# NJCAT TECHNOLOGY VERIFICATION

# BayFilter™

## BaySaver Technologies, Inc.

**June 2008**

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# 1. INTRODUCTION

## 1.1 New Jersey Corporation for Advanced 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 through the use 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 (USEPA), other local 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 Technology Verification Report

On January 22, 2008, BaySaver Technologies, Inc. (1302 Rising Ridge Road, Unit One, Mount Airy, MD 21771) submitted a formal request for participation in the NJCAT Technology Verification Program. The request (after pre-screening by NJCAT staff personnel in accordance with the technology assessment guidelines) was accepted into the verification program. The technology proposed by BaySaver, the BayFilter™, is a filtration device designed to remove fine sediments and nutrients from stormwater runoff.

This verification report covers the evaluation based upon the performance claim of the vendor, BaySaver (see Section 4). The verification report differs from typical NJCAT verification reports in that final verification of the BayFilter™ (and subsequent NJDEP certification of the technology) awaits completed field testing that meets the full requirements of the Technology Acceptance and Reciprocity Partnership (TARP) – Protocol for Stormwater Best Management Practice Demonstrations, and New Jersey Tier II Stormwater Test Requirements. This verification report is intended to evaluate the BayFilter™ initial performance claim for the technology based on laboratory studies. This claim is expected to be modified and expanded following completion of the field-testing in accordance with the TARP and New Jersey Tier II Stormwater Test Requirements.

This verification project included the evaluation of assembled company's manuals, literature, and laboratory testing reports to verify that the BayFilter™ satisfies the performance claim made by BaySaver Technologies, Inc.

## 1.3 Technology Description

### 1.3.1 Technology Status: general description including elements of innovation/uniqueness/competitive advantage

In 1990 Congress established deadlines and priorities for USEPA to require permits for discharges of stormwater that is not mixed or contaminated with household or industrial wastewater. Phase I regulations established that a NPDES (National Pollutant Discharge Elimination System) permit is required for stormwater discharge from municipalities with a separate storm sewer system that serves a population greater than 100,000 and certain defined industrial activities. To receive a NPDES permit, the municipality or specific industry has to develop a stormwater management plan and identify Best Management Practices (BMPs) for stormwater treatment and discharge. BMPs are measures, systems, processes or controls that reduce pollutants at the source to prevent the pollution of stormwater runoff discharge from the site. Phase II stormwater discharges include all discharges composed entirely of stormwater, except those specifically classified as Phase I discharge.

The nature of pollutants emanating from differing land uses is very diverse. There is growing interest to remove very fine suspended sediments and the associated pollutants. Other water quality constituents transported in storm water such as nutrients (i.e., phosphorous) and metals are becoming significant concerns of many watersheds. Dissolved constituents of these pollutants are not able to be removed from the runoff stream using traditional solid-liquid separation technologies. In a response to this growing awareness and need, BaySaver Technologies has developed the BayFilter™ to treat the storm water runoff and remove very fine particles and nutrients to meet the regulatory requirements for protected watersheds or water bodies.

*General*

The BayFilter™ system removes contaminants from stormwater runoff via media filtration. Media filtration has long been used in drinking water and wastewater treatment processes. This technology has proven effective at removing sediments, nutrients, heavy metals, and a wide variety of organic contaminants. The target pollutants, hydraulic retention time, filter media, pretreatment, and flow rate all affect the removal efficiency of the filter.

The BayFilter™ removes pollutants from water by two mechanisms: 1) interception/attachment and 2) adsorption. Interception occurs when a pollutant becomes trapped within the filter media. A sediment particle, for example, may be carried into the filter media by the water and become stuck in the interstices of the media. Such a particle will typically remain trapped within the media until the media is removed or the filter is backwashed. Attachment occurs when pollutants bind themselves to the surface of the filter media, and this happens primarily through adsorption. Adsorption is a surface process by which dissolved ions are removed from a solution and chemically bind themselves to the surface of the media. This occurs when the surface of the filter media particle contains sites that are chemically attractive to the dissolved ions. The BayFilter™ system uses a proprietary media containing activated alumina to enhance adsorption of anions such as phosphates.

BayFilter™ relies on a spiral wound media filter cartridge with approximately 43 square feet of active filtration area. The filter cartridges are housed in a concrete vault structure that evenly distributes the flow between cartridges. System design is offline with an external bypass that routes high intensity storms away from the system to prevent sediment resuspension. Flow through the filter cartridges is gravity driven and self-regulating. The BayFilter™ has no moving parts or electrical power requirements. Some of its key design features include:

- **Spiral Wound Design:** The filter is constructed with continuous spiral winding. This enables the inlet chamber to be continuous and facilitates influent flow over the entire surface area.

- **"Up Flow Filtration":** Because of the spiral winding, the inlet and outlet can be either upflow or downflow. The BaySaver Filter Cartridge (BFC) utilizes the upflow configuration. This allows for more effective pollutant removal and full area utilization of the vault.

- **Hydrodynamic Backwash:** The BFC has a periodic backwash component unique to the BaySaver filter design. This backwash has the effect of dislodging particles captured in the filtration layers and reestablishing filter porosity. Dislodged particles are then accumulated in the vault.

The filter also has a siphon component which enables the filter to flow evenly throughout its operation even when the inflows are very low.

#### 1.3.2 Specific Applicability

BayFilter™ has been developed for a wide variety of applications where control of fine particles and achievement of the 80% TSS removal has been established as a regulatory requirement. These applications may include, but are not limited to:

- Parking lots at commercial and industrial sites
- Medium and high-density residential areas
- Maintenance facilities and corporation yards
- Transportation – roadways, bridges and transit facilities

#### 1.3.3 Range of Contaminant Characteristics

The BayFilter™ has been shown to capture a wide range of pollutants of concern. These include, but are not limited to fine sediments and nutrients.

#### 1.3.4 Range of Site Characteristics

BayFilter™ systems are usually designed to treat moderate to low flow rates. In the vast majority of applications, the peak design flow through the storm drain system will be significantly greater than the treatment design flow through the BayFilter™. Because of this difference, a bypass structure is required for most BayFilter™ installations.

If the anticipated sediment load is particularly heavy, or if there will be a significant oil load the system may require pretreatment. Pretreatment may also be required by local regulations. Pretreatment systems will remove a portion of the influent pollutant load.

The BayFilter™ is designed to accommodate a wide range of moderate to low flows. Higher flow rates can be accommodated by increasing the number of cartridges. Each BFC has a maximum nominal flow of 30 gpm. At this flow and at a 34-in driving head, each cartridge can treat 125 lbs of the total sediment load (based on the Sil-Co-Sil 106 test load) before maintenance. At higher driving heads the total sediment load that can be treated prior to maintenance increases. In addition, through the use of different size flow control orifice(s), the BFC flow is regulated. As the flow is lowered, the treated sediment load increases. For example, when the flow is lowered to 15 gpm, the cartridge is able to treat 300 lbs of the total sediment load (based on the Sil-Co-Sil 106 test load) before maintenance. (See Section 5.5 for the laboratory test data and discussions that support this information.) A chart of the flows and total sediment loads (based on the Sil-Co-Sil 106 test loads) can be found on Table 1.

**Table 1. Design Guidelines for BayFilter™ Cartridges**

| Design Flow per BFC-gpm Nominal | Treated Sediment Load for 80% Sediment Removal-lbs | Total System Head at Design Flow-Inches |
|---|---|---|
| 30 | 125 | 34 |
| 30 | 150 | 40 |
| 23 | 200 | 40 |
| 20 | 250 | 40 |
| 15 | 300 | 40 |

(*) Sediment with $d_{50}$ = 23 microns

### 1.3.5 Material Overview, Handling and Safety

Access to the BayFilter™ for inspection or maintenance is achieved through a minimum 30″ frame and cover.

Maintenance residuals should be disposed in accordance with local and state regulations. Solids recovered from the BayFilter™ can typically be land filled and liquids disposed of at a wastewater treatment plant. It is possible that there may be some specific land use activities that create contaminated solids, which will be captured in the system. Such material would have to be handled and disposed of in accordance with the appropriate regulatory requirements.

## 1.4 Project Description

This project included the evaluation of assembled reports, company manuals, literature, and laboratory testing reports to verify that the BayFilter™ meets the performance claim of BaySaver Technologies, Inc.

### 1.5 Key Contacts


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## 2. EVALUATION OF THE APPLICANT

### 2.1 Corporate History

BaySaver Technologies, Inc. was founded in 1997 by Tom Pank, owner of Accubid, a large commercial excavation firm located in Mount Airy, Maryland. Mr. Pank saw a need for a more effective and economical solution to the stormwater treatment requirements for his construction clients. He began experimenting with a 3-chamber box and quickly learned that a dual-manhole system with three treatment paths, as provided by the BaySeparator Separation System, yields an effective manner for treatment without re-suspension of sediments and debris. Mr. Pank's first unit was installed in January 1997. The patent was officially awarded in 1998 for the BaySeparator Stormwater Separation System (Pank 5,746,911). This system treats the influent water according to the rate of the flow removing sediment, debris and oil throughout the entire storm.

In 1998, BaySaver Technologies, Inc. initiated a product development effort related to stormwater filtration technology and designed the BayFilter™ cartridge. Since then, several filter configurations and designs have been tested. In 2005 BaySaver committed to further invest in a state-of-the-art process testing facility to evaluate several of the filtration design concepts it had developed over the last several years. This facility was designed as a full-scale testing laboratory for stormwater filtration devices.

The key product features that BaySaver targeted for the BayFilter™ stormwater filtration system were:

1. Achieve at least 80% solids removal efficiency when challenged with test sediment
2. Capable of removing over 50% Total Phosphorus (not yet verified)
3. Turbidity reduction (not yet verified)
4. No leaching of contaminants such as nitrogen from the trapped materials (not yet demonstrated)
5. Capable of sustaining nominal flow of 30 gpm when challenged with 125 lbs of test sediment
6. Easy to install
7. Favorable treatment economics
8. Capable of treating 300 pounds of incoming test sediments before requiring maintenance at 15 gpm

### 2.2 Organization and Management

BaySaver Technologies, Inc. is headquartered in Mount Airy, Maryland, with a second office located in Vancouver, Washington. Both offices work with distributors located throughout the United States. BaySaver has three Regional Managers, Laddie Fromelius, Garvin Cox, and Craig Phelps who oversee eight Area Mangers. BaySaver also works with 89 Independent Representatives and Distributors around the country. Growth of the distribution chain will continue until all areas around the U.S. and Canada are represented. The key personnel are: Tom Pank, President, Rex Hansen, Vice President of Sales and Marketing, Alexander Weisz, Engineering Service Manager, Brad Gianotti, Regulatory Compliance Coordinator and Robert Bilter, Director of Manufacturing. Mr. Pank has over ten years of experience in the stormwater industry and has extensive background and resources to accommodate the demands found in the stormwater industry.

### 2.3 Operating Experience with respect to the Proposed Technology

Over 23 BayFilter™ Systems have been installed throughout the United States.

### 2.4 Patents

The BayFilter™ stormwater filtration system is protected by U.S. Patent #6869528, in addition to several pending patents.

### 2.5 Technical Resources, Staff and Capital Equipment

BaySaver Technologies, Inc.'s corporate headquarters and manufacturing facilities are located in Mount Airy, Maryland. All design and technical support is also performed at the main office. The staff consists of an Engineering Team made up of four Applications Engineers and an outsourced Hydraulic Engineer, as well as a Plant Manager and eight craftsmen. In addition to the BaySaver Team two consultants with engineering and physics backgrounds have been added to work on product enhancements and new product design. When a product is specified for a particular application, BaySaver Application Engineers provide shop drawings for independent concrete pre-casters chosen by the site contractors. BaySaver products are shipped directly to the site within two weeks of purchase order. The site contractor is responsible for installation. Complete installation guidelines are supplied at the time of delivery to the job site and include step-by-step instructions for installation. BaySaver's representatives provide on-site support and guidance for installation upon request.

BaySaver also has a state-of-the-art, full-scale stormwater technology testing facility, which is being used to extensively test all BaySaver products before they become available on the market.

## 3. TREATMENT SYSTEM DESCRIPTION

### 3.1 The BayFilter™ Cartridge

The main building block of the BayFilter™ stormwater filtration system is the BayFilter™ cartridge (BFC). BFCs are housed in a structure which may be a vault, manhole or other structure. This structure contains the inlet and outlet pipes as well as an internal manifold that delivers treated water to the outlet of the BayFilter™ system. A schematic diagram of the BFC is shown in Figure 1. The filter feed water enters the vault via an inlet pipe. Water then flows through the BayFilter™ driven by either hydrostatic head or siphon action.

### 3.2 The Draindown Cartridge Filter

Each BayFilter™ Stormwater Treatment System will include a number of standard BFCs and one or more draindown filter cartridges depending on site conditions. The draindown cartridge (Figure 2) which has a flow capacity of 1 gpm, will allow the manhole/vault to empty after the siphon has broken and the standard BFCs are no longer operating. The draindown filter cartridge prevents the system from retaining standing water between storm events, thereby reducing the chance of mosquitoes or other disease vectors breeding within the system and preventing the system from becoming anaerobic during dry periods. This cartridge also uses the same media as the BFC.

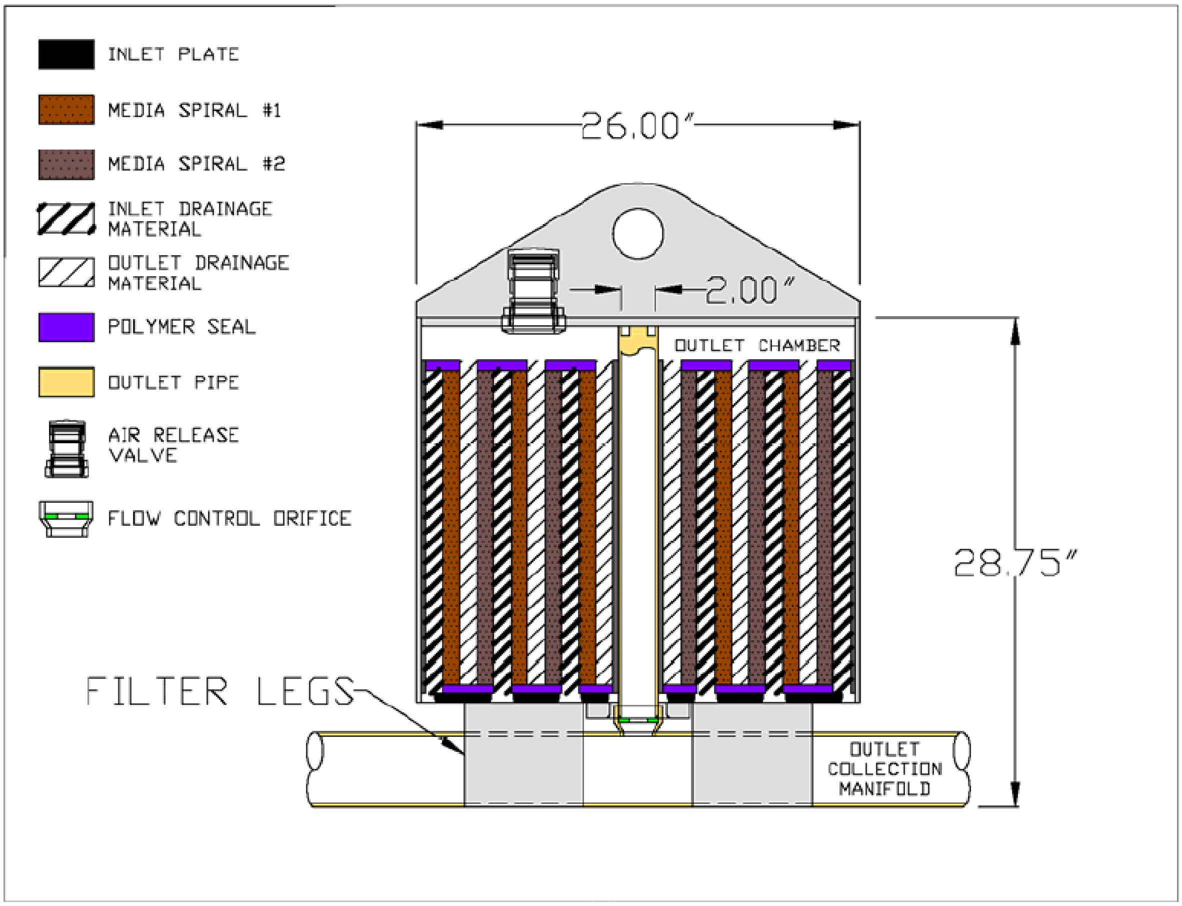



**Figure 1. BayFilter™ Cartridge**

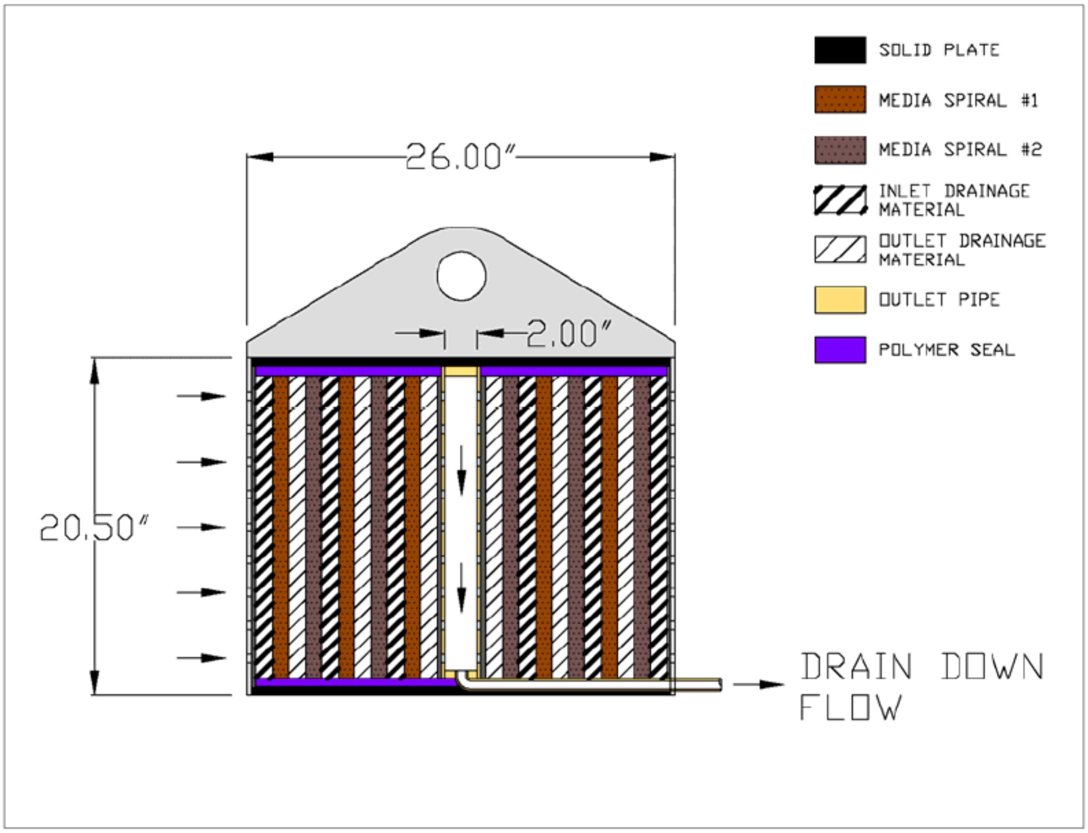



**Figure 2. Draindown Cartridge**

### 3.3 Operation

The cycle of operation of the BayFilter™ is as follows:

<u>A. Vault Fill and Air Release:</u> As water fills the BayFilter™ stormwater filtration system vault, it enters through an inlet pipe to an energy dissipator/level spreader. This allows for even flow into the vault and limits any high velocity scouring of the sediment. As the water fills the vault, influent water passes through the inlet plate at the bottom of the filter cartridge.

As the level rises in the vault, air from inside the BFC is exhausted via an air release valve. This operation is critical for the proper functioning of the siphon, which drives the BayFilter™ during periods of low water level in the vault. (Refer to Figure 3 for details on this operation).

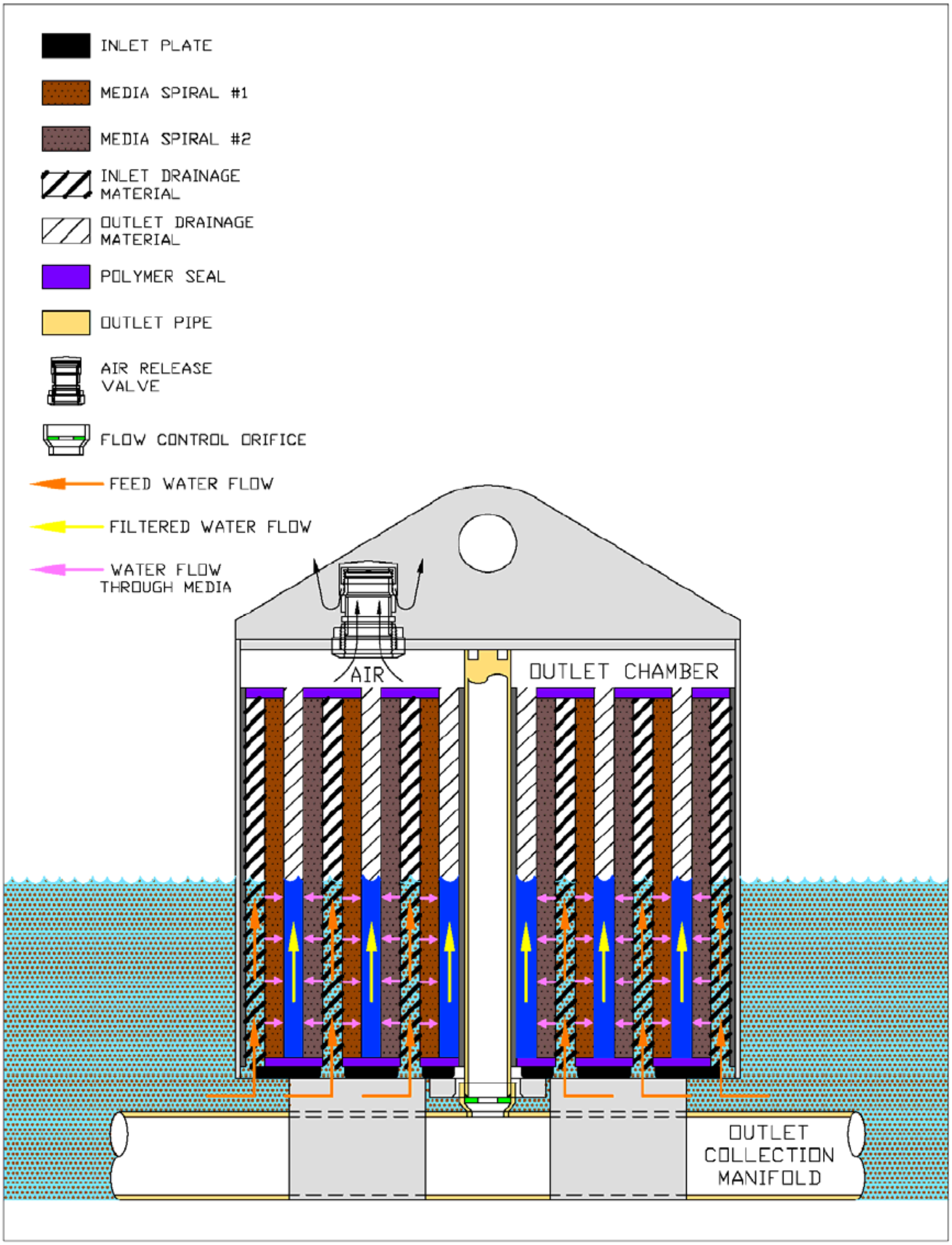



**Figure 3. Vault Fill Operation and Air Release**

B. Filtration: As water enters the inlet drainage material spiral, which is one continuous spiral wrap, the air is exhausted. Water then flows horizontally through the engineered media. Next it flows to the outlet drainage spiral, which is also one single spiral wrap of outlet material. The filtered water then flows vertically to the outlet chamber located on the inside top of the filter. Finally, the filtered water flows to the center outlet drain and out through the collector pipe below the inlet plate. (Figure 4**)**

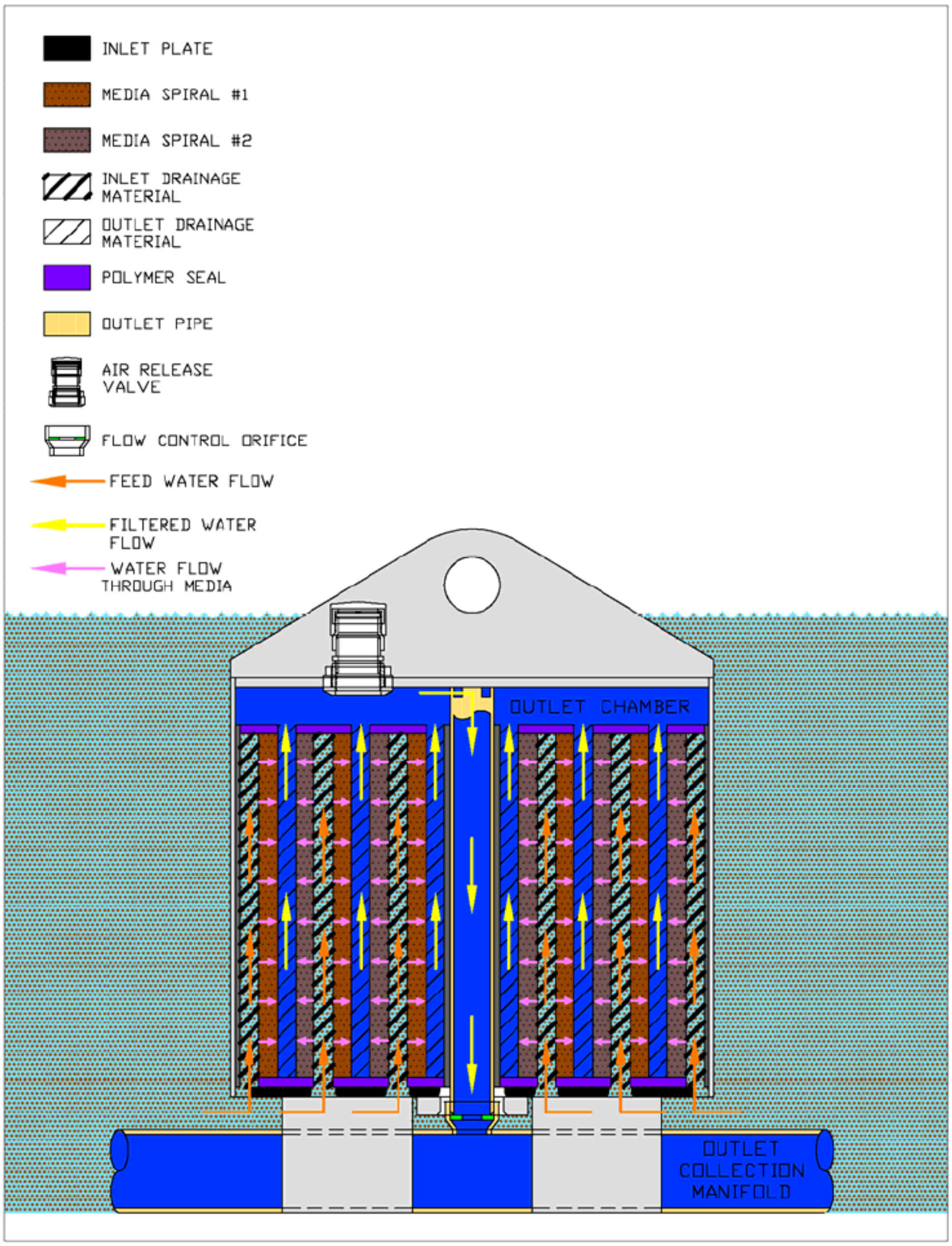



**Figure 4. Normal Filter Operation**

C. Siphon Filtration: Once the water level in the vault falls below the top of the filter, a siphon is established and water will continue to flow (Figure 5) until the siphon is broken. During siphon flow, the level in the vault will decrease until it reaches the base of the BFC; air enters the filter, breaks the siphon, filtration flow stops, and the hydrodynamic backwash begins.

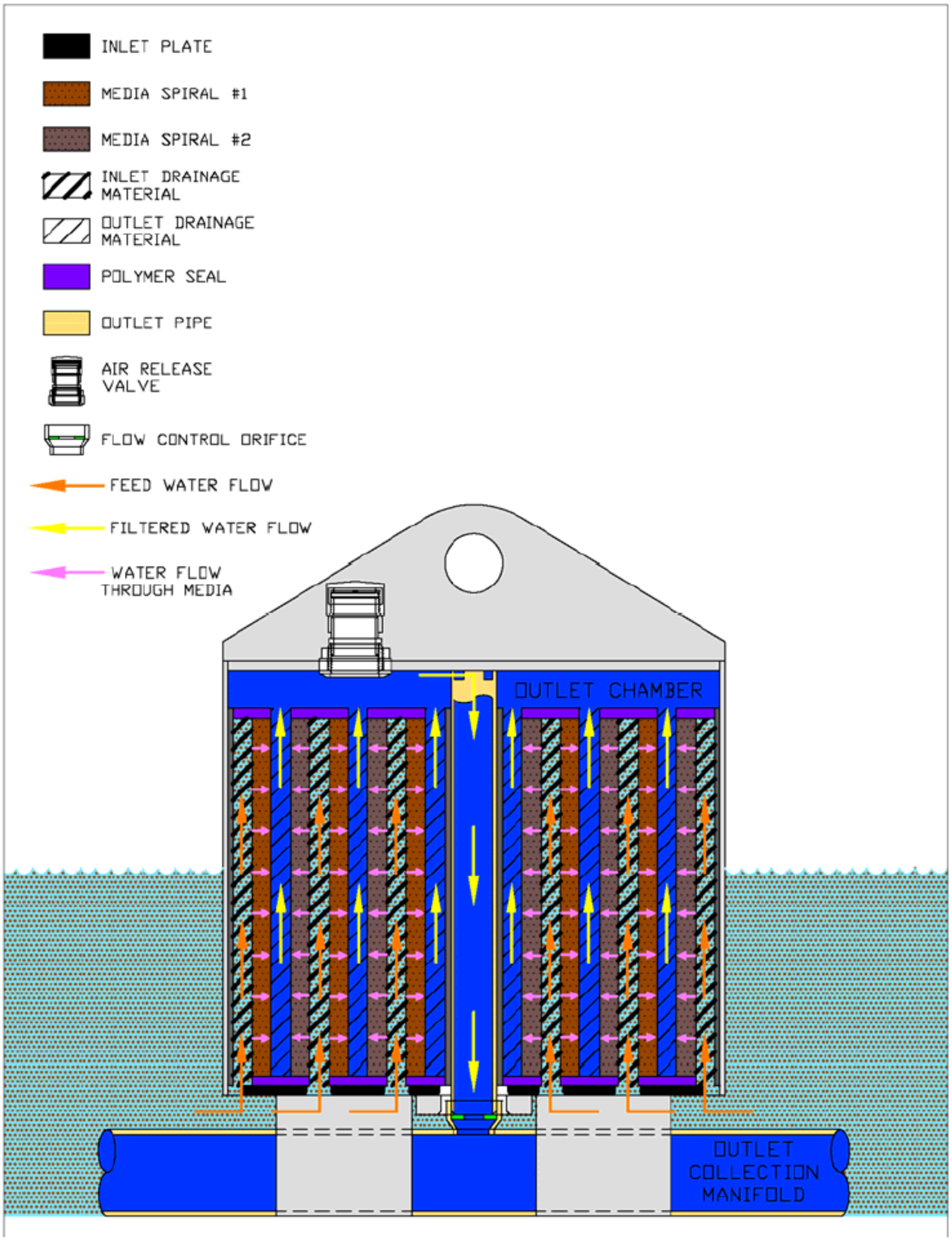



**Figure 5. Siphon Filtration**

D. Siphon Break and Hydrodynamic Backwash: When the inflow stops or the rate of inflow is below the rate of outflow, the system will go into siphon mode where the water continues to flow through the filter the same as in the normal operation mode (as described in the previous paragraph). The flow will be reduced by about 40% toward the end of the siphon cycle. (This also enables the filter to remain in siphon mode for an extended period of time).

When air enters the filter, the siphon breaks (Figure 6), and a gravity-driven backwash occurs with all of the water flowing from the outlet chamber backwards through the filter (Figure 7). This backwash has the effect of dislodging particles captured in the filtration layers and reestablishing filter porosity. Dislodged particles are transported by the backwash and accumulate on the vault floor.

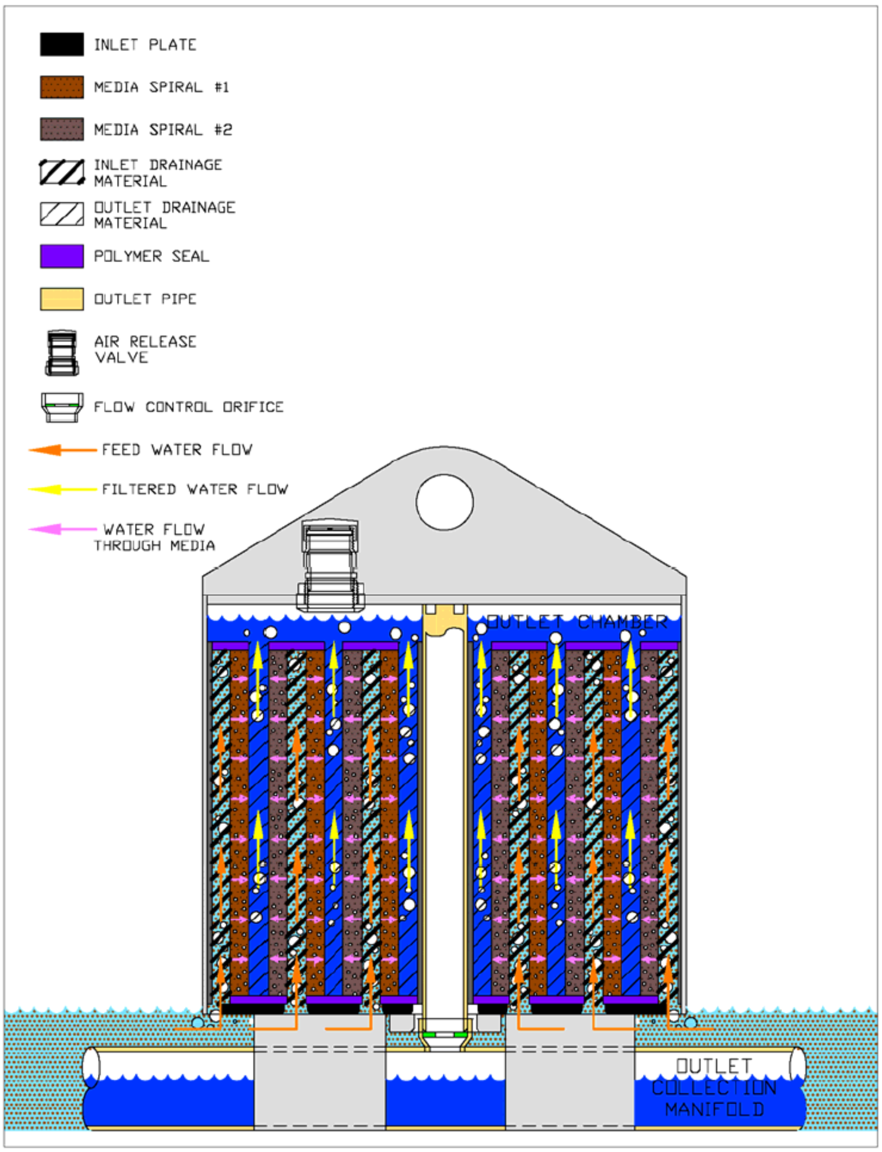



**Figure 6. Siphon Break**

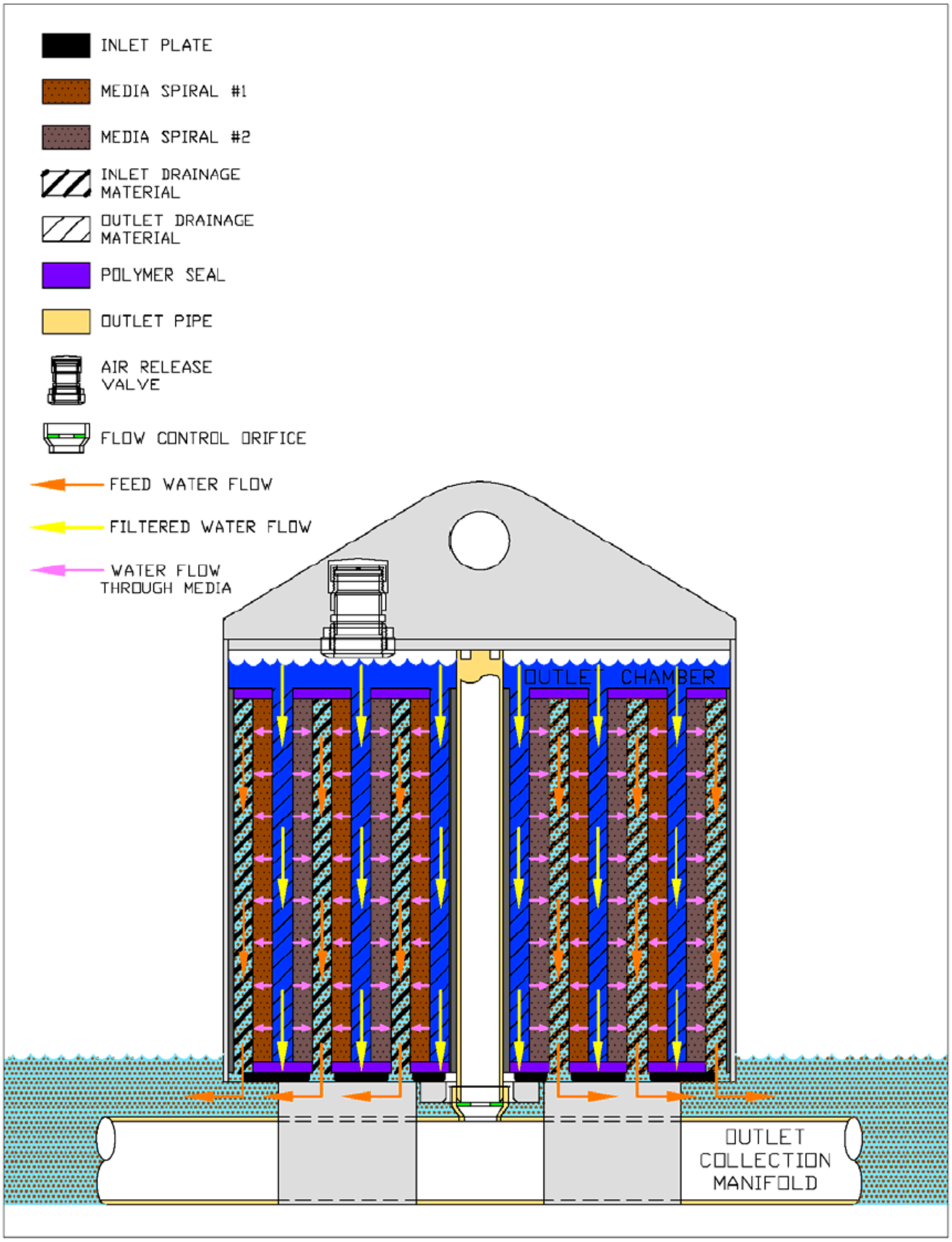
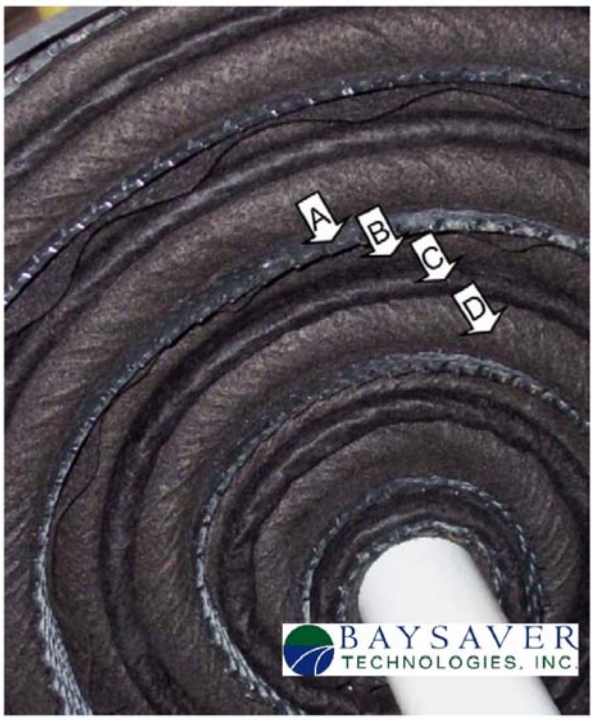



**Figure 7. Hydrodynamic Backwash**

### 3.3 Filtration Media

The filtration media consists of a proprietary blend of silica sand, perlite, and Activated Alumina. The media is packaged in a patented spiral wound configuration and contained within layers of polymer cloth for structural support and added filtration performance (Figure 8). Each cartridge has approximately 43 square foot of active filtration area. Two (2) drainage spirals provide for inlet (feed water) and outlet (filtered water) flow paths in the filter. Figure 9 depicts a top view of the BFC, illustrating its complete spiral structure.




**Explanation:**

**A** – Inlet drainage spiral

**B** – Polymer cloth structure containing filtration media – Layer 1

**C** – Outlet drainage spiral

**D** – Polymer cloth structure containing filtration media – Layer 2

**Figure 8. Detailed View of BFC Spiral Wound Configuration**


**Figure 9. Top View of BFC Showing the Full Spiral Wound Configuration**

### 3.4 System Configuration

The BayFilter™ Stormwater Treatment Systems are available in three different configurations: (1) Manhole filter, (2) Precast vault filter, and (3) Cast-in-place vault filter.

#### *Manhole BayFilter™*

The manhole configuration BayFilter™ system is the most economical BayFilter™ system available. It is usually used for small drainage areas, and has a treatment capacity ranging from 60 gpm (0.13 cfs) for a 60″ manhole to 330 gpm (0.74 cfs) for a 120″ manhole. Filter cartridges, underdrain components, and manholes are supplied by BaySaver Technologies, Inc. as a complete system. Manhole BayFilter™ sizes and flow capacities are shown in Table 2. The minimum system drop is typically determined on a site specific basis by BaySaver Technologies, Inc. in conjunction with the engineer.

**Table 2. Manhole BayFilter™ Capacities**

| BayFilter™ Model | Manhole Size (inches) | Maximum Number of BFCs | Maximum Treatment Flow gpm (cfs) |
|---|---|---|---|
| MHF-60-2 | 60 | 2 | 60 (0.13) |
| MHF-72-3 | 72 | 3 | 90 (0.20) |
| MHF-84-4 | 84 | 4 | 120 (0.27) |
| MHF-96-6 | 96 | 6 | 180 (0.40) |
| MHF-120-11 | 120 | 11 | 330 (0.74) |

A 72″ Manhole BayFilter™ Model MHF-72-3 is shown in Figure 10. See BaySaver's "BayFilter™ Technical and Design Manual" for the drawings of other models. The 72″ Manhole BayFilter™ contains 3 BFCs for a maximum treatment flow of 90 gpm (0.20 cfs), as well as a single draindown filter cartridge (the lower left cartridge in Figure 10, labeled DDC1). The draindown filter, which has a flow rate of 1 gpm (0.002 cfs), allows the manhole to be dewatered between storms after the siphon is broken and the standard BFCs stop filtering stormwater. The inlet and outlet pipes of the 72″ Manhole BayFilter™ are each 4″ PVC; these pipes are connected to the manhole using watertight boots to prevent leakage when the filter is operating. In the Manhole BayFilter™, the PVC outlet pipe is directly connected to the outlet manifold.

The Manhole BayFilter™ includes an energy Dissipator/Level Spreader at the inlet to the structure. This component spreads the influent water evenly through the structure and prevents high flows from impacting the BFCs directly.

Manhole BayFilter™ systems have a small footprint, and can be fit into site plans easily without interfering with other underground utilities. Manhole BayFilter™ systems are ideal for applications downstream from extended detention structures.

Access to the Manhole BayFilter™ for inspection or maintenance is achieved through a minimum 30″ frame and cover. In each Manhole BayFilter™ system, the BFCs are arranged so that a maintenance worker can stand on the floor of the manhole while installing or removing the cartridges. Dry and wet weights of the filter cartridge are approximately 350 pounds and 450 pounds, respectively.

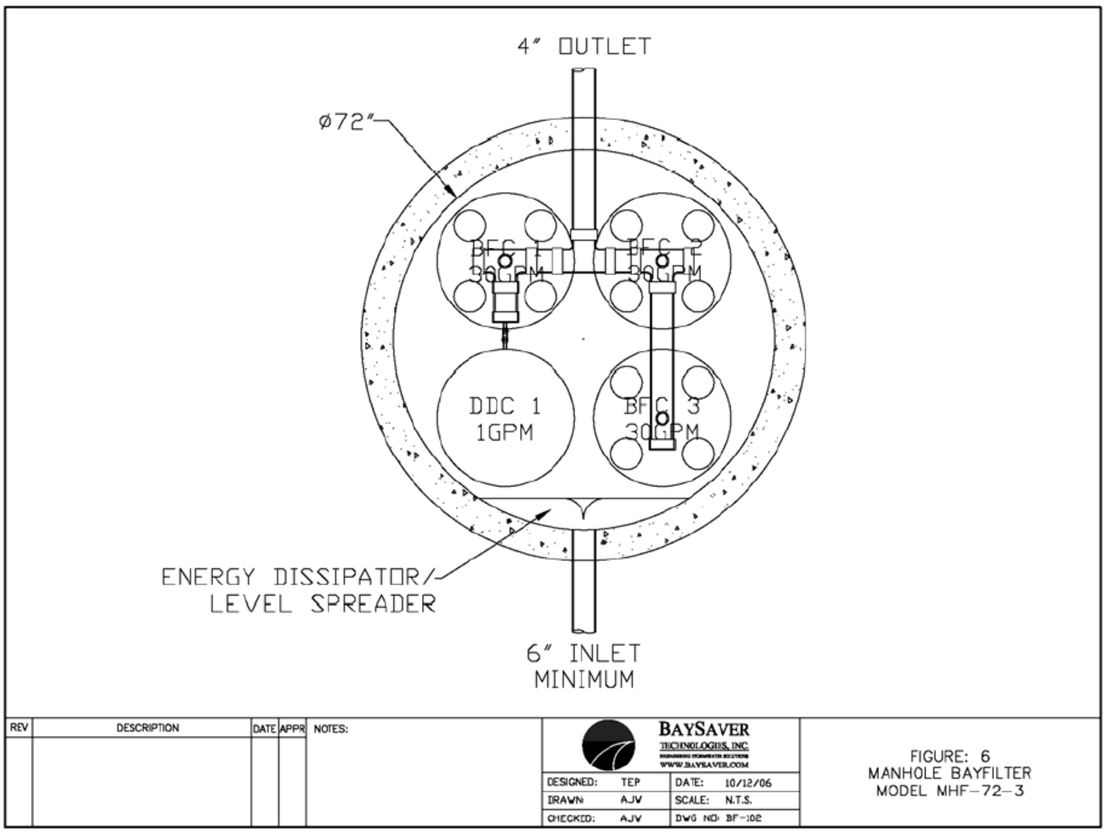



**Figure 10. Manhole BayFilter™ Model MHF-72-3**

### *Precast Vault BayFilter™*

When more BFCs are required, Precast Vault BayFilter™ systems may be used on larger sites or sites with more impervious area. The Precast Vault BayFilter™ system is larger than the Manhole BayFilter™. Constructed within a precast concrete vault, it has a treatment capacity ranging from 240 gpm (0.53 cfs) in an 8’ x 10’ vault to 2,010 gpm (4.48 cfs) in a 10’ x 48’ vault.

Should precast vaults of the dimensions outlined in Table 3 not be available locally, these structures can be cast in place. Table 3 shows the available Precast Vault BayFilter™ systems, along with the maximum number of filter cartridges and treatment capacities. The minimum system drop is typically addressed on a site specific basis by BaySaver Technologies, Inc. in conjunction with an engineer.

**Table 3. Precast Vault BayFilter™ Capacities**

| BayFilter™ Model | Vault Size (ft x ft) | Maximum Number of BFCs | Maximum Treatment Flow gpm (cfs) |
|---|---|---|---|
| PVF-10-8-8 | 8' x 10' | 8 | 240 (0.53) |
| PVF-10-16-20 | 10' x 16' | 20 | 600 (1.34) |
| PVF-10-24-31 | 10' x 24' | 31 | 960 (2.14) |
| PVF-10-32-43 | 10' x 32' | 43 | 1290 (2.87) |
| PVF-10-40-55 | 10' x 40' | 55 | 1650 (3.68) |
| PVF-10-48-66 | 10' x 48' | 66 | 2010 (4.48) |

Figure 11 shows the layout of a PVF-10-8-8, an 8' x 10' Precast Vault BayFilter™ system. The system comprises eight standard BFCs and a single draindown filter. Like the Manhole BayFilter™, the Precast Vault BayFilter™ also includes an energy dissipator/level spreader to evenly distribute the water through the structure. Unlike the Manhole BayFilter™, the outlet manifold in the Precast Vault BayFilter™ does not connect directly to the outlet pipe. Instead, each of the six underdrain lines enters an HDPE outlet manifold and discharges filtered water to an outlet chamber. The outlet pipe drains this outlet chamber.

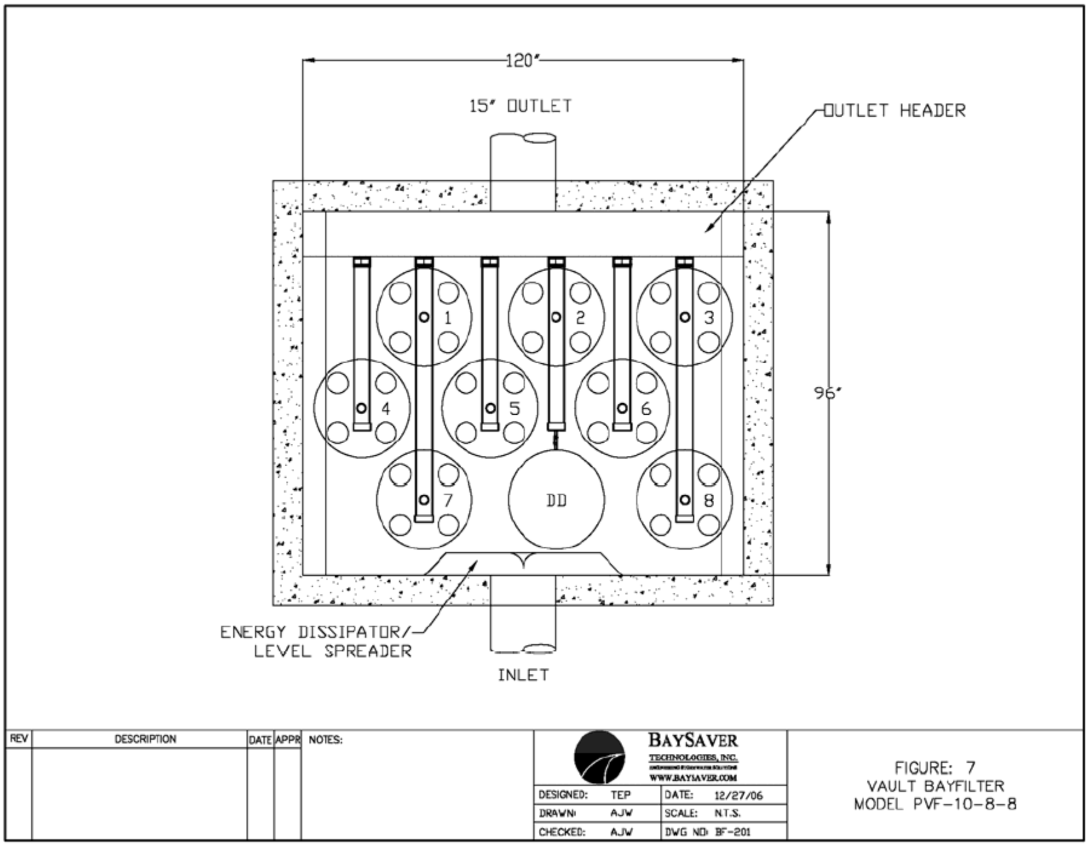



**Figure 11. Vault BayFilter™ Model PVF-10-8-8**

Like the Manhole BayFilter™, access to the Precast Vault BayFilter™ is provided through the hinged access hatch. The Precast Vault BayFilter™ is constructed in 10' x 8' sections. Each vault has at least one access hatch. The BFCs and outlet manifolds are arranged to allow maintenance personnel to stand on the concrete floor while working inside the structure.

### *Cast-in-place BayFilter™*

For sites requiring more than 66 BFCs or for projects on which a large Precast Vault BayFilter™ is not feasible, BaySaver Technologies, Inc. can supply custom designed BayFilter™ systems. These custom systems utilize a cast in place vault or other system, and can be designed around specific site constraints. High flow rates, shallow installations, very flat sites, limited footprints, and other design considerations can be addressed with a cast in place system.

# 4. TECHNICAL PERFORMANCE CLAIM

**Claim:** The BayFilter™ cartridge at 30 gallons per minute (0.70 gpm/ft$^2$) of flow and 34 inches of driving head using a sand and perlite media mix has been shown to have a total suspended solids (TSS) removal efficiency of 83.8% with 95% confidence limits of 82.9% and 84.7%, for Sil-Co-Sil 106 (comprised of 7.5% sand, 80.2% silt and 12.3% clay with a median grain size by mass of $d_{50}$ equal to 23.2 microns) with influent concentrations ranging from 105 to 232 mg/L in laboratory studies using simulated stormwater.

# 5. TECHNICAL SYSTEM PERFORMANCE

## 5.1 Laboratory Testing Facility

### 5.1.1 Test Facility Description

Figure 12 shows a simplified process diagram of BaySaver's laboratory testing facility. See also Figures 13 and 14 for more detailed information on the testing facility configuration.

***Head Tanks and Water Source Delivery***

The testing facility used for the evaluation of the BayFilter™ was specifically designed to provide reproducible conditions for the evaluation of stormwater treatment devices. Specifically, the following design features are incorporated into the plant:

- Closed water loop design to minimize external water requirements
- Maximum mixing and turbulence for suspended solids transport
- Minimal amounts of zero velocity areas
- Use of reliable equipment and ability to perform system mass balances

There are two (2) 1,500 gallon elevated head tanks (T-1 and T-2) that supply water to the filter testing system. From these two tanks, water flows by gravity at a controlled rate into the BayFilter™ vault. The filter feed flow rate is adjustable from 0 gpm to approximately 50 gpm. The head tanks were filled with city water before the test commenced. Refill of these tanks was not necessary since the system is designed to recirculate test water back to the head tanks. It was determined through experience that there was sufficient chlorine residue in the water to prevent microorganism growth during testing.

***Slurry Addition***

The Slurry Tank consists of a 16 gallon conical bottom tank (T-3), an eccentrically mounted mixer (MX-1) to keep the solids in suspension, and a slurry dosing pump (SP-1). See Figure 15 for setup of the system.

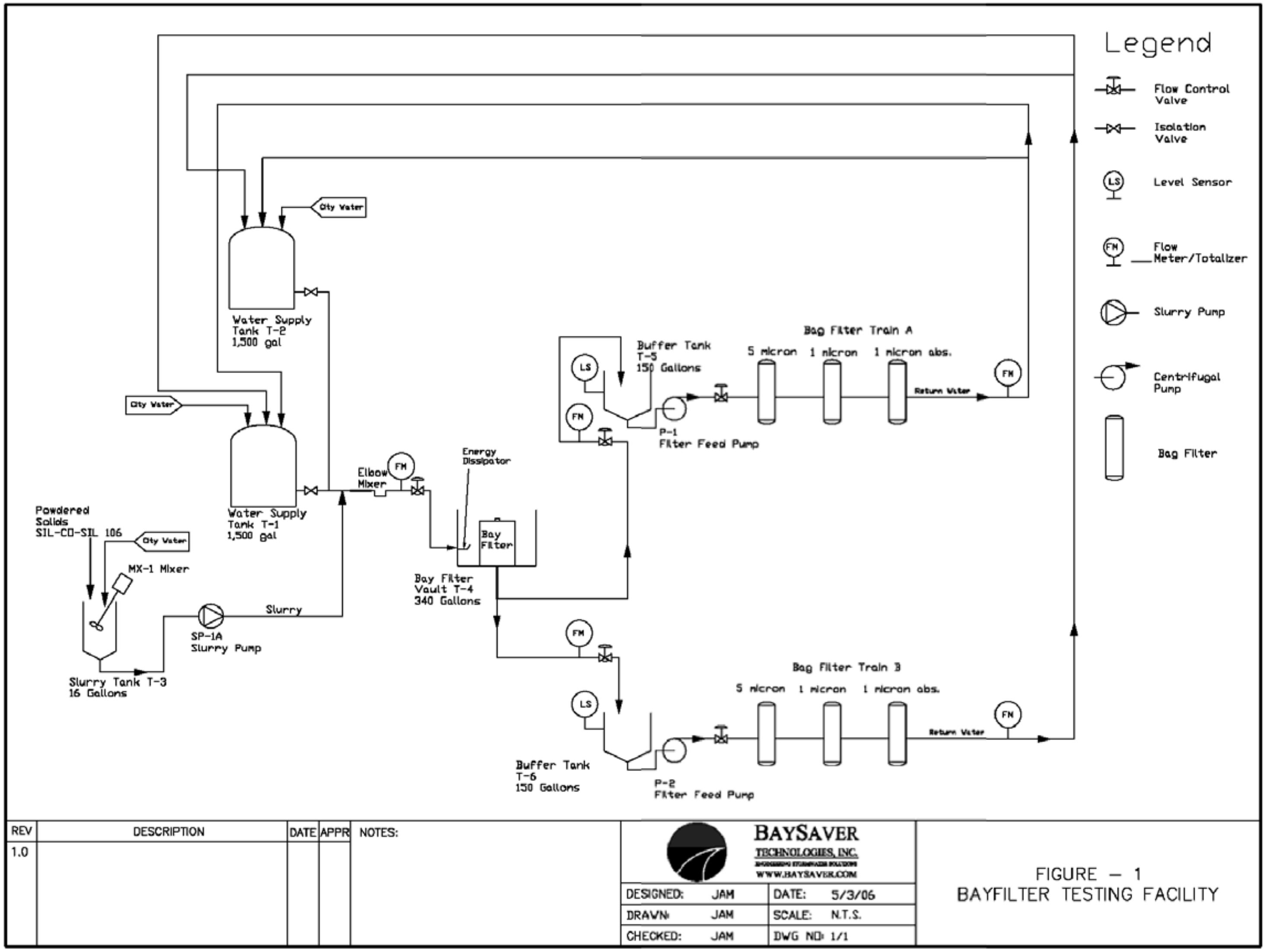



**Figure 12. BayFilter™ Laboratory Testing Facility**

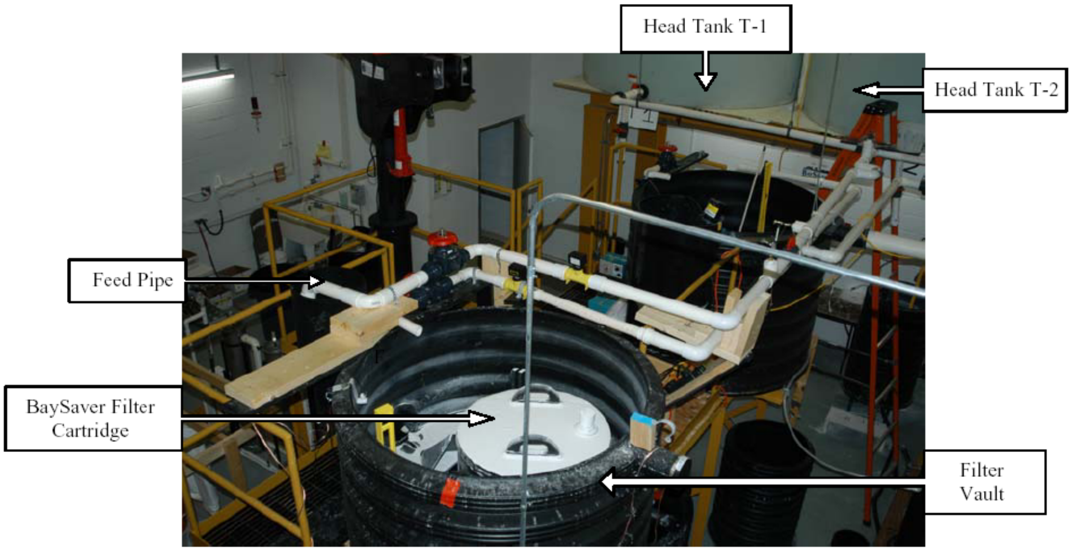



**Figure 13. Top View of Test Facility with a View of BayFilter™ Vault and Slurry Addition System. Head Tanks are in the Top Right Hand Corner of Photograph**


**Figure 14. Floor Level of Test Facility. Bag Filter Trains are in the Foreground, Bay Filter (Test Bay) is in the Top Center, on the Right**

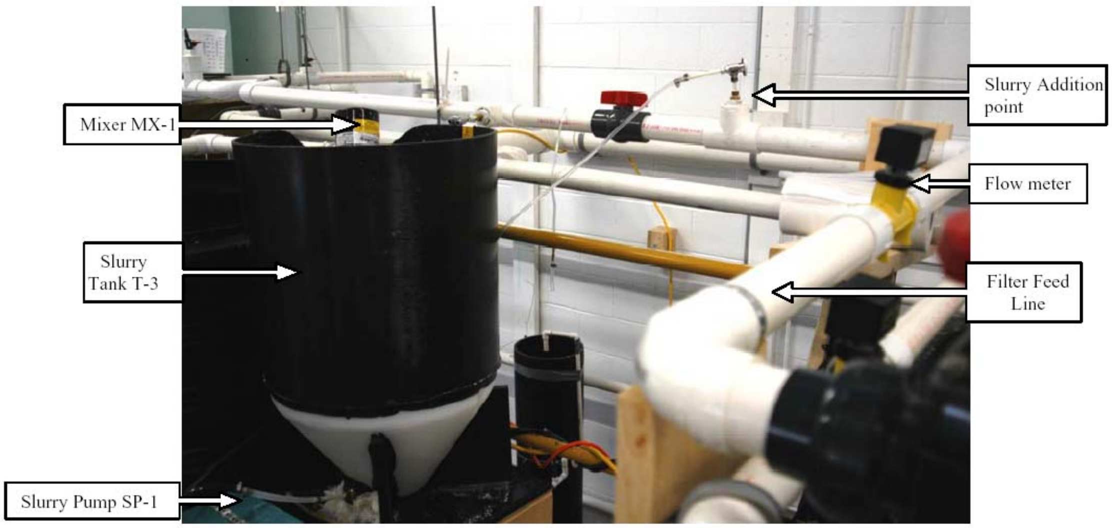



**Figure 15. Slurry Dosing and Delivery System**

### *BayFilter™ Filtration System*

The BayFilter™ stormwater filtration system consists of a filter vault and the BayFilter™ Cartridge (BFC), (See Figures 13 and 16). The filter feed (water-sediment mixture) enters the vault via an inlet pipe (Figure 12). Water then flows through the BayFilter™ driven by either hydrostatic head or siphon action. There is an energy dissipator at the vault inlet to aid in the dissipation of energy of the incoming sediment-laden water. The tested BFC was operated at a water level of four (4) inches above the flat top part of the cartridge. Figure 17 illustrates key dimensional details of the Generation # 8 BFC and key piping arrangements that are part of the system. The flat top part of the cartridge was 37.5 inches (= 5 inches + 19 inches + 13.5 inches, Figure 17, right side) above the vault floor. Therefore, the driving head was forty-one and half (41.5) inches (= 37.5 inches + 4 inches) above the vault floor (the invert of vault outlet).

**Figure 16. Photograph of BayFilter™ Cartridge**

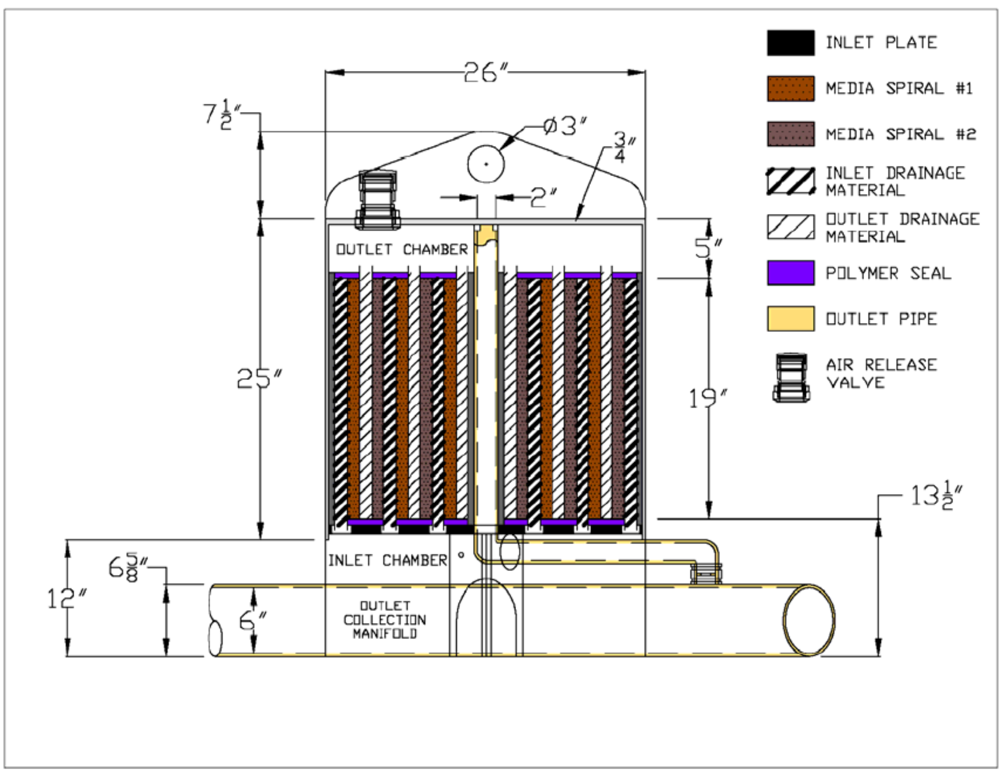



**Figure 17. Dimensional Details of the BayFilter Cartridge and Key Piping Connections (Generation #8)**

### *Test Sediment SIL-CO-SIL 106*

SIL-CO-SIL 106 ground silica product (test sediment) was used as the sediment source for these tests. SIL-CO-SIL 106 is a powdery white silica material consisting of very fine particles. This material disperses well in water when added to a stirred tank.

A particle size distribution analysis was performed by an external laboratory on the test sediment used during these tests using ASTM D 422, Particle-Size Analysis of Soils by an accredited laboratory (Hillis-Carnes Engineering Associates, Inc., Frederick, MD). The reported $d_{50}$ for this material was 23.2 microns. The test sediment has a specific gravity of approximately 2.65. The PSD analysis showed that this material consists of 7.5% sand, 80.2% silt, and 12.3% clay sized particles.

The test sediment was added to the source water to produce a range of target solids concentrations.

### *Filtrate Collection, Polish Filtration, and Return*

The filtrate from the BayFilter™ is directed to conical bottom Buffer Tanks where it is pressurized via Filter Feed Pumps (P-1 and P-2) and pumped through the bag filter trains (Figure 18). In the bag filters, sediment is filtered out via the following filter bag sizes: 5-micron, 1-micron, and 1-micron absolute. Once the bags were changed, the bags were oven dried for 24-48 hours at 170° F, until there was no weight change. At this time, the mass increase in the bags was determined. This mass increase is the mass of sediment not captured by the BaySaver Filter System.

### *Bag Filters*

The bag filtration system used in this test had two purposes:

1. Collect mass sediment from the BayFilter™ filtrate so that it could be quantified to determine the mass removal efficiency of the BayFilter™ stormwater filtration system.

2. Enable the facility to recycle water thus minimizing its external water requirements.

The bag filtration system consists of two 20-gpm trains of 5-micron, 1-micron, and 1-micron absolute bag filters (Figure 14). The two trains are installed in parallel, for a total filtration capacity of 40 gpm. The bag filters are housed in stainless steel vessels equipped with pressure gauges. Bag filters were changed when the pressure drop reached 20 psi across a bag filter.

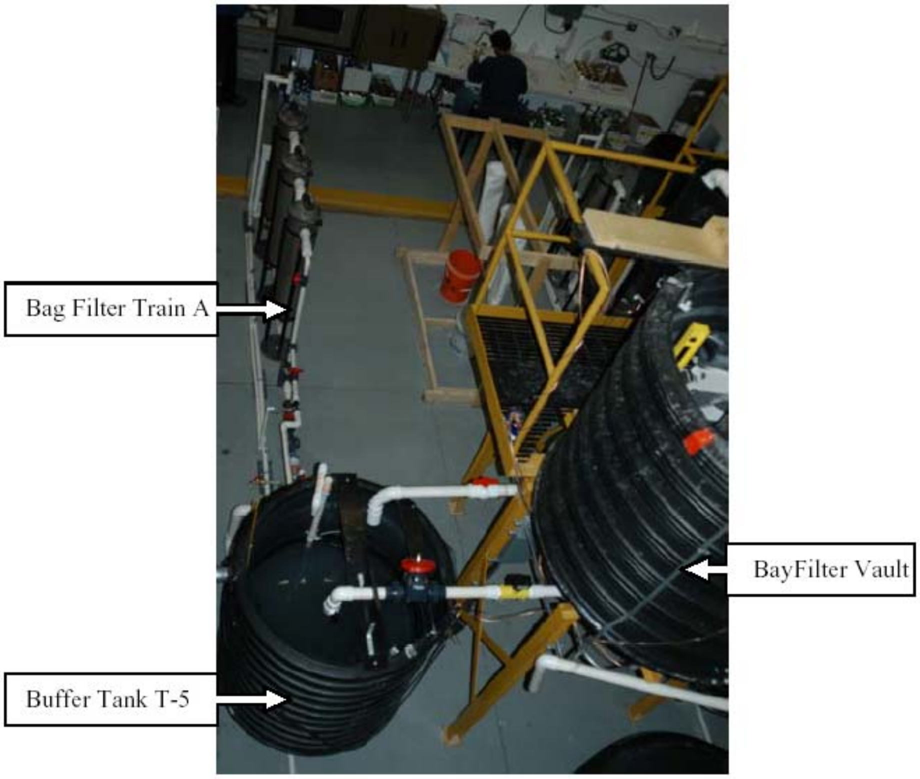



**Figure 18. Top View of Buffer Tank, Bag Filter Train A and Partial View of BayFilter™ Vault (Right Center)**

### 5.1.2 Equipment and Instrumentation

The following equipment was used during the tests. Also see Figure 12 – Facility Process Flow Diagram

***Balance and Scale:*** The balance (low range scale) used was an Acculab Vicon Model VIC-123 electronic scale. Range 1 mg to 120,000 mg manufactured by Sartorius Group. The higher range scale was an Acculab electronic scale Model SVI 10A. Range 1 g to 10 kg also manufactured by Sartorius Group.

***Water pH and Temperature:*** A portable pH and temperature probe was used to measure the filter vault water temperature and pH. The probe used for these measurements was a pHep Hanna handheld meter pH and temperature meter.

***Bench Top Turbidity Meter:*** The unit used was a Hach Laboratory Turbidimeter Model 2100A. Hach StablCal™ Stabilized Formazin Turbidity Standards were used to calibrate the unit prior to sample testing.

***Metering Pumps:*** Metering pumps used were MITFLEX Peristaltic Pump Model 913 Variable Speed, capacity 1.7 ml/min to 987 ml/min manufactured by Anko Products, Inc. Prior to the test, the pump was calibrated with a graduated cylinder and an electronic chronometer.

***Flow Control Valves:*** The flow control valves used were Asahi America Diaphragm Valves, manual operation with EPDM seals. These flow control valves are designed for both uses in slurry applications and providing adequate flow control capabilities.

***Mixer:*** The mixer used in the slurry tank is a 1/20 HP direct drive electric mixer with stainless steel shaft and propeller.

***Piping System:*** The piping for this system consists of smooth wall PVC pipe. It was designed in such a way that it offers a minimal amount of accumulation opportunities for solids. The minimum Reynolds Number in the piping system was estimated at approximately 25,000.

***Tanks:*** The water supply tanks, Head Tanks T-1 and T-2, Slurry Tank T-3, Buffer Tanks T-5 and T-6, and BayFilter™ Vault T-4 are constructed of high-density polyethylene (HDPE). All engineered tanks were hydrostatically tested before being put into service.

***Flowmeters:*** Flowmeters were used to measure flows in different parts of the process. Digiflow Electronic Flowmeters Model F-1000-RT with rate indication and totalizer manufactured by Blue-White Industries, Ltd were used to measure feed and filtrate flow rate and total flow from the BayFilter™.

### 5.2 Experimental Design

***Objective:***

The general objectives of this experiment were:

1. Determined filtration and hydraulic performance of the BayFilter™ stormwater filtration system (cartridge plus vault) when running at different target SIL-CO-SIL 106 (target sediment) loading rates from 50 mg/l to 400 mg/l with 50 mg/l increment changes

2. Calculated the % sediment removal efficiency of the BaySaver Filter System based on TSS sampling and a mass balance total test sediment added

3. Performed BayFilter™ stormwater filtration system Inlet/Outlet turbidity analysis to determine turbidity reduction characteristics of the BayFilter™ stormwater filtration system

4. Investigated the dissolved Phosphorus removal characteristics of the BaySaver Filter

5. Fed 100 lbs of test sediment to the BayFilter™ stormwater filtration system to determine the impact of sediment loading on performance.

Between each run of a sediment concentration, the filter went through a complete siphon down and backwash cycle. This was done to help simulate real storm operations.

***Process Analysis and Sampling***

One of the important advantages to laboratory testing vs. field testing is the ability to control and stabilize inlet concentrations to the system through careful testing operations. Stable inlet concentrations allow for more accurate stable outlet concentrations. With field testing steady state operation can be very difficult and substantial swings in efficiency will occur based solely on the variation in inlet concentrations. This situation makes it challenging to characterize the efficiency and performance of a stormwater filtration device in the field.

In controlled settings it is important that filter inlet concentration as well as the vault concentration be stabilized before the TSS and Turbidity testing begins. For example, if the sediment dosing into the system is not constant, TSS removal efficiency tests as well as turbidity reduction performance will be hard to correlate. The input concentration must also be kept constant for a long enough period of time for the concentration in the vault to reach steady state. This will enable inlet/outlet sample comparisons that are representative of the true efficiency of the filter system.

*For example if the inlet concentration was initially 400 mg/l and 10 minutes into the test it went to 200 mg/l, at 80% efficiency (actual performance) initially the system would show an outlet concentration of 80 mg/l. However, if the inlet sample were then taken when the inlet flow reduced, the actual concentration in the vault would still be closer to the 400 mg/l concentration than the 200 mg/l concentration, and lets say it was at 380 mg/l. The filter actually being 80% efficient would have an outlet concentration of 76 mg/l, but because the inlet concentration was 200 mg/l the data would indicate an efficiency of only 62%. This can be in reverse as well if the inlet concentration is greater than the vault concentration, thereby increasing the efficiency as well.*

*To achieve accurate, meaningful results it is very important to test a stabilized system. In doing this, the samples were taken in 10 minute intervals starting 10 minutes after the first outflow started from the filter and ending just before the inflow stopped.*

***Preliminary***

1. Zero out all flowmeter totalizers
2. Flush the filter to drain waste without any bag filters in trains.
3. Verify flow and operation
4. Zero out all flowmeter totalizers again
5. Take city water temperature and pH

***Process Conditions for Each Experiment***

1. Feed SIL-CO-SIL 106 per the target inlet TSS concentrations

2. Sample for the target inlet TSS concentrations
3. Mass feed objective is 100 pounds of SIL-CO-SIL 106
4. System feed flow target 30 gpm
5. Water level in vault ~39 inches high as measured from vault floor
6. Initiate flow (or resume flow)
7. Let filter reach backwash conditions
8. Complete Log sheet
9. Repeat step 1 until the 100 lbs. of sediment has been input to filter

***Bag Filter Train Operation:***

1. 5 micron nominal to 20 psi delta p
2. 1 micron nominal to 20 psi delta p
3. 1 micron absolute to 20 psi delta p
4. Rotameter flow target ~ 18 gpm
5. Keep Log sheet of bags as they fill
6. All full bag filters to be dried for 24 hrs at ~170° F, until there is no significant weight change
7. Full bag filters to be bagged in trash bags labeled per day after processing
8. Complete Log sheet

***Slurry Tank***

1. Set slurry pump to1 liter per minute constant feed for all runs
2. Fill the slurry tank with city water to the 16 gallon mark
3. Add the pre-weighed test sediment to slurry tank
4. Mix for 15 minutes before starting to dose sediment
5. Each run will last approximately 60 minutes
6. Make sure all test sediment was added to the corresponding run
7. Complete Log sheet

***Turbidity Tests***

1. Calibrate the meter with the appropriate turbidity calibration vial
2. Rinse sample bottle with water to be tested
3. Take sample of filter inlet and outlet every 10 minutes
4. Agitate the sample before inserting into meter making certain no air bubbles are in sample before inserting into meter.
5. Wait 5 seconds for the reading to stabilize to make the reading
6. Take reading
7. Fill Log sheets

***Total Suspended Solids Tests (Modified EPA Method 160.2)***

1. Weigh empty sample bottle
2. Rinse sample bottle with water to be tested

3. Take water sample using a wide mouth 950 ml glass bottle every 10 minutes or as deemed sufficient
4. Within 24 hours of the sampling, weigh the entire sample plus bottle and calculate ml in sample from weight of water
5. Weigh pre-dried filter paper
6. Pour all contents of sample through the Gooch funnel-filter paper assembly under 3-5 psi of vacuum
7. Dry filter paper plus solids for 2 hours (determined through trial and error to produce no weight change) and weigh collected test sediment in filter paper.
8. Fill Log sheets
9. Calculate the TSS for each sample

***Phosphate Testing***

1. Prepare a 25 mg/l inorganic phosphate solution using liquid fertilizer
2. Confirm target concentration with phosphate analysis kit
3. Run 1,600 gallons of water – sediment feed (50 mg/l) at a target 30 gpm flow rate
4. Analyze filter system inlet/outlet every 10 minutes

## 5.3 Experimental Results

Three sets of laboratory testing data will be discussed. They represent three generations of BayFilter™ product evolution. The data from generation # 10 is for the product that will be marketed and is used for verification of the performance claim. The data from two prior generation products are included for technology performance support.

***Total Suspended Solids (TSS) Removal: BayFilter™ Generation # 8***

Table 4 shows the average percent TSS removal per test run for Generation #8 of the filter cartridge and piping connections. (See BaySaver's "BayFilter™ Performance Evaluation" for the raw data.) A total of 272 BayFilter™ Inlet/Outlet TSS analyses were performed during this evaluation (5 to 6 paired data points per run). TSS sample collection points included:

1. BayFilter™ Feed (Water-test sediment slurry mixture)
2. BayFilter™ Product (Filtrate)

Based on the above analysis, the percent TSS removal of the BayFilter™ was calculated on a per run basis. There were 23 runs. Each run consisted of feeding a target TSS concentration to the filter.

As shown in Table 4, the targeted 100 pounds of test sediment were added to the filter during the course of the 23 runs. On a weighted average basis, the TSS removal was 80.5%. The weighted average approach is representative of the solids mass removal ability of the BayFilter™ since it weights the discrete TSS measurements in relation to the total mass that was available from removal.

Based on the reported particle size distribution (PSD) of the test sediment, it is inferred that 100% of the sand-sized particles and approximately 90% of the silt-sized particles were removed by the BayFilter™. Also, as can be seen from Table 5, the total mass removal efficiency by the BayFilter™ stormwater filtration system was 81.5%. The test sediment Particle Size Distribution Report shows that on a mass basis approximately 18.5% of the sediment is below 7 microns in size. Hence, it can be inferred that the BayFilter™ stormwater filtration system removed the particles in the range of 8 microns and above during this test. On the basis of mass removal efficiency and the PSD report, it can be stated that the BayFilter™ removed approximately 95% of the mass of particles above 5 microns during the test.

The maximum percent TSS removal was 87% in Run 12 which had a target inlet TSS of 400 mg/l. The minimum percent TSS removal of 67% was observed in Run 10. At 50 mg/l, Run 10 also had the minimum TSS target dose of the evaluation.

**Table 4. Generation #8 Test Summary: BayFilter™ Average Percent TSS Removal**

| Run # | Test Run ID | Target Inlet TSS mg/l | Actual Inlet TSS mg/l | Cum Lbs Sediment Input | % TSS Reduction | % Turbidity Reduction |
|---|---|---|---|---|---|---|
| **1** | 8-400 | 400 | 405 | 6.0 | 84.3% | 54% |
| **2** | 8-350 | 350 | 351 | 11.3 | 81.8% | 52% |
| **3** | 8-300 | 300 | 290 | 15.8 | 80.7% | 46% |
| **4** | 8-250 | 250 | 221 | 19.5 | 79.3% | 45% |
| **5** | 8-250-A | 250 | 241 | 23.3 | 80.2% | 50% |
| **6** | 8-200 | 200 | 247 | 26.3 | 82.0% | 51% |
| **7** | 8-200-A | 200 | 143 | 29.3 | 82.2% | 48% |
| **8** | 8-150 | 150 | 130 | 31.5 | 80.4% | 51% |
| **9** | 8-100 | 100 | 99 | 33.0 | 82.0% | 44% |
| **10** | 8-50 | 50 | 58 | 33.8 | 66.6% | 24% |
| **11** | 8-400-1 | 400 | 401 | 39.8 | 81.7% | 60% |
| **12** | 8-400-2 | 400 | 432 | 45.8 | 86.7% | 59% |
| **13** | 8-400-3 | 400 | 464 | 51.8 | 81.8% | 56% |
| **14** | 8-400-4 | 400 | 397 | 57.8 | 79.9% | 55% |
| **15** | 8-400-5 | 400 | 284 | 63.8 | 80.0% | 53% |
| **16** | 8-400-6 | 400 | 321 | 69.8 | 81.4% | 58% |
| **17** | 8-400-7 | 400 | 355 | 75.8 | 85.9% | 61% |
| **18** | 8-400-8 | 400 | 331 | 81.8 | 79.7% | 65% |
| **19** | 8-350-2 | 350 | 374 | 87.0 | 77.9% | 60% |
| **20** | 8-300-2 | 300 | 334 | 91.5 | 75.3% | 55% |
| **21** | 8-250-2 | 250 | 272 | 95.3 | 74.6% | 48% |
| **22** | 8-200-2 | 200 | 244 | 98.3 | 74.0% | 47% |
| **23** | 8-150-2 | 150 | 182 | 100.5 | 70.6% | 45% |
| **Average** | ---- | ---- | ---- | ---- | ---- | 52% |
| **Weighted Average** | | ---- | ---- | ---- | 80.5% | ---- |

**Notes**

*1.Total of 23 solids addition runs in experiment*

*2. Total Flow for experiment was approximately 45,000 gallons*

*3. Total SIL-CO-SIL 106 mass added during experiment was 100.5 lbs*

*4. Average estimated mg/l TSS for entire experiment was 268 mg/l*

**Table 5. Generation # 8 BayFilter™ Mass Balance Calculation**

| | | |
|---|---|---|
| Total Solids Added to System - measured | 100.53 | lbs |
| Solids Collected in Bag Train - measured (1) | 17.24 | lbs |
| Solids Removed BayFilter stormwater filtration system | 83.29 | lbs |
| Solids in Background (2) | 1.33 | lbs |
| Net Solids Collected by BayFilter | 81.96 | lbs |
| **% Solids Removal Efficiency of BayFilter stormwater filtration system** | **81.5%** | **%** |

**Notes**

*1. Test sediment collected in the 5 micron, 1 micron, and 1 micron absolute bag filters.*

*2. Calculated solids, based on total volume of water in the test facility, background TSS, and efficiency of the 1-micron absolute bag filters.*

### *Filter Flow Rate Performance and Monitoring*

Measurements of BFC filtrate flow versus water level in the vault were taken during the course of evaluation to establish the nominal 30 gpm filtrate flow. Similar data were collected during the Generation # 10 test and will be presented later in this report.

### *Turbidity Reduction*

See Appendix A for not yet verified results and performance statements.

### *Mass Balance*

The total mass of test sediment solids added during the test was 100.53 pounds. Of this amount 17.24 pounds were collected from the BayFilter™ filtrate via the bag filters. Based on this determination it can be calculated that the mass removed by the BayFilter™ stormwater filtration system during this test was approximately 81.96 pounds or 81.5% of the incoming solids. See Table 5 for more detailed information.

The 81.5% mass of solids removed by the BayFilter™ stormwater filtration system is in agreement with the 80.5% TSS reduction as determined by the TSS analysis presented previously. It is therefore concluded that the BayFilter™ removed at least 80% of the incoming test sediments during the course of this test.

### *Total Phosphorus Removal*

See Appendix B for not yet verified results and performance statements.

### 5.4 BayFilter™ Generation # 9 Test Summary

After Generation # 8 testing was completed, some changes were done to the cartridge and the testing methods, this test was to reaffirm the efficiencies of the BayFilter™ Cartridge (BFC), test the system as a whole, and examine the efficiency of the Draindown Cartridge (DDC).

1.) A new test vault was configured to allow the test to be done in conjunction with the draindown cartridge.
2.) The draindown cartridge was tested in conjunction with the BayFilter™ Cartridge. This was to simulate a complete system test.
3.) The new test chamber included a horizontal outflow to mimic a field condition, instead of the vertical outflow that was previously used.
4.) Piezometers were included to measure relative headlosses during the operation of the system.
5.) The test interval protocols were changed slightly and the test duration went to 2 hours for each run.
6.) This was the first test using the new hot melt adhesive on the top and bottom of the cartridges. Prior tests had been done using silicone sealant.
7.) This test was also run to stress the unit to 125 lbs of sediment exposure to determine if flow and efficiency was attainable at that level with equivalent of 34-in driving head (water level above the vault floor). The filter cartridge of generation # 9 was lowered to the vault floor by 8.75 inches in comparison to the generation # 8 (8.75 inches = 37.5 inches in Figure 17 for generation # 8 minus 28.75 inches in Figure 1 for generation #9).

Revisions to Test procedures:

1.) Tests were conducted at different input concentrations ranging from 50 mg/l to 400 mg/l, only this time each test was for a 2-hour duration instead of 1 hour.
2.) The system was started and stabilized for each test within the first 15 minutes of each run. Test measurements were also taken at intervals of 30, 45, 60, 75, 90, 105 minutes from start of run.
3.) At the 15 minute interval and each 15 minutes after that, the following tests were done:
    - Background TSS
    - Background Turbidity (NTU)
    - Dual Inlet TSS
    - Dual Inlet Turbidity (NTU)
    - Outlet A TSS
    - Outlet A Turbidity (NTU)
    - Outlet B TSS
    - Outlet B Turbidity (NTU)
    - Draindown TSS
    - Draindown Turbidity (NTU)

4.) Mass balance filter: discharge water to determine sediments remaining after filtration. During this test a 0.5 um absolute bag filter was added to the train and the 5 um bag filters were eliminated.

5.) The flow of the draindown cartridge was checked with a timed bucket periodically to verify its flow rate, and determine the rate of degradation of this flow.

<u>Summary of Results:</u>

BayFilter™ Cartridge Results:

1.) Flow:

Flow of 30 gpm was attained throughout the test.

2.) TSS Removal:

TSS sampling resulted in an 82.7% Reduction (mass weighted) (see Table 6 for removal efficiency for each individual run)

Mass balance confirmed this with an 83.1% Reduction (Total input mass = 57,072 grams = 125 lbs, total mass in bags = 9,666 grams = 21 lbs)

3.) Turbidity reduction (see not yet verified results in Appendix A)

Draindown Cartridge Results

1.) Flow:

Flow of 1.7 +/- gpm was attained throughout the test.

2.) TSS Removal:

TSS sampling resulted in a 91.9% reduction (mass weighted)

3.) Turbidity reduction (see not yet verified results in Appendix A)

<u>Comments on Results:</u>

This test did involve some minor changes, and the efficiencies overall improved. Furthermore, the test of the draindown cartridge proved successful; however it was concluded that it still needed to be tested for a longer duration to further test its load capacity.

### 5.5 BayFilter™ Generation # 10 Test Summary

See Figure 1 for Generation # 10 filter cartridge and piping connections. See Figure 19 for vault layout during lab testing of Generation # 10 filter cartridge and piping connections.

Based on the results of the testing of BayFilter™ Generation # 9, it was determined that some additional slight modifications were warranted. To better determine the operational efficiencies a steady state input was considered over a longer period of time. This test also involved a new configuration of the BFCs which were lowered (relative to the outlet manifold, see Figures 1 and 17 for comparison), and included a revised 4” outlet system and connection point. The DDC tested during the Generation # 9 test was reinstalled (as removed from the Generation # 9 test) to further determine its long term capacity.

Some additional changes were done to the testing from Generations # 8 and # 9:

**Table 6. Filter Generation # 9 Data Summary**

| Run # | Cumulative Sediment Input gms | Avg Inlet Concentration mg/l | TSS Reduction BFC Average TSS Red | TSS Reduction DDC Average TSS Red | Turbidity Reduction BFC Average NTU Red | Turbidity Reduction DDC Average NTU Red | Flow at Start GPM | Flow at end 2 hours |
|---|---|---|---|---|---|---|---|---|
| 9-400-1 | 5,443 | 369 | 87% | 93% | 58% | 76% | 30 | 30 |
| 9-50-1 | 680 | 42 | 59% | 66% | 40% | 60% | 30 | 30 |
| 9-100-1 | 1,361 | 94 | 82% | 92% | 46% | 66% | 30 | 30 |
| 9-150-1 | 2,041 | 131 | 79% | 89% | 48% | 67% | 30 | 30 |
| 9-200-1 | 2,722 | 190 | 85% | 90% | 44% | 70% | 30 | 30 |
| 9-250-1 | 3,402 | 237 | 84% | 94% | 51% | 72% | 30 | 30 |
| 9-300-1 | 4,082 | 282 | 85% | 93% | 58% | 73% | 30 | 30 |
| 9-350-1 | 4,763 | 318 | 84% | 93% | 53% | 67% | 30 | 30 |
| 9-400-2 | 5,443 | 354 | 84% | 94% | 52% | 69% | 30 | 30 |
| 9-50-2 | 680 | 44 | 62% | 93% | 28% | 44% | 30 | 30 |
| 9-50-2A | 735 | 50 | 76% | 95% | 45% | 52% | 30 | 30 |
| 9-100-2 | 1,470 | 92 | 83% | 97% | 51% | 72% | 30 | 30 |
| 9-150-2 | 2,204 | 148 | 81% | 94% | 52% | 70% | 30 | 30 |
| 9-200-2 | 2,939 | 179 | 81% | 95% | 53% | 73% | 30 | 30 |
| 9-250-2 | 3,674 | 234 | 81% | 94% | 57% | 71% | 30 | 30 |
| 9-300-2 | 4,409 | 270 | 84% | 96% | 51% | 71% | 30 | 30 |
| 9-350-2 | 5,144 | 312 | 82% | 93% | 53% | 70% | 30 | 30 |
| 9-400-3 | 5,879 | 392 | 82% | 92% | 52% | 69% | 30 | 30 |
| Overall Averages: | 57,072/454 = 125 lbs. exposure | 208 | 80% | 92% | 50% | 67% | 30 | 30 |

1.) The cartridge manifold is now connected vertically downward to the "Tee" fitting in the manifold.
2.) The test interval protocols increased to 3 hour durations, and 20 minute test intervals.
3.) This test was run to 125 lbs at 34-in driving head (water level above the vault floor, Figure 4) and then from there to 300 lbs of exposure with a 40-in driving head. During the runs flows and head were closely monitored.

Revisions to Test procedures:

1.) Tests were conducted at constant input concentration of 150 mg/l.
2.) The system was started and stabilized for each test within the first 20 minutes of each run. Test measurements were also taken at intervals of 40, 60, 80, 100, 120, 140, 160 minutes from start of run.
3.) The following tests were done at the 20 minute intervals:
- Background TSS
- Background Turbidity (NTU)
- Dual Inlet TSS
- Dual Inlet Turbidity (NTU)
- Outlet A TSS
- Outlet A Turbidity (NTU)
- Outlet B TSS
- Outlet B Turbidity (NTU)
- Draindown TSS
- Draindown Turbidity (NTU)

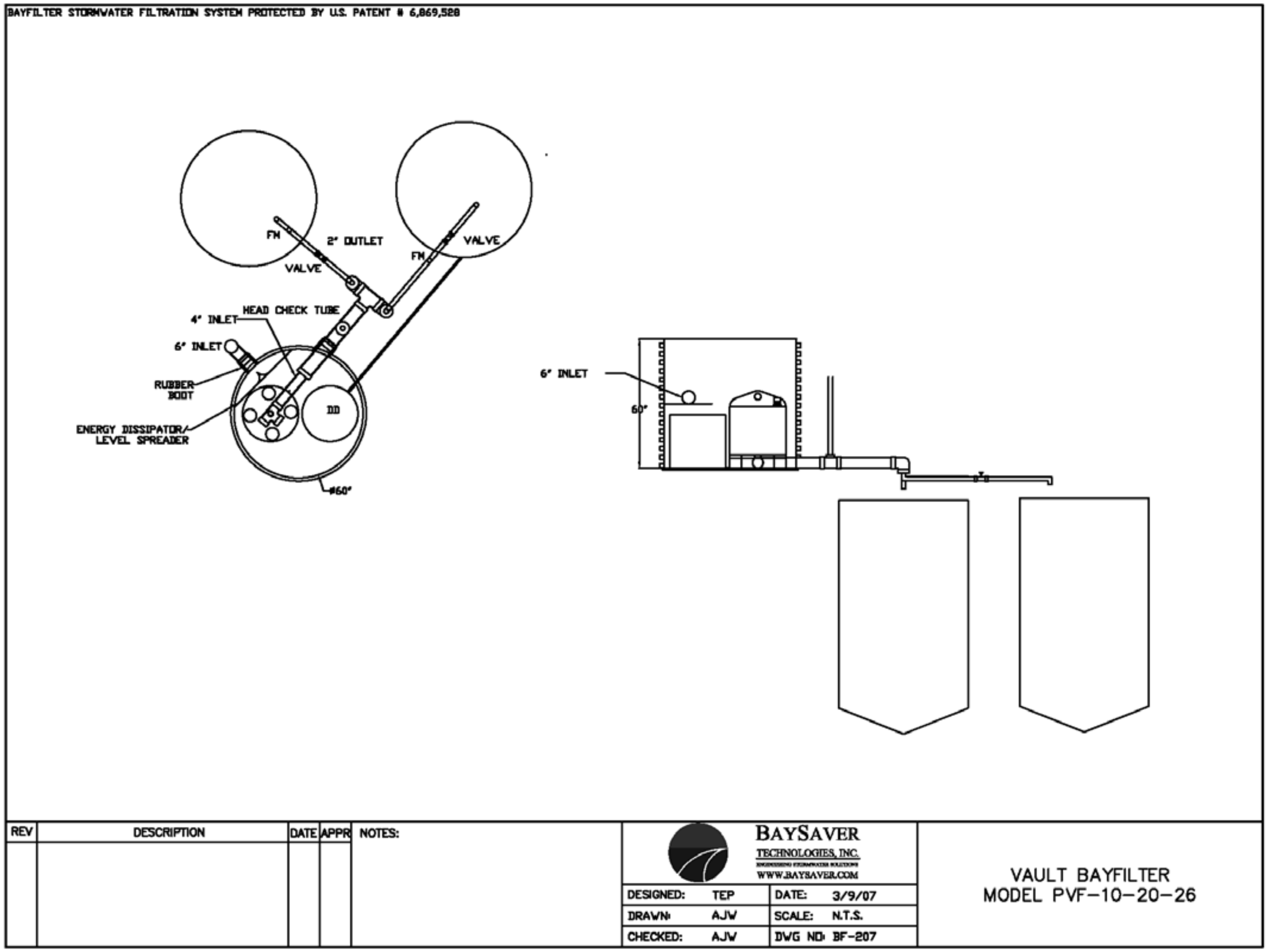



**Figure 19. Vault Layout for Laboratory Testing of Generation #10 Filter Cartridge and Piping Connections**

4.) Mass balance filter: discharge water to determine sediments remaining after filtration. During this test a 0.5 um absolute bag filter was added to the train and an additional 0.5 um absolute bag filter was added to further eliminate any background sediment concentration and insure all solids are collected. In addition, a new style filter canister was used that exactly matched the 0.5 um absolute bags.

5.) The draindown cartridge was reinstalled and its flow rate was checked with a timed bucket periodically for verification; and the rate of flow degradation was determined.

<u>Summary of Results:</u>

BayFilter™ Cartridge Results:

1.) Flow:
   - Flow of 30 gpm was essentially attained throughout the 125 lb sediment addition portion of the test.
   - Flow decrease was observed during the test above 125 lbs of exposure (see Table 7)
   - An important observation was made that the backwash restored over 90% of the flow loss between runs; this proved the ability of the filter to restore itself between storms.

2.) TSS Removal:
   - TSS sampling resulted in an 83.7% reduction (mass weighted) (see Table 7 for removal efficiency for each individual run)
   - Mass balance confirmed this with an 81.7% reduction

3.) Turbidity Reduction (see not yet verified results in Appendix A)

Draindown Cartridge Results

1.) Flow:
   - Flow of 1.7 +/- gpm was attained throughout the test.

2.) TSS Removal:
   - TSS sampling resulted in a 93.5% Reduction (mass weighted)

3.) Turbidity Reduction (see not yet verified results in Appendix A)

<u>Comments on Results:</u>

This test did involve some minor changes, and the efficiencies overall improved. Furthermore, the test of the draindown cartridge proved that with an equivalent exposure of 425 lbs/cartridge it retained its TSS removal efficiency as well as its flow.

This test also demonstrated that the revised configuration works as designed, as well as the fact that the cartridge can maintain its TSS removal efficiency to up to 300 lbs of sediment loading although flow reductions must be taken into consideration at higher loading.

## Table 7. Filter Generation # 10 Data Summary

| Run # | Cumulative Sediment Input lbs. | Avg Inlet Concentration mg/l | TSS Reduction BFC Average TSS Red | TSS Reduction DDC Average TSS Red | Turbidity Reduction BFC Average NTU Red | Turbidity Reduction DDC Average NTU Red | Flow at Start GPM | Flow at end 3 hours | Average flow For 3 hrs | Avg as % of target 3 hrs | Flow at end 4 hours | Average flow For 4 hrs | Avg as % of target 4 hrs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-150- 1 | 7.12 | 124 | 85% | 96% | 57% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 2 | 14.25 | 105 | 84% | 89% | 54% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 3 | 21.37 | 115 | 88% | 91% | 51% | 68% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 4 | 28.50 | 135 | 84% | 93% | 49% | 68% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 5 | 35.62 | 153 | 78% | 95% | 51% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 6 | 42.75 | 146 | 88% | 93% | 50% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 7 | 49.87 | 153 | 86% | 95% | 49% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 8 | 56.99 | 121 | 86% | 95% | 49% | 70% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 9 | 64.12 | 160 | 85% | 91% | 50% | 70% | 30 | 28 | 29 | 96% | na | na | na |
| 10-150- 10 | 71.24 | 138 | 86% | 94% | 49% | 67% | 30 | 29 | 30 | 100% | na | na | na |
| end bagset 1 | | | | | | | | | | | | | |
| 10-150- 11 | 78.37 | 146 | 87% | 94% | 48% | 67% | 30 | 28 | 29 | 97% | na | na | na |
| 10-150- 12 | 85.49 | 149 | 86% | 95% | 53% | 68% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 13 | 92.62 | 139 | 82% | 93% | 49% | 67% | 30 | 30 | 30 | 100% | na | na | na |
| 10-150- 14 | 99.74 | 154 | 83% | 93% | 50% | 66% | 30 | 29 | 29 | 97% | na | na | na |
| 10-150- 15 | 106.87 | 138 | 83% | 94% | 50% | 66% | 30 | 30 | 30 | 99% | na | na | na |
| 10-150- 16 | 113.99 | 142 | 80% | 93% | 57% | 70% | 30 | 28 | 29 | 96% | na | na | na |
| 10-150- 17 | 121.11 | 142 | 80% | 92% | 59% | 72% | 30 | 26 | 28 | 92% | na | na | na |
| 10-150- 18 | 128.24 | 133 | 79% | 93% | 55% | 71% | 30 | 27 | 29 | 96% | na | na | na |
| 10-150- 19 | 135.36 | 134 | 87% | 94% | 58% | 71% | 30 | 25 | 28 | 94% | na | na | na |
| 10-150- 20 | 142.49 | 156 | 85% | 96% | 60% | 73% | 30 | 25 | 27 | 90% | na | na | na |
| 10-150- 21 | 149.61 | 148 | 82% | 94% | 62% | 69% | 30 | 23 | 27 | 89% | na | na | na |
| end bagset 2 | | | | | | | | | | | | | |
| 10-150- 22 | 156.74 | 168 | 82% | 96% | 58% | 71% | 28 | 20 | 24 | 79% | na | na | na |
| 10-150- 23 | 163.86 | 172 | 84% | 95% | 62% | 74% | 30 | 20 | 25 | 82% | na | na | na |
| 10-150- 24 | 170.98 | 165 | 86% | 94% | 67% | 78% | 29 | 20 | 23 | 78% | na | na | na |
| 10-150- 25 | 178.11 | 184 | 87% | 95% | 68% | 76% | 29 | 19 | 23 | 76% | na | na | na |
| 10-150- 26 | 185.23 | 232 | 88% | 97% | 75% | 78% | 21 | 21 | 18 | 60% | na | na | na |
| 10-150- 27 | 192.36 | 178 | 85% | 94% | 63% | 75% | 28 | 18 | 23 | 75% | na | na | na |
| 10-150- 28 | 199.48 | 197 | 86% | 90% | 65% | 75% | 26 | 17 | 21 | 68% | na | na | na |
| end bagset 3 | | | | | | | | | | | | | |
| 10-150- 29 | 206.61 | 215 | 85% | 95% | 67% | 75% | 22 | 16 | 17 | 58% | na | na | na |
| 10-150- 30 | 213.73 | 218 | 85% | 96% | 67% | 76% | 25 | 16 | 20 | 65% | na | na | na |
| 10-150- 31 | 220.86 | 149 | 81% | 93% | 59% | 73% | 25 | 18 | 21 | 71% | 17 | 20 | 67% |
| 10-150- 32 | 227.98 | 149 | 81% | 94% | 63% | 77% | 28 | 19 | 23 | 76% | 18 | 21 | 72% |
| 10-150- 33 | 235.10 | 138 | 74% | 90% | 51% | 74% | 28 | 18 | 23 | 75% | 17 | 21 | 70% |
| 10-150- 34 | 242.23 | 143 | 83% | 95% | 60% | 73% | 27 | 19 | 22 | 75% | 17 | 21 | 70% |
| 10-150- 35 | 249.35 | 156 | 81% | 95% | 58% | 76% | 26 | 17 | 21 | 70% | 16 | 20 | 66% |
| end bagset 4 | | | | | | | | | | | | | |
| 10-150- 36 | 256.48 | 151 | 82% | 98% | 59% | 78% | 24 | 16 | 19 | 62% | 15 | 20 | 66% |
| 10-150- 37 | 263.60 | 152 | 84% | 95% | 59% | 74% | 27 | 18 | 21 | 69% | 15 | 20 | 66% |
| 10-150- 38 | 270.73 | 154 | 86% | 92% | 62% | 74% | 24 | 17 | 20 | 68% | 15 | 19 | 64% |
| 10-150- 39 | 277.85 | 148 | 81% | 93% | 63% | 75% | 23 | 16 | 18 | 61% | 15 | 18 | 61% |
| 10-150- 40 | 284.97 | 148 | 82% | 91% | 61% | 74% | 22 | 16 | 17 | 58% | 15 | 17 | 58% |
| 10-150- 41 | 292.10 | 144 | 83% | 86% | 58% | 71% | 25 | 15 | 17 | 56% | 15 | 17 | 56% |
| 10-150- 42 | 300.22 | 182 | 87% | 89% | 57% | 67% | 20 | 15 | 16 | 54% | 15 | 16 | 54% |
| Overall Averages: | | 154 | 83.7% | 93.5% | 57.4% | 71.8% | | | | | | | |

| | TSS BFC | TSS DDC | NTU BFC | NTU DDC |
|---|---|---|---|---|
| Avg Bagset 1 | 84.8% | 93.2% | 50.9% | 69.2% |
| Avg Bagset 2 | 83.2% | 93.7% | 54.6% | 69.0% |
| Avg Bagset 3 | 85.4% | 94.8% | 65.5% | 75.3% |
| Avg Bagset 4 | 81.4% | 94.0% | 60.5% | 74.9% |
| Avg Bagset 5 | 82.9% | 92.3% | 60.3% | 74.2% |
| Avg Bagset 1, 2, 3, 4, 5 combined | 83.7% | 93.5% | 57.4% | 71.8% |

| | |
|---|---|
| Mass Bal Bagset 1 | 85.0% |
| Mass Bal Bagset 2 | 81.5% |
| Mass Bal Bagset 3 | 82.5% |
| Mass Bal Bagset 4 | 77.8% |
| Mass Bal Bagset 5 | 81.1% |
| Mass Bal Bagset 1, 2, 3, 4,5 comb. | 81.7% |

note at this point, we changed dosing pump setting to 30% less concentr= longer duration

### 5.6 Assessment and Verification of Measured TSS Removal Efficiencies

All the data provided to NJCAT were reviewed to fully understand the capabilities of the BayFilter™ System. However, only the TSS removal efficiency is assessed and verified in this report since only TSS has a numerical removal efficiency requirement in the New Jersey stormwater rules and only TSS has established laboratory-testing protocols in New Jersey. Removal efficiencies for turbidity and phosphorus are not assessed and verified and they are presented above for informational purposes only.

**Claim: The BayFilter™ cartridge at 30 gallons per minute (0.70 gpm/ft$^2$) of flow and 34 inches of driving head using a sand and perlite media mix has been shown to have a total suspended solids (TSS) removal efficiency of 83.8% with 95% confidence limits of 82.9% and 84.7%, for Sil-Co-Sil 106 (comprised of 7.5% sand, 80.2% silt and 12.3% clay with a median grain size by mass of $d_{50}$ equal to 23.2 microns) with influent concentrations ranging from 105 to 232 mg/L in laboratory studies using simulated stormwater.**

Three sets of laboratory data were presented above for three generations of BayFilter™. The Generation # 10 BFC (Figure 1) is final version that is being and will be marketed. The data from tests on Generation # 10 were used in this performance claim verification. Table 8 shows the measured data from a total of 42 runs at the flow rate of 30 gpm and target concentration of 150 mg/L. Values of the inlet (influent) TSS concentration and the percent TSS reduction (removal efficiency) in Table 8 are the same as those listed in Table 7. Values of the outlet (effluent) TSS concentration are included in Table 8 as an additional performance indicator. The statistical summary (the mean and the 95% confidence limits) of the TSS removal efficiencies is the same as those in the claim.

The minor modifications from Generation # 8 to Generation # 9 and to Generation # 10 should have not significantly altered the TSS removal performance of the filter cartridge. The mass-weighted TSS removal efficiencies for the three generations are 80.5%, 82.7%, and 83.7%, respectively. The statistical summary of the data from all the three generations (Tables 4, 6 and 7) combined are: Mean TSS removal efficiency of 82.7% with 95% confidence limits of 81.4% and 84.0%. This statistical summary is similar to that based on the Generation #10 data alone.

The solids removal efficiencies calculated from the mass balance are 81.5%, 83.1%, and 81.7% for Generation #s 8, 9, and 10, respectively. They are very close to each other and very close to the mean (82.7%) calculated from the influent and effluent TSS measurements.

The use of Sil-Co-Sil 106 as the materials feed is consistent with the NJDEP requirement. The influent TSS concentrations (150 mg/L for Generation #10 and from 50 to 400 mg/L for Generations #8 and #9) are similar to the range from 100 mg/L to 300 mg/L recommended by the NJDEP TSS laboratory testing procedures.

**Table 8. BayFilter™ Generation #10 TSS Data**

| Test Run No. | Actual Average Inlet TSS Concentration (mg/l)* | Average Outlet TSS Concentration (mg/l) | Average % TSS Reduction** |
|---|---|---|---|
| 10-150-1 | 124 | 17 | 85 |
| 10-150-2 | 105 | 15 | 84 |
| 10-150-3 | 115 | 18 | 88 |
| 10-150-4 | 135 | 24 | 84 |
| 10-150-5 | 153 | 33 | 78 |
| 10-150-6 | 146 | 20 | 88 |
| 10-150-7 | 153 | 24 | 86 |
| 10-150-8 | 121 | 18 | 86 |
| 10-150-9 | 160 | 25 | 85 |
| 10-150-10 | 138 | 15 | 86 |
| 10-150-11 | 146 | 20 | 87 |
| 10-150-12 | 149 | 20 | 86 |
| 10-150-13 | 139 | 23 | 82 |
| 10-150-14 | 154 | 28 | 83 |
| 10-150-15 | 138 | 21 | 83 |
| 10-150-16 | 142 | 24 | 80 |
| 10-150-17 | 142 | 26 | 80 |
| 10-150-18 | 133 | 23 | 79 |
| 10-150-19 | 134 | 19 | 87 |
| 10-150-20 | 156 | 24 | 85 |
| 10-150-21 | 148 | 23 | 82 |
| 10-150-22 | 168 | 30 | 82 |
| 10-150-23 | 172 | 29 | 84 |
| 10-150-24 | 165 | 23 | 86 |
| 10-150-25 | 184 | 25 | 87 |
| 10-150-26 | 232 | 29 | 88 |
| 10-150-27 | 178 | 28 | 85 |
| 10-150-28 | 197 | 30 | 86 |
| 10-150-29 | 215 | 33 | 85 |
| 10-150-30 | 218 | 33 | 85 |
| 10-150-31 | 149 | 28 | 81 |
| 10-150-32 | 149 | 27 | 81 |
| 10-150-33 | 138 | 35 | 74 |
| 10-150-34 | 143 | 26 | 83 |
| 10-150-35 | 156 | 32 | 81 |
| 10-150-36 | 151 | 31 | 82 |
| 10-150-37 | 152 | 26 | 84 |
| 10-150-38 | 154 | 22 | 86 |
| 10-150-39 | 148 | 29 | 81 |
| 10-150-40 | 148 | 29 | 82 |
| 10-150-41 | 144 | 25 | 83 |
| 10-150-42 | 182 | 26 | 87 |

* The target TSS concentration was 150 mg/L.
** Averaged from % reductions of the eight sample pairs

During the laboratory testing, only one filter cartridge (plus one draindown cartridge) was placed in the 60-in manhole vault (Figure 19). However, in the more common actual installation (Table 2), two filter cartridges (plus one draindown cartridge) will be placed in the 60-in manhole. The floor area per unit of cartridge in the laboratory setting is 9.8 squared feet, in comparison to 6.5 squared feet in the more common actual installation. Therefore, during the laboratory testing, the floor area outside the cartridges could have resulted in additional gravitational settling of solids in comparison to that in the more common actual installation. On the other hand, the feed material is very fine Sil-Co-Sil 106 sand with mean particle diameter of 23.6 micrometers, and removal by gravitational settling of the very fine particles within a relatively short detention time is not expected to be significant. Among a total of 91 possible configurations (including 11 listed in Tables 2 and 3), the floor area per cartridge ranges from 6.4 to 19 squared feet with the overall average of 8.3 squared feet. The floor area per cartridge of the laboratory settling (9.8 $ft^2$) is not extremely different from the overall average floor area (8.3 $ft^2$).

It is concluded: The full scale BayFilter™ stormwater filtration system delivered at least 80% average mass removal of SIL-CO-SIL 106 standardized silica sediment. The tested BayFilter™ stormwater filtration cartridge is capable of delivering a nominal 30 gpm flow at 34-in driving head when challenged with a total sediment loading of up to 125 lbs of SIL-CO-SIL 106, and is capable of delivering a nominal 15 gpm flow at 40-in driving head when challenged with a total sediment loading of up to 300 lbs of SIL-CO-SIL 106.

# 6. TECHNICAL EVALUATION ANALYSES

## 6.1 Verification of Performance Claim

Based on the evaluation of the results from laboratory studies, sufficient data are available to support the BaySaver Claim: The BayFilter™ cartridge at 30 gallons per minute (0.70 $gpm/ft^2$) of flow and 34 inches of driving head using a sand and perlite media mix has been shown to have a total suspended solids (TSS) removal efficiency of 83.8% with 95% confidence limits of 82.9% and 84.7%, for Sil-Co-Sil 106 (comprised of 7.5% sand, 80.2% silt and 12.3% clay with a median grain size by mass of d50 equal to 23.2 microns) with influent concentrations ranging from 105 to 232 mg/L in laboratory studies using simulated stormwater.

## 6.2 Limitations

### 6.2.1 Factors Causing Under-Performance

If the BayFilter™ is designed and installed correctly, there is minimal possibility of failure. The media will be replaced on a regular basis, allowing for proper maintenance of the cartridges at that time. Lack of maintenance may cause the system to operate at a reduced efficiency, and it is possible that eventually the system will become totally plugged with pollutants.

The BayFilter™ system requires periodic maintenance to continue operating at the design efficiency. The maintenance process comprises the removal and replacement of each BayFilter™ cartridge and the cleaning of the vault or manhole with a vacuum truck. BayFilter™ maintenance should be performed by a BaySaver Technologies, Inc. (BTI) certified maintenance contractor.

The BayFilter™ cartridges are provided on an exchange basis and are refilled by BTI and reused for exchange cartridges. Certain components are replaced such as the filter fabric and the media and any part that would not fully function for the next life cycle such as perhaps the air release valve. The media and any non-recyclable components are disposed of by BTI as part of the exchange.

The maintenance cycle of the BayFilter™ system will be driven mostly by the actual solids load on the filter. The system should be periodically monitored to be certain it is operating correctly. Since stormwater solids loads can be variable, it is possible that the maintenance cycle could be more or less than the projected duration.

When a BayFilter™ system is first installed, it is recommended that it be inspected every six (6) months. The inspection should include all components of the system. The BayFilter system has two indicators that it may not be operating correctly and that maintenance is required. The two indicators are sediment storage capacity and flow capacity.

*Sediment Storage Capacity:*

Since the majority of the sediments are ultimately collected on the vault floor (some are contained within the media and fabric) and the flow enters the cartridge through the bottom, there is a limit to the practical storage capacity of sediments between the vault floor and the bottom of the cartridge. At the point that the sediments cover the 4” outlet manifold pipes, there is only about 1.5” of capacity remaining until the sediments will be at a level that the water will no longer flow into the filter. As the outlet manifold becomes covered by sediment the BayFilter System must be maintained. During this maintenance the cartridges should be exchanged and the vault cleaned.

*Flow capacity:*

Each BayFilter system is designed to operate at a specific minimum flow. A simple check of the system after any storm event will indicate if it is operating properly. For flow-based systems they should be checked within a few hours of the end of the inflow to make certain there is no standing water above the bottom of the cartridges. For a detention/water quality volume-based system, this inspection should occur around 40 hours after the cessation of inflow. In either case if it is clear that the system is not draining down in that timeframe, the systems must be maintained.

#### 6.2.2 Pollutant Transformation and Release

The BayFilter™ will not increase the net pollutant load to the downstream environment. However, pollutants may be transformed within the unit. For example, organic matter may decompose and release nitrogen in the form of nitrogen gas or nitrate. Accumulated sediment will not be lost from the system under normal operating conditions.

#### 6.2.3 Sensitivity to Heavy Sediment Loading

Heavy loads of sediment will increase the needed maintenance frequency. The BayFilter™ System with its vault treatment capability will function without the need for pretreatment in most applications. Prudent engineering calls for primary clarification to pre-treat any media filtration processes. Pretreatment increases filter run duration, reduces the maintenance frequency and the associated costs by trapping these pollutants before introduction to the BayFilter™ System. Additionally, oil and grease in storm water runoff has been found to be largely associated with sediments and attached to trash and debris and its removal may be necessary to extend the period before cartridge replacement.

#### 6.2.4 Mosquitoes

The draindown filter cartridge prevents the system from retaining standing water between storm events (by draining the water depth down to approximately half inches, the diameter of the outlet tube), thereby reducing the chance of mosquitoes or other disease vectors breeding within the system.

## 7. NET BENEFICIAL EFFECT

Once the BayFilter™ system has been verified and granted interim certification by the NJDEP, BaySaver will then proceed to install and monitor systems in the field for the purpose of achieving goals set by the Tier II Protocol and final certification. At that time a net beneficial effect evaluation will be completed. However, it should be noted that the BayFilter™ technology requires no input of raw material, has no moving parts, and therefore, uses no water or energy.

## 8. REFERENCES

BaySaver Technologies, Inc. (2007). *BayFilter™ Technical and Design Manual*, Version 1.3 January 9, www.BaySaver.com, Mount Airy, Maryland.

BaySaver Technologies, Inc. (2007). BayFilter™ Performance Evaluation, Rev. November 26, Mount Airy, Maryland.
New Jersey Department of Environmental Protection (2006). *Particle Size Distribution Testing Requirements*, June 28
New Jersey Department of Environmental Protection (2003). *Total Suspended Solids Laboratory Testing Procedure*, December 23.

## Appendix A. Turbidity Reduction

The following results  and performance statements have not been verified by NJCAT. They are provided for informational purposes only.

Turbidity is an important indicator of the “health” of rivers, lakes, etc. For this reason, BaySaver believes that in the future, turbidity measurements will become a more important stormwater quality indicator. Therefore, turbidity removal efficiencies in the BaySaver Filter System were also analyzed as part of the performance evaluation.

For the BayFilter™ Generation #8 test (see the main report), the 23 runs were also analyzed for turbidity using a Hach Laboratory Turbidimeter. Each run consisted of 4 to 5 data points for a total of 210 Inlet/Outlet turbidity data points. This data indicates that the BayFilter™ stormwater filtration system removed, on average, 52% of the incoming turbidity over the course of the testing. Inlet turbidity range was between 72 to 11 NTU while outlet turbidity range was 45 to 8 NTU. The average NTU data by run is summarized in Table 4 of the main report.

Samples were taken every 10 minutes starting at the 10-minute mark from initiation of water flow from the filter vault. Turbidity samples were collected simultaneously in the following two locations:

1. Filter Feed (Feed water-solids mixture)
2. Filter Product Water (Filtrate)

The maximum percent turbidity removal was 65% and corresponded to a 400 mg/l solids test run (the maximum target solids concentration as well.) The minimum percent turbidity removal was 24% and corresponded to a 50 mg/l solids test run (minimum TSS).

For the BayFilter™ Generation #9 test (see the main report), turbidity reduction of the filter cartridge averaged 50%, and turbidity reduction of the draindown cartridge averaged 67%. See Table 6 in the main report for removal efficiencies of the individual test runs.

For the BayFilter™ Generation #10 test (see the main report), turbidity reduction of the filter cartridge averaged 57%, and turbidity reduction of the draindown cartridge averaged 71.8%. See Table 7 in the main report for removal efficiencies of the individual test runs.

## Appendix B. Total Phosphorus Removal

The following results and performance statements have not been verified by NJCAT. They are provided for informational purposes only.

Phosphorus (P) can exist in stormwater in both particulate and dissolved forms. It is anticipated that significant amounts of particulate P would be removed via processes such as filtration. On the other hand, dissolved Phosphorus would tend to exist mostly as phosphate ($PO4^{-3}$) in stormwater and would not be removed by processes such as inert media filtration. Therefore, for the evaluation of Total P removal performance of a stormwater filtration device it is necessary to characterize both its particulate P and dissolved P removal capabilities.

Because BaySaver was not able to locate an established protocol to evaluate Total P removal performance of stormwater filtration devices in laboratory settings, BaySaver used both experimental results together with in-depth literature research to draw projections on the Total P removal capabilities of the BayFilter™. Additionally, to better understand the dissolved P removal capabilities of the BayFilter™, BaySaver also conducted a dissolved P removal test.

*Experimental Results*

Removal of significant amounts of dissolved P is typically not accomplished through filtration unless the media mix has Phosphorus selectivity. Activated alumina, an adsorbent widely used in water and wastewater purification, was used as Phosphorus adsorbing media based on its reported capacity to adsorb phosphate from water. Commercially available liquid fertilizer (PCI Sales Ammonium Polyphosphate) was used as a source of Phosphorus for these tests. This fertilizer is a light green liquid mixture with no visible suspended particles.

The average inlet dissolved phosphate concentration used was a 25 mg/l (5.5 mg/l as dissolved P). Approximately 1,600 gallons of water were processed during this test. The BayFilter™ flow rate during these tests was maintained at approximately 30 gpm. The average outlet dissolved phosphate concentration was approximately 22 mg/l (4.8 mg/l as dissolved P). The calculated average dissolved P reduction was approximately 12%. It is important to note that a color change was observed between inlet and outlet samples (except for the 30 minute sample) confirming a positive reduction of dissolved P concentration between the inlet and outlet of the BayFilter™. (Refer to Table B1 for more information).

**Table B1. Dissolved Phosphorus Reduction Investigation - BayFilter™ Generation # 8 Test Summary**

| Sample Time Minutes | Phosphate IN mg/l | Dissolved Phosphorus IN mg/l | Phosphate OUT mg/l | Dissolved Phosphorus OUT mg/l | Dissolved Phosphorus Reduction % |
|---|---|---|---|---|---|
| 10 | 27 | 5.9 | 21 | 4.6 | 22% |
| 20 | 25 | 5.5 | 20 | 4.4 | 20% |
| 30 | 22 | 4.8 | 22 | 4.8 | 0% |
| 40 | 25 | 5.5 | 23 | 5.0 | 8% |
| 50 | 26 | 5.7 | 23 | 5.0 | 12% |
| **Average** | **25** | **5.5** | **21.8** | **4.8** | **12%** |

*Bibliographical Research Data Analysis*

BaySaver's literature research indicates that by removing particles larger than 10-11 microns, 80% to 92% of the particulate P is removed, and 48% to 60% Total P removal was achieved. See BaySaver's "BayFilter™ Performance Evaluation" for details of the literature research.

*Statements on Total Phosphorus Removal*

The literature research indicates that particle removal down to the less than 10 micron size is key to producing significant Total P removal in a stormwater filtration device. The experimental work performed by BaySaver concluded that:

1. The BayFilter™ nominally removed all particles in the range of 8 microns and above.

2. Additional Total P removal is accomplished by the BayFilter™ via removal of dissolved P (Approximately 12% of dissolved P was removed during the evaluation).

Using these experimental results obtained as part of this evaluation and literature research, it was anticipated by BaySaver that the BayFilter™ would have on average a Total P removal capability of more than 50%.

Future studies should also include effective life of the activated alumina for targeted dissolved ions.