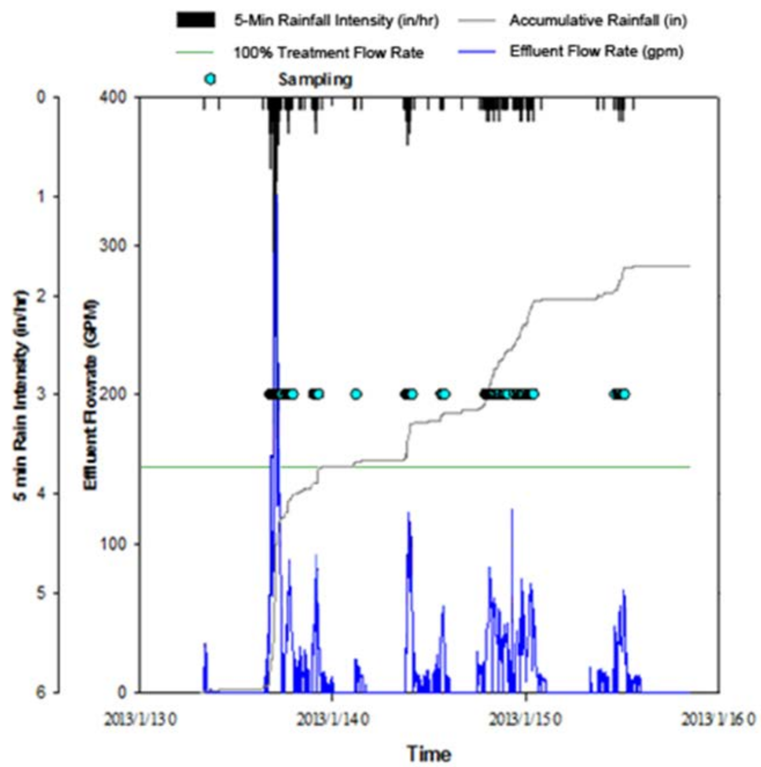
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-21		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		January 13, 2013		
Hydrology				
Total Outflow (gal):		52199	Total Precipitation (inch):	2.15
Peak Rain Intensity (in/hr):	5-min: 2.04	15-min: 1.36	Rain Duration (hours):	53.5
Peak Runoff Rate (gal/min):		332	Inter-Event Time since prior rain (hours)	27.67
Peak Runoff Rate (% of Design Flow Rate):		221%	Number of Subsamples in event:	92
Bypassed flow volume (gal):		13,613	Samples Coverage of total storm flow (%)	96.19



Analytical Data

Constituent	Influent				Effluent1				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	401	24	892	>1180	27	6	30	750	93.3
TSS (measured)[3]	79	N/A	N/A	N/A	23	N/A	N/A	N/A	70.9
PM <273µm [4]	67	11	22	110	22	5	24	90	67.2

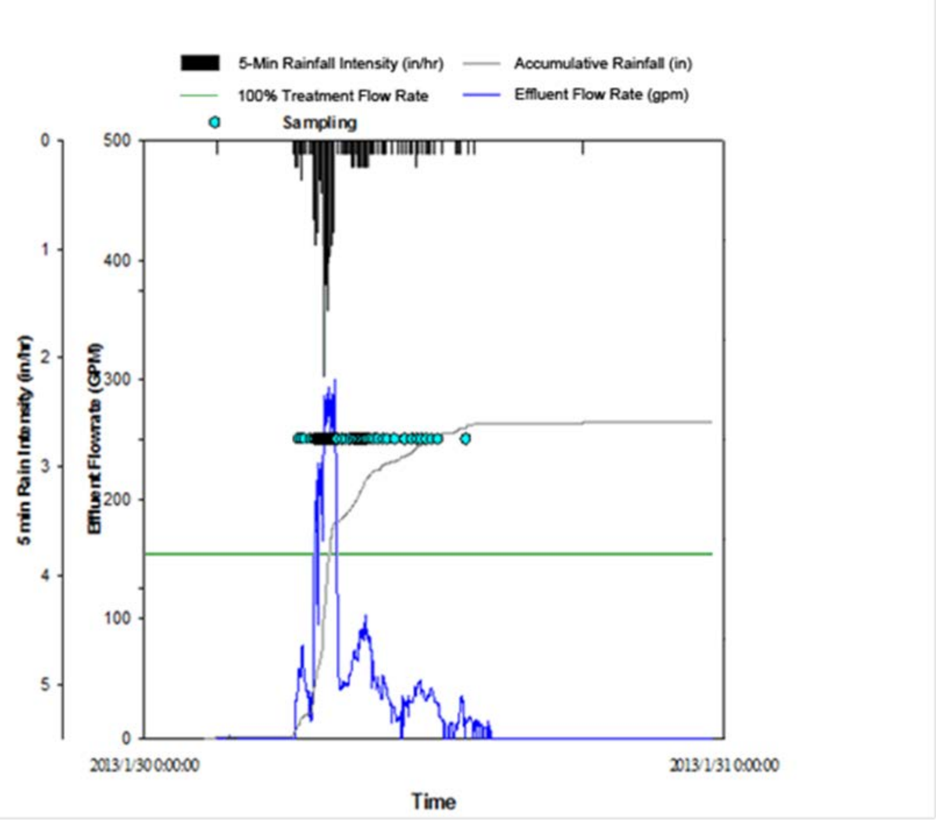
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-22		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		January 30, 2013		
Hydrology				
Total Outflow (gal):		28721	Total Precipitation (inch):	1.59
Peak Rain Intensity (in/hr):	5-min: 2.16	15-min: 1.72	Rain Duration (hours):	15.22
Peak Runoff Rate (gal/min):		297	Inter-Event Time since prior rain (hours)	99.12
Peak Runoff Rate (% of Design Flow Rate):		198%	Number of Subsamples in event:	57
Bypassed flow volume (gal):		14,429	Samples Coverage of total storm flow (%)	96.92



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	2655	277	920	>1180	47	13	23	550	98.2
TSS (measured)[3]	313	N/A	N/A	N/A	40	N/A	N/A	N/A	87.2
PM <273µm [4]	181	5	22	260	40	13	21	29	77.9

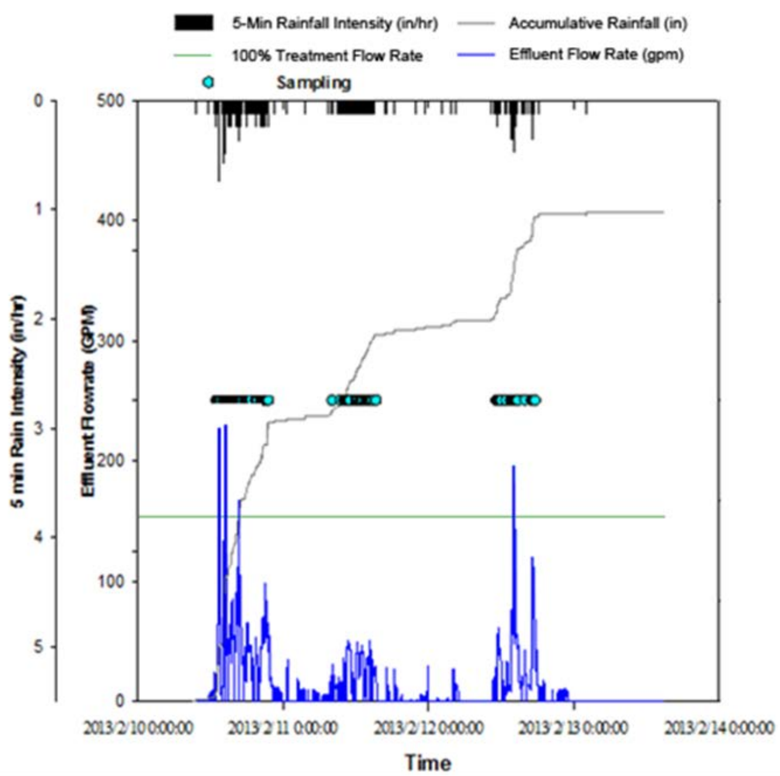
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-23	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	February 10, 2013		
Hydrology			
Total Outflow (gal):	61131	Total Precipitation (inch):	2.44
Peak Rain Intensity (in/hr): 5-min: 2.28	15-min: 1.04	Rain Duration (hours):	64.68
Peak Runoff Rate (gal/min):	290	Inter-Event Time since prior rain (hours)	79.10
Peak Runoff Rate (% of Design Flow Rate):	193%	Number of Subsamples in event:	109
Bypassed flow volume (gal):	14,552	Samples Coverage of total storm flow (%)	96.83



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	1864	275	869	>1180	29	10	24	600	98.4
TSS (measured)[3]	354	N/A	N/A	N/A	25	N/A	N/A	N/A	92.9
PM <273µm [4]	126	10	25	260	25	8	21	120	80.2

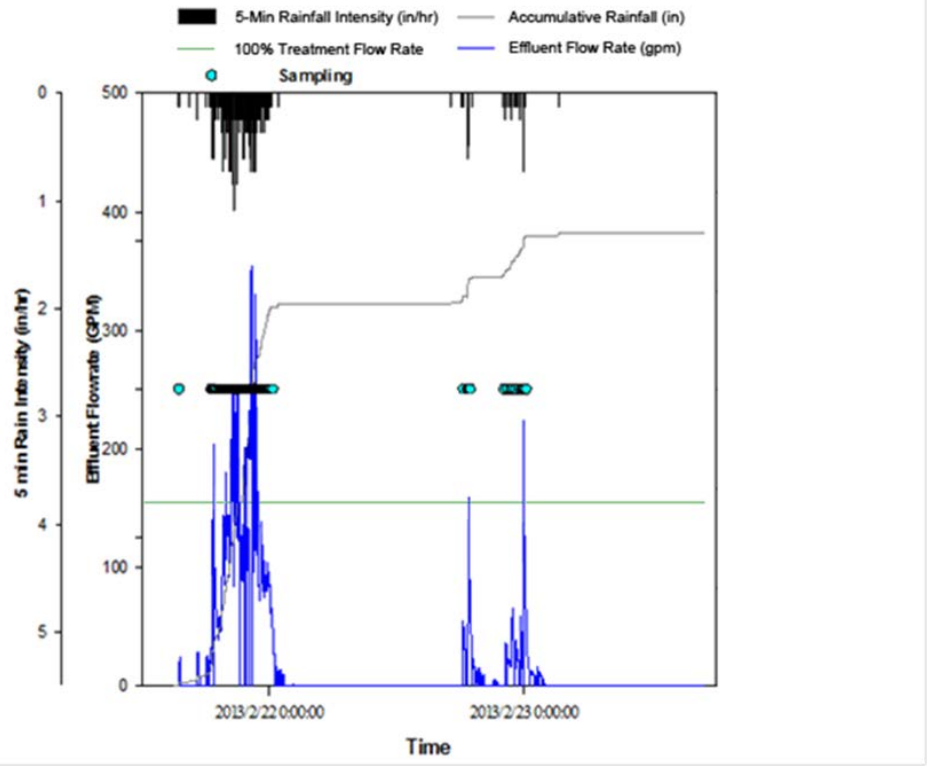
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-24	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	February 21, 2013		
Hydrology			
Total Outflow (gal):	54490	Total Precipitation (inch):	2.29
Peak Rain Intensity (in/hr): 5-min: 1.08	15-min: 0.56	Rain Duration (hours):	35.88
Peak Runoff Rate (gal/min):	353	Inter-Event Time since prior rain (hours)	56.58
Peak Runoff Rate (% of Design Flow Rate):	235%	Number of Subsamples in event:	110
Bypassed flow volume (gal):	16,145	Samples Coverage of total storm flow (%)	98.39



Analytical Data

Constituent	Influent Conc. (mg/L)	Influent d10 (µm)	Influent d50 (µm)	Influent d90 (µm)	Effluent[1] Conc. (mg/L)	Effluent[1] d10 (µm)	Effluent[1] d50 (µm)	Effluent[1] d90 (µm)	% Reduction
SSC (measured)[2]	6231	284	881	>1180	35	12	71	>1180	99.4
TSS (measured)[3]	478	N/A	N/A	N/A	29	N/A	N/A	N/A	93.9
PM <273µm [4]	299	13	28	260	23	7	29	120	92.3

[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

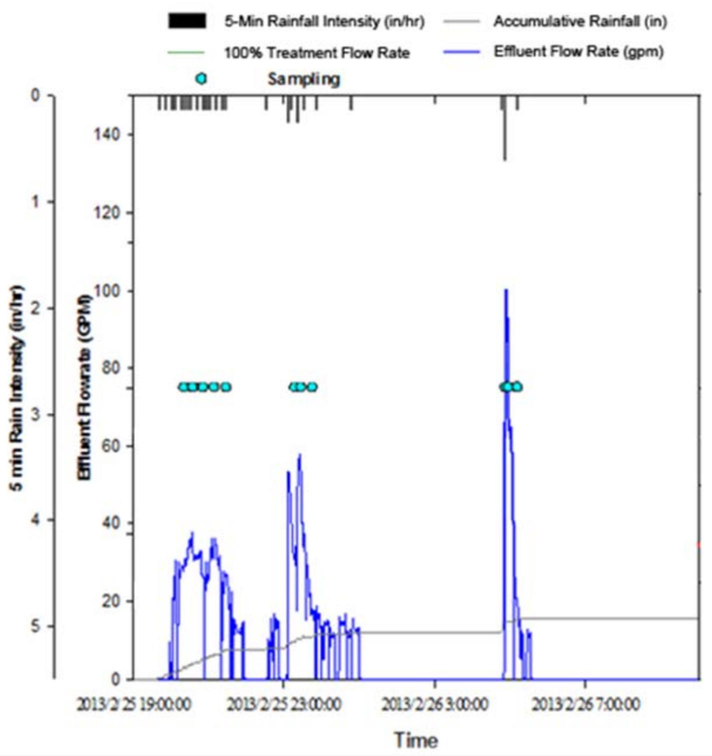
[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-25	6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:	Bama Belle Parking Deck		
Location:	N(33°12'50") W(87°34'17")		
Date	February 25, 2013		

Hydrology			
Total Outflow (gal):	6432	Total Precipitation (inch):	0.31
Peak Rain Intensity (in/hr): 5-min: 0.60	15-min: 0.24	Rain Duration (hours):	9.5
Peak Runoff Rate (gal/min):	98	Inter-Event Time since prior rain (hours)	64.43
Peak Runoff Rate (% of Design Flow Rate):	65%	Number of Subsamples in event:	11
Bypassed flow volume (gal):	1,341	Samples Coverage of total storm flow (%)	90.44



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	524	36	872	>1180	8	13	66	>1180	98.5
TSS (measured)[3]	210	N/A	N/A	N/A	4	N/A	N/A	N/A	98.1
PM <273µm [4]	81	12	26	245	4	8	20	28	95.1

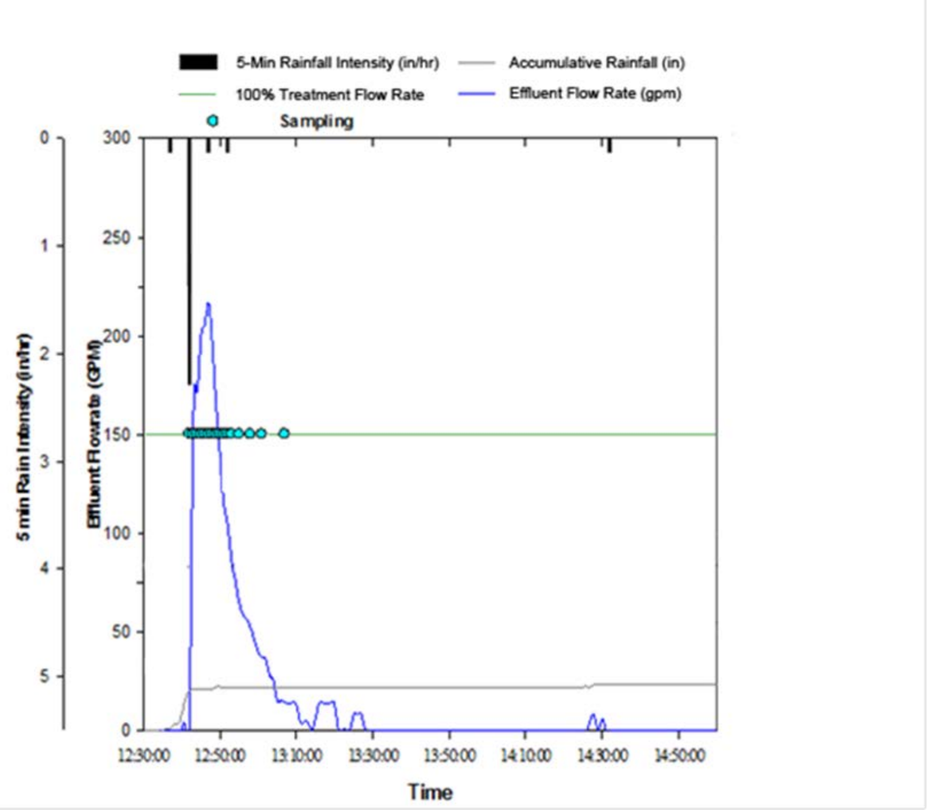
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-26		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		March 5, 2013		
Hydrology				
Total Outflow (gal):		2492	Total Precipitation (inch):	0.23
Peak Rain Intensity (in/hr):	5-min: 2.28	15-min: 0.88	Rain Duration (hours):	1.87
Peak Runoff Rate (gal/min):		217	Inter-Event Time since prior rain (hours)	175.43
Peak Runoff Rate (% of Design Flow Rate):		145%	Number of Subsamples in event:	19
Bypassed flow volume (gal):		1,485	Samples Coverage of total storm flow (%)	93.14



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	495	24	901	>1180	68	7	52	>1180	86.3
TSS (measured)[3]	197	N/A	N/A	N/A	56	N/A	N/A	N/A	71.6
PM <273µm [4]	79	6	22	120	42	5	22	80	46.8

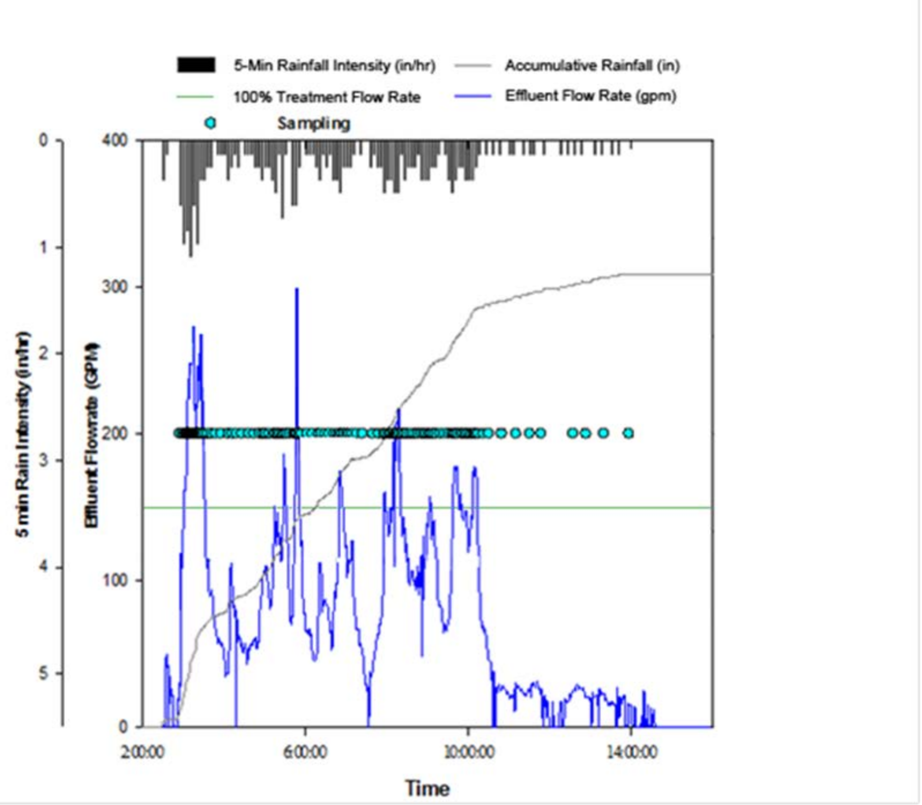
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-27		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		March 11, 2013		
Hydrology				
Total Outflow (gal):		53629	Total Precipitation (inch):	2.32
Peak Rain Intensity (in/hr):	5-min: 1.08	15-min: 0.96	Rain Duration (hours):	11.20
Peak Runoff Rate (gal/min):		299	Inter-Event Time since prior rain (hours)	132.03
Peak Runoff Rate (% of Design Flow Rate):		199%	Number of Subsamples in event:	110
Bypassed flow volume (gal):		33,802	Samples Coverage of total storm flow (%)	98.80



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	2386	306	1175	>1180	30	6	44	>1180	98.7
TSS (measured)[3]	245	N/A	N/A	N/A	28	N/A	N/A	N/A	88.6
PM <273µm [4]	111	5	22	260	20	5	22	85	82.0

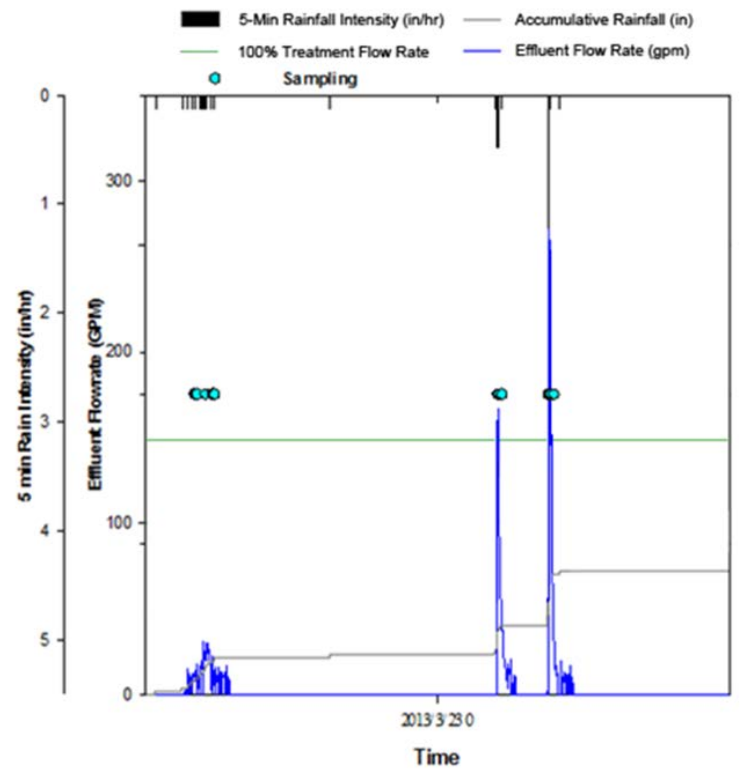
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-28		6-Module Up-Flo® Filter		Design Flow rate: 150 gpm
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		March 22, 2013		
Hydrology				
Total Outflow (gal):		7129	Total Precipitation (inch):	0.41
Peak Rain Intensity (in/hr):	5-min: 1.92	15-min: 0.68	Rain Duration (hours):	23.52
Peak Runoff Rate (gal/min):		265	Inter-Event Time since prior rain (hours)	87.25
Peak Runoff Rate (% of Design Flow Rate):		177%	Number of Subsamples in event:	21
Bypassed flow volume (gal):		2,627	Samples Coverage of total storm flow (%)	91.26



Analytical Data

Constituent	Influent				Effluent[1]				% Reduction
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	
SSC (measured)[2]	302	15	711	>1180	42	4	32	>1180	86.1
TSS (measured)[3]	197	N/A	N/A	N/A	43	N/A	N/A	N/A	78.2
PM <273µm[4]	91	7	23	75	32	4	17	90	64.8

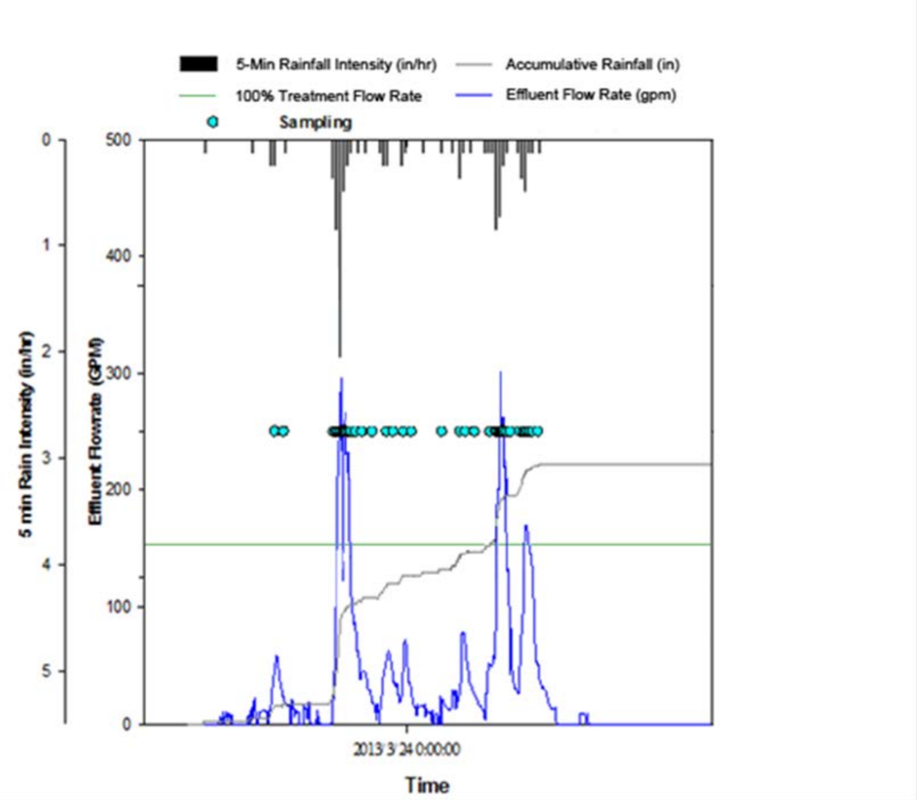
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-29		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		March 23, 2013		
Hydrology				
Total Outflow (gal):		20583	Total Precipitation (inch):	0.89
Peak Rain Intensity (in/hr):	5-min: 2304	15-min: 1.16	Rain Duration (hours):	7.68
Peak Runoff Rate (gal/min):		299	Inter-Event Time since prior rain (hours)	12.27
Peak Runoff Rate (% of Design Flow Rate):		199%	Number of Subsamples in event:	41
Bypassed flow volume (gal):		9,364	Samples Coverage of total storm flow (%)	94.22



Analytical Data									
Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	3243	327	>1180	>1180	41	6	48	>1180	98.7
TSS (measured)[3]	369	N/A	N/A	N/A	26	N/A	N/A	N/A	93.0
PM <273µm[4]	137	10	24	260	28	5	25	80	79.6

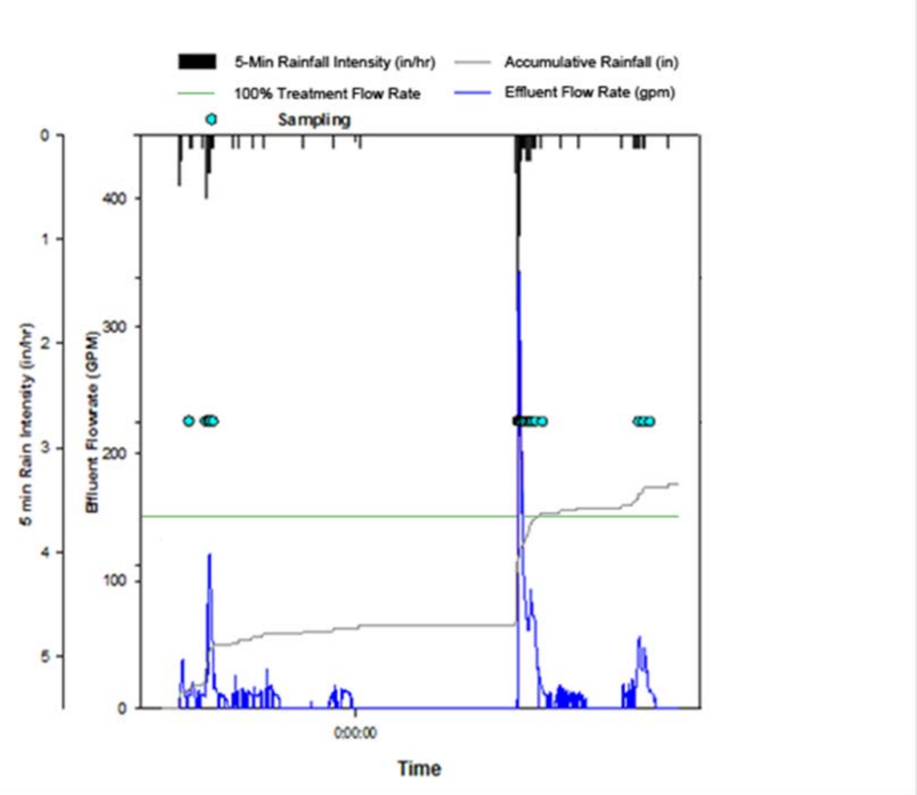
[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

Appendix C-30		6-Module Up-Flo® Filter	Design Flow rate: 150 gpm	
Site Name:		Bama Belle Parking Deck		
Location:		N(33°12'50") W(87°34'17")		
Date		March 30, 2013		
Hydrology				
Total Outflow (gal):		13978	Total Precipitation (inch):	0.78
Peak Rain Intensity (in/hr):	5-min: 1.68	1.08	Rain Duration (hours):	22.78
Peak Runoff Rate (gal/min):		340	Inter-Event Time since prior rain (hours)	156.70
Peak Runoff Rate (% of Design Flow Rate):		227%	Number of Subsamples in event:	22
Bypassed flow volume (gal):		4,602	Samples Coverage of total storm flow (%)	96.09



Analytical Data

Constituent	Influent				Effluent[1]				%
	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Conc. (mg/L)	d10 (µm)	d50 (µm)	d90 (µm)	Reduction
SSC (measured)[2]	879	30	1003	>1180	51	12	50	>1180	94.2
TSS (measured)[3]	389	N/A	N/A	N/A	46	N/A	N/A	N/A	88.2
PM <273µm[4]	186	5	33	110	37	8	29	90	80.1

[1] Effluent samples were composites of filtered and non-filtered (i.e. bypassed) flow.

[2] SSC concentration measured by ASTM D3977-97B. The particle size distribution was measured using wet sieving, a Coulter Counter and a 0.45µm filter.

[3] TSS concentration measured by SM 2540D. Particle size distribution was not measured for TSS.

[4] PM <273µm is reported as the fraction of measured SSC less than 273µm.

APPENDIX D

INSTALLATION REQUIREMENTS AND MAINTENANCE PLANS

Installation Requirements

The Up-Flo® Filter is an engineered system and as such, Hydro International's engineers work with site designers to generate a detailed engineering submittal package for each installation. Design limitations resulting from specific installation requirements are typically identified and managed during the design process. Design parameters and limitations are discussed in general terms below.

Required soil characteristics

The Up-Flo® Filter is a flow-through system contained within a water tight manhole, therefore it can be installed and function as intended in all soil types.

Depth to seasonal high water table

Although as a water-tight flow-through system the functionality of the Up-Flo® Filter is not impacted by high groundwater, Hydro International recommends consulting their engineering staff to determine whether the addition of anti-flotation collars to the base of the Up-Flo® Filter chamber are necessary to counterbalance buoyant forces.

Slope of Drainage Pipe

Hydro International recommends contacting our design engineers when the Up-Flo® Filter is going to be installed on a drainage line with a slope greater than 10%. With steeply sloping pipe, site specific parameters such as pipe size, the module arrangement within the Up-Flo® Filter and the frequency of peak flow are taken into consideration by the Hydro International design team.

Drainage Pipe Drop across Up-Flo® Filter

The Up-Flo® Filter is designed with 9.48" of drop from inlet invert to outlet invert. The drop is provided to prevent unnecessary standing water upstream of the unit, to reduce the stress on the drain down filter, and to prevent the filter media from remaining saturated with water for extended periods of time, reducing the life of the filter media. Any water surface elevation less than 9.48", relative to the outlet invert is directed through the drain down filter. Any water surface elevation greater than 9.48", relative to the outlet invert creates head to drive flow through the filter media (a small amount of flow still goes through the drain down filter). See **Figure D-1** below.

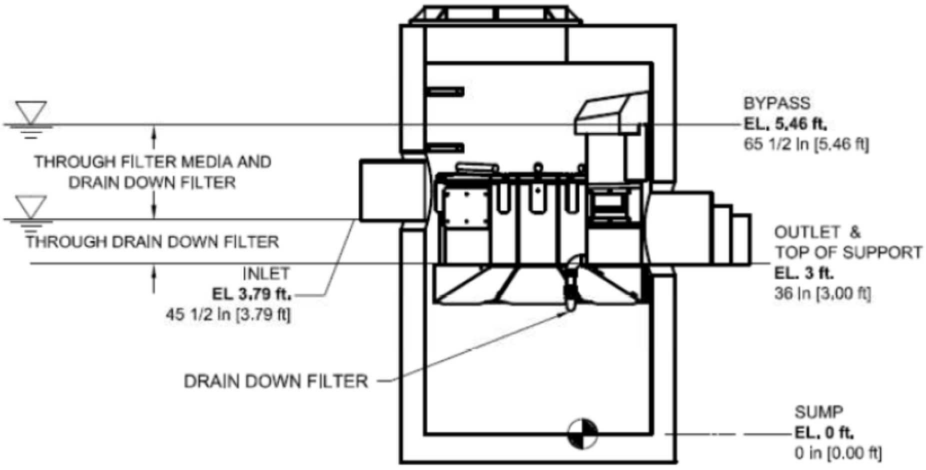


Fig.D-1 The Up-Flo® Filter is designed with 9.48" of Drop from Inlet Invert to Outlet Invert

Tail water

A tail water condition in a detention system or pond will not adversely impact the operation of the Up-Flo® Filter until the level of tail water surpasses the elevation of the outlet invert by 9.5". Once the tail water surpasses this elevation, it will start to restrict the flow rate through the filtration media. If a higher tail water is expected at a given site, Hydro International recommends contacting their engineering department for design assistance.

Maintenance Requirements

The Up-Flo® Filter should be inspected and maintained in line with the recommendations and guidelines set forth in the Operations and Maintenance (O&M) Manual (http://www.hydro-int.com/UserFiles/downloads/UFF-Operation%20and%20Maintenance_0.pdf.pdf).

The O&M Manual outlines the minimum recommended frequency for maintaining each component of the Up-Flo® Filter, a description of the events that cause the need for inspection and/or maintenance, the location of inspection and maintenance access ports, an outline of equipment and steps required for inspection and maintenance, and links to instructional training videos.