

NJCAT TECHNOLOGY VERIFICATION
AQUA-SWIRL[®] MODEL AS-5 STORMWATER
TREATMENT SYSTEM

AquaShield[™], Inc.

November 2012

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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

AquaShield™, Inc. (AquaShield™) manufactures a stormwater treatment system known as the Aqua-Swirl® Stormwater Treatment System. Treatment to stormwater runoff is accomplished via hydrodynamic separation technology. AquaShield™ received NJCAT verification of claims for the Aqua-Swirl® Stormwater Treatment System in September 2005 and a Conditional Interim Certification (CIC) was issued by NJDEP dated November 28, 2005 based upon the results of independent laboratory studies. The Aqua-Swirl® received Manufactured Treatment Device (MTD) Laboratory Test Certification from NJDEP effective September 1, 2011. This certification was issued subsequent to rescinding the Conditional Interim Certification for the Aqua-Swirl®. The current laboratory certification status applies to all eligible hydrodynamic separators.

A major condition of the 2005 CIC was the execution of a field evaluation in accordance with the Technology Acceptance Reciprocity Partnership (TARP) Tier II Protocol (TARP, 2003) and New Jersey Tier II Stormwater Test Requirements—Amendments to TARP Tier II Protocol (NJDEP, 2006). A Quality Assurance Project Plan (QAPP) for the Field Evaluation was completed in December of 2009 and revised in May 2010; monitoring activities commenced in March 2009. The TARP Tier II Protocol is designed to evaluate Total Suspended Solids (TSS) removal on an annual basis.

1.3 Applicant Profile

AquaShield™ manufactures stormwater treatment systems used worldwide to protect sensitive receiving waters from the harmful effects of stormwater. The commitment of AquaShield™ to provide quality environmental solutions began in the early 1980s with its founder solving surface water and groundwater contaminant issues at industrial and commercial facilities through his previously owned environmental consulting/contracting companies. The first product, a catch basin insert (now known as the Aqua-Guardian™), was introduced in 1997 for use at point source problem sites such as gas stations, fast food restaurants and high traffic parking lots. The AquaShield™ stormwater filtration technology expanded into underground structures in 1999 with the installation of a "treatment train" structure utilizing pretreatment sediment removal incorporated with a filtration chamber to remove fine contaminants. This became the Aqua-Filter™ Stormwater Filtration System.

Early in 2000, AquaShield™ formed its corporate office in Chattanooga, Tennessee. AquaShield™ received patents for treatment systems that integrated hydrodynamic swirl separation technology for pretreatment with high flow filtration technology in a single device. In 2001, the stand-alone Aqua-Swirl® hydrodynamic swirl concentrator was introduced to meet the increasing requests for primary pollutant removal of sediment and floatable debris and oils. Accordingly, AquaShield™ offers three essential patented alternatives for treating stormwater and industrial runoff: the Aqua-Swirl® Stormwater Treatment System, the Aqua-Filter™ Stormwater Filtration System, and the Aqua-Guardian™ Catch Basin Insert. Other derivatives of these core products have been adapted for customers needing further enhanced water treatment. These products distinguish themselves from other systems with their high performance and lightweight construction material, providing flexibility and adaptation to site-specific conditions. Each product arrives at the project job site completely assembled and ready for installation.

1.4 Key Contacts

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2. The Aqua-Swirl® Stormwater Treatment System

The Aqua-Swirl® is a single chamber hydrodynamic separator that provides for the removal of sediment, debris and free-floating oil. The Aqua-Swirl® uses a swirl chamber as the effective horizontal treatment area that creates a swirling or vortex motion. The decreasing flow rate in the swirl chamber causes suspended material to fall out of suspension and settle to the bottom of the chamber. An inner arched baffle minimizes the potential for oil and debris to be discharged.

Operation begins when stormwater enters the Aqua-Swirl® through a tangential inlet pipe which produces a circular (or vortex) flow pattern that causes contaminants to settle. Since stormwater flow is intermittent by nature, the Aqua-Swirl® retains water between storm events providing both dynamic and quiescent settling of inorganic solids. Dynamic settling occurs during each storm event, while the quiescent settling takes place between successive storms. A combination of gravitational and hydrodynamic drag forces allows the solids to drop out of the flow and migrate toward the center of the chamber where velocities are the lowest.

It is recognized that the small sized settleable solids in stormwater runoff exhibit low settling velocities. Therefore, the volume of water retained in the Aqua-Swirl® provides the quiescent settling that increases suspended sediment removal performance. Furthermore, due to finer sediment adhering onto larger particles, these large particles settle rather than remain in suspension.

The Aqua-Swirl[®] provides full treatment of the most contaminated first flush, while the cleaner peak storm flow is diverted and channeled through the main conveyance pipe. The treated flow exits the Aqua-Swirl[®] behind the arched inner baffle. The top of the baffle is sealed across the treatment channel, thereby eliminating any possibility of floatable pollutants to escape the system. A vent pipe is extended up the riser to expose the back side of the baffle to atmospheric conditions, thereby preventing a siphon from forming at the bottom of the baffle. **Figure 1** illustrates stormwater flow through the Aqua-Swirl[®] treatment unit. The Aqua-Swirl[®] can be operated in an offline configuration providing full treatment of the first flush with installation of additional manhole structures for diverging flow to the Aqua-Swirl[®] for treatment and converging back to the exiting main conveyance storm drainage.

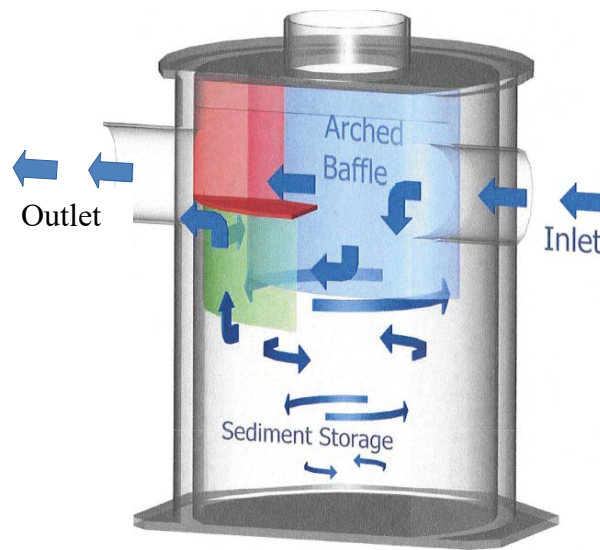


Figure 1. Aqua-Swirl[®] Mode of Operation

Cleanout of captured material is required when the sediment storage capacity has been reached. The depth to the sediment pile can easily be determined using a stadia rod or tape. A vacuum truck is typically used to remove the accumulated sediment and debris.

3. Technology System Evaluation: Project Plan

3.1 Introduction

The TARP field test of the Aqua-Swirl[®] Model AS-5 (5-ft. swirl diameter chamber; 45 ft³ sediment storage capacity) that is the subject of this report (AECOM 2012) was conducted by AECOM, 4 Neshaminy Interplex, Suite 300, Trevose, Pennsylvania 19053. Prior to initiating the field test the source area rainfall and pollutant characteristics were reviewed with NJCAT and confirmed as acceptable for performing a TARP field study.

3.2 Site and System Description

Field verification testing was conducted at the Burnt Mills Shopping Center in Silver Spring, Montgomery County, Maryland. The test site drainage area is an asphalt covered parking lot with landscaped areas and roof runoff on an urban retail shopping center. The total drainage area is estimated at 1.19 acres. An offline Aqua-Swirl[®] AS-5 treatment unit was installed as the upstream component of a treatment train system to provide sediment removal from parking lot stormwater runoff. An aerial site plan of the Burnt Mills Shopping Center is presented as **Figure 2**. A site plan of the Burnt Mills Shopping Center including the location of the Aqua-Swirl[®] is presented as **Figure 3**. Parking lot stormwater runoff is collected in catch basins and conveyed to the Aqua-Swirl[®] via underground piping.

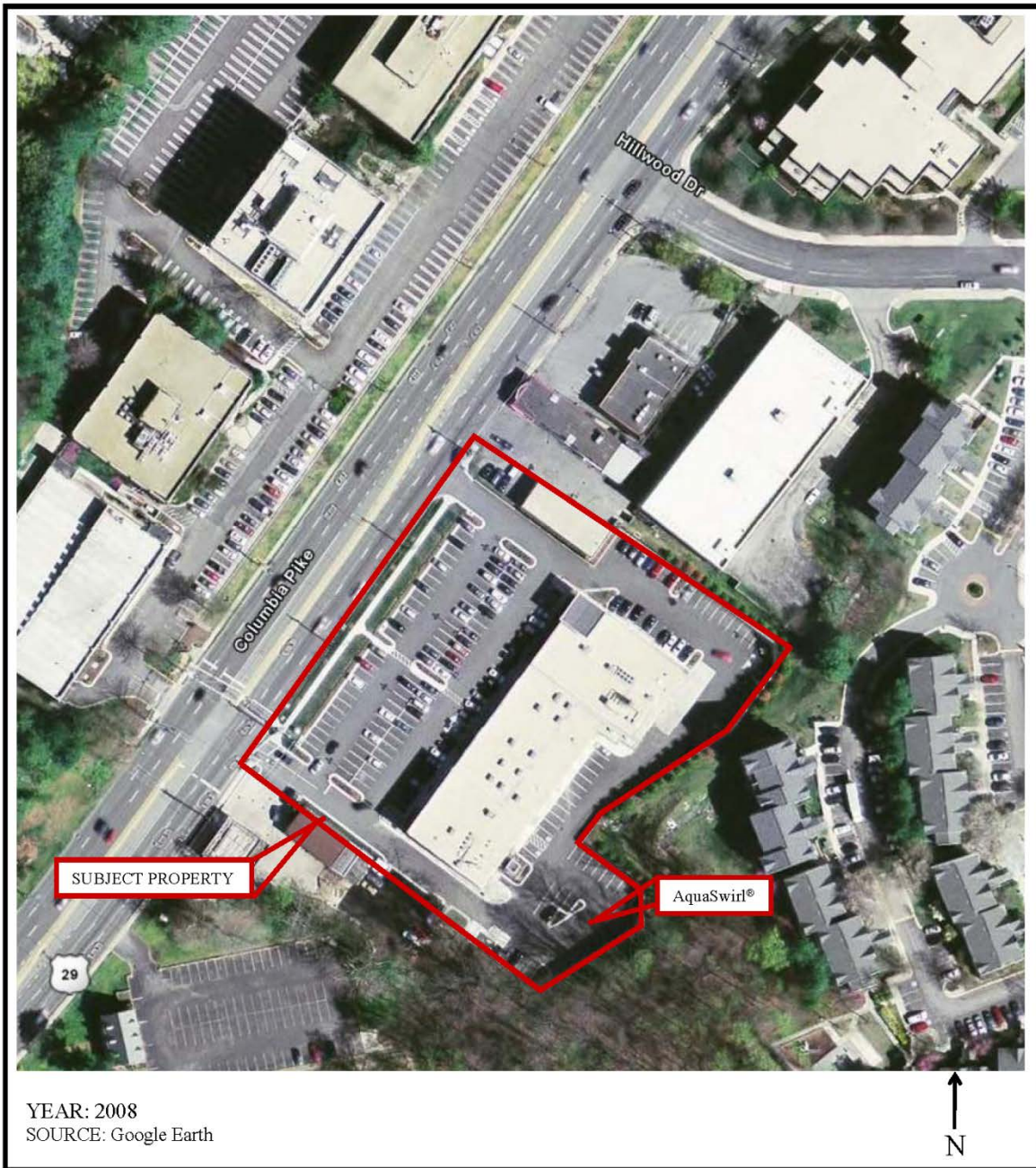
Specific requirements for field verification testing under the TARP Tier II protocol includes the definition of a qualified storm event, representative sample collection, the number of storm events required to be tested and specific conditions regarding the influent characteristics of the stormwater to be treated. Qualified storm event sampling is defined as:

- a storm event with at least 0.1 inch of rainfall;
- a minimum inter-event period of six hours, where cessation of flow from the system is the inter-event period;
- flow-weighted composite samples were obtained covering a minimum of 60% of the total storm flow, including as much of the first 20% of the storm as possible; and
- a minimum of six water quality samples were collected per storm event.

3.3 Sampling Design


Sampling activities involved the collection of stormwater influent and effluent sample pairs during qualified storm events. Sampling procedures were developed according to guidance given in TARP and in the "Field Sampling Procedures Manual," NJDEP, August 2005.

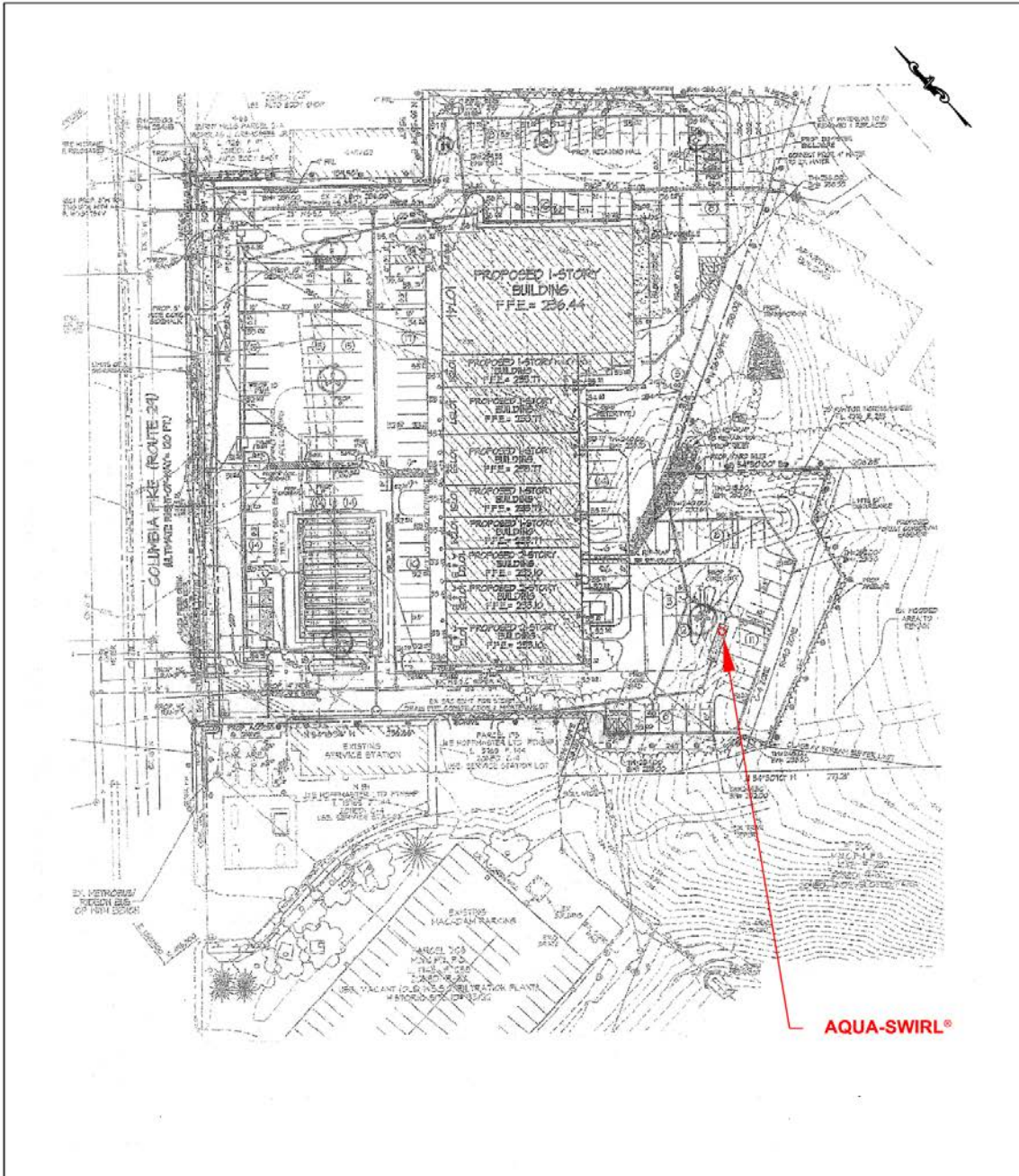
The influent and effluent samples were collected from locations that were as close in proximity to the Aqua-Swirl[®] as possible to minimize potential sources of contamination that would impact the Best Management Practice (BMP) efficiency data. Influent samples were collected immediately upstream of the Aqua-Swirl[®]. Piping from the divergence structure conveys stormwater to the Aqua-Swirl[®]. Effluent samples were collected from the effluent pipe that leads directly from the swirl chamber to the downstream component of the treatment train system. **Figure 4** presents the sampling locations for the Aqua-Swirl[®].



Four Neshaminy Interplex, Suite 300
Trevose, Pennsylvania 19053

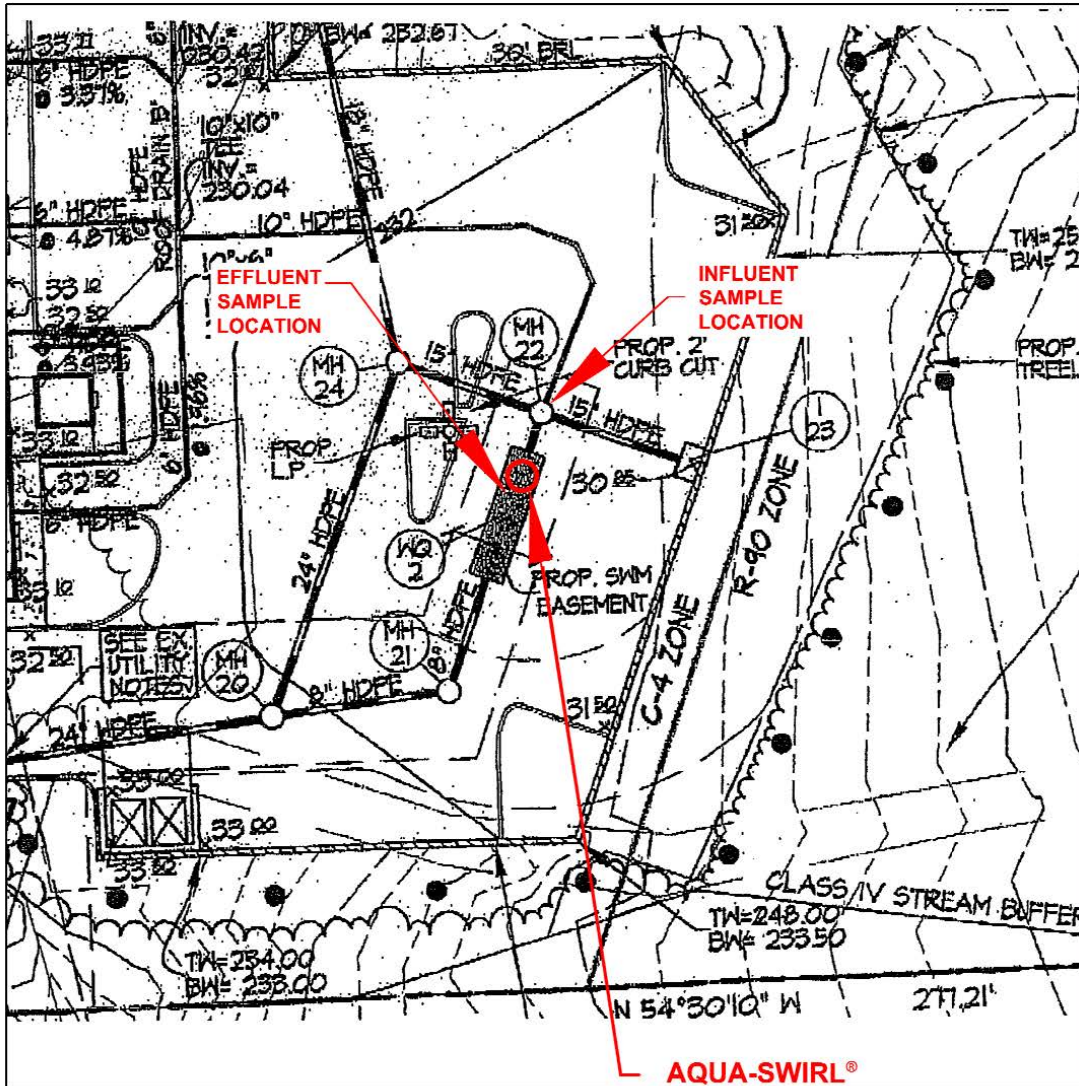
ENVIRONMENTAL/CONSULTING ENGINEERS

	PROJECT: Burnt Mills Shopping Center 10731 Columbia Pike Silver Spring, MD 20901	Site Location Map
		Figure 2 Project No: 60135194



SOURCE: GLW GUTSCHICK LITTLE & WEBER, P.A. SITE PLAN, DATED 1-2004


	PROJECT: BURNT MILLS SHOPPING CENTER 10731 COLUMBIA AVENUE SILVER SPRING, MARYLAND 20901		ENVIRONMENTAL / CONSULTING ENGINEERS	
	TITLE: SITE PLAN		SCALE:	DATE:
			NTS: As Shown	10/2009
			PROJECT NO. 60135194	FIGURE NO. 3



SOURCE: GLW GUTSCHICK LITTLE & WEBER, P.A., SITE PLAN, DATED 1-2004

FOUR NESHAMINY INTERPLEX, SUITE 300
TREVOSE, PENNSYLVANIA 19053

ENVIRONMENTAL / CONSULTING ENGINEERS

	PROJECT:	BURNT MILLS SHOPPING CENTER 10731 COLUMBIA AVENUE SILVER SPRING, MARYLAND 20901		TITLE:	SAMPLE LOCATIONS			
				SCALE:	NTS: As Shown	DATE:	10/2009	
				PROJECT NO.	60135184		FIGURE NO.	4

3.4 Test Equipment and Apparatus

The ISCO Portable Sampler Model 6712 was used as the programmable automatic sampler for field verification testing. This sampler can be programmed to collect specific sample volumes over specified time periods and can be used in conjunction with an area velocity meter to allow flow proportional composite sampling. An ISCO 750 Area Velocity Meter was used to record flow during a storm event. The ISCO 750 uses Doppler technology to measure average velocity in the flow stream. A pressure transducer measures liquid depth to determine flow area. The ISCO 6712, when interfaced with the ISCO 750, calculates flow rate (cubic feet per second) by multiplying the area (square feet) of the flow stream by its average velocity (feet per second). A liquid level actuator was used to simultaneously activate the ISCO 750 Area Velocity Meter and the ISCO 6712 sampler once flow was present ensuring that the first flush of each storm event was sampled.

Six influent and effluent sample pairs were collected and submitted to the laboratory for 17 of the 18 storm events. For the 18th event five samples were collected and submitted. Collected samples were transferred through a cone sample splitter (Dekaport Cone Sample Splitter) fitted with a 4-inch diameter 1,000 micron (μm) sieve. Particles smaller than 1,000 μm passed through the sieve and were collected in sample bottles. The sample bottles were placed on ice and promptly shipped to the laboratory to ensure that all analytical methodology holding times were met.

The TARP requirement for a minimum of six samples to be collected from each storm was interpreted that a minimum of six *individual composite samples* of the influent and effluent were required to be submitted for laboratory analysis. The six individual sample analytical results were then averaged to establish an overall influent and effluent composite analytical result. For 17 of the 18 events a total of twenty-four 1-liter aliquots were collected during each sampling event providing the volume required to prepare six individual composite samples for laboratory analysis. For one event only twenty 1-liter aliquots were collected since the samplers shut off due to insufficient flow (liquid level actuator). The collection of six individual samples from 24 aliquots provided additional data concerning the fluctuation of influent loading and removal efficiency over the storm period, and well exceeded the TARP guidelines of a minimum of six and a goal of 10 sample aliquots collected during each storm. Due to the need to collect sufficient sample volumes for the required analyses, storm durations had to be conservatively predicted which led to varying sampling durations, and consequently event coverage, within the rainfall period. Sampling was suspended when the 24 1-liter aliquots were collected.

3.5 Test Methods and Procedures

Table 1 presents the analytical methods used for the field testing program. Suspended sediment was determined by both the Total Suspended Solids (TSS) and Suspended Sediment Concentration (SSC) methods. Total Volatile Suspended Solids (TVSS) analysis was also performed to assess the organic content of the suspended sediment. The TSS, SSC and TVSS results are reported as mg/L by the laboratory. Particle size distribution (PSD) was determined by serial filtration techniques using sieves sized at 1,000, 500, 250, 125, 63 μm and filter paper at 1.5 μm .

Table 1
Summary of Analytical Methods

Parameter	Matrix	Method Reference
Total Suspended Solids Suspended-Sediment Concentration Total Volatile Suspended Solids	Water (Influent, Effluent)	SM 2540D ASTM D3977 EPA Method 160.4
Particle Size Distribution	Water (Influent, Effluent)	Serial Filtration Method

All analyses of samples were performed by a NELAC and New Jersey certified laboratory, Test America, Inc. of Burlington, Vermont.

3.6 Precipitation Measurements

An on-site rain gauge was used to measure the total precipitation for each sampling event. In addition, the nearest available documented weather station (Kemp Mill/Silver Spring), located approximately 1.5 miles from the Burnt Mills Shopping Center, was used to verify qualified storm events and the total precipitation for each sampling event. The weather station's recorded precipitation data over time was also used to determine rainfall intensity during each sampling event.

Table 2 presents a summary of the sampling precipitation events and sampling duration for each event. The total precipitation sampled was 15.16 inches with storm sizes ranging from a low of 0.11 inches to a high of 4.40 inches. TARP guidelines specify that a minimum qualifying event is 0.1 inches. Storm durations ranged from 30 minutes to 12 hours 5 minutes. The average precipitation during the stormwater sampling program was 0.84 inches. The storm duration coverage for each storm fluctuated from 30 to 80 percent with an overall average sampling time period of the storms of 60%. Storm durations were estimated based upon the recorded precipitation at the Kemp Mill/Silver Spring weather station, which only had a 2.6% variance from the test site measured participation. For all storm events, samples were collected from the first 20% of the total storm event flow.

Hydrographs of the recorded effluent flows over time during each sampling event and the measured precipitation over time as recorded at the Kemp Mill/Silver Spring weather station were developed and are presented in **Appendix A**. The hydrographs provide a graphic illustration of the recorded flows, rainfall intensity and when flow-weighted composite samples were collected during each storm event. The hydrographs also provide a graphic presentation of the sampling duration for each storm event; the area under the precipitation curve illustrates the percent storm coverage (**Table 3**).

3.7 Flow Measurements

Flows were recorded during each sampling event, downloaded and summarized to provide flow measurements for each sampling interval. These flow measurements were used to calculate

hydraulic loading rates to the Aqua-Swirl[®] as well as to determine mass loading of suspended solids during each sampling event.

Table 2
Summary of Storm Sampling Events – Storm Duration

Sampling Event	Sample Date	Storm Duration	Storm Size	Sampling Duration	Storm Coverage (%)
		(hr:min)	(inches)	(hr:min)	
1	March 14, 2009	0:30	0.11	0:22	70
2	April 1, 2009	0:50	0.18	0:33	70
3	April 6, 2009	2:00	0.15	1:15	60
4	December 25-26, 2009	11:45	0.56	7:22	60
5	January 17, 2010	4:48	0.59	3:15	70
6	July 25, 2010	0:46	0.55	0:38	80
7	August 12, 2010	3:00	1.82	1:42	60
8	September 12, 2010	3:45	0.61	2:59	80
9	September 29-30, 2010	12:05	4.40	4:52	40
10	December 1, 2010	6:20	0.71	3:12	50
11	December 11, 2010	3:40	0.72	1:25	40
12	February 25, 2011	2:15	0.29	1:30	70
13	March 6, 2011	4:50	1.42	1:59	40
14	March 15-16, 2011	5:06	0.42	3:00	60
15	April 8, 2011	3:55	0.52	1:31	40
16	April 28, 2011	2:19	0.23	1:33	70
17	May 14, 2011	3:05	0.85	1:12	40
18	June 16, 2011	3:20	1.03	0:59	30
		Average	0.84		60
		Total	15.16		

3.8 Stormwater Data Collection

Table 3 summarizes the storm characteristics (coverage, size, peak intensity and peak loading rate). Peak storm intensities ranged from 0.15 to 5.49 inches per hour (in/hr.). Peak loading rates ranged from 1.9 to 35.4 gallons per minute per square foot (gpm/ft²). The AS-5 uses a five foot diameter (19.6 square foot) effective treatment area. The recorded flows for each sampling interval were converted from cfs to gpm. The loading rates were then calculated by dividing the flow rate for each sampling interval by the cross-sectional area of the AS-5. **Figure 5** compares the storm intensities to the peak loading rates for the 18 storms. The plot demonstrates that the relationship between peak intensities and peak loading rates were consistent during the testing period. TARP guidelines specify that at least two storms must exceed 75% of the design treatment capacity. Sampling events #7 and #9 exhibited the highest loading rates of 30.9 and 35.4 gpm/ft² respectively, only exceeding 75% of a treatment capacity of 41.2 gpm/ft².

Table 3
Storm Characteristics-(coverage, size, peak intensity and peak loading rate)

Sampling Event	Sample Date	Storm Duration (hr:min)	Storm Size (inches)	Storm Coverage (%)	Peak Storm Intensity (in/hr)	Peak Loading Rate (gpm/ft ²)
1	March 14, 2009	0:30	0.11	60	0.26	4.1
2	April 1, 2009	0:50	0.18	50	0.46	8.1
3	April 6, 2009	2:00	0.15	60	0.26	4.8
4	December 25-26, 2009	11:45	0.56	60	0.38	4.8
5	January 17, 2010	4:48	0.59	60	0.42	10.4
6	July 25, 2010	0:46	0.55	100	1.21	16.9
7	August 12, 2010	3:00	1.82	90	5.49	30.9
8	September 12, 2010	3:45	0.61	80	0.49	13.1
9	September 29-30, 2010	12:05	4.40	20	2.56	35.4
10	December 1, 2010	6:20	0.71	70	1.82	4.1
11	December 11, 2010	3:40	0.72	50	0.58	2.3
12	February 25, 2011	2:15	0.29	80	0.25	4.1
13	March 6, 2011	4:50	1.42	50	0.46	11.0
14	March 15-16, 2011	5:06	0.42	40	0.35	1.9
15	April 8, 2011	3:55	0.52	80	0.15	3.4
16	April 28, 2011	2:19	0.23	90	0.23	12.5
17	May 14, 2011	3:05	0.85	20	0.47	5.7
18	June 16, 2011	3:20	1.03	80	0.91	13.1
Average			0.84	60	0.93	10.4
Total			15.16			

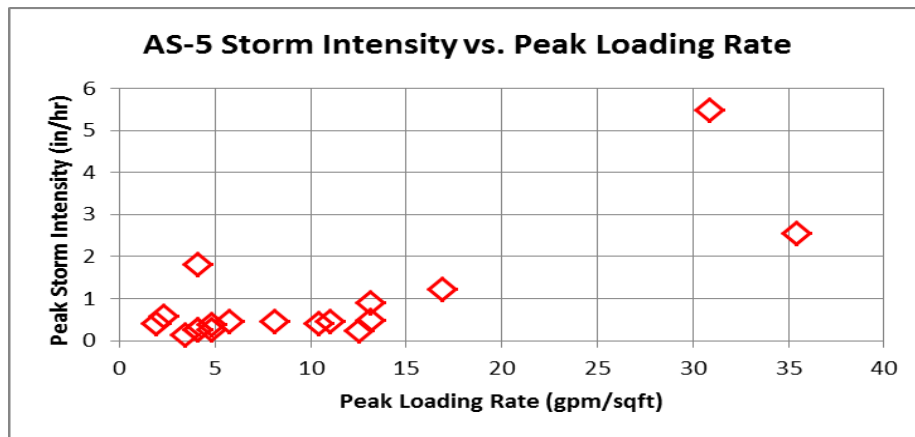


Figure 5. Storm Intensity vs. Peak Loading Rate

Sizing a hydrodynamic separator is typically based on a peak design water quality flow. This peak flow is calculated by one of several different methodologies that can include the USDA Natural Resources Conservation Service (NRCS) methodology, the Rational Method or the Modified Rational Method. Utilizing the NRCS methodology to size a hydrodynamic separator for this site, pertinent site-specific data was entered into *Technical Release 20 – Computer Program for Project Formulation: Hydrology* (TR-20). This sizing method established a peak runoff flow rate of 2.3 cfs which required installation of an Aqua-Swirl[®] AS-5 (NJDEP certified water quality treatment flow rate (WQTFR) of 52.6 gpm/ft²).

Field test data indicates a maximum storm intensity of 5.49 in/hr. with an associated peak loading rate of 30.9 gpm/ft². The highest peak loading rate recorded was 35.4 gpm/ft² with an associated maximum storm intensity of 2.56 in/hr. Unfortunately, these two storms did not generate a loading rate greater than 75% of the NJDEP certified WQTFR of 52.6 gpm/ft², thus limiting the field verification WQTFR to 41.2 gpm/ft². These results demonstrate that a calculated site design loading rate may not actually occur within the field testing program timeline.

3.9 Treatment System Maintenance

Annual maintenance of the Aqua-Swirl[®] system was conducted at the Burnt Mills Shopping Center by technicians affiliated with the Montgomery County Stormwater Sewer Maintenance Program. A vacuum truck was used to empty all captured materials (floatables and settleable solids) and flush the Aqua-Swirl[®] and associated catch basins and divergence and convergence structures. Continued inspections of the Aqua-Swirl[®] during the testing program indicated that the device exhibited long term functionality and had been properly maintained as recommended by the manufacturer. Disposal of recovered materials from the Aqua-Swirl[®] was not the responsibility of AquaShield[™] or its agent(s) during the testing program.

4. Technology System Performance

4.1 Data Quality Assessment

In accordance with the QAPP, quality assurance/quality control (QA/QC) samples were collected during the certification program to confirm the precision and accuracy of the sampling and analysis program. Two types of QA/QC samples were collected: field duplicates and field blanks. Field duplicate stormwater samples were collected in identical, laboratory prepared bottles and analyzed for the same parameters. The field duplicate sample was collected at the same location and from the same sample aliquot as the original sample. One field duplicate stormwater sample and one field blank sample was collected for each of the last 15 sampling events (the first three sampling events characterized the site). The field blank was collected by pouring laboratory provided distilled/deionized water through the cone sample splitter into a decontaminated sample bottle, then into the appropriate sample containers for analysis.

Field duplicate analytical results showed acceptable reproducibility of the majority of sampling events. There were two isolated events with field duplicate sample results that were outliers; however, the overall relative percent difference (RPD) indicated acceptable reproducibility in

sampling results. The overall average RPD was within 30%. If the two identified outliers (3/15/2011 and 5/14/2011) were not included, the average RPD decreased to less than 20% which is the RPD objective identified in the QAPP.

All field blank results were below the method detection limits with the exception of two sampling events (12/11/2010 and 4/8/2011) that exhibited very low TVSS, TSS and SSC concentrations compared to measured influent and effluent concentrations.. The field blank results confirmed that the decontamination procedures used for the sampling apparatus and the cone splitter were effective at minimizing any cross contamination during sampling and analysis.

Review of the overall QA/QC procedures and analytical results confirmed that the field sampling procedures and analytical methodologies employed produced reliable and representative analytical results.

4.2 Test Results

Particle Size Distributions (PSD)

Influent samples from three storm events were analyzed for PSD by the serial filtration method. **Table 4** summarizes the influent particle size gradations. Average particle sizes from the three samples exhibited 72% silt (2 to 63 μm), 20% very-fine to fine-grained sand (>63 to 250 μm), 2% medium-grained sand (>250 to 500 μm) and 6% coarse sand (>500 to 1,000 μm)

Table 4
Influent PSD Summary (percent finer than each sieve/filter)

Storm Event	1,000 μm	500 μm	250 μm	125 μm	63 μm	1.5 μm
September 12, 2010	100.00	97.41	92.48	84.44	62.96	0.00
December 1, 2010	100.00	93.16	90.99	87.19	73.71	0.00
December 11, 2010	100.00	92.04	91.59	85.08	78.56	0.00
Average	100.00	94.20	91.68	85.57	71.74	0.00

TARP protocol specifies that influent particles PSD d_{50} be <100 μm in size. The site PSD complies with the testing protocol and indicates a clay-loam texture sediment influent.

Figure 6 compares the test site influent PSD to the NJDEP laboratory test PSD standard for hydrodynamic separators. The graph indicates overall that the test site particulates were finer grained than the NJDEP PSD standard.

Particulate Matter Removal Efficiency

Six influent and effluent sample pairs (in one case only 5 pairs) were composited for laboratory analysis from the 24 (or in one case 20) 1-liter aliquots that were collected during each sampling event. **Table 5** summarizes the average of the six (or 5) TSS and SSC influent and effluent results and the average of the six (or 5) removal efficiencies for each stormwater event.

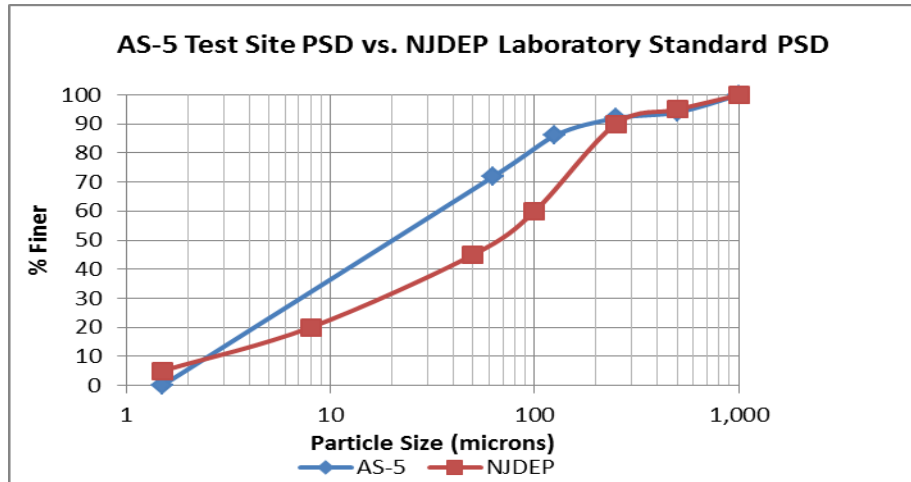


Figure 6. Field Test PSD vs. Laboratory PSD

**Table 5
Summary of TSS and SSC Removal Efficiencies and Influent Organic Content**

Sampling Event	Date	Average Influent TSS Concentration (mg/L)	Average Effluent TSS Concentration (mg/L)	Average TSS Removal Efficiency (%)	Average Influent SSC (mg/L)	Average Effluent SSC (mg/L)	Average SSC Removal Efficiency (%)	% TVSS of TSS
1	March 14, 2009	221	3.7	98.3	169.5	1.0	99.3	NA
2	April 1, 2009	85.0	9.6	86.8	57.8	10.0	80.0	NA
3	April 6, 2009	93.8	14.3	82.5	59.8	7.7	85.5	NA
4	December 25-26, 2009	223.7	2.2	99.0	297.3	1.4	99.5	NA
5	January 17, 2010	174.0	8.1	94.8	169.7	5.9	96.3	NA
6	July 25, 2010	55.7	2.2	94.1	73.4	1.7	96.5	38.8
7	August 12, 2010	27.9	8.6	63.9	27.0	7.0	68.0	22.3
8	September 12, 2010	266.3	6.1	96.5	352.7	6.7	96.6	31.0
9	September 29-30, 2010	338.9	78.8	59.9	420.0	104.6	57.4	20.9
10	December 1, 2010	72.2	6.2	89.1	98.2	7.4	86.9	16.7
11	December 11, 2010	85.7	3.1	96.1	85.9	1.6	97.7	29.2
12	February 25, 2011	183.3	18.5	73.0	241.3	25.8	72.8	29.0
13	March 6, 2011	95.4	12.9	86.1	275.8	17.0	92.5	25.4
14	March 15-16, 2011	40.3	5.3	88.1	79.7	6.8	91.7	24.4
15	April 8, 2011	91.9	3.5	94.1	113.1	3.6	95.8	25.2
16	April 28, 2011	132.9	12.3	80.4	168.7	13.1	82.0	71.4
17	May 14, 2011	155.5	11.6	90.6	154.6	12.9	90.3	48.9
18	June 16, 2011	27.8	6.0	74.3	34.3	5.1	82.7	48.9
Average		131.7	11.8	86.0	144.5	13.3	87.3	33.2

Cumulative average sediment removal efficiencies for the 18 storms was 86% for the TSS method and 87% for the SSC method. Individual removal efficiencies ranged from 60 to 99% for TSS, and 57 to 99% for SSC. Average influent TSS and SSC concentrations were 132 and 145 mg/L, respectively. Average effluent TSS and SSC concentrations were 12 and 13 mg/L, respectively. Data indicates that the sediment concentrations determined by the TSS and SSC methods compare closely.

The average TVSS removal rate was 68%, with an average influent concentration of 39 mg/L. The percentage TVSS of the TSS concentrations averaged 33% (Table 5). It is concluded that the influent TSS concentrations and percentages of organic material in the suspended sediment are acceptable for this field evaluation program.

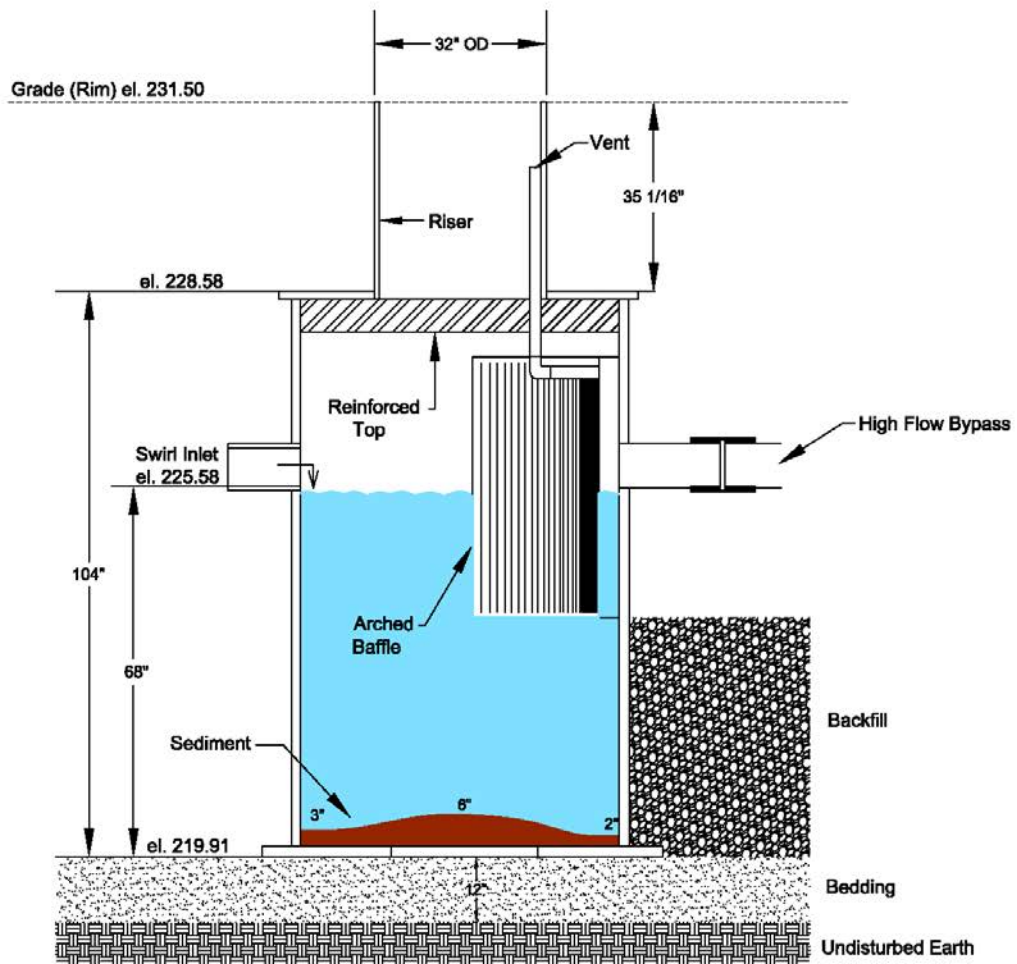
Particle Size Distribution of Captured Sediment

In order to determine the PSD of the solids that had settled and have been retained within the swirl chamber since the prior maintenance event on November 30, 2010, three sediment samples were collected on October 13, 2011. Samples were collected on the influent side, center and effluent side of the accumulated sediment layer. The PSD analysis was performed by the serial filtration method as cited above. **Table 6** summarizes the PSD of samples retained in the swirl chamber. **Figure 7** illustrates the accumulated form of the captured sediment in cross-sectional view. The influent side, center and effluent side locations were measured to be three, six and two inches thick, respectively. As designed, the vortex motion of water within the swirl chamber provides for the capture of sediment and retention toward the center of the chamber. AquaShield cites a maximum of 30 inches sediment depth to trigger a maintenance event. This is based on a cone shaped sediment pile such that the edges of the cone measure 24 inches up from the base and the crest (top) of the cone measures 36 inches up from the base.

Table 6
Captured Sediment PSD in Swirl Chamber

% Finer than Each Filter Summary						
Sample ID	Filter Size (µm)					
	1,000	500	250	125	63	1.5
SWIRL Influent (side)	100.00%	62.93%	43.10%	30.60%	30.60%	0.00%
SWIRL Center	100.00%	93.32%	85.80%	59.29%	59.29%	0.00%
SWIRL Effluent (side)	100.00%	87.61%	77.04%	59.69%	38.81%	0.00%
Average	100.00%	81.29%	68.65%	49.86%	42.90%	0.00%

The swirl chamber PSD data indicates that the solids retained within the tested Aqua-Swirl[®] can be classified a sandy-clay textured sediment. Average particle sizes from the three swirl chamber sediment samples exhibited 43% silt (2 to 63 µm), 26% very-fine to fine-grained sand (>63 to 250 µm), 12% medium-grained sand (>250 to 500 µm) and 19% coarse sand (>500 to 1,000 µm).



SOURCE: AQUASHIELD

SCALE: 1:30



SEDIMENT ACCUMULATION PROFILE
IN AS-5 SWIRL CHAMBER

Burnt Mills, Maryland

60135194

FIGURE 7

Figure 8 illustrates the particulate distribution for the three swirl chamber samples. Data indicates that the sediment accumulation in the center portion of the swirl chamber is finer grained than the influent and effluent edge samples. This would be expected as the fine-grained, low-settling velocity sediment continues to accumulate in the center of the swirl chamber as a result of the vortex water motion during repeated storm events.

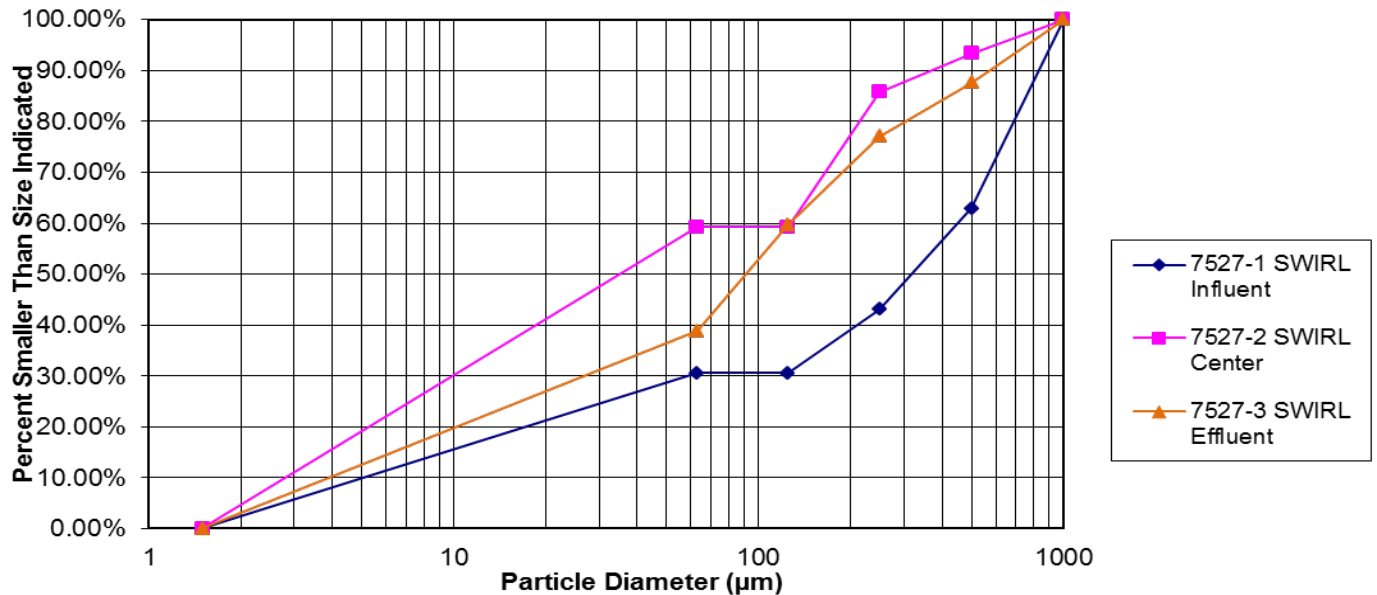


Figure 8. Swirl Chamber PSD – Influent (side), Center, Effluent (side)

4.3 Statistical Analysis

Statistical analysis was conducted on the sampling program data to ensure that the collected data were reliable, significant and within confidence limits. Initially the removal efficiency for each analytical parameter was evaluated to determine confidence intervals and associated variance. The coefficient of variation (COV) was calculated using the calculated TSS and SSC removal efficiencies for all sampling events. The calculated COV for TSS and SSC removal efficiencies for all sampling events was estimated at 13%. Review of the removal efficiency data revealed there was one data set (September 29-30, 2010) that was an outlier with reduced removal efficiencies for TSS and SSC (59.9% and 57.4%, respectively) when compared to the remaining removal efficiencies. If this one outlier event is removed from the data set the COV reduces to 10% indicating that the calculated removal efficiencies for both TSS and SSC removal were within acceptable limits identified in the TARP protocol.

To evaluate the significance of differences between influent and effluent mean concentrations, the Mann-Whitney Rank U Test was used. The Mann-Whitney Rank U Test is a non-parametric statistical hypothesis test for assessing whether two independent samples of observations have equally large values. The null hypothesis concluded that there was a statistically significant difference between influent and effluent mean TSS and SSC concentrations.

The summation of loads method was used to validate calculated removal efficiencies. This method defines removal efficiency as a percentage based on the ratio of the summation of all incoming loads to summation of all outlet loads. The loads were calculated based upon the sample concentrations and associated recorded flow through the treatment unit. For values that were reported as non-detect, one-half of the laboratory method detection limit was used for calculating loadings. **Table 7** presents a summary of the calculated summation of loads for each sampling event and the overall removal efficiencies. The summation of loads method calculated an overall removal efficiency of 84% for TSS and SSC. The summation of loads calculations were affected by the September 29-30, 2011 storm event that had significantly higher loadings and reduced removal efficiency when compared to the other 17 events. If this outlier storm event is excluded from the summation of loads calculations, the overall removal efficiency increases to 95% for TSS and 96% for SSC. The summation of loads calculations confirmed the calculated removal efficiencies based upon TSS and SSC concentrations as applied to the overall sampling program.

Table 7
Suspended Solids Event Sum of Loads Removal Efficiencies

Sampling Event	Date	Influent TSS Mass (lbs)	Effluent TSS Mass (lbs)	Influent SSC Mass (lbs)	Effluent SSC Mass (lbs)
1	March 14, 2009	3.3	0.06	2.1	0.02
2	April 1, 2009	3.8	0.32	2.7	0.33
3	April 6, 2009	1.3	0.73	0.9	0.38
4	December 25-26, 2009	64.6	0.60	92.1	0.36
5	January 17, 2010	43.3	2.16	42.5	1.57
6	July 25, 2010	4.0	0.17	5.4	0.14
7	August 12, 2010	5.2	0.87	5.2	0.71
8	September 12, 2010	37.3	0.76	42.5	0.87
9	September 29-30, 2010	109.7	42.1	135.9	57.3
10	December 1, 2010	7.9	0.59	10.9	0.74
11	December 11, 2010	1.7	0.07	1.7	0.03
12	February 25, 2011	5.7	0.74	7.3	1.01
13	March 6, 2011	11.7	1.79	34.5	2.3
14	March 15-16, 2011	1.4	0.18	2.8	0.23
15	April 8, 2011	3.4	0.15	4.1	0.17
16	April 28, 2011	14.4	0.67	18.5	0.71
17	May 14, 2011	3.1	0.31	3.1	0.35
18	June 16, 2011	2.4	0.38	3.0	0.29
	Total	324.2	52.65	415.2	67.51
	Removal Efficiency	84%		84%	

4.4 Summary

Table 8 summarizes the storm characteristics (duration, size, intensity, peak loading rate) as well as the associated sediment removal efficiencies. **Figure 9** presents performance curves based upon both the TSS and SSC analytical results. The curves are derived for any given storm by plotting average removal efficiency (%) against peak surface area loading rate (gpm/ft²). The TSS and SSC performance curves are similar, with the SSC curve showing slightly higher performance

Table 8
Storm Characteristics vs. Performance

Sampling Event	Sample Date	TSS Removal Efficiency (%)	SSC Removal Efficiency (%)	Storm Duration (hr:min)	Storm Size (inches)	Peak Storm Intensity (in/hr)	Peak Loading Rate (gpm/ft ²)
1	March 14, 2009	98.3	99.3	0:30	0.11	0.26	4.1
2	April 1, 2009	86.8	82.7	0:50	0.18	0.46	8.1
3	April 6, 2009	82.5	85.5	2:00	0.15	0.26	4.8
4	December 25-26, 2009	99.0	99.5	11:45	0.56	0.38	4.8
5	January 17, 2010	94.8	96.3	4:48	0.59	0.42	10.4
6	July 25, 2010	94.1	96.5	0:46	0.55	1.21	16.9
7	August 12, 2010	63.9	68.0	3:00	1.82	5.49	30.9
8	September 12, 2010	96.5	96.6	3:45	0.61	0.49	13.1
9	September 29-30, 2010	59.9	57.4	12:05	4.40	2.56	35.4
10	December 1, 2010	89.1	86.9	6:20	0.71	1.82	4.1
11	December 11, 2010	96.1	97.7	3:40	0.72	0.58	2.3
12	February 25, 2011	73.0	72.8	2:15	0.29	0.25	4.1
13	March 6, 2011	86.1	92.5	4:50	1.42	0.46	11.0
14	March 15-16, 2011	88.1	91.7	5:06	0.42	0.35	1.9
15	April 8, 2011	94.1	95.8	3:55	0.52	0.15	3.4
16	April 28, 2011	80.4	82.0	2:19	0.23	0.23	12.5
17	May 14, 2011	90.6	90.3	3:05	0.85	0.47	5.7
18	June 16, 2011	74.3	82.7	3:20	1.03	0.91	13.1
Average		86.0	87.3		0.84	0.93	10.4
					Total	15.16	

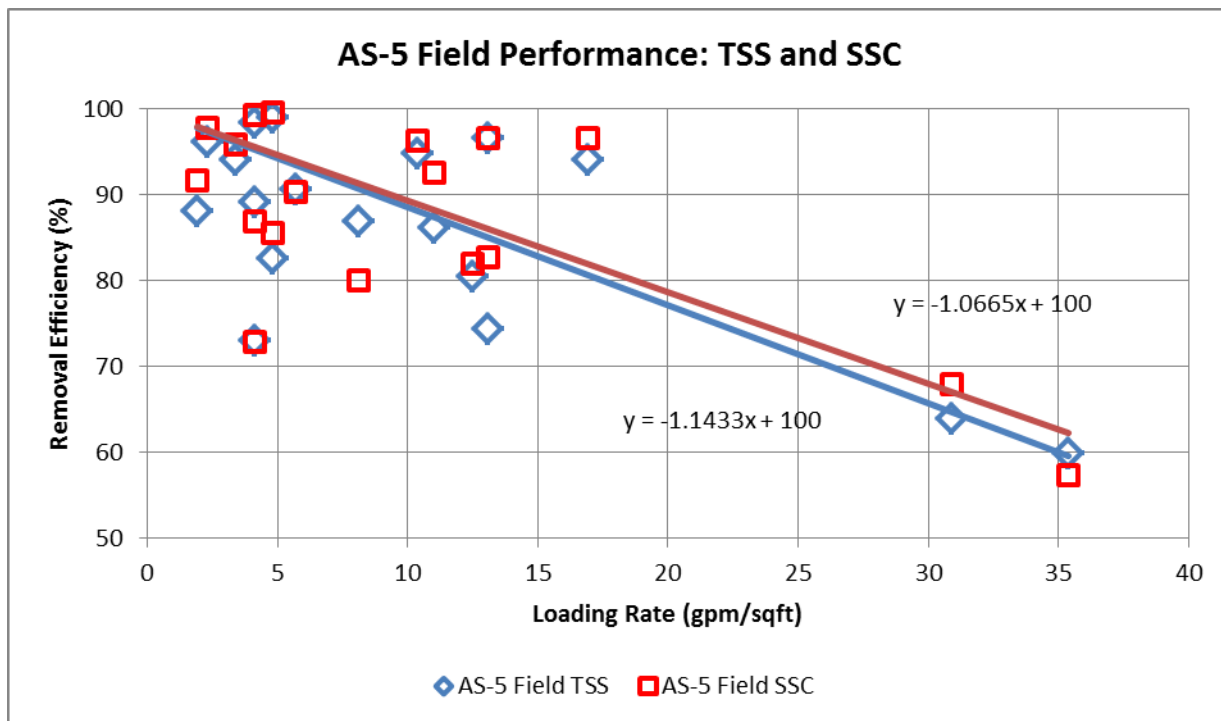


Figure 9. AS-5 Field Performance Curves

5. Performance Verification

A 27-month field test of an Aqua-Swirl[®] Model AS-5 has been completed at an urban shopping center in Silver Spring, Montgomery County, Maryland. Analytical results and performance analysis from 18 storm events and over 15 inches of rainfall demonstrated that 78% of the storms achieved greater than 80% TSS removal efficiency and 83% of the storms achieved greater than 80% SSC removal efficiency for the clay-loam textured sediment influent.

The TARP requirement that a minimum of six samples be collected from each storm was interpreted by AECOM that a minimum of six individual *composite* samples of the influent and effluent were required to be submitted for laboratory analysis. To ensure that sufficient sample volumes were collected for the required analyses, storm durations had to be conservatively predicted which led to varying sampling durations, and consequently event coverage, within the rainfall period. The storm duration coverage for each storm fluctuated from 30 to 80 percent with an overall average sampling duration of 60%. The storm flow coverage (round to the nearest 10%) varied between 20 and 100 percent with an overall average storm event coverage of 60%. For all storm events, samples were collected from the first 20% of the total storm event flow.

TARP qualifying storms require flow-weighted composite samples be obtained covering a minimum of 60% of the total storm flow. An average of 60% storm flow coverage and 60% storm duration coverage was achieved over the field testing period. Six of the 18 sampled storm events had flow coverage below 60%. Analysis of the TSS and SSC removal efficiencies for

these six events indicated slightly lower removal efficiencies than for the other 12 qualifying events. Consequently, utilizing these six storms for the AS-5 performance evaluation resulted in a lower average removal efficiency and a more conservative assessment. Similarly, seven storm events had less than 60% storm duration coverage; these events also had slightly lower removal efficiencies than for the other 11 storm events. Finally, the four storm sampling events that fell below either 60% storm flow coverage or 60% storm duration coverage had slightly lower removal efficiencies than for the other 14 storm events. Hence, it is concluded that including the results from all 18 storms resulted in a lower overall removal efficiency for the AS-5 and consequently a more conservative performance evaluation. This is also true when evaluating the suspended solids event sum of loads removal efficiencies (**Table 7**).

The relatively high TSS and SSC removal efficiencies for the AS-5 achieved under typical rainfall conditions for the geographic area was largely a result of the resulting storm intensities sampled over the 27-month field performance test. Specifically, 10 (55.6%) of the 18 storm events had peak loading rates below 25% of an Aqua-Swirl[®] stormwater treatment system loading rate of 41.2 gpm/ft² and another 6 events (33.3%) had peak loading rates between 10- 20 gpm/ft².

6. Net Environmental Benefit

The Aqua-Swirl[®] Model AS-5 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 18 storm events monitored during the 27-month monitoring period the mass of materials captured and retained by the Aqua-Swirl[®] Model AS-5 would otherwise have been released to the environment.

7. References

AECOM (2010). Quality Assurance Project Plan for Field Performance Verification Testing of the Aqua-Swirl[®] Model AS-5 Stormwater Treatment System, Burnt Mills Shopping Center, Silver Spring, Maryland.

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Technology Acceptance and Reciprocity Partnership (TARP). (2003). *The Technology Acceptance Reciprocity Partnership for Protocol for Stormwater Best Management Practice Demonstrations*.

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APPENDIX A

INDIVIDUAL STORM REPORTS

