Evaluation of MASWRC Sample Collection, Sample Analysis, and Data Analysis

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Prepared For:

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EXECUTIVE SUMMARY

In 1972, the federal Clean Water Act (CWA) was enacted and as a result the National Pollution Discharge Elimination System (NPDES) was created in 1990 to regulate stormwater discharges. Phase I of the NPDES program covered medium to large municipal stormwater sewer systems (MS4) in municipalities with greater than 100,000 residents, industrial activities, and construction activities that disturbed greater than 5 acres. In 2003, small MS4 systems and construction activities on 1 to 5 acres were added as regulated activities under Phase II of the NPDES program. Phase II has opened up a market for stormwater treatment devices, as municipalities and businesses strive to meet NPDES regulations. BaySaver Technologies, Inc. (BaySaver) of Mount Airy, MD is a stormwater treatment device manufacturer and vendor whose products are used by site owners to meet the regulatory requirements under the NPDES.

This project was conducted in collaboration with BaySaver as part of the collection and submission of field testing data of their stormwater treatment devices to New Jersey Corporation for Advanced Technology (NJCAT). The Mid-Atlantic Stormwater Research Center (MASWRC), also located in Mount Airy, MD is conducting the field testing of the BaySeparator™ and BayFilter™ as a treatment train at Richard Montgomery High School in Rockville, MD (site). The field data being collected will be used for approval of the BaySeparator™ and BayFilter™, as stormwater treatment devices, under the Tier II protocol developed by the Technology Acceptance and Reciprocity Partnership (TARP). The University of Maryland (UMD) is serving as an independent third party, auditing laboratory analysis and sampling methods, and evaluating the accuracy of the data reporting. In this project, UMD is evaluating the sampling, testing, and data being reported on three water quality constituents, suspended sediment, total phosphorus, and turbidity. UMD involvement began in June 2008 and continued for approximately 6 months, encompassing 17 qualified storm events.

The concentration removal efficiencies of the BaySeparator™ and BayFilter™, as well as the two devices functioning in series as a treatment train (system), were calculated from water quality samples collected at the site. Overall the system demonstrated 92% suspended sediment concentration (SSC), 67% total phosphorus (TP), and 68% turbidity removal efficiency. The BaySeparator™ had 47% SSC, 27% TP, and 11% turbidity removal efficiency. The BayFilter™ had 86% SSC, 58% TP, and 64% turbidity removal efficiency. Progress in meeting TARP standards in data collection, analysis, and reporting is documented. Based on this evaluation, MASWRC monitoring and data analysis methods and techniques appear to be satisfactory.

LIST OF ACRONYMS AND TERMS

BaySaver	BaySaver Technologies, Inc.
BFC	BayFilter™ Cartridge
BMP	Best Management Practice
CWA	Clean Water Act
DDC	Drain Down Cartridge
DDM	Drain Down Module
EMC	Event Mean Concentration
FB	Field Blank
FD	Field Duplicate
FOG	Fats, Oil, and Grease
HDPE	High Density Polyethylene
LD	Laboratory Duplicate
MASWRC	Mid-Atlantic Stormwater Research Center
MDE	Maryland Department of the Environment
MS4	Large Municipal Stormwater Sewer Systems
NJCAT	New Jersey Corporation for Advanced Technology
NJDEP	New Jersey Department of Environmental Protection
NPDES	National Pollution Discharge Elimination System
PSD	Particle Size Distribution
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RMHS	Richard Montgomery High School
Site	Richard Montgomery High School in Rockville, Maryland
SM	Standard Method
SSC	Suspended Solids Concentration
System	BaySeparator™, Horizontal Detention System, and BayFilter™ Vault
TAPE	Technological Assessment Protocol Ecology
TARP	Technical Assurance Reciprocity Partnership
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United States Geological Survey
UMD	University of Maryland
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION

Impairment of waterbodies due to stormwater runoff has recently come into focus as an area of concern by government agencies and municipalities. Stormwater runoff, the dominant contributor of non-point source pollution, especially in urban areas, carries sediment, nutrients, and heavy metals into nearby waterbodies. Until recently, much of the government's and public's focus had been on cleaning up the nation's waterbodies due to point source pollution. Point source pollution, or the pollution being discharged by an identifiable source, has been a much easier target for regulations and enforcement by federal and state environmental agencies. The challenge facing these agencies is regulating the treatment of non-point source pollution, which does not have a readily identifiable discharge point into a waterbody. Non-point source pollution is a major source of pollutants in waterbodies nationwide, whether it is from highway or agriculture runoff.

2.0 GOALS

The evaluation of this field testing program is being done at the request of BaySaver as part of their submittal for TARP approval of their stormwater treatment devices. The goal of this evaluation is to audit and evaluate the field testing program currently being conducted by MASWRC for BaySaver. The scope of work is included in Appendix A. This was accomplished by examining the existing sampling procedures, laboratory methods, and sample results reporting, and making recommendations throughout the evaluation process. Precipitation amounts and flow rates being reported were also analyzed. Concerns identified during the evaluation are explained in sections 7.6.1 and 7.6.2. Corrective actions taken by MASWRC and BaySaver to address the concerns raised are discussed in section 7.6.1, and additional recommendations are in section 7.6.2.

3.0 BACKGROUND

3.1 Federal Regulatory History

The basis for the current regulations governing water quality was enacted in 1948 as the Federal Water Pollution Control Act. The United States Environmental Protection Agency (USEPA) did not gain administration and enforcement powers for water quality until 1972, when the CWA was enacted by the United States Congress. In 1972 the mandate of the CWA was to reduce industrial (point-source) discharges of pollutants into waterbodies. The National Pollution Discharge Elimination System (NPDES) was created as part of the CWA. NPDES permits that governed the discharge of pollution were issued to industry. However, non-point source pollution, mainly stormwater runoff, was not a subject of these original amendments, and it was not until 1987 with the Water Quality Acts that non-point source pollution was regulated. The NPDES permit program was created to regulate large municipal stormwater sewer discharges, industrial discharges, and discharges into waterbodies that were already impaired. However in 2003, NPDES regulations were modified to include construction sites, 1 to 5 acres in size, and smaller municipal stormwater sewer discharge in the NPDES permit program. (USEPA, NPDES History) The EPA has primary oversight of the water quality programs in the United States, but as part of the CWA, the USEPA has the authority to place responsibility for regulating and enforcing water quality on the states. Individual states set water quality standards, which are approved by the USEPA, enforce the standards, and also issue NPDES permits. Maryland was one of the states granted the authority, by the USEPA, to oversee its own water quality program. (MDE, Stormwater Program Fact Sheet)

2.2 Local Regulatory Background

In Maryland, the Maryland Department of Environment (MDE) sets, administers, and enforces the water quality standards for the state of Maryland. If a waterbody is consistently not reaching the established water quality standard for a given contaminant, it is subject to even greater regulations and those industries discharging into it have to meet more stringent standards. A total maximum daily load (TMDL), which is contaminant specific, is assigned to the impaired waterbody. The TMDL is scientific assessment of the waterbody's tolerance to that contaminant and at a load that will not have a detrimental impact on aquatic organisms. The calculation of the TMDL takes into account both point and non-point sources, plus projected growth and a margin of safety. (MDE, TMDL) The TMDL is used when issuing NPDES permits for discharge into the impaired waterbody. Once a NPDES permit has been issued to an individual company or municipality, then it is their responsibility to enact best management practices (BMPs) that meet the NPDES permit requirement(s). BMPs can be either structural, such as retention ponds, grass swales, or proprietary treatment devices, such as the BaySeparator™, or non-structural or housekeeping practices, such as street sweeping the property. It is up to the company or municipality to balance BMP effectiveness and efficiency with cost. It is this burgeoning market that BaySaver is concerned with serving through the manufacture and sales of its stormwater treatment devices.

State approval of stormwater treatment devices is necessary for use in meeting the NPDES regulations. Because of the variation from state to state regarding requirements for approval as an acceptable stormwater treatment device, a multi-state coalition, Technology Acceptance and Reciprocity Partnership (TARP), has been formed, geared towards creating uniformity and consistency in testing and approval of these devices. TARP is administered by the New Jersey Corporation for Advanced Technology (NJCAT) a private/public company that is part of the New Jersey Department of Environmental Protection (NJDEP). TARP approval for a stormwater treatment device is accepted by the states of California, Illinois, Maryland, Massachusetts, New Jersey, New York, Pennsylvania, and Virginia. UMD became involved with the project as part of the Tier II protocol in TARP, and is serving as an independent third party auditing laboratory analysis and sampling methods, and evaluating the accuracy of the data reporting.

BaySaver is also applying for approval under the Technology Assessment Protocol-Ecology (TAPE) program administered by the Washington State Department of Ecology, Water Quality Program. However, field testing for the TAPE program must be conducted on the west coast. TAPE has similar requirements to TARP for treatment requirements and what constitutes a qualified rainfall event. Table 1 shows a comparison of TAPE and TARP requirements.

Table 1 - Comparison of TARP and TAPE field testing requirements.

	TARP	TAPE
Suspended Sediment Analysis	SSC and TSS	TSS, but SSC = TSS if sediment <250 microns
Dry Period	6 hour	6 hours
Precipitation Minimum	0.1 inches	0.15 inches
Percent of Rainfall Event Captured	70%	75%
TSS removal	80%	80% if TSS between 100 and 200 mg/L
		effluent TSS <20 mg/L if TSS <100 mg/L
		>80% if TSS >200 mg/L
		50% if TSS between 100 and 200 mg/L (pretreatment)
		effluent TSS <50 mg/L if TSS <100 mg/L (pretreatment)
Rainfall Event Duration	none	1 hour
Field Duplicates	required	10% of samples

2.3 Stormwater Treatment

Urban areas are largely impervious surfaces, such as asphalt or concrete pavement or roofs; various pollutants are picked up by the flow of stormwater across them. Dry deposition of contaminants on impervious surfaces creates an accumulation on the surface, until a rainfall event mobilizes the contaminants (sediment, heavy metals, etc.). Excessive stormwater runoff can inundate surface waterbodies with pollutants and nutrients leached from the ground surface. The excess nutrients (phosphorus, nitrogen) can cause algal blooms and increase biological growth in the water, which ultimately depletes the dissolved oxygen (eutrophication) thus inhibiting growth of other organisms (fish). Land development often reduces the amount and diversity of vegetation on the land. The decrease in vegetation limits the amount of water trapped during a precipitation event. Land development also adds more impervious surfaces, which increases stormwater runoff by decreasing the land available for infiltration.

Stormwater sewers that carry stormwater runoff into a constructed wetland or sedimentation basin, prior to discharge to a surface water body, would allow for suspended sediments to settle out and nutrient uptake by aquatic microorganisms and vegetation. However, the area required for a basin or wetland is often not available or is too valuable. This is especially relevant in urban settings, where the cost per acre of open land makes it financially unattractive to use as a basin. Instead, a stormwater treatment device (such as the BaySeparator™) can be installed underground in a parking lot. Spatial and temporal constraints are addressed through the use of proprietary stormwater treatment devices as structural BMPs.

BaySaver Technologies, Inc. headquartered in Mount Airy, MD is in the business of developing and manufacturing stormwater treatment devices that address the problems associated with stormwater runoff. Their current line of products includes the BaySeparator™ and BayFilter™, both which were tested under field conditions as part of this project.

3.0 THE TREATMENT SYSTEM

3.1 The Site

The site is located at Richard Montgomery High School in Rockville, Maryland, Figure 1. The system treats stormwater runoff from an approximately 3.6 acre drainage area, which is approximately 83% impervious surface, mainly asphalt pavement, concrete, and the building roof, and 17% landscaped or grassy areas (medians in the parking lot), Figure 2.

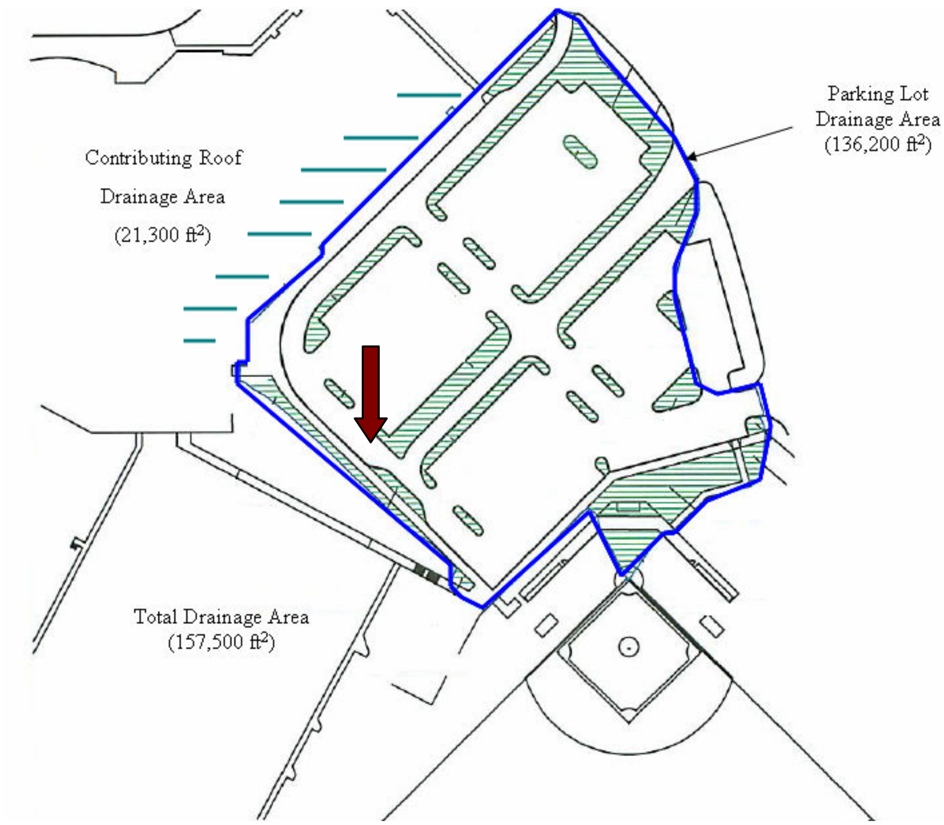

Figure 1 - As-built drawing of the site (Courtesy of BaySaver)**. Arrow marks the approximate location of the treatment devices.**

Figure 2 - View of Richard Montgomery High School parking lot (the site). Arrow on the picture marks the approximate location of the treatment devices.

3.2 The System

The system consists of a BaySeparator™ model 3K unit (Figure 3) and a pre-cast 8 by 12 foot concrete vault (BayFilter™ vault) containing 5 BayFilter™ Cartridges (BFC) and 1 drain down cartridge (DDC). The system was installed in March 2008 as part of construction activities occurring at the site. The configuration was altered in June 2008, according to the MASWRC, when the DDC was removed and a drain down module (DDM) was installed with each BFC. The stormwater runoff is collected by inlets in the parking lot and flow is carried to the BaySeparator™, Figure 4. Flow from the BaySeparator™ goes into a diversion structure, a pre-cast concrete manhole, then into a horizontal detention system. The horizontal detention system is constructed of three 8-foot diameter corrugated metal pipes, a total of 205 feet in length.

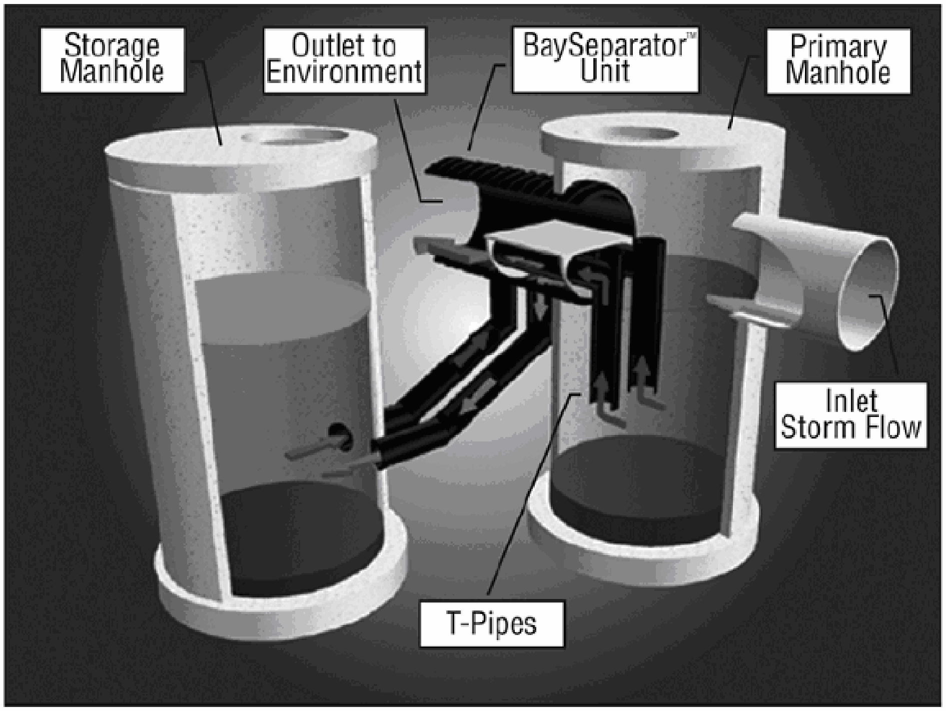

Figure 3 - Overview of the BaySeparator (Courtesy of BaySaver).

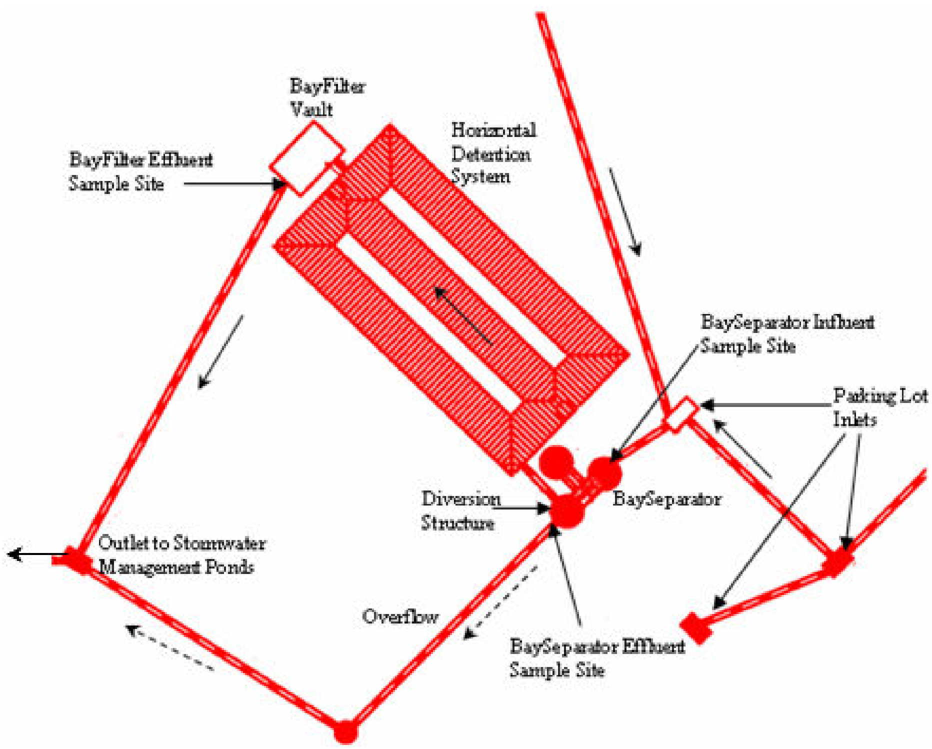

Figure 4 - Layout of the BaySeparator™ and BayFilter™ (Courtesy of BaySaver).

For the purposes of this study the BayFilter™ system consists of both the horizontal detention system and the filter vault. The stormwater treatment performance of the filter vault can not be properly evaluated separate from the horizontal detention system, because flow paced samples were taken at the outlet from the BaySeparator™, in the diversion structure. The outlet of the BaySeparator™ is considered the same as the inlet to the BayFilter™ system. Ultimately, treated stormwater from the filter vault is discharged through 4-inch PVC underdrains to two stormwater management ponds located on the Richard Montgomery High School property. The horizontal detentions system, 10,300 cubic foot volume, is designed to store stormwater runoff for a 1-inch rainfall event on a 3.6 acre drainage area. The horizontal detention system has a dry storage of approximately 6 inches in the bottom of the pipes.

3.3 Site Characterization

The site was evaluated in March 2008, shortly after the BaySeparator™ was installed, for suitability as a site to conduct field testing under the NJDEP Tier II protocol. The Tier II protocol calls for collecting water quality samples to determine influent suspended solids concentration and particle size distribution (PSD). To qualify, the site needs to have stormwater runoff with TSS concentrations between 100 to 300 mg/L and contain sediment particles with a diameter less than 100 μm.

Five rainfall events, March 8, March 16, March 20, April 1, and April 6, 2008 had TSS influent concentrations of 180, 29, 64, 9, and 33 mg/L respectively. Only one of the rainfall events resulted in an influent TSS concentration within the Tier II protocol range of 100 to 300 mg/L. PSD analysis was conducted on samples collected from the March 8, 2008 rainfall event. Results indicated that 74% of the influent particles had a diameter less than 100 μm. The PSD analysis was conducted by the Particle Engineering Research Center at the University of Florida.

4.0 BAYSAVER STORMWATER TREATMENT DEVICES

4.1 The BaySeparator™

The BaySeparator™ is a hydrodynamic separator that uses gravity to settle out sediment. According to the BaySeparator™ Technical and Design Manual, 80% of suspended sediments are removed by the BaySeparator™. The BaySeparator™ consists of a primary storage chamber (primary manhole), an internal HDPE separator (BaySaver) and secondary storage chamber (storage manhole), Figures 3, 5, and 6. The stormwater flows from the parking lot into the inlet pipe, then into the primary manhole. Large sediment particles settle out in the primary manhole. The flow continues from the primary into the storage manhole, where the fine sediments settle out.

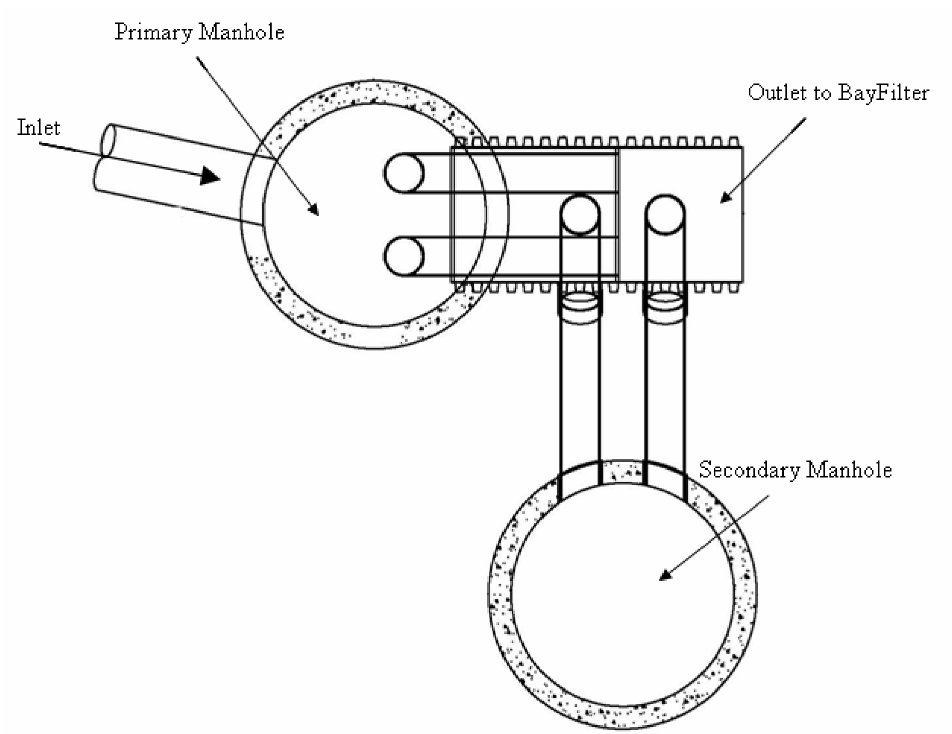

Figure 5 - Plan View of the BaySeparator™ (Courtesy of BaySaver)

Fats, oils, and grease (FOG) are collected in the secondary manhole as floatable materials (Figures 5 and 7). The treatment capacity of the BaySeparator™ model 3K unit is 3.4 cfs or 25.4 gpm. Above 25.4 gpm, the flow bypasses the secondary manhole and is discharged through the outlet pipe into the horizontal detention system with little or no treatment. The internal flow splitter (Figures 6 and 8) governs the three flow paths that stormwater can take: 1. flow from the primary to secondary manhole; 2. flow from the secondary manhole to the outlet; and 3. flow bypass to the outlet.

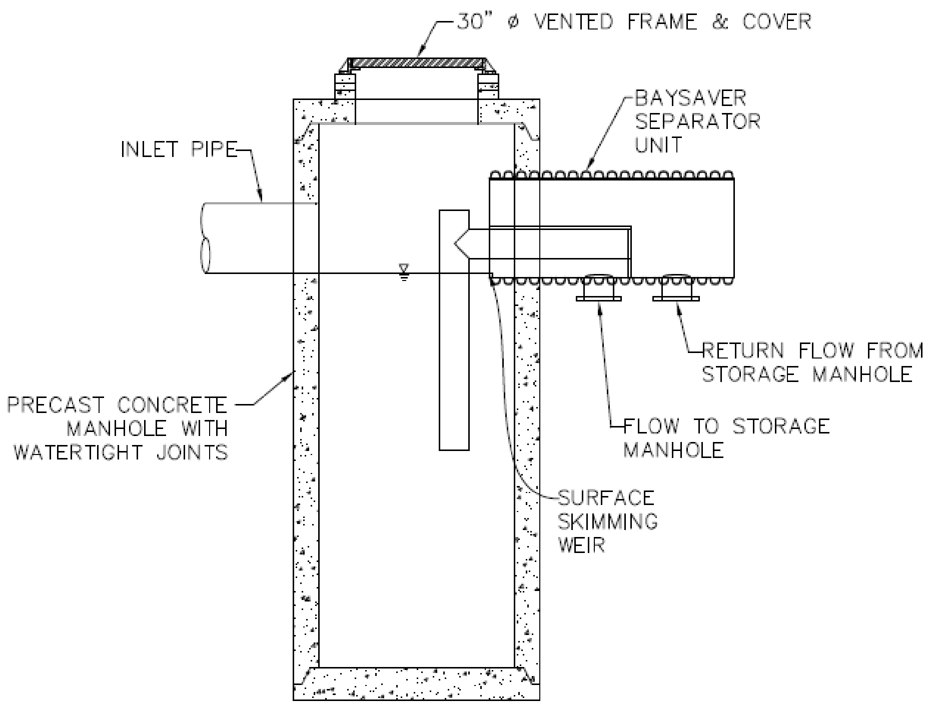

Figure 6 - Profile View of the BaySeparator™ Primary Manhole (Courtesy of BaySaver).

Figure 7 - View of trash collected in the storage manhole.

Figure 8 - View of the internal flow splitter in the primary manhole.

If the horizontal detention system is full, and the runoff flow rate is greater than the BayFilter™ flow rate, then the excess flow is discharged from the diversion structure directly into the stormwater management pond, Figure 4.

4.2 The BayFilter™

The BayFilter™ is a media filter used to remove fine suspended sediments, organics, nutrients, and heavy metals from stormwater. The historical use of sand filters in water and wastewater treatment is the basis for the BayFilter™. The media and filter fabric trap suspended contaminants and the contaminants are adsorbed onto the surface of the media particles. The adsorption is driven by the high surface area of the media particles combined with the ionic interactions between the media particles and the contaminants. The BayFilter™ cartridge (BFC) consists of a filter fabric with layers of media, Figure 9. The media used in the BFC is a mix of sand, perlite, and activated alumina designed for maximum nutrient, heavy metal, and organics removal. There are 43 square feet of surface area in each BFC that filters stormwater. The filtering process is gravity driven.

When the level in the filter vault reaches 28 inches, the height of the BFC, the stormwater flows through the media and the treated stormwater is forced up to the top of the BFC. The treated stormwater flows out through the center of the BFC into the outlet pipe. A siphon allows for treatment of stormwater until the water level in the filter vault reaches 6 inches, the bottom of the BFC. Once the water drops below 6 inches (bottom of the BFC), the siphon is broken and the filter is backwashed with the treated stormwater remaining in the BFC. This backwashing process re-suspends sediment trapped by the filter and flows out into the filter vault, where sediment settles out. The drain down cartridge (DDC) was used to completely drain the filter vault, because the BFC is located 6 inches from the bottom of the vault. However, in June 2008 the DDC was removed and 5 DDMs, one for each BFC, were installed. The DDM (Figure 10) is a 4-inch PVC pipe with a sand filter inside and is connected to the underdrains. The DDM functions similar to the DDC in treating the remaining 6 inches of stormwater in the vault. The filter vault at the site contains 5 BFCs as depicted in Figure 11.

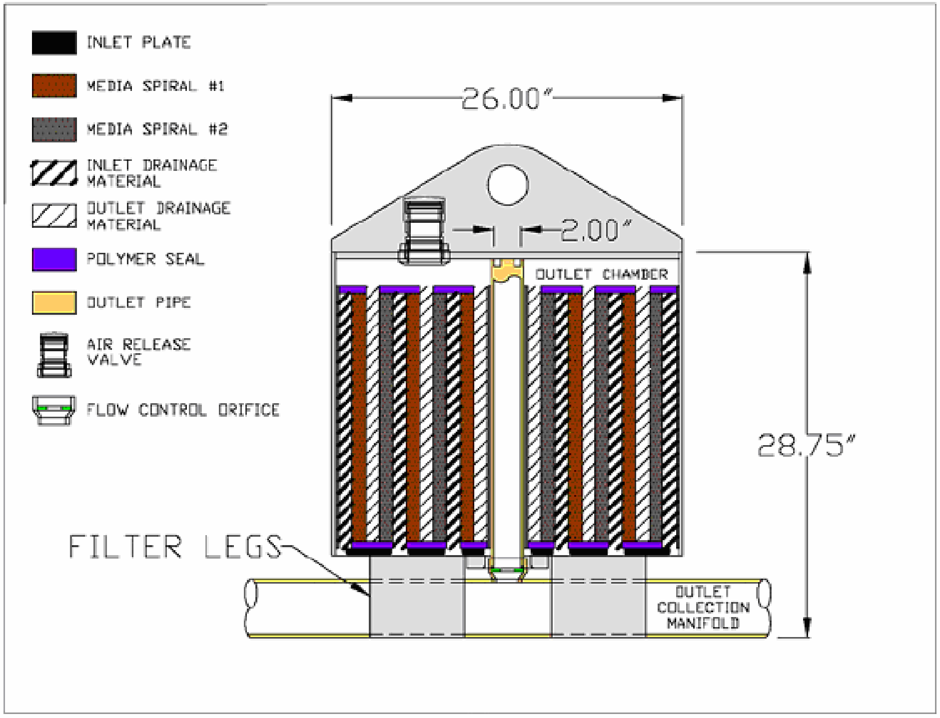

Figure 9 - Profile view of the BayFilter™ cartridge (Courtesy of BaySaver).

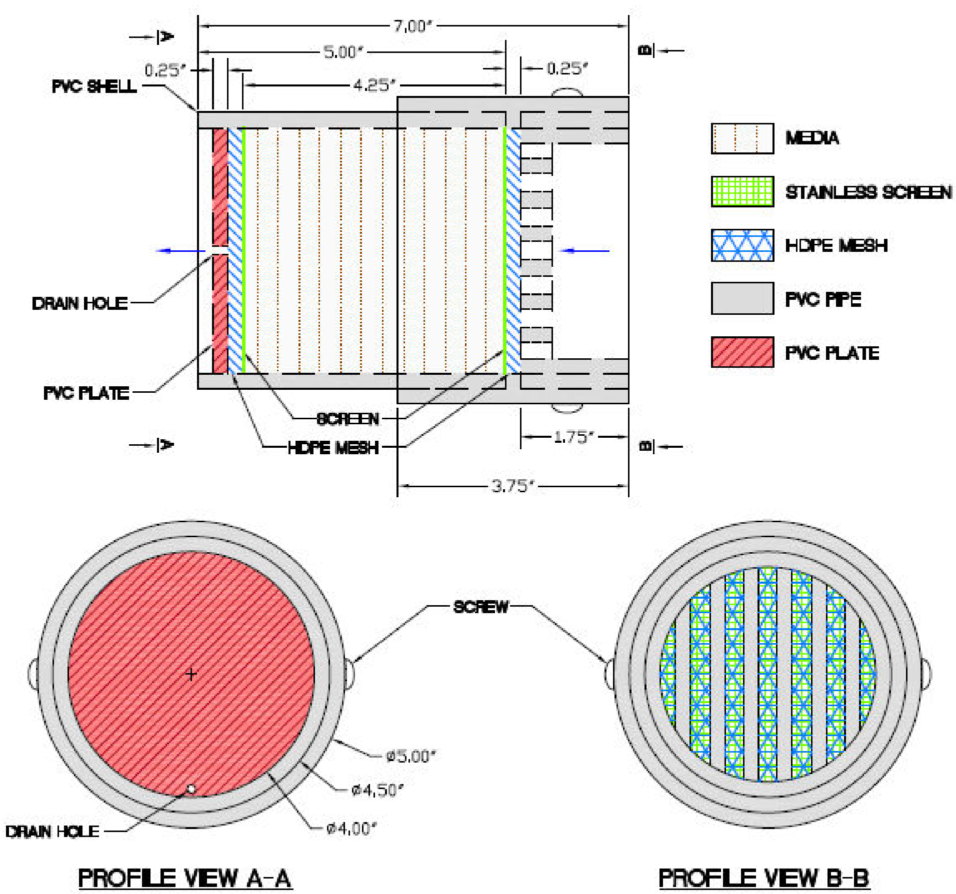

Figure 10 - View of the BayFilter™ draw down module (Courtesy of BaySaver).

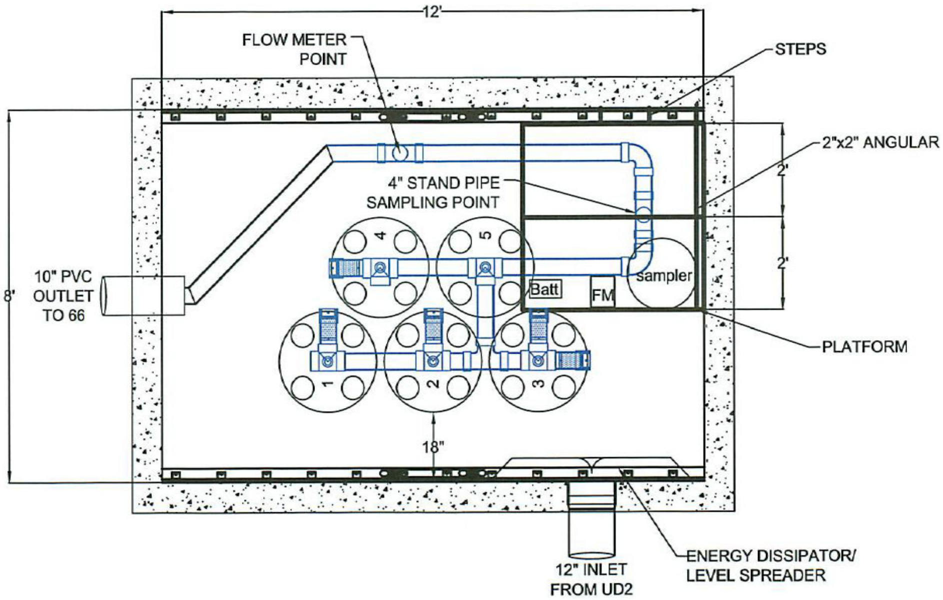

Figure 11 - Plan view of the BayFilter™ vault at the RMHS site (Courtesy of BaySaver).

The horizontal detention system is an integral part of the overall treatment system at the Richard Montgomery site; it attenuates the flow rate of the stormwater. The attenuation is necessary, because the number of BFCs used is not capable of treating the stormwater at the influent flow rate. The filter vault is cleaned of sediment and the BFCs exchanged when the filter vault does not fully drain within forty hours of the end of the stormwater inflow.

5.0 SAMPLING

5.1 TARP Tier II Protocol Requirements

An event is considered qualified if: there has been at least a 6 hour dry period prior to subsequent rainfall; there is greater than 0.1 inches of precipitation; and at least 70% of the stormwater runoff volume has been sampled. It should be noted that BaySaver is considering a qualified event to have greater than 0.15 inches of precipitation, which is the requirement for TAPE. The Tier II protocol, Appendix B, requires at least 15 qualified events and recommends at least 20 qualified events. In addition to the minimum number of qualified events, the total precipitation from the qualified events must be at least 50% of the total annual rainfall. The site has an annual rainfall of approximately 42 inches (NOAA, Climate of Maryland), therefore, the qualified events need to have a cumulative precipitation of greater than 21 inches. As of November 14, 2008, a total of 17 qualified events have been sampled with a total of 10.3 inches of precipitation. Tier II protocol requires some of the qualified events to be "adverse conditions" for the stormwater treatment device. Of the current qualified events, at least 2 events can be considered adverse conditions, which have high intensity or long duration rainfall events that may approach or exceed the design capacity of the system. Requirements relating to site qualification, sample collection, and laboratory analysis are discussed as part of each specific section (TARP Protocol, section 3.3.1.3).

5.2 QAPP

A Quality Assurance Project Plan (QAPP) was developed by BaySaver to provide guidance to MASWRC when conducting the field testing of the system, Appendix C. The QAPP is site specific and is meant to ensure that sampling and analysis of field data is done safely and accurately. According to the QAPP, MASWRC will conduct quality assurance/quality control (QA/QC) on the water quality samples throughout the duration of the field testing program. The QA/QC is a required part of the TARP Tier II protocol, and is necessary to ensure accuracy of data reporting. The QAPP was prepared and edited by BaySaver during the course of the evaluation process. A final version was submitted to NJCAT on November 5, 2008.

5.3 Qualified Events

A qualified event must meet certain criteria outlined in the TARP protocol. The rainfall event has to have greater than 0.1 inches of precipitation (TARP Protocol section 3.3.1.2), and the QAPP identifies 0.15 inches as the minimum qualified rainfall event being used (BaySaver, QAPP). The water quality samples collected must be representative samples that cover 70% of the stormwater runoff volume during an event (TARP Protocol, section 3.3.1.2). In addition, a minimum of 10 influent and 10 effluent samples need to be collected (TARP Protocol, section 3.3.1.2).

5.4 Experimental Methods

The sampling and analytical methods discussed below include both the methods used and procedures conducted by MASWRC in gathering data. Where applicable, the analytical methods used by UMD in determining the concentrations of select water quality constituents are identified below.

5.4.1 Field Sampling

The site is equipped with Rainwise rain gauge and HOBO logger to gather precipitation data. The rain gauge collects and records precipitation in 0.01 inch increments using a tipping bucket method. The rain gauge and logger are installed on an 8-foot post located approximately 20 feet from the BaySeparator™.

The flow weighted water quality samples are collected using three ISCO 3700 auto-samplers that are connected to ISCO 4250 area/velocity flow meters. One flow meter is located in the inlet pipe to the primary manhole in the BaySeparator and it triggers the two auto-samplers in the BaySeparator™. The auto-samplers in the BaySeparator™ collect samples at the inlet to the primary manhole and the outlet from the secondary manhole, Figure 12. These sample locations are termed BaySeparator™ Influent and BaySeparator™ Effluent. The second flow meter is located and the outlet from the filter vault, and governs the flow pacing of the auto-sampler located there. This sample location is termed BayFilter™ Effluent. (Figure 4)

Figure 12 - View of the BaySeparator™ influent flow meter and effluent auto-sampler set-up.

The auto-samplers are flow paced, collecting a discrete sample (200 mL to 250 mL), for a set volume of flow (2000 to 6000 L). Each sample bottle contains a composite of 4 discrete samples for a total of 0.8 to 1 liter. The samples are taken using a 3/8 inch suction line, which is set 0.5 inches off the bottom of the pipe, Figure 13. The volume of pacing is based upon expected intensity of the rainfall event. The auto-samplers are programmed to purge and rinse the suction line between samples, reducing the potential for cross contamination between samples.

Figure 13 - View of the inlet pipe to the BaySeparator™, including the suction line and flow meter sensor.

The flow meters and auto-samplers were calibrated by MASWRC prior to installation. There is no set schedule to replace flow meters and check calibration. Currently, MASWRC will replace a flow meter if the readout in the vault does not properly balance after an event. MASWRC visually inspects and checks programmed settings after every rainfall event, even if the flow is less than 0.1 inches, a non-qualifying event. The deep cycle marine batteries used to power the instruments are checked weekly and exchanged regularly.

The samples are collected by MASWRC within 24 hours of the end of the rainfall event and are transported to the MASWRC laboratory for analysis of water quality parameters. (Figure 13) The sample bottles that are collected by MASWRC are replaced with clean sample bottles after each event. The sample bottles are washed and prepared at the MASWRC laboratory with an Alconox solution (non-phosphorus containing detergent) and rinsed with deionized water.

Figure 13 - View of cooler used to transport sample bottles. The colored labels (3 sheets) next to the cooler are used to color code the bottles based on the location of the auto-sampler (BaySeparator™ influent and effluent and BayFilter™ effluent).

5.4.2 UMD Sample Collection

For the October 25 and November 13, 2008 rainfall events, selected samples were split in the field by re-suspending the sample in the sample bottle by rapid shaking. The top half of the sample was poured into another sample bottle, which was taken back to the UMD lab for water quality analysis.

5.4.3 Sampling Protocol

Field blanks are specified in the QAPP to be analyzed twice during the field testing program, before the first stormwater runoff event and the mid-point of the program (between events 6 and 9). All three auto-samplers should have field blanks collected using deionized water. The field blanks are used to quantify any effects the equipment might have on the water quality samples. To date, field blanks were collected from the BaySeparator™ influent and effluent auto-samplers. The field blank results were less than 1 mg/L for SSC and less than 0.1 mg/L for TP. These results are at or below the detection limit of the analysis methods. A second set of field blanks has not been collected yet.

Field duplicates are to be collected and analyzed over the course of the program at least three times. The water quality samples collected for analysis, including SSC, TP, and turbidity, should be split and the two results compared for representativeness. The samples were split for SSC, starting with the May 31, 2008 event. For the April 11, 2008 event, duplicate samples were collected and analyzed for TP. In a sample to duplicate sample comparison, the results have a range in percentage difference from 0 to 100%. However, the mean values (sample and duplicate samples) for the BaySeparator™ influent (46 and 47 mg/L), effluent (34 and 34 mg/L), and BayFilter™ effluent samples (0.27 and 0.23 mg/L) show no significant difference. While there may be some variability on a sample to sample basis, the overall agreement between results is satisfactory. However, no other water quality constituents have had duplicates collected or analyzed.

Tier II protocol and the QAPP both specify a chain of custody for all water quality samples collected. The chain of custody is used to track samples and protect sample integrity. Prior to the end of September 2008, MASWRC was not using a formal chain of custody. However, samples were being collected from only one site for the duration of the field testing program and MASWRC personnel retained custody of the samples upon collection at the site. A copy of the chain of custody currently being used is included in Appendix D.

A key component of any field testing program, and a requirement of the Tier II protocol is a health and safety plan. As part of the health and safety component of the QAPP and Tier II protocol, confined space entry training and permit is required. Not only is this a requirement of the documents governing the field testing program, but also the Occupational Safety and Health Administration (OSHA) regulations. The appropriate OSHA regulations can be found in 29 CFR 1910.146 (Permit-required confined space). Currently, no health and safety plan has been developed. However, confined space entry training was conducted for MASWRC personnel.

5.4.4 Analytical Methods

The samples are collected in the field in plastic sample bottles, then transported back to the MASWRC laboratory, where they are analyzed. Although other water quality constituents are analyzed by MASWRC, under the scope of this project, UMD was only concerned with suspend sediment concentration (SSC), total phosphorus (TP), and turbidity.

5.4.4.1 Suspended Sediment

MASWRC uses TSS and SSC to determine the concentration of suspended sediment in a sample. There has been an ongoing discussion in the scientific community regarding the proper method for determining concentrations of suspended sediment in samples. The historical method (water and wastewater industry) has been total suspended solids (TSS), where a representative 100 mL sample is withdrawn from the center of a well mixed sample. There has been a trend to analyze stormwater samples using SSC, where the entire sample volume is used.

The United States Geological Survey (USGS) has been leading the push towards using SSC to analyze stormwater, because it is the most representative indication of sediment in a sample. The USGS argues that SSC is better for natural systems, and that TSS is being misapplied. They have found that there is no correlation between TSS and SSC because of the wide range of conditions possible in natural systems (Gray et al., 2000). In environments where larger particles are more prevalent (i.e., urban environments with sand), the TSS concentrations have been less than SSC, because the larger particles are not being sampled from the center of the container. Other studies have found a closer correlation between TSS and SSC, but still regard SSC as the more accurate representation of the entire sample (Clark and Pitt, 2008).

5.4.4.1.1 MASWRC Analyses

Sampling and analysis for SSC is done according to the American Society for Testing and Materials (ASTM) D 3977-97 standard. The glass fiber filter (Whatman A/H 90 mm) is prepped by filtering approximately 30 mL of deionized water through it, then drying it for at least an hour at 103°C to 105°C. The filters are stored in aluminum weighing pans in a humidity controlled container prior to weighing and use.

A stormwater sample is weighed in the sample bottle, then poured into a glass jar with a stirrer bar and the sediment is re-suspended. A 60 mL sub-sample is withdrawn by pipette for turbidity, color, and total phosphorus analysis. The empty sample bottle is weighed, the difference between initial full mass and the empty bottle mass, minus the sub-sample, is calculated as the suspended sediment sample volume (assuming a density of 1 g/mL).

Half the sample in the glass jar is poured back into the sample bottle, weighed, and poured through the filter using a vacuum pump. The remaining sample in the glass jar is poured through a second filter, and the glass jar and sample bottle are rinsed with deionized water into the filter. The filters are placed in the drying oven (103°C to 105°C) for at least one hour, and then are weighed. The difference in filter mass determines the mass of sediment in each part of the sample. The SSC for each of the two parts of the sample are calculated and recorded as sample A and B. The mean SSC value is based on the total sediment mass and the total sample volume filtered. Samples collected from high intensity rainfall events are sieved for large particles (greater than 250 μm). Sieving has occurred, for the April 20, 2008 rainfall event, a non-qualifying event, and the August 14 and 28, 2008 rainfall events.

Since the June 3, 2008 rainfall event, MASWRC has been splitting the samples as describe above. Prior to that, the whole sample volume was filtered through one filter. By splitting the sample into an A and B part, MASWRC uses these as two TSS samples. The current SM 2540 uses a 100 mL sub-sample for TSS, and previous standard methods require the sub-sample to be collected with a wide-bore pipette (Clark and Siu, 2008).

It should be noted that SM 2540 requires samples to be preserved at 4°C to limit bacterial decomposition. Samples should never be held more than 7 days, and if possible, analyzed in less than 24 hours after collection. Since the end of September 2008, MASWRC has been using ice to transport samples from the site and a refrigerator to store samples in the laboratory prior to analysis. Prior to that event, samples were not kept below 4°C, but often were analyzed immediately following collection. There were times when multiple rainfall events in close succession prevented the immediate analysis of samples.

5.4.4.1.2 UMD Analyses

SSC was determined using ASTM D 3977-97. The glass fiber filters (VWR 90 mm) were prepared the same way as MASWRC. The sample was re-suspended by hand (shaking) and a sub-sample (approximately 100 mL) was taken from the sample bottle for TP and turbidity analyses. The sample bottle was weighed with the sample in it and at the end as an empty sample bottle to determine volume filtered. Because the sample was a split sample, it was not necessary to weigh an “A” and “B” sample as MASWRC does; only one sample was filtered. The filters were dried for at least 24 hours at 103°C to 105°C, then weighed to determine sediment mass. The SSC was calculated using a density of 1 g/mL for the sample mass, and the difference in mass between the prepped filter and the filter with sediment.

5.3.4.2 Total Phosphorus Analysis

Total phosphorus concentration is determined using persulfate digestion to convert organic phosphate into orthophosphate (PO_4) and measured using the ascorbic acid method (colorimetric measurement). Persulfate digestion is conducted according to the SM 4500 method, by MASWRC and UMD. The only difference is that MASWRC uses a 20 mL sub-sample, instead of the 30 mL sub-sample specified by SM 4500.

MASWRC uses the ascorbic acid molybdenum blue method (EPA 365.2) with an ascorbic acid reagent from HACH to determine the total phosphorus (TP) concentration. Samples were analyzed by MASWRC using a HACH DR-2800 spectrophotometer. A 1.5 dilution factor is used in calculating TP concentrations, because the original sample was 20 mL, but the current 30 mL sample volume was used to determine the colorimetric measurement (20 mL original volume:30 mL current volume).

UMD analyzed the samples according to the ascorbic acid method in SM 4500. UMD correlated spectrophotometer results to known TP standards (range 0 to 1.0 mg/L). For both UMD and MASWRC, the "A" and "B" samples are the same sample measured with the spectrometer twice. A mean value of the "A" and "B" samples is reported as the samples value.

5.3.4.3 Turbidity

Turbidity is analyzed by both UMD and MASWRC according to SM 2130 (Nephelometric method). The "A" sample was the first reading, then withdrawn, wiped clean again, and re-run to determine the "B" sample. Occasionally, turbidity samples were not immediately analyzed by MASWRC following sample collection. Since the August 2008 events, MASWRC has been running turbidity samples immediately upon sample collection.

6.0 RESULTS

6.1 Precipitation

Precipitation data gathered at the site by MASWRC was compared to three other sites in the surrounding area (Rockville, MD). Precipitation data were obtained from www.wunderground.com (zip code 20852) for each of the rainfall events monitored by MASWRC. Not all the dates had data available for them on www.wunderground.com. The rainfall event number corresponds to the date samples were collected (Table 2). The data collected at the site (RMHS) was within the range of the surrounding sites, Figure 14.

Table 2 - Correlation of date, rainfall event number, precipitation amount measured, and percentage of total precipitation.

Event Date	Rainfall Event	Precipitation (in)	Percentage of Total Precipitation
11-Apr-08	#1	0.29	3%
26-Apr-08	#2	0.58	6%
28-Apr-08	#3	0.63	6%
31-May-08	#4	0.26	3%
3-Jun-08	#5	0.55	5%
4-Jun-08	#6	0.62	6%
16-Jun-08	#7	0.40	4%
23-Jun-08	#8	0.24	2%
27-Jun-08	#9	0.72	7%
9-Jul-08	#10	0.44	4%
13-Jul-08	#11	0.94	9%
23-Jul-08	#12	0.46	4%
2-Aug-08	#13	0.26	3%
14-Aug-08	#14	0.28	3%
28-Aug-08	#15	1.75	17%
25-Oct-08	#16	1.16	11%
13-Nov-08	#17	0.75	7%
Total	--	10.33	100%

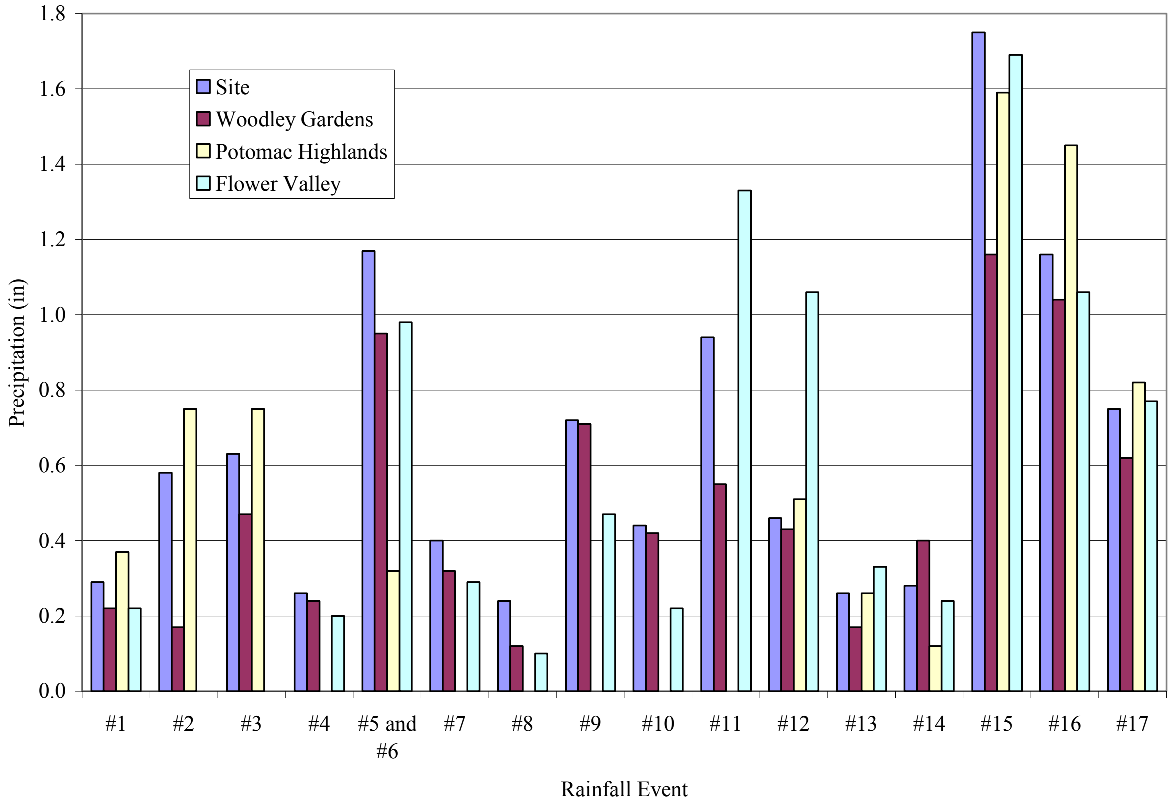

Figure 14 - Graph of precipitation from the site (RMHS) and three surrounding locations. Surrounding locations precipitation data was obtained from www.wunderground.com.

6.2 Runoff/Volume Balance

Precipitation data gathered from the site by MASWRC was used to determine the precipitation volume, Table 3. The site is 3.62 acres and a volume (gal) was calculated using the rainfall depth. The BaySeparator™ and BayFilter™ flow volumes (gal) were calculated from the ISCO flow meter data, which directly measured cumulative volumes (liters). The runoff percent is the BaySeparator™ flow volume divided by the precipitation volume. The runoff percent was on average 60% of the rainfall measured by the rain gauge, which is to be expected on a site largely covered by an impervious surface, Table 3. The site was approximately 83% impervious surfaces. The rational method runoff coefficients for this site, based on 83% impervious and 17% pervious landscaping, would be between 0.61 and 0.82. The average runoff coefficient measured on the site (0.6) is on the low side of that range, but still acceptable. Based upon reasonable agreement between the BaySeparator™ and precipitation volume, some questions arrise regarding the BayFilter™ volume, Figure 15. The flow into the BaySeparator™ should be the same volume as the flow into the BayFilter™. The unaccounted flow (fraction not going to the

BayFilter™) is the BayFilter™ flow volume divided by the BaySeparator™ flow volume. On average there was 24% less flow measured into the BayFilter™ as into the BaySeparator™, Table 3.

Table 3 - Precipitation volume calculated from rainfall data collected and BaySeparator™ and BayFilter™ volumes recorded by the flow meters. Average Runoff and Percent Not Going to BayFilter™ are flow weighted averages based on precipitation for each event.

Event	Precipitation Volume (gal)	BaySeparator™ Flow Volume (gal)	Runoff	BayFilter™ Flow Volume (gal)	BaySeparator™ and BayFilter™ Difference (gal)	Percent Not Going to BayFilter™
11-Apr-08	28,000	15,000	53%	8,000	7,000	47%
26-Apr-08	55,000	32,000	58%	25,000	7,000	21%
28-Apr-08	60,000	39,000	64%	34,000	5,000	13%
31-May-08	25,000	17,000	67%	11,000	6,000	35%
3-Jun-08	52,000	30,000	58%	22,000	8,000	27%
4-Jun-08	59,000	36,000	61%	24,000	12,000	34%
16-Jun-08	38,000	23,000	60%	17,000	6,000	25%
23-Jun-08	23,000	13,000	55%	11,000	2,000	16%
27-Jun-08	68,000	45,000	65%	39,000	5,000	12%
9-Jul-08	42,000	23,000	56%	22,000	1,000	4%
13-Jul-08	89,000	52,000	58%	41,000	11,000	21%
23-Jul-08	44,000	28,000	64%	20,000	7,000	27%
2-Aug-08	25,000	16,000	64%	11,000	4,000	28%
14-Aug-08	27,000	13,000	50%	7,000	6,000	45%
28-Aug-08	166,000	104,000	62%	73,000	31,000	30%
25-Oct-08	110,000	60,000	55%	55,000	6,000	9%
13-Nov-08	71,000	41,000	57%	23,000	18,000	44%
Average	80,000	48,000	60%	36,000	12,000	24%
Total	982,000	587,000	--	443,000	142,000	--

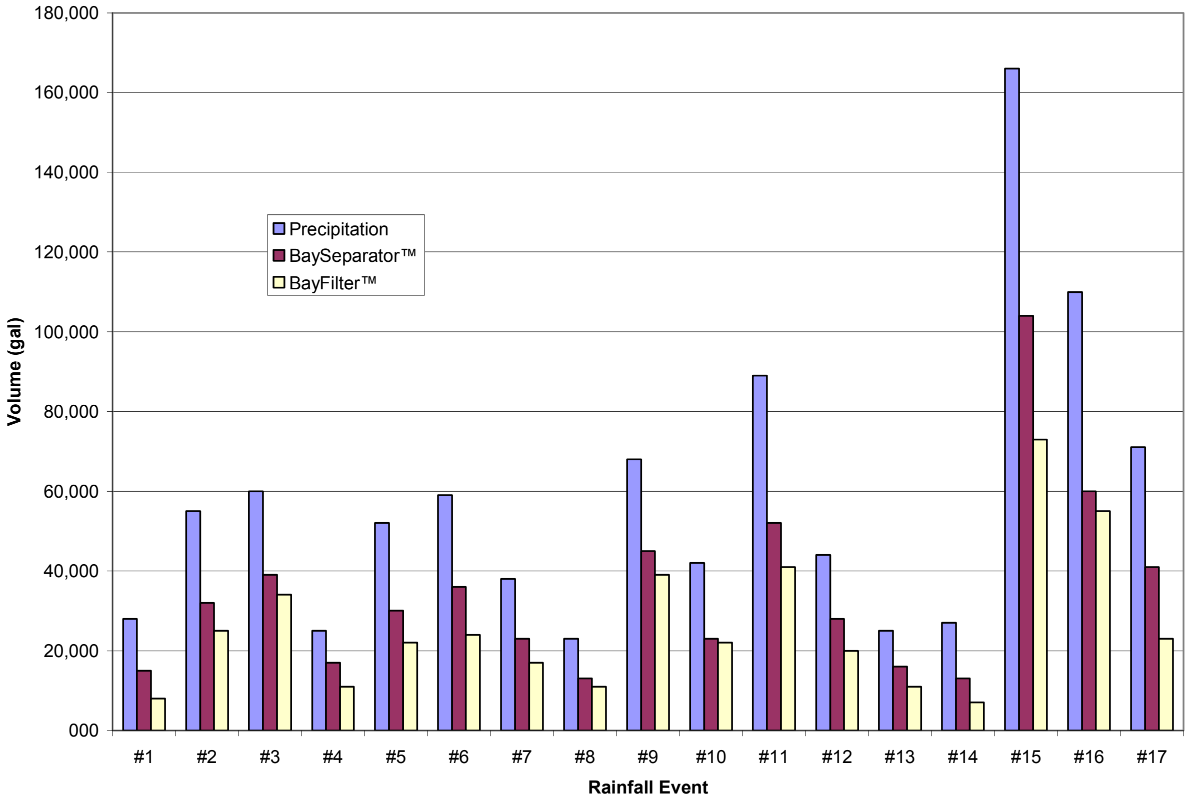

Figure 15 - Graph of the precipitation, BaySeparator™, and BayFilter™ volumes by rainfall event.

6.3 Field Flow Test

Due to the differences in flow volumes between the BaySeparator™ and BayFilter™, a field flow test was conducted on November 9, 2008. A water truck, filled with potable water, was used to provide a measurable steady flow rate, Figure 16. The BayFilter™ effluent flow meter was measured first. A 2-inch flexible hose was attached to the underdrain system in the filter vault, Figure 17. The water truck had a 2-inch flexible hose connected to straight section of approximately 20 feet of rigid PVC pipe. The flow rate was governed by a PVC ball valve at the beginning of the rigid PVC pipe. Two electronic flow meters were inline with the rigid section of pipe. The aboveground flow meters were factory calibrated to within 3% according to the manufacturer. The ball valve was adjusted to reach 7 discrete steady flow rates. The flow rate being measured in the filter vault was allowed to reach a steady state and the corresponding flow rate on the aboveground meters was recorded. Table 4 shows the recorded flow rates and the difference (gpm) between the aboveground flow meters and the ISCO flow meter in the filter vault.

Figure 16 - View of the 2-inch flex hose connected to the BayFilter™ underdrain system (November 9, 2008).

Figure 17 - Water truck used during field flow test. Two flow meters are located on the PVC piping in the picture (November 9, 2008).

Table 4 – BayFilter™ flow rates from field flow test conducted on November 9, 2008.

BayFilter™ Vault					
Aboveground Flow Meters			BayFilter	Difference (gpm)	Difference
#1 (gpm)	#2 (gpm)	Mean Flow (gpm)	ISCO Flow Meter (gpm)		
22	23	22	13	9	41%
33	35	34	22	12	35%
43	46	44	33	12	27%
56	61	59	44	15	26%
67	71	69	56	13	19%
76	80	78	67	11	14%

The BaySeparator™ flow meter was measured second. The same hose was run from the water truck to the rigid section of pipe, but only one flow meter was used, because of good agreement between the flow meters. A second 2-inch flexible hose was run from the rigid section to the inlet closest to the BaySeparator™, Figure 18. The water in the flow test entered the concrete inlet pipe directly, and was approximately 30 feet from the flow meter in the BaySeparator™. The same procedure as before was used; flow rates reached a steady state and an average of the steady state readings was taken. The results of the flow rate test in the BaySeparator™ are listed in Table 5. The correlated rainfall intensity was calculated by the Rational Method using the drainage area of 3.62 acres and a runoff coefficient of 0.6 and the aboveground flow meter data.

Figure 18 – Flow test hose entering the inlet closest to the BaySeparator (approximate location marked by the arrow). (November 9, 2008)

Table 5 – BaySeparator™ flow rates from field flow test conducted on November 9, 2008.

BaySeparator™				
Flow (gpm)	**ISCO Flow Meter (gpm)**	**Difference (gpm)**	**Difference**	**Correlated Rainfall Intensity (in/hr)**
22	25	-3	12%	0.02
41	43	-2	4%	0.04
72	68	4	-5%	0.07
95	175	-80	84%	0.10
110	188	-78	70%	0.11
147	285	-138	94%	0.15

6.3 Monitoring Results

The results being reported as part of this testing program have been submitted to NJCAT twice, in June 2008 and November 2008. The results reported are summarized below in two sections, Constituent Concentrations (Event Mean Concentrations) and Removal Efficiency Values.

6.3.1 Constituent Concentrations (Event Mean Concentrations)

The results in Tables 6, 7, and 8 show the calculated values and the reported event mean concentrations (EMC). The calculated values are the event mean concentrations calculated by UMD from the raw data supplied by MASWRC. In the case of SSC, the solids mass and sample volumes were calculated for each sample taken, and an event mean concentration was determined. In instances where a sample was not collected (i.e., an empty sample bottle), the mean value of the samples collected before and after that missing sample was calculated and used for that missing sample value (i.e., sample before the missing sample with a SSC concentration of 100 mg/L and a sample after the missing sample with a SSC concentration of 50 mg/L would result in a calculated SSC of 75 mg/L for the missing sample value). There were five events that had an uncollected sample.

In some instances, only half the expected sample volume was collected in the sample bottle; this occurred in 8 events. In those instances, splitting the sample into "A" and "B" samples for SSC analysis was not possible. The entire volume was analyzed as one sample and the result calculated the same as the mean values determined from the "A" and "B" samples for the other sample bottles.

The reported values are those event mean concentrations reported by MASWRC to BaySaver in their September 19, 2008 report (Liu, 2008). Reported values highlighted in red are values that are much greater or smaller than the calculated values ($\pm$ 5%). It should be noted that the reported values for TP from the May 31, 2008 and June 3, 2008 event appear to be flipped.

Table 6 – UMD calculated and reported EMC values for SSC. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC 5% less than or greater than the EMC calculated by UMD. Average calculated EMC value is flow weighted based on event precipitation.

	BaySeparator™ Influent		BaySeparator™ Effluent		BayFilter™ Effluent	
Event	**Calculated SSC (mg/L)**	**Reported SSC (mg/L)**	**Calculated SSC (mg/L)**	**Reported SSC (mg/L)**	**Calculated SSC (mg/L)**	**Reported SSC (mg/L)**
11-Apr-08	718	718	166	170	19	19
26-Apr-08	129	129	65	65	9	9
28-Apr-08	47	47	20	20	6	6
31-May-08	168	168	104	104	12	12
3-Jun-08	185	185	97	98	6	6
4-Jun-08	184	184	105	105	13	13
16-Jun-08	28	28	38	38	8	8
23-Jun-08	47	47	50	50	13	13
27-Jun-08	225	225	131	138	17	18
9-Jul-08	350	350	201	201	23	23
13-Jul-08	105	100	42	40	18	17
23-Jul-08	81	81	45	45	17	17
2-Aug-08	480	412	181	174	20	20
14-Aug-08	636	642	272	286	25	26
Average (Prior to 28-Aug-08)	202	--	96	--	14	--
28-Aug-08	150	Not Reported Yet	73	Not Reported Yet	11	Not Reported Yet
25-Oct-08	237		185		19	
13-Nov-08	24		34		12	
Overall	184	--	97	--	14	--

Table 7 – UMD calculated and reported EMC values for TP. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC 5% less than or greater than the EMC calculated by UMD. Average calculated EMC value is flow weighted based on event precipitation.

	BaySeparator™ Influent		BaySeparator™ Effluent		BayFilter™ Effluent	
Event	**Calculated TP (mg/L)**	**Reported TP (mg/L)**	**Calculated TP (mg/L)**	**Reported TP (mg/L)**	**Calculated TP (mg/L)**	**Reported TP (mg/L)**
11-Apr-08	0.46	0.46	0.34	0.34	0.27	0.27
26-Apr-08	0.47	0.47	0.44	0.44	0.01	0.01
28-Apr-08	0.16	0.16	0.08	0.08	0.04	0.04
31-May-08	0.41	0.29	0.35	0.27	0.26	0.12
3-Jun-08	0.29	0.41	0.27	0.35	0.12	0.26
4-Jun-08	0.56	0.56	0.25	0.25	0.11	0.11
16-Jun-08	0.16	0.16	0.18	0.18	0.07	0.07
23-Jun-08	0.30	0.30	0.23	0.23	0.11	0.11
27-Jun-08	0.42	0.42	0.41	0.41	0.07	0.07
9-Jul-08	0.45	0.45	0.46	0.46	0.14	0.14
13-Jul-08	0.49	0.49	0.18	0.18	0.09	0.06
23-Jul-08	0.28	0.28	0.15	0.15	0.07	0.07
2-Aug-08	1.56	1.35	0.71	0.63	0.16	0.13
14-Aug-08	0.82	0.82	0.54	0.55	0.30	0.30
Average (Prior to 28-Aug-08)	0.45	--	0.30	--	0.11	--
28-Aug-08	0.29	Not Reported Yet	0.37	Not Reported Yet	0.16	Not Reported Yet
25-Oct-08	0.34		0.35		0.21	
13-Nov-08	0.15		0.22		0.14	
Overall	0.39	--	0.31	--	0.13	--

Table 8 – UMD calculated and reported EMC values for turbidity. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC 5% less than or greater than the EMC calculated by UMD. Average calculated EMC value is flow weighted based on event precipitation.

	BaySeparator™ Influent		BaySeparator™ Effluent		BayFilter™ Effluent	
Event	Calculated Turbidity (NTU)	Reported Turbidity (NTU)	Calculated Turbidity (NTU)	Reported Turbidity (NTU)	Calculated Turbidity (NTU)	Reported Turbidity (NTU)
11-Apr-08	44	44	44	44	13	13
26-Apr-08	23	23	26	26	5	5
28-Apr-08	9	9	13	13	7	7
31-May-08	37	37	38	38	10	10
3-Jun-08	29	29	27	27	9	9
4-Jun-08	101	70	62	62	9	9
16-Jun-08	16	16	16	16	10	10
23-Jun-08	21	21	23	23	10	10
27-Jun-08	66	66	70	70	23	23
9-Jul-08	44	44	51	51	15	18
13-Jul-08	23	24	21	21	13	13
23-Jul-08	29	29	28	28	19	19
2-Aug-08	144	126	80	78	16	16
14-Aug-08	162	162	101	101	28	28
Average (Prior to 28-Aug-08)	47	--	40	--	13	--
28-Aug-08	33	Not Reported Yet	34	Not Reported Yet	11	Not Reported Yet
25-Oct-08	164		148		57	
13-Nov-08	13		17		12	
Overall	56	--	49	--	18	--

6.3.2 Removal Efficiency

The removal efficiencies of the BaySeparator™, BayFilter™, and the system were presented in the same reports as the EMC values. Tables 9, 10, and 11 are a comparison of calculated and reported removal efficiencies. Reported values highlighted in red are values that are much greater or smaller than the calculated values (± 5%). It should be noted that the reported values for TP from the May 31, 2008 and June 3, 2008 event appear to be flipped.

The removal efficiencies are based on EMC values and not mass removal, because there is a difference between the flow volumes measured in the BaySeparator™ and BayFilter™. The BayFilter™ flow volume would cause the mass based removal efficiency to be over reported.

Table 9 – UMD calculated and reported EMC removal efficiency values for SSC. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC removal efficiency 5% less than or greater than the EMC removal efficiency calculated by UMD. (Note: MASWRC included the April 20, 2008 event, a non-qualifying event, in their average reported change value.)

	BaySeparator™		BayFilter™		System	
Event	**Calculated SSC Change**	**Reported SSC Change**	**Calculated SSC Change**	**Reported SSC Change**	**Calculated SSC Change**	**Reported SSC Change**
11-Apr-08	77%	76%	88%	89%	97%	97%
26-Apr-08	50%	50%	87%	87%	93%	93%
28-Apr-08	57%	58%	72%	71%	88%	88%
31-May-08	38%	38%	89%	89%	93%	93%
3-Jun-08	47%	47%	94%	94%	97%	97%
4-Jun-08	43%	43%	88%	87%	93%	93%
16-Jun-08	-37%	-36%	78%	78%	70%	70%
23-Jun-08	-6%	-57%	74%	75%	73%	73%
27-Jun-08	42%	39%	87%	87%	92%	92%
9-Jul-08	43%	43%	89%	89%	94%	94%
13-Jul-08	60%	60%	58%	59%	83%	83%
23-Jul-08	45%	45%	62%	62%	79%	79%
2-Aug-08	62%	58%	89%	89%	96%	95%
14-Aug-08	57%	56%	91%	91%	96%	96%
Average (Prior to 28-Aug-08)	53%	51%	85%	85%	93%	93%
28-Aug-08	51%	Not Reported Yet	84%	Not Reported Yet	92%	Not Reported Yet
25-Oct-08	22%		90%		92%	
13-Nov-08	-41%		66%		52%	
Overall	47%	--	86%	--	92%	--

Table 10 – UMD calculated and reported EMC removal efficiency values for TP. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC removal efficiency 5% less than or greater than the EMC removal efficiency calculated by UMD. (Note: MASWRC included the April 20, 2008 event, a non-qualifying event, in their average reported change value.)

	BaySeparator™		BayFilter™		System	
Event	**Calculated TP Change**	**Reported TP Change**	**Calculated TP Change**	**Reported TP Change**	**Calculated TP Change**	**Reported TP Change**
11-Apr-08	26%	26%	22%	21%	43%	41%
26-Apr-08	6%	6%	97%	98%	97%	98%
28-Apr-08	50%	50%	50%	50%	75%	75%
31-May-08	15%	7%	27%	56%	38%	59%
3-Jun-08	8%	15%	56%	26%	59%	37%
4-Jun-08	55%	55%	57%	56%	81%	80%
16-Jun-08	-11%	-13%	59%	61%	55%	56%
23-Jun-08	25%	23%	54%	52%	65%	63%
27-Jun-08	3%	2%	83%	83%	83%	83%
9-Jul-08	-1%	-2%	70%	70%	70%	69%
13-Jul-08	63%	63%	52%	67%	83%	88%
23-Jul-08	47%	46%	53%	53%	75%	75%
2-Aug-08	55%	53%	77%	79%	90%	90%
14-Aug-08	33%	33%	46%	46%	64%	63%
Average (Prior to 28-Aug-08)	33%	30%	64%	66%	76%	76%
28-Aug-08	-29%	Not Reported Yet	58%	Not Reported Yet	45%	Not Reported Yet
25-Oct-08	-3%		40%		38%	
13-Nov-08	-48%		37%		7%	
Overall	20%	--	58%	--	67%	--

Table 11 – UMD calculated and reported EMC removal efficiency values for turbidity. Reported values were reported by MASWRC to BaySaver on September 19, 2008. Reported values in red signify an EMC removal efficiency 5% less than or greater than the EMC removal efficiency calculated by UMD. (Note: MASWRC included the April 20, 2008 event, a non-qualifying event, in their average reported change value.)

	BaySeparator™		BayFilter™		System	
Event	**Calculated Turbidity Change**	**Reported Turbidity Change**	**Calculated Turbidity Change**	**Reported Turbidity Change**	**Calculated Turbidity Change**	**Reported Turbidity Change**
11-Apr-08	0%	2%	70%	70%	70%	70%
26-Apr-08	-12%	-12%	79%	79%	76%	76%
28-Apr-08	-44%	-37%	46%	46%	22%	26%
31-May-08	-4%	-4%	73%	73%	72%	72%
3-Jun-08	9%	9%	66%	66%	69%	69%
4-Jun-08	39%	11%	85%	85%	91%	87%
16-Jun-08	-4%	-4%	40%	40%	38%	38%
23-Jun-08	-12%	-12%	57%	57%	51%	51%
27-Jun-08	-6%	-6%	67%	66%	65%	64%
9-Jul-08	-17%	-17%	70%	65%	65%	60%
13-Jul-08	11%	15%	35%	35%	43%	45%
23-Jul-08	3%	3%	32%	32%	34%	35%
2-Aug-08	44%	38%	80%	80%	89%	87%
14-Aug-08	38%	38%	72%	72%	83%	83%
Average (Prior to 28-Aug-08)	16%	7%	67%	68%	72%	70%
28-Aug-08	-2%	Not Reported Yet	68%	Not Reported Yet	67%	Not Reported Yet
25-Oct-08	10%		61%		65%	
13-Nov-08	-30%		33%		13%	
Overall	11%	--	64%	--	68%	--

6.3.3 Split Samples

6.3.3.1 October 25, 2008

Nine split samples were collected from the October 25, 2008 rainfall event. Three samples from each of the three sampling locations were split. The samples were analyzed for SSC, TP, and turbidity; results are presented in Tables 12, 13, and 14. Generally, UMD SSCs (first half of the sample) were lower, -1 to -34%, than MASWRC SSCs (second half of the sample). The only exception was sample number 6 from BayFilter™ effluent, which UMD found to be 95% higher than the value MASWRC found. The UMD and MASWRC TP concentrations ranged widely, between -66 to 52%. The BayFilter™ number 6 (BFe6) sample was not analyzed for TP. Turbidity values were within 15% for six of the nine samples, and the other three were between 27 and 68%. Although the percent differences may appear to be large, agreement is generally satisfactory. The variability in values between UMD and MASWRC is to be expected with splitting samples in the field, different laboratory equipment, and slight differences in laboratory handling and analysis.

Table 12 – SSC results of the split samples collected on October 25, 2008.

10/25/2008				
Sample ID	**UMD SSC (mg/L)**	**MASWRC SSC (mg/L)**	**Difference (mg/L)**	**Difference**
BSi2	15	17	3	-16%
BSi6	125	190	64	-34%
BSi8	335	427	92	-22%
BSe5	163	193	29	-15%
BSe7	108	110	2	-2%
BSe9	432	437	5	-1%
BFe1	29	33	4	-11%
BFe3	17	25	8	-33%
BFe6	25	13	-12	95%

Table 13 - TP concentration results from the split samples collected on October 25, 2008.

10/25/2008					
Sample ID	**UMD TP (mg/L)**	**UMD TP Duplicate (mg/L)**	**MASWRC TP (mg/L)**	**Difference (mg/L)**	**Difference**
BSi2	0.06	---	0.04	-0.02	52%
BSi6	0.20	---	0.26	0.06	-23%
BSi8	0.68	---	0.91	0.23	-25%
BSe5	0.14	---	0.21	0.07	-32%
BSe7	0.28	---	0.23	-0.05	22%
BSe9	0.79	---	0.80	0.01	-1%
BFe1	0.12	0.15	0.36	0.24	-66%
BFe3	0.12	---	0.27	0.15	-57%

Table 14 - Turbidity results from the split samples collected on October 25, 2008.

10/25/2008				
Sample ID	**UMD Turbidity (NTU)**	**MASWRC (NTU)**	**Difference (NTU)**	**Difference**
BSi2	22	15	-7	45%
BSi6	97	93	-4	5%
BSi8	355	316	-39	12%
BSe5	67	59	-8	13%
BSe7	88	83	-5	6%
BSe9	541	427	-114	27%
BFe1	91	88	-3	3%
BFe3	72	66	-6	9%
BFe6	65	39	-26	68%

6.3.3.2 November 13, 2008

Nine split samples were collected from the November 13, 2008 rainfall event. Three samples from each of the three sampling locations were split. The samples were analyzed for SSC, TP, and turbidity; results are presented in Tables 15, 16, and 17. UMD SSCs (first half of the sample) were lower, 0 to -85%, than MASWRC SSCs (second half of the sample). The UMD and MASWRC TP concentrations ranged widely, between -33 to 380%, with no clear correlation. Turbidity values reported by UMD were generally higher, 4 to 87%, than values found by MASWRC. Although the percent differences appear to be large, agreement is generally satisfactory. The variability in values between UMD and MASWRC is to be expected with splitting samples in the field, different laboratory equipment, and slight differences in laboratory handling and analysis. The largest abnormality is the TP results from the BSi2 and BSe8 samples, which UMD calculated values three to four times greater than the values reported by MASWRC. The values UMD found were not typical of the other samples results reported by MASWRC and UMD, but no bias was determined.

Table 15 – SSC results of the split samples collected on November 13, 2008.

11/13/2008				
Sample ID	**UMD SSC (mg/L)**	**MASWRC SSC (mg/L)**	**Difference (mg/L)**	**Difference**
BSi2	47	56	9	-16%
BSi4	29	38	9	-25%
BSi8	20	24	4	-17%
BSe2	40	41	1	-3%
BSe4	49	50	1	-2%
BSe8	3	17	14	-85%
BFe2	6	8	2	-22%
BFe6	10	10	0	-4%
BFe10	8	9	1	-12%

Table 16 - TP concentration results from the split samples collected on November 13, 2008.

11/13/2008					
Sample ID	**UMD TP (mg/L)**	**UMD TP Duplicate (mg/L)**	**MASWRC TP (mg/L)**	**Difference (mg/L)**	**Difference**
BSi2	0.96	---	0.20	-0.76	380%
BSi4	0.18	---	0.14	-0.04	27%
BSi8	0.15	0.17	0.18	0.03	-19%
BSe2	0.19	---	0.21	0.02	-12%
BSe4	0.24	---	0.23	-0.01	4%
BSe8	0.92	---	0.29	-0.63	217%
BFe2	0.13	---	0.20	0.07	-33%
BFe6	0.15	0.13	0.11	-0.04	33%
BFe10	0.15	---	0.09	-0.06	67%

Table 17 – Turbidity results of the split samples collected on November 13, 2008.

11/13/2008				
Sample ID	**UMD Turbidity (NTU)**	**MASWRC (NTU)**	**Difference (NTU)**	**Difference**
BSi2	41	27	-13	48%
BSi4	29	19	-9	48%
BSi8	20	11	-9	87%
BSe2	35	26	-9	36%
BSe4	44	30	-14	49%
BSe8	9	7	-2	36%
BFe2	13	12	-1	4%
BFe6	21	12	-9	78%
BFe10	22	12	-9	75%

7.0 DISCUSSION

7.1 Precipitation

The precipitation data collected at the site demonstrate good agreement with precipitation data collected in the surrounding area, Figure 14. One discrepancy was the June 27, 2008 event which original had a value of 0.36 inches reported. That data appeared to be half the actual value, and the value was adjusted by MASWRC to 0.72 inches. The collection of the precipitation data, downloaded from the HOBO logger appears to be done in a thorough manner. MASWRC checks the precipitation data from the site against data from www.wunderground.com (Woodley Gardens monitoring station) for similarities and differences. The rain gauge appears to be collecting accurate data, and the data are being checked by MASWRC against additional known values.

7.2 Flow Balance

The differences in reported flows between the BaySeparator™ and BayFilter™ were the most troubling aspect of the data being evaluated. Between 4% to 45% of the flow into the BaySeparator™ was not being recorded in the BayFilter™. The difficulty and uncertainty associated with area/velocity flow meters has been noted in many other studies. The flows do not usually balance easily as these test are conducted under field conditions. ETV, in their testing of the BaySeparator™ in 2003, noted wide ranging differences in reported flows from the influent to the effluent of the BaySeparator. However, the cumulative volumes being reported by the flow meters should be in agreement with each other. The two values should balance with 10 to 20%. Currently, the flow volumes are varying on average by 24%.

The field flow test results show that the BaySeparator™ flow meter may be over reporting the flow rate and the BayFilter™ flow meter may be under reporting the flow rate, Tables 4 and 5. Based on the flow test results, the BayFilter™ flow meter was under reporting flow rates by as much as 50%, and likewise the BaySeparator™ flow meter, at flow rates greater than 100 gpm, was over reporting by as much as 50%. Also, under high intensity or long duration rainfall events, the detention system can be completely full and flow is diverted from the BaySeparator™. This bypass is estimated to have occurred during the August 28, 2008 according to MAWSRC and BaySaver.

The final consideration to be taken into account for the flow balance is a break in the structures or piping. Construction activities have been occurring on site throughout the duration of the project, and it is possible that damage was done. Notably, the construction activities occurred in the vicinity of the treatment devices during August and September 2008. Data from events after those activities had flow balance differences of 9% and 44%.

Although damage to the treatment devices is possible, based on the under and over reporting of the flow meters in the field flow test, and no clear trend on the percentage of flow unaccounted for, it seems unlikely that damage is the cause of the discrepancies in flow data. Most likely the over reporting of BaySeparator™ flow rate and under reporting of BayFilter™ flow rate is the cause of the unbalanced flow volumes.

7.3 Monitoring Results

The EMC data calculated by UMD were found to be similar to the data reported by MASWRC. Discrepancies in the data are likely due to UMD using mean values of the samples before and after an uncollected (empty bottle) sample, while MASWRC does not take into account a sample bottle being empty. A half full or empty sample bottle was found in many of the events. This was likely due to the flow being below the suction line (approximately 0.5 inches off the bottom of the pipe) or the suction line clogging.

The water quality samples were potentially affected by the lack of sample preservation, exceeding recommended hold times, and the absence of QA/QC laboratory methods. Sample preservation has only been used by MASWRC for the October 25 and November 13, 2008 events. Hold times potentially have been exceeded for the samples over the course of the project. Without laboratory duplicates of TP and turbidity, there are no means to evaluate consistency between the results being reported. Further QA/QC, both on sample handling and sample analyses, needs to be a priority, to ensure accurate results.

7.4 Cumulative Mass

Cumulative mass values were reported in the two reports to NJCAT, however these data are likely to be inaccurate due to the differences in reported flow volumes. If cumulative mass loadings are to be calculated, the same volume must be used for both, unless flow is bypassing the detention system.

7.5 Non-Qualifying Events

During the course of the field testing some field testing data that were gathered were not used, because the rainfall or sampling event was determined to be a non-qualifying event. Other events were not used due to problems with the collection of samples. A few key events are noted below as to why samples were not collected and/or reported.

The September 6, 2008 event was a high volume rainfall event that caused flooding in the filter vault. Samples were not collected, because the filter vault auto-sampler capsized and the BaySeparator™ auto-sampler was jammed.

During the month of May 2008, rainfall events were not sampled, with the exception of the May 31, 2008 event. During that time period MASWRC was in the process of compiling an interim field testing data report for MDE.

The month of July 2008 had 3 small rainfall events that occurred from July 1, 2008 to July 5, 2008 that did not qualify as rainfall events because the precipitation amounts were too low, less than 0.15 inches.

The April 20, 2008 rainfall event did not meet the requirement of 70% of flow collected. Flow sampling was not paced properly and there was a time gap between the 24th and 25th samples collected.

The September 25, 26, and 30, 2008 rainfall events occurred while construction activities were occurring on the site.

7.6 Concerns

Over the course of the project an ongoing dialogue has taken place between UMD and MASWRC regarding the sampling and data evaluation. Discrepancies and deficiencies have been identified between current practices and the necessary practices. These necessary practices are based on information in the Standard Methods, the QAPP, and the Tier II protocol. To date some of these concerns have been addressed, while others remain to be rectified.

7.6.1 Concerns Addressed

The concerns that have been addressed are listed below, including what MASWRC did to solve the problem *(listed in italics).*

- Sample Labels – The labels needed to be more descriptive. Suggested using color coded dots, repeat labeling, date, and sample location included on labels. *Currently, color coded dots (one on each side of sample bottle) and a computer generated label with the sample ID and date are being affixed to the sample bottles.*
- Sample Cross Contamination – Potential cross contamination of total phosphorus (TP) sample due to using same pipette to extract from sample bottle. *According to MASWRC, the pipette is now rinsed between samples sets (i.e., between sampling the BaySeparator influent and effluent sample sets) and the last sample collected (i.e. #24) is the first sample being extracted (lowest expected TP).*
- Field Log Book – Log book detailing site activities is required (TARP Protocol, Appendix F, section A9) and use of a log book is also included in QAPP as, "The samples taken will also be recorded in the field logbook, along with the depth of precipitation, duration of the storm event, peak rainfall intensity, and peak runoff flow rate for the event." *Starting with the September 25, 2008 event, MASWRC is using a set of field checklists as their field log book (see Appendix E).*
- Chain of Custody (COC) – A COC is required by TARP (TARP Protocol, section 3.3.5) and the QAPP states a COC will be used. *MASWRC started using a COC for the October 25, 2008 event, Appendix D.*
- Sample Preservation is required by TARP and Standard Methods (TARP protocol, section 3.3.5, SM 4500 and SM 2540) and specified in the QAPP. *Starting with the October 25, 2008 event, samples are placed on ice as soon as they are collected in the field. Samples are stored at 4 ^{o}C (i.e,. in a refrigerator) while awaiting analysis.*
- Plastic Bottles – Plastic bottles are being used, which may adsorb phosphate (SM 4500). *Per MASWRC, TP sub-sample is now being taken immediately upon return to the laboratory.*

7.6.2 Concerns Remaining

The remaining concerns listed below are related to both the sample handling and analysis and overall system performance. Potential solutions are listed below also *(in italics).*

QAPP/TARP Tier II Protocol Requirements

- QAPP Approval – QAPP needed to be approved prior to field testing (TARP Protocol, section 2.2). A final version of the QAPP was submitted to NJCAT on November 9, 2008. *Going forward, the QAPP should be closely followed and any deficiencies between the current practices and those listed in the QAPP need to be addressed immediately.*
- QAPP Requirements – Required sections in the QAPP are identified in TARP Protocol in Appendix E. The required QAPP sections are derived from EPA Requirements for Quality Assurance Project Plans (EPA QA/R-5). *Examine the TARP Protocol requirements and the EPA requirements and address all deficiencies between the requirements and the current QAPP. Possible modifications to the current QAPP may be necessary.*
- Laboratory Accreditation – An accredited/certified laboratory is required for sample analysis (TARP Protocol, section 3.3.7). MASWRC is currently applying for accreditation. *Continue with the accreditation process, and discuss with NJCAT the retroactive application of this requirement.*

Laboratory Procedures

- Holding Time – TSS samples should be analyzed within 24 hours because of bacterial decomposition, and they never should go longer than 7 days without being analyzed (SM 2540). Turbidity samples should be run immediately (SM 2130). *Run all samples immediately after transporting them back to the laboratory. Samples should be collected from the site within 24 hours of the end of the rainfall event.*
- Sample Labels – QAPP states “bottles will be labeled with the sample location (inlet or outlet), the date and time of the first aliquot (this time will mark the beginning of the holding time), and the type of sample (flow weighted composite discrete flow composite).” *Could also use samples labels, including sample ID, on sub-samples being used in the laboratory (i.e., on TSS filter pans and TP digestion beakers).*

- Sample Preservation – Samples taken for TP analysis should be preserved with sulfuric acid (SM 4500). *Use sulfuric acid to preserve TP samples if analysis is not being done immediately.*
- Plastic Bottles – TP samples should be stored in glass containers if being held more than 24 hours. *Transfer TP samples to glass containers if TP analysis is not being done immediately.*
- Consistency – Data analysis revealed a gap in QA/QC and the lack of documentation regarding field activities (field book) and laboratory analysis. *MASWRC personnel should visit a laboratory to see their protocols and procedures. This would give MASWRC a better understanding of sample handling and analysis. Create a sample handling and analysis handbook, which would aid in training new laboratory technicians and have all personnel confident in their procedures. Keep a laboratory record book that notes all samples irregularities and why they occurred (i.e., half samples, missing samples, suction line clogged, filter vault flooded, etc.).*
- Sample correlation – Currently, very limited number of laboratory duplicates have been taken or analyzed, besides SSC, which tends to be lower in the first half of the sample than the second half of the sample. *Conduct more laboratory duplicates to check values by splitting samples to measure TP and turbidity. Send split samples to a commercial laboratory to correlate with MASWRC values.*

Field Procedures

- Health and Safety Plan– A health and safety plan is required as part of the field testing (TARP Protocol, section 4), but currently no health and safety plan exists for the field testing being conducted. *The health and safety plan should contain information regarding confined space entry (the most critical part of the plan), traffic hazards at the site, and contact numbers in the event of an emergency. The location, including a map, of the nearest hospital should be included in the health and safety plan. The plan should be with personnel at the site.*

Data Reporting

- Volume Balance – The balance in flow between the BaySeparator and BayFilter has not been closed. The field flow test helped address some of the concerns, and the presence of an ultrasonic pressure sensor in the filter vault further aids in the understanding of flow differences. *Continue to examine why the flows do not agree within 10 to 20% of one another. Consider conducting a longer flow test, pulling and checking the flow meters calibration, and also try to determine if the filter vault or horizontal detention system is leaking.*
- Monitoring Results Reported – The differences in the reported values from the UMD calculated values most likely are due to flow weighting of half samples. *In examining the data, MASWRC should enact a stricter QA/QC program. The tables are often cumbersome to use and cannot be checked quickly and efficiently. Keeping all the information calculated for each sample, in one row, would aid in the checking process. (i.e., The formulas used to calculate mean concentration can be dragged down, with no errors introduced through cutting and pasting.)*
- Split Samples – The differences between the concentrations UMD found and MASWRC found were generally minor and could be due to sample handling procedures, sample preservation, or analyses conducted. *The applicable method for each constituent should be strictly followed, and an intensive QA/QC program implemented, including equipment blanks, field blanks, field duplicates, baseline (deionized water) samples, and known value samples.*

Field Testing Program

- Loading – The amount of sediment concentration dropped in the summer due to a decrease in vehicular traffic. *Continue the monitoring program for at least one year to account for seasonal variations.*
- Clay Material – There has been an influx of silt and clay material into the system from the construction activities, which may be impacting the removal efficiencies. *Sediment and erosion controls should be installed on the construction site to prevent erosion onto the site. (Figures 19 and 20.)*

Figure 19 - View of construction activities at the site (Courtesy of BaySaver).

Figure 20 - View of sediment washed onto the site. The grassy area was previously silt and clay with no erosion and sediment controls present.

- BayFilter™ Influent – The BaySeparator™ effluent sample is being considered as the influent to BayFilter. However, a horizontal detention system exists between the BaySeparator™ effluent and BayFilter™ vault. *To properly evaluate the removal efficiencies of the BayFilter™, samples need to be taken at the influent pipe to the filter vault, unless the horizontal detention system is considered part of the BayFilter™.*
- Oil and Grease Removal – The BaySeparator™ is claimed to have oil and grease removal, but an auto-sampler (TARP) cannot be used to collect volatile organic samples (VOCs). *A grab sample is needed to analyze oil and grease; once the MASWRC facility is online, the oil and grease claim should be evaluated.*
- Independent testing – BaySaver and MASWRC work in close conjunction on the field testing of the system. However, the TARP protocol calls for independent third party field testing of the system. *For future studies, BaySaver should provide MASWRC with an annual budget and allow MASWRC to determine which tests are necessary to provide accurate data. By ceding control of the budget to MASWRC for the field testing, the degree of influence that BaySaver could potentially exert over MASWRC would be limited.*

8.0 SUMMARY/CONCLUSION

Currently, the MASWRC has qualified samples for approximately 10 inches of precipitation and 17 qualified events have been sampled. Overall, the field activities being conducted by MASWRC are in line with acceptable industry practices, except where noted above in the concerns section. However, the laboratory practices, including sample preservation and laboratory validation, have been deficient at times. The concerns identified above have been addressed in many instances, but the remaining discrepancies and deficiencies should be addressed immediately. The data previously reported should undergo a stringent QA/QC process to ensure accuracy, and data reported in the future should also be subject to a comprehensive QA/QC review. Based upon UMD's evaluation of the MASWRC field testing program, the EMC and removal efficiency results are within an acceptable range with previous stormwater field testing programs. There appears to be no significant error or omission on the part of the sampling and analysis conducted by MASWRC to invalidate the data being collected.

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