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Inventory and Analysis of Proprietary, Small-Footprint Storm Water Best Management Practices

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Abstract

According to the 2000 National Water Quality Inventory Report to Congress, over forty percent of our nation's lakes and rivers still do not meet water quality standards. Urbanization is one of the main causes of poor water quality in America. Increased impervious surface area due to new buildings and roadways means more water discharging when it rains and thus, more pollutants entering the receiving water bodies. One of the main pollutants of concern in storm water discharge is Total Suspended Solids (TSS). Other pollutants such as metals and nutrients may bind to the TSS particles, so a measurement of TSS is a good indicator of other pollutants in the water.

Small-footprint storm water best management practices (BMPs) are products installed underground to provide primary treatment of storm water before it enters the receiving water body. Treatment consists of some form of sedimentation vault and a means for containing floatables such as oil and trash. These BMPs come in three main configurations: vertically cylindrical vault, horizontal vault, or filter combination. It was found through analysis of field studies submitted by the BMP companies that one configuration does not provide better removal efficiencies over another one. Removal efficiency is more a function of size than of configuration. The TSS removal efficiencies ranged from 0.75% to 98% for all BMP products analyzed.

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CHAPTER 1: INTRODUCTION

1.1 General Overview

Over 40 percent of surveyed U.S. water bodies still do not meet water quality standards according to the 2000 National Water Quality Inventory Report to Congress. Urbanization is one of the main causes of poor water quality in lakes and rivers. As natural lands are converted to urban areas, large amounts of impervious surface areas are created which readily transport storm water and pollutants to receiving water bodies. The pollutants in storm water come from a myriad of sources, including lawn fertilizers, engine and brake wear, exhaust emissions, drippings (such as oil) from cars, and the use of grit and deicing compounds. “Pollutants of concern in urban runoff include heavy metals (such as Cd, Cr, Cu, Ni, Pb, and Zn), nutrients, organic chemicals (such as polyaromatic hydrocarbons), and organic compounds (such as oil and grease) in the dissolved and particulate phases” (Mitchell, 2002). Total suspended solids (TSS) is another pollutant of concern in storm water, and is a measure of the amount of fine particles suspended in water. High TSS in a water body can often mean high concentrations of nutrients such as nitrogen and phosphorus, metals, and pesticides. These pollutants adsorb to soil particles and get carried into water bodies by storm water. During storm events, pollutants are washed from the surface into storm water collection systems, and are eventually discharged into receiving waters, often untreated. This storm water pollution problem, if left uncontrolled, could result in the loss of aquatic and wildlife habitat, along with the degradation of the quality of water used for drinking and recreation.

The Clean Water Act (CWA) of 1972 mandated that a program be enacted which monitors and regulates the non-agricultural sources of discharges that adversely affect the quality of our nation’s waters. The National Pollution Discharge Elimination System (NPDES) created a permitting system designed to implement controls which would prevent harmful pollutants from being discharged into receiving water bodies unknowingly (EPA NPDES, 2003).

Initial efforts to improve water quality under the NPDES program focused primarily on reducing pollutants in industrial process wastewater and municipal sewage, which were the most obvious sources of pollutant discharges resulting in poor water quality. Pollution control measures for industrial and municipal discharges were implemented and refined, and more diffuse sources of water pollution became significant causes of water quality impairment. Thus, in 1987 Congress amended the CWA to require implementation in two phases (Phase I and Phase II) of a comprehensive national program for addressing storm water discharges. The two phases address the permitting required for storm water discharges from a large number of sources including municipal separate storm sewer systems ("MS4s"), construction sites, industrial facilities, and sewage treatment plants (Storm Water Phase II Compliance Assistance Guide, 2000).

Phase I and Phase II require cities and/or states to develop storm water management plans to reduce the amount of pollutants that enter receiving water bodies via storm water. Many local governments intending to improve the quality of their runoff-impacted streams are incorporating best management practices (BMPs) into their storm water management plans. EPA defines stormwater BMPs as "methods that have been determined to be the most effective, practical means of preventing or reducing pollution from nonpoint sources."

BMPs may be structural or nonstructural. Nonstructural storm water BMPs may include educating the public on ways to prevent pollutants from going into the storm sewer system, such as not pouring used motor oil into the storm drain and cleaning up animal waste. Structural storm water BMPs, on the other hand, may either be natural (ponds, grassy swales, etc.) or manufactured products designed specifically for the removal of pollutants.

Small-footprint storm water BMPs are designed to be installed underground and usually replace some part of the storm water collection system. For example, a BMP that is designed to be shaped like manhole (vertically cylindrical) may replace an existing manhole so that water enters either from a subgrade pipe or through a top grate and flows through a treatment process before continuing through the collection system. These BMPs are offered in a variety of shapes and sizes, and small-footprint refers only to the fact that the system is placed underground, so there is virtually no footprint on land. Although very few municipalities have set requirements for the removal of total suspended solids (TSS) from storm water, those that have requirements commonly call for 80% removal of TSS in influent storm water. The Edwards Aquifer Recharge Zone in Austin, Texas, for example, is a sensitive drainage area and municipal regulations call for the removal of 80% TSS in influent storm water. Practically all storm water BMP manufacturers claim their products provide 80% removal of TSS in storm water but do not have proper documentation (lab and field studies) to back up these claims.

1.2 Statement of Objectives

This report focuses on the comparison and evaluation of small-footprint structural BMPs specifically designed to remove sediment and oils from storm water. The main objectives are identification of manufactured storm water BMPs currently on the market, identification of the main characteristics of each BMP, assessment of the pollutant removal efficiency of each product, and establishing which parts of each product, if any, are proprietary.

Company websites were researched and each product's manufacturing facility or sales representative was contacted to obtain information about the BMP. The information compiled includes engineering data for each BMP such as hydraulic and treatment flow capacities, the patent number(s) and descriptions associated with the product, the number of BMPs that each company has installed in the United States and if any are Texas Department of

Transportation (TxDOT) projects, maintenance information such as cleanout schedules, and field studies conducted to evaluate the product's pollutant removal efficiency.

CHAPTER 2: GENERAL OVERVIEW OF BMPS

2.1 Introduction

Best management practices have been instrumental in reducing the amount of pollution that enters rivers and lakes as a result of urbanization and overpopulation over the past 20 years. Traditional storm water BMPs include detention basins, constructed wetlands, retention ponds, infiltration basins and trenches, vegetated swales and buffer strips, and sand and organic filters (See Figures 2.1 and 2.2). These treatment technologies are effective to varying degrees, but they are land-intensive and can be quite costly. Land frequently is limited in urban and industrial areas; therefore the need for small-footprint BMPs becomes all the more important.

Figure 2.1 Grassy Swale

Figure 2.2 Sand Filter Basin

Proprietary small-footprint storm water BMPs are installed underground and replace some part of the storm water collection system. Therefore, storm water flows through the BMP and is treated between the time the water enters the curb inlet and is subsequently discharged into the water body. The treatment is considered primary; it consists of some form of a sedimentation vault and a means to collect floatables such as trash, oil, and grease. Small-footprint storm water BMPs come in three main configurations: vertically cylindrical, horizontal vault, and filter combination.

2.2 BMP Configurations

2.2.1 VERTICALLY CYLINDRICAL VAULTS

Vertically cylindrical BMPs may be installed to replace an existing manhole and consist of one or two vaults in series. Two types of treatment technologies generally are employed for this configuration, and the resulting flow pattern is either plug flow or centrifugal. The first treatment technology involves directing the influent water into a basin that allows settling to occur. Trash, oil, and grease float atop the water and are contained so as not to be carried down stream. Water leaves the system through a pipe that is located below the top of the water. The second treatment technology involves introducing the influent flow tangential to the inner wall of the manhole. The centrifugal flow forces water to follow the perimeter of the manhole creating a circular motion or vortex. The velocity at the center of the vortex is slower than at the edges; therefore particles and floatables are directed towards the center and downwards into a sump, where they are contained. All circular manhole BMPs maintain a constant level of water in the system between storms. See Section 4.7 for the discussion on permanent pools.

Circular manhole BMPs are designed with some form of overflow device that mitigates situations when the inflow rate is greater than the design treatment rate. This device directs the excess water through a bypass system that transports the water to the outlet. A more in-depth discussion on bypass systems is presented in Section 2.4. The following products analyzed in this report are considered to be vertically cylindrical: Aqua-Swirl™. Baysaver®, CDS®, Downstream Defender®, ecoStorm™, Stormceptor®, VortSentry™, and V2B1™. See Table 2.1 for a summary of these products.

Table 2.1 Summary of Vertically Cylindrical BMPs

SYSTEM	SURFACE OR SUBSURFACE	TREATMENT FLOW CAPACITIES [cfs]	HYDRAULIC FLOW CAPACITIES [cfs]	GENERAL CONFIGRUATION	SPACE USED Dia x D or W x L x D
AquaSwirl	Subsurface	1.0, 3.0, 4.5, 6.5, 8.5, 11.0, 14.0, 17.5 and 25.2 cfs offline	Same as treatment flow capacities.	One circular manhole vault	Min: 2.5' x 3' Max: 12' x open
BaySaver	Subsurface	1.1, 2.4, 7.8, 11.1, and 21.8 cfs	8.5, 10, 30, 50, and 100 cfs	Two circular manhole vaults	Min: 10' x 14' x 4' Max: 13' x 18' x 8'
CDS	Subsurface	0.7 to 6 cfs online 2 to 64 cfs offline 148 to 300 cfs offline and cast in place 27 total models	X	One circular manhole vault	Min: 4.8' dia Max: 17.5' dia precast 41' dia cast in place
Downstream Defender	Subsurface	3, 8, 15, and 25 cfs.	3, 8, 15, and 25 cfs	One circular manhole vault	Min: 6' x 8' Max: 12' x 15'
EcoStorm	Subsurface	2, 3, 4, 5.5, and 7 cfs	8, 12, 16, 22, and 28 cfs	One circular manhole vault	Min outer dimensions: 6' x 10' Max outer dimensions: 12' x 10'
Stormceptor	Subsurface	0.28, 0.64, 1.06, 1.8, 2.4 cfs 9 models	Available height over weir and the storm drain	One circular manhole vault	Min: 4' x 5' to 5.75' Max: 12' x 15.5'
VortSentry	Subsurface	0.3 to 11.9 cfs 8 models	1.2 to 47.6 cfs	One circular manhole vault	Min: 3' x 5.4' Max: 12' x 16.5'
V2B1	Subsurface	0.21 to 8.19 cfs16 7 models	1.0 to 38.0 cfs	Two circular manhole vaults	Min Sump Dimensions: 4' x 7' Max Sump Dimensions: 12' x 11'

2.2.2 HORIZONTAL VAULTS

Horizontal vaults may be rectangular or cylindrical, and typically are constructed of concrete or some form of piping (e.g. HDPE). A series of baffles and weirs are installed to direct the flow of water. Influent and/or effluent flow-distributing chambers may be included to distribute the water more evenly into and out of the system. The baffles and weirs form chambers that allow settling to occur and containment of floatables. The capture of floatables is often accomplished by positioning a baffle to extend from the top of the vault down to some small distance above the floor, creating a clearance though which water must travel to exit the system. The majority of horizontal vaults retain water between storm events in the form of a permanent pool. See Section 4.7 for the discussion on permanent pools. Absorbent mats or bags may be placed in the oil/grease chamber to float on the water and absorb the floatable pollutants. Some rectangular vault BMPs are designed to contain the water from an entire storm event instead of only the first flush. In theory, this design is ideal for treating storm water, as the first flush may be more voluminous than a BMP can contain and treat effectively. A more in-depth discussion on first flush is presented in Section 2.5. The following products analyzed in this report are considered to be horizontal vaults: ADS Water Quality Unit, CrystalStream™ Technologies, StormGate Separator™, Stormvault™, Nutrient Separation Baffle Box, and Vortechs® System. See Table 2.2 for a summary of these products.

Table 2.2 Summary of Horizontal Vault BMPs

SYSTEM	SURFACE OR SUBSURFACE	TREATMENT FLOW CAPACITIES [cfs]	HYDRAULIC FLOW CAPACITIES	GENERAL CONFIGRUATION	SPACE USED (+)^2 Dia x D or W x L x D
ADS Water Quality Unit	Subsurface	0.7, 0.86, 1.13, 1.47, 1.5, 1.6, 1.73, 1.83, 2.26, 2.39, 2.95, 3.12, 3.2, 3.66, 4.78, and 6.23 cfs 16 models	Same as treatment flow capacities.	Horizontal cylinder with three chambers. 3' to 5' diameters	Min: 3' x 20' Max: 5' x 40'
CrystalStream Technologies	Subsurface	1.2, 2.5, 3.5, 4.8, 6.0, 7.2 cfs 6 models	6.0, 12.5, 17.5, 9.6, 30.0, 36.0 cfs	Rectangular vault	Min: 5' x 6' x ? Max: 8' x 14' x ?
Nutrient Separation Baffle Box	Subsurface	12, 31.2, 46.2, 61.2, 64.8, 97.2 cfs. 7 models.	Same as treatment flow capacities.	Rectangular Vault	Min inside dimensions: 4' x 8' x 7' Max inside dimensions: 8' x 14' x 8'
StormGate Separator	Subsuface	0.86, 1.17, 2.03, 2.46, and 2.89 cfs	1.68, 2.01, 3.14, 3.58, and 4.03 cfs	Rectangular vault	Min: 6' x 10' x 5.5' Max: 8' x 18' x 6.5'
Stormvault	Subsurface	Each configuration holds the entire storm runoff and slowly meters it out	NA (offline)	Rectangular Vault	Min: 12' x 24' x 6' Max: open
Vortechs	Subsurface	1.6 to 25 cfs 9 models	1.6 to 25 cfs	Rectangular vault	Min: 3' x 9' x 7' Max: 12' x 18' x 8'

2.2.3 Filter Combinations

BMPs using filter combinations take a variety of forms. Rectangular vaults or circular configurations, or a combination of the two are used. Filters typically take the form of bags or siphon-actuated containers that are filled with a filter media such as zeolite or granulated activated carbon. Pre-treatment is necessary for both types of filtration; typically vaults are used that contain the floatable such as trash and provide for some sedimentation of particles. Treatment using bags occurs when pre-treated storm water is directed through the bag and permeates through the filter media. The bag may be stand-alone and placed in front of an inlet, or a number of bags may be placed together to create a filter bed. Siphon-actuated filters are designed to treat a certain flow rate (e.g. 15 cubic feet per second (cfs)). The number of filters needed is a function of the amount of the design flow rate. The filters are placed on a raised bed and are filled with a filtration media that treats a specific pollutant such as zinc, phosphorus, or fine silt. Water is drawn through a siphon and into the filtration media, where direct contact allows for optimal treatment. The following products are considered to be filter combinations: Aqua-Filter™, StormFilter®, StormScreen™, and StormTreat. See Table 2.3 for a summary of the aforementioned products.

Table 2.3 Summary of Filter Combination BMPs

SYSTEM	SURFACE OR SUBSURFACE	TREATMENT FLOW CAPACITIES [cfs]	HYDRAULIC FLOW CAPACITIES	GENERAL CONFIGRUATION	SPACE USED (+)[2] Dia x D or W x L x D
AquaShield - AquaFilter	Subsurface	0.5, 1, 1.5, 2.5, 3.0, 4.0, 5.0 and 6.0 cfs	1.8, 3.0, 4.25, 6.25, 8.5, 11.0, 14.0 and 17.5 cfs	Two chambers. Swirl chamber 2.5' to 12' diameter. Filter chamber 6.7' dia x 9.6' to 36' length	Min: 6.7' x 9.6' Max: 6.7 x 36'
StormFilter	Subsurface	Precast: 0.033 to 4.22 cfs Linear: 0.033 to 0.27 cfs Catch Basin: 0.033 to 0.13 Manhole: 0.10 cfs Cast in place: 0.8 cfs to >8 ** each cartridge treats 0.033 cfs. Calculations are given to determine the # of cartridges needed	Precast: NA Linear: 1.3 cfs Catch Basin: 1.0 cfs Manhole: 1.0 cfs Cast in place: NA	Cylinder cartridges placed in rectangular vault	Precast Min: 7'x 9'x 4.5'(1) ** Max: 10'x 64'x INF (128)** Linear Min: 3' x 10' x 3.5' (1)** Max: 3' x 20' x 5.5' (8)** Catch Basin Min: 4'9"x 2'5"x 2.3' (1)** Max: 10'8" x 2'5" x 3.3' (4)** Manhole: 48" dia x 5' and up Cast in Place Min: 12'x41'x 6' (24)** Max: 21.5' x 85' x INF (320)**
StormScreen	Subsurface	Precast: 0.5 to 10 cfs Cast-in-Place: > 10cfs 0.5 cfs / cartridge	NA	Cylinder cartridges placed in rectangular vault	Precast Min: 6' x 12' x 5' (<8)** Max: 8' x 16' x 20' (9-20)** Cast-in-place; Multiple precast units: size varies (W x L) x 4' (>20)**
StormTreat	Surface	7,000 gallons/unit	NA (offline)	Circular	9.5' x 4'

** (#) number of cartridges in vault

2.3 Hydraulic and Treatment Flow Capacities

Most storm water BMPs are designed for a hydraulic flow capacity and a treatment flow capacity. The hydraulic flow capacity is the maximum amount of flow that the system can handle at any given time and is a function of the inner dimensions of the BMP. The treatment flow capacity is typically less than the hydraulic capacity, and is defined as the maximum flow rate at which the system can effectively provide sedimentation of particles and containment of floatables. Any flow rate above this maximum will result in a decrease in removal efficiency and may necessitate the use of a bypass device. For example, one of the Baysaver® models has a treatment capacity of 1.1 cfs and a hydraulic capacity of 8.5 cfs. This means that maximum settling of particles occurs at influent flows of 1.1 cfs and less. Flows between 1.1 cfs and 8.5 cfs provide increasingly less settling of particles, and influent flows over 8.5 cfs necessitate the use of a bypass system to compensate for the excess flow in the system.

2.4 Bypass Systems

Most BMPs are designed with some form of overflow device that directs storm water out of the system quickly during storm events when the influent flow rate exceeds the hydraulic flow capacity. This device directs the excess influent water through a bypass system that transports the water to the outlet. Therefore a mixture of treated and untreated water is continuously discharged from the BMP until the influent flow rate becomes less than the hydraulic capacity, and the bypass device is no longer necessary. Ideally, bypass devices are only utilized during large storm events; however, even smaller storm events may have periods of intense rain when the hydraulic flow capacity is exceeded and the overflow device is necessary.

2.5 Maintenance

Most small-footprint storm water BMPs are designed to be easily accessible. All BMPs evaluated in this report contain at least one manhole, and the number of manholes increases with increasing BMP length. Generally, maintenance on a BMP involves the removal of collected sediment and water, and is performed by a vacuum truck that transports the debris and solids to a landfill. If the BMP contains filter bags, they must be inspected and, if necessary, replaced. A good rule of thumb for setting a maintenance schedule consists of inspecting the system after each large storm event, or every three months (whichever is more frequent), during the first year of operation. The yearly maintenance schedule can then be set according to the noted observations.

2.6 First Flush

The phenomenon describing influent storm water concentrations that are higher at the beginning of a storm than at the end is commonly referred to as the "first flush" of a storm event. This increased concentration is due to the initial flushing of solids that have built up on urban surfaces (roadways, sidewalks, roofs, etc.) between storm events. Many manufacturers claim their proprietary small-footprint storm water BMPs contain and treat the first flush of a storm event. However, the first flush can only be effectively treated if it is diverted offline, or off the main path of the pipe, and held until it can be slowly released back into the pipe system. When the water is diverted offline, it is directed into a holding device such as a tank or vault. Once the holding device is full, the influent water bypasses it and continues down the pipe. This offline structure is effective at containing and treating the first flush because it allows ample time for particles to settle before the water is released back into the pipe system.

Some conventional controls, such as sand filters, are installed offline specifically to contain and treat the first flush of storm events. Most of the BMPs evaluated in this report are installed inline with the pipe system. Therefore, the first flush enters the BMP and goes through the treatment process, but as water continues to enter the system the highly concentrated first flush water is pushed out and might not attain the proper treatment level. The BMP products Aqua-Swirl™, CDS®, StormFilter®, StormScreen™ and Stormgate™ Separator are all offered as offline treatment units, and therefore can better contain and treat the first flush of a storm. Stormvault™ is a rectangular vault BMP that can be designed large enough to contain entire storm events, thus eliminating the concern for first flush.

2.7 Permanent Pool

The majority of proprietary small-footprint stormwater BMPs are designed to maintain a constant level of water in the system between storms.

Manufacturers claim this aids in maintaining a quiescent environment, prevents resuspension of sediments, and provides for better treatment conditions overall. However, in practice this design makes it impossible to drain the system without using a vacuum truck and requires floatables to stay suspended in water between cleanings. Most systems only get vacuumed out a few times a year, so the standing water promotes degradation of organic matter that may be floating in the water. If left in the system, sticks, leaves, and other degradable materials will decompose into nutrients that can then be washed out with the next storm. This addition of nutrients is potentially harmful the receiving body of water.

A study of BMPs done by Caltrans in 2003 found that water standing for more than 72 hours in all BMPs studied (retention basins, sand filters, small-footprint stormwater BMPs, etc.) became a breeding ground for mosquitoes. To minimize vector concerns, it was recommended that the potential for standing water be avoided during the design phase (Caltrans 2003).

CHAPTER 3: PRODUCT REVIEW

3.1 Introduction

This section presents the characteristics of each product evaluated. The summary includes the general configuration and description of treatment technology, range of treatment and hydraulic flow capacities, maintenance scheduling, cost information, installations in the United States (U.S.), where they are installed, and patented part(s) of the product.

3.2 Advanced Drainage Systems (ADS) Water Quality Structure

3.2.1 DESCRIPTION OF TREATMENT TECHNOLOGY

ADS Water Quality Structures are designed to remove sediments and hydrocarbons and manage the quality of water discharged during a storm event. A typical design involves an underground pipe assembly made of N-12 high-density polyethylene (HDPE) with three chambers and two manhole access risers (Figure 3.1). Water enters the first chamber and heavier particles settle out. The water flows over a weir to the second chamber in which traps floatables and oil/grease are trapped. Water flows under a third weir to leave the system.

3.2.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

ADS Water Quality Structures consist of a horizontal cylinder with three chambers. The diameter of the system ranges from 3 feet (ft) to 5 ft and the length can either be 20 ft or 40 ft, based on the volume water to be treated. ADS offers 16 models that treat flows ranging from 0.7 cubic feet per second (cfs) to 6.23 cfs. The hydraulic flow rates are the same as the treatment flow rates for this product.

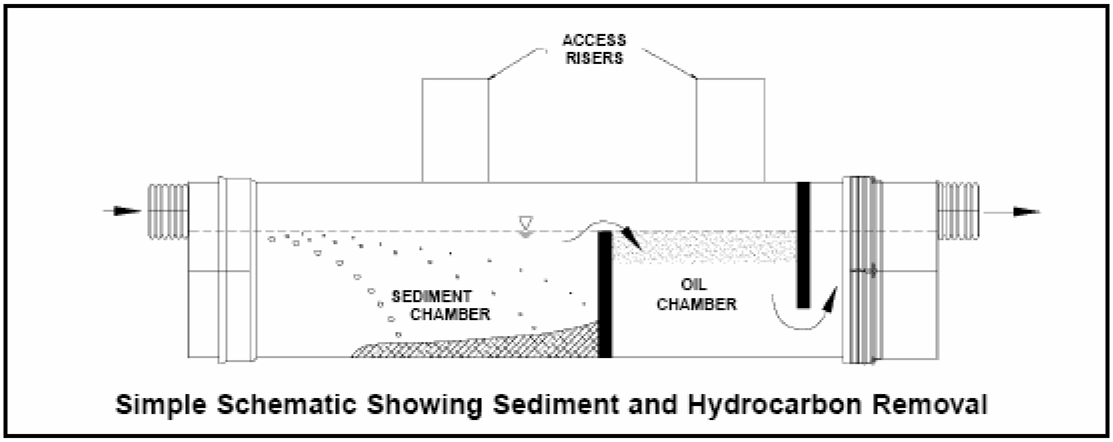

Figure 3.1 ADS Water Quality Unit

3.2.3 MAINTENANCE SCHEDULE,

A routine inspection and maintenance program must be established based on the volume of sediment, debris, and oil collected from the treated drainage area. Quarterly inspections of the sediment and oil chambers are recommended during the first year of operation to develop a schedule of maintenance. The inspection and cleaning schedule should be revised based on the contaminant loads determined during inspection. At a minimum, the unit should be cleaned annually to provide peak performance (Product Note 3.140, 2003).

3.2.4 COST INFORMATION AND INSTALLATION STATUS

The cost of an ADS Water Quality Unit ranges in price from $4,000 to $350,000. Installation costs are approximately 20 percent of the material (or product) cost. Currently, 32 units are installed nationwide with eight units installed in Texas. The majority of the Texas installations are located in Houston where they treat runoff from commercial applications such as apartment complexes and car dealerships.

3.2.5 PATENTED COMPONENT OF SYSTEM

No patents are held for this product.

3.3 AquaShield Storm Water Treatment Systems – Aqua-Swirl™ Concentrator

3.3.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The Aqua-Swirl™ Concentrator removes sediment, floating debris and free-oil. The product consists of a circular manhole that utilizes vortex separation to enhance the settling of small particles (Figure 3.2). A baffle wall separates floatables from the outlet pipe. Treated water exits the treatment chamber through a flow control orifice that is located behind the baffle wall. The Aqua-Swirl™ Concentrator detains water between storm events (Aqua-Swirl Operation, webpage).

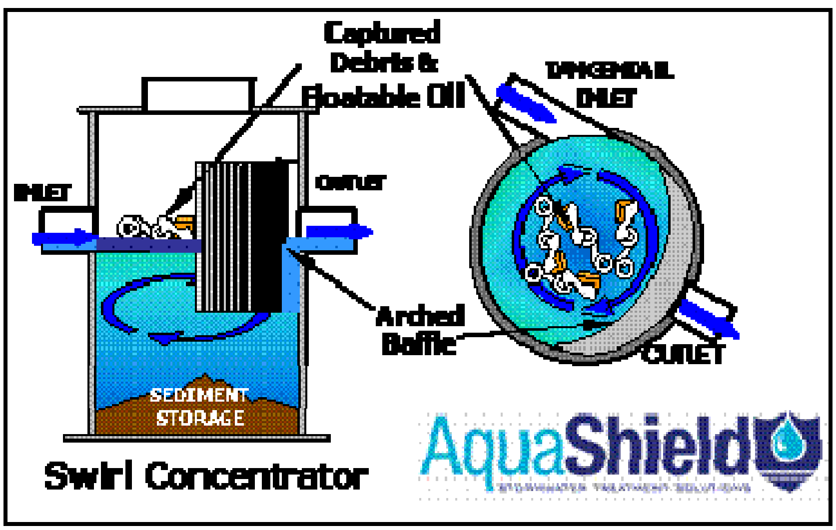

Figure 3.2 Aqua-Swirl™ Concentrator

3.3.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The general configuration of the Aqua-Swirl™ consists of one circular manhole with diameters ranging from 2.5 ft to 12 ft. The depth of the system ranges from a minimum of 3ft to a maximum that is open to design criteria such as level of treatment needed, maximum storm size, and drainage area. Nine flow models are offered in an offline system to treat storm water runoff. The treatment flow rates range from 1.0 cfs to 25.2 cfs. The hydraulic flow rates are the same as the treatment flow rates for this system.

3.3.3 MAINTENANCE SCHEDULE

Cleanout of accumulated sediment should be performed when the usable sediment storage volume is reached, or approximately 50 percent of the vault capacity. Sediment depths can be determined by lowering a measuring device such as a stadia rod to the top of the sediment pile and to the water surface. The difference in the two values is the depth of the water. The depth of the sediment is calculated as the depth of the floor to the water surface minus the depth of the water. A vacuum truck can be used to remove the accumulated sediment and debris. Disposal of the material typically is treated in the same fashion as a catch basin cleanout.

3.3.4 COST INFORMATION AND INSTALLATION STATUS

Typical costs of Aqua-Swirl™ units range from $5,000 to $40,000. Installation costs range from $5,000 to $10,000. These numbers represent the costs associated with offered treatment flow models. Aqua-Swirl™ units can be designed for site-specific requirements, such as level of treatment needed, maximum design storm size, and drainage area. More than 450 units have been installed in the U.S. and 209 units are in the design stages or are ready to be installed, as of January 2004.

3.3.5 PATENTED COMPONENT OF SYSTEM

The patent number held by AquaShield, Inc for the Aqua-Swirl™ Concentrator is 6,524,473 B2. The patent claims are:

- water is directed by the entrance pipe tangentially along the inside surface of the sidewalls to impart a swirling motion
- the cavity has substantially circular sidewalls
- the baffle plate, or "separator", spans the mouth of the exit opening and only permits water to leave the system from under and behind it when the level of drainwater collected within the system reaches the level of the exit opening
- the separator is joined to the sidewalls of the cavity so as to be in relatively close proximity of the mouth of the exit opening
- the separator is spaced from the mouth of the exit opening by no more than 4.0 inches
- the separator is arcuate in shape

3.4 AquaShield Storm Water Treatment Systems – Aqua-Filter™

3.4.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The Aqua-Filter™ is a two chamber system designed for sites that require advanced treatment of storm water runoff that is discharged to sensitive receiving waters. Pretreatment is achieved in the first chamber by using the Aqua-Swirl™ Concentrator to collect floatables and to settle out heavy particles. Vortex separation accelerates gravitational separation, and a baffle located just before the exit retains all large trash and debris within the system. A pipe transports the effluent of the first chamber to the Aqua-Filter™ filtration chamber, where the pre-treated water is evenly distributed across the filter bed and permeates through filter media. The filter media are contained in individual bags, which are layered in a criss-cross pattern to avoid short-circuiting. The natural filter media are capable of removing the remaining water-borne pollutants such as dissolved oils, fine silts and clays, certain nutrients (phosphates), and heavy metals (zinc) (Figure 3.3). The most commonly used media is medium grain perlite and reclaimed hydrophobic cellulose. Other filter media, such as zeolite, granulated activated carbon and synthetic textiles are available (Aqua-Filter Operation, webpage).

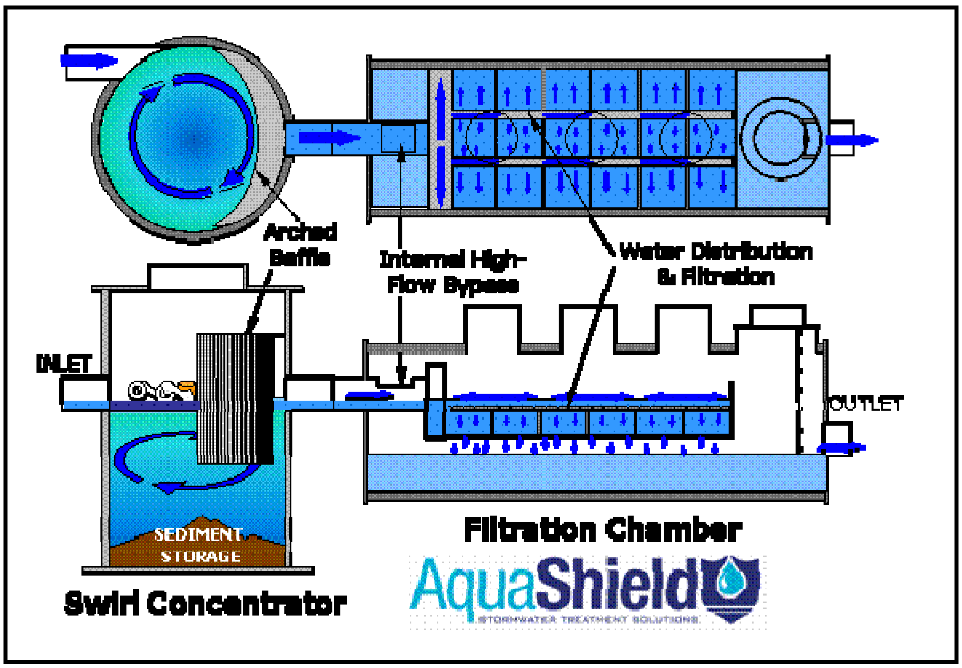

Figure 3.3 Aqua-Filter™ Schematic

3.4.2 CONFIGURATION AND TREATMENT CAPACITIES

The general configuration of the Aqua-Filter™ system consists of two chambers. The first chamber is the Aqua-Swirl™ Concentrator, which has a diameter range of 2.5 ft to 12 ft. The second chamber is the Aqua-Filter™, whose layout resembles a horizontal cylinder. It consists of an internal diameter of 6.7 ft and a length that varies from 9.6 ft to 36 ft. The Aqua-Filter™ system offers eight flow-size models, with treatment capacities ranging from 0.5 cfs to 6.0 cfs. The hydraulic capacities range from 1.8 cfs to 17.5 cfs.

3.4.3 MAINTENANCE SCHEDULE

Inspection of the Aqua-Filter™ filtration chambers can be performed from the surface by observing the color change of the filter media from its original light color to dark brown. Entry into the system is required to replace the filter bags. The spent filter bags are lifted from the chamber, and fresh filters are then lowered into the system and maneuvered into position. The filters are placed into 2 ft x 2 ft foot holders and should be overlapped such that the lower two bags are parallel to the length of the filtration chamber, and the upper two bags are perpendicular to the length of the chamber. Care must be taken to ensure that the bags are seated into position to promote good contact with the wall holders on all sides. Typically, the spent filters do not require any special treatment or handling for disposal. AquaShield recommends that all materials removed be handled and disposed of in accordance with local and state requirements (Aqua-Filter Maintenance, webpage).

3.4.4 COST INFORMATION AND INSTALLATION STATUS

The Aqua-Filter™ system ranges in price from $25,000 to $110,000 with installation costs ranging from $5,000 to $10,000. More than 100 systems have been installed nationwide, and many are in the design stage in Texas, as of January 2004.

3.4.5 PATENTED COMPONENT OF SYSTEM

Aqua-Filter™ shares the same patent as the Aqua-Swirl™ system, numbered US 6,524,473 B2. The patent claims about the Aqua-Filter™ are:

- the Aqua-Swirl Concentrator is located directly upstream of the Aqua-Filter system, so discharge from the Concentrator is subsequently routed through the filtration system
- drainwater that enters the Aqua-Filter system is directed through the filter
- the filter is supported above the floor of the chamber so that drainwater which is directed through the filter is gravitationally directed downward toward the floor of the chamber
- the filter includes a hydrophobic material
- the exit is spaced above the floor of the chamber so that drainwater is permitted to exit the chamber only when the level of the drainwater reaches the level of the exit.

3.5 BaySaver® Separation System

3.5.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The BaySaver® Separation System is designed to be effective throughout the entire storm event, not only during the first flush. Influent runoff flows into the first manhole where treatment occurs via gravity separation. When the flow becomes too large for the first manhole to contain, the excess storm water passes through a diversion pipe into a second manhole for additional treatment where gravity settling occurs and floatables such as trash and oil/grease are retained. If the flow exceeds the capacity of the two manholes, the storm water bypasses the system over a weir located above the transfer pipes through a device called the BaySaver® Separator Unit (Figure 3.4).

3.5.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The BaySaver® Separation System is composed of two standard precast manholes and the BaySaver® Separator Unit. The two manholes allow the removal and storage of pollutants, and the separator unit directs the flow of water. The diameters of the manholes range from 4 ft to 6 ft. BaySaver® Separator Units are manufactured in five standard sizes. The sizes of both the primary and storage manholes may be varied to suit site-specific conditions (Baysaver Specification, webpage). The treatment capacities range from 1.1 cfs to 21.8 cfs, and hydraulic capacities range from 8.5 cfs to 100.0 cfs.

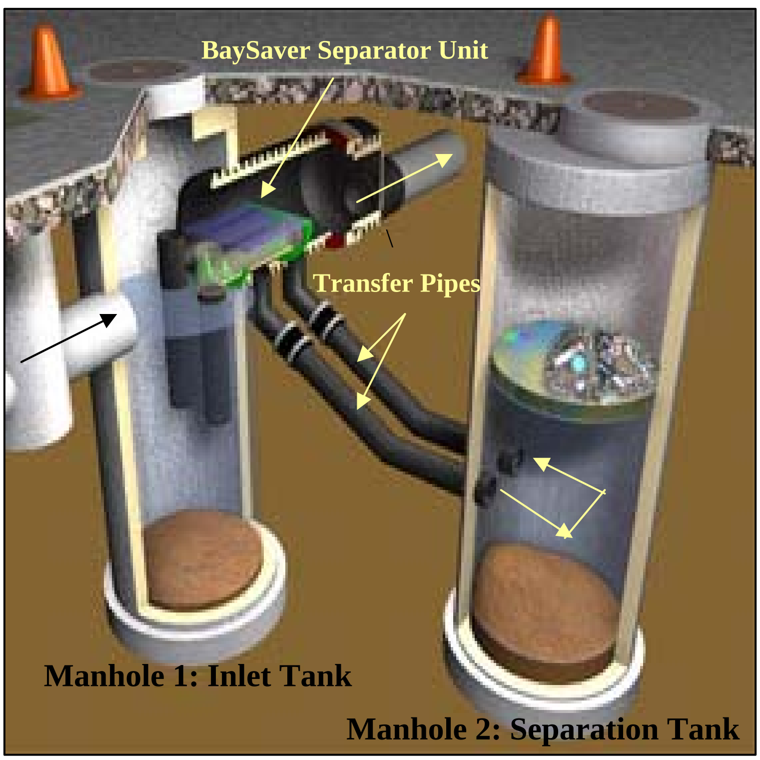

Figure 3.4 BaySaver® Separation System

3.5.3 MAINTENANCE SCHEDULE

Inspection of the system is recommended quarterly for the first year to establish the appropriate maintenance cycle based on site characteristics. Maintenance involves removing the manhole covers, placing a vacuum hose in the manholes and removing the accumulated material. A vacuum truck or like service truck can perform the necessary removal operations. A maintenance person can easily reach the entire floor area of both manholes with a vacuum hose to remove all of the sediments from the manhole floor.

3.5.4 COST INFORMATION AND INSTALLATION STATUS

The cost of BaySaver® Separation Systems range in price from $4,350 to $16,040 and installation costs average 100% of the product cost. Approximately 1,000 units are installed nationwide, with 12 units installed in Texas. The Texas unit installations are located on residential, commercial and school properties, and at an airport in Houston.

3.5.5 PATENTED COMPONENT OF SYSTEM

The patent number held by BaySaver® Storm water Treatment Systems for the BaySaver Separation System is 5,746,911. The patent claims are:

- an inlet tank for receiving storm water
- a main separation tank for separating at least some of the relatively light fluid from the relatively heavy fluid
- an outlet means which feeds fluids from the surface of the inlet tank to the main separation tank during low flows
- an outlet conduit having an overflow device in connection with the inlet tank, which when the stream has a relatively large flow rate allows fluid to flow from the inlet tank to the outlet conduit without passing through the main separation tank

- a means for receiving relatively heavy fluid from below the surface of the inlet tank and feeding it to the outlet conduit
- the BaySaver Separation Unit: a device that allows water to flow from the inlet tank into the separation tank under low to moderate flow conditions and under high flows allows water to bypass the second tank and leave the system.
    - it has a top and is closed on all sides, except at the entrance from the inlet tank and on the outlet side to release the treated water downstream.
    - an L-shaped pipe extends from inside the inlet tank (vertically) and travels horizontally through the Separation Unit to the outlet to transport cleaner water from the inlet tank during higher flows directly to the outlet of the system.

3.6 Continuous Deflective Separation (CDS®) – Storm Water Treatment

3.6.1 DESCRIPTION OF TREATMENT TECHNOLOGY

CDS® units remove sediments, gross debris and floatables such as free oil and grease (Figure 3.5). The unit is a cylindrical manhole consisting of a device that directs the influent flow of water, a cylindrical mesh screen located below the inlet, and a sump located below the screen. Storm water is “introduced in a direction tangent to the arc of the separation chamber. Using this approach, the dominant velocity vector is parallel to the unit screen, which tends to keep the screen from blocking with debris. Water passes through the screen to an outer peripheral chamber where it reverses direction and flows back into the storm drain system. The screen retains gross pollutants from the diverted flow except for material smaller than the openings in the screen” (BMP Retrofit Pilot Program Final Report, 2003). Floatables and suspended solids are directed to the slow moving center of the vortex, and down into the sump below. The sump is isolated from the flows through the unit, thus preventing resuspension of solids. A counter-current flow is produced along the outside of the mesh screen, which aids in the removal of any particles that may be caught.

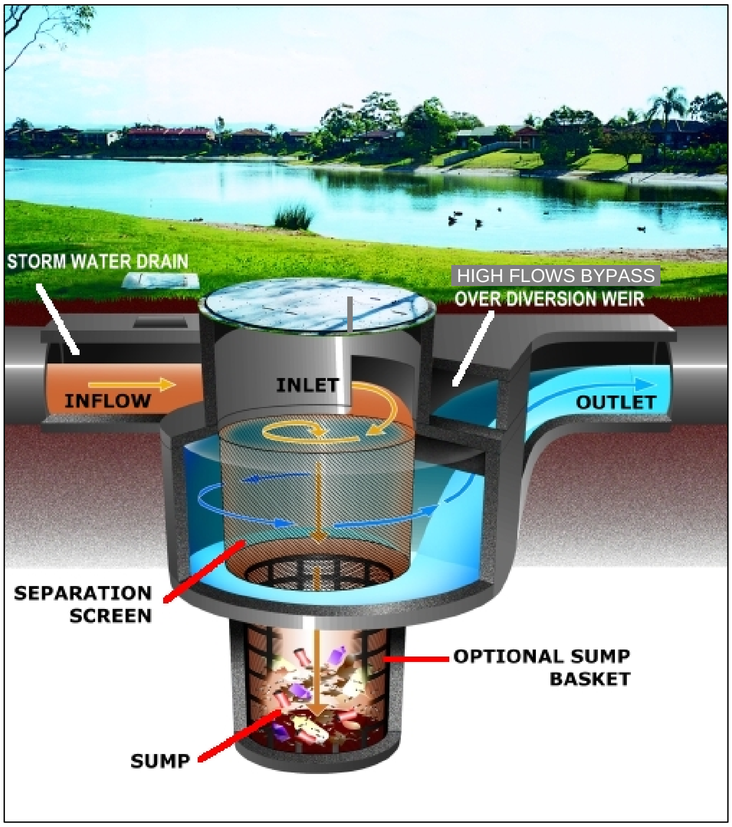

Figure 3.5 CDS® Storm Water Treatment Unit

3.6.2 General Configuration and Treatment Capacities

The CDS® unit consists of a single manhole and is manufactured as a precast online or offline unit, or cast-in-place. The diameter of the precast system ranges from 4.8 ft to 17.5 ft. The cast-in-place diameters range from 25.5 ft to 41 ft. The depth of each system will vary with site-specific constraints. The precast online treatment capacities range from 0.7 cfs to 6.0 cfs, the precast offline treatment capacities range from 2.0 cfs to 64.0 cfs, and the cast-in-place treatment capacities range from 148.0 cfs to 300.0 cfs. The hydraulic capacity of each system will also vary with each site. A total of 27 models are available.

3.6.3 Maintenance Schedule

The frequency of cleaning depends upon the generation of trash, debris and sediments in each application. Cleanout and preventative maintenance schedules will be determined based on operating experience unless precise pollutant loadings are known. The unit should be inspected periodically to assure that the system can treat the anticipated runoff. To maintain proper performance of the system, the company recommends cleaning the sump seasonally four times per year and inspecting the screen annually. The sump should be cleaned when it is 85% full or if floatables exceed 2 ft thickness.

3.6.4 Cost Information and Installation Status

The cost of a CDS® unit ranges from $6,900 to $128,000 (64 cfs unit), with installation costs from $2,400 to $115,000 (offline unit, includes diversion structure). Over 1,900 units are installed nationwide. The Texas Department of Transportation (TxDOT) is considering the installation of two units for applications in the Houston and Rockwall districts. Other state departments of transportation currently using one or more CDS® units include California, Florida, Minnesota, Nevada, New York, North Carolina, Oregon, and Virginia (Thomas Fletcher, personal communication, May 18, 2004).

3.6.5 Patented Component of System

The CDS® Storm water Treatment Unit is patented under the US patent numbers 6,511,595 B2 and 5,788,848. Claims made under the two patents are:

- a cylindrical separation panel surrounds an interior space and is oriented so as to have a generally upright axis

- the separation panel has a plurality of vertically and horizontally spaced openings which are adapted to remove solid material larger than a predetermined size from liquid passing through the separation panel
- a chamber member surrounds the separation panel and provides a chamber portion into which the liquid passes after passing through the separation panel
- an inlet through which the liquid stream is delivered to the interior space and which is arranged such that the liquid circulates about the vertical axis so as to pass the separation panel
- the panel has a plurality of vertically and horizontally spaced deflective segments adjacent the openings and which project inwardly towards the interior space to inhibit particulate matter of at least a predetermined size from blocking the openings by the openings being positioned behind the deflective segments relative to the flow of liquid there passed
- a receptacle, positioned below the separation panel, which receives particulate matter removed from the stream by the separation panel
- the system inlet and outlet are positioned at substantially the same height and are substantially aligned

3.7 CrystalStream^{TM} Technologies

3.7.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The CrystalStream^{TM} Technologies storm water treatment device consists of a rectangular vault with a mesh basket positioned at the inlet, a series of baffles throughout the system, and a filter through which the effluent must pass before it is discharged (Figure 3.6). The vault remains full of water at all times. During a storm event, incoming storm water flows through a fine meshed trash basket in which floating debris and vegetative matter are removed and retained. Holding the debris above the permanent pool level minimizes the possibility of it becoming water-logged or decomposed. The water then flows around baffles that reduce velocity and distribute flow to ensure that oil rises to the top and remains in the first part of the system. Towards the rear of the system, a large baffle spans the width of the vault and is secured to the top, leaving a few inches of clearance at the bottom of the vault to allow clean water to flow underneath and into the back chamber. As the water rises out of the unit in the back chamber it passes through a 3/4 inch coconut fiber filter, designed to remove smaller floating or suspended materials. Other elements, such as absorbents, flocculants, or charcoal canisters, can be added to target specific pollutants.

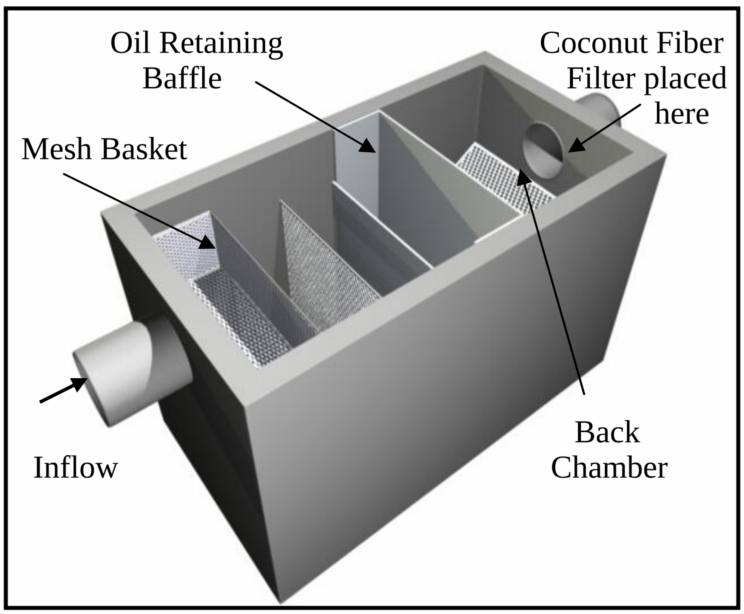

Figure 3.6 CrystalStream^{TM} Technologies

3.7.2 General Configuration and Treatment Capacities

The CrystalStream^{TM} Technologies storm water treatment system consists of a rectangular vault, an inlet and an outlet mesh basket, and a series of baffles placed in the middle to direct flow and retain debris and oil/grease. The minimum model size is 5 ft x 6 ft and the maximum model size is 8 ft x 14 ft. The depth and overall dimensions are adjustable, depending on site-specific conditions. Treatment capacities range from 1.2 cfs to 7.2 cfs with six models available. Hydraulic capacities range from 6.0 cfs to 36.0 cfs. These systems are designed to meet local water quality regulations, and as such these flow rates are national averages estimated for each model size.

3.7.3 MAINTENANCE SCHEDULE

Maintenance is performed on an as-needed basis, usually every three months, through a locked access lid on top of the device. It is recommended that the system be cleaned out at most every 6 months. Cleaning out the system consists of removing floating debris from the trash basket, pumping out sediment from the bottom of the device, and pumping oil out of the storage reservoir.

3.7.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a CrystalStream™ Technologies storm water treatment device ranges from $9,000 to $20,000, and installation costs typically are less than $1,500. Over 400 units are currently installed, and most are used for residential purposes such as subdivisions. The departments of transportation of North and South Carolina use this product.

3.7.5 PATENTED COMPONENT OF SYSTEM

This product is currently patent pending.

3.8 Downstream Defender®

3.8.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The Downstream Defender® is a hydrodynamic vortex separator that removes settleable solids (grits and silts) and oils from urban runoff, including that from roads, motorways and construction sites. The device consists of a concrete chamber with internal components manufactured from a co-polymer polypropylene material or grade 304 stainless steel (Figure 3.7). The runoff enters the unit and is directed downwards around the periphery an inner cylindrical chamber, inducing a rotational flow. This flow creates a flow pattern which encourages solids separation and draws the settleable solids down into the sediment storage chamber, while the floatables are directed to the top of the unit. The treated effluent is passed to the outlet via the vertical central shaft which also provides access to the sediment storage chamber. This BMP contains a permanent pool (Hydro International Storm Water Products – Downstream Defender, webpage).

3.8.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The Downstream Defender® consists of one circular manhole vault, ranging in inner diameter from 4 ft to 10 ft. The minimum depth of the system is 8 ft and the maximum depth is 15 ft. This product is designed to treat flows ranging from 3.0 cfs to 25.0 cfs, with four flow size models offered. The hydraulic flow rates are the same as the treatment flow rates.

3.8.3 MAINTENANCE SCHEDULE

Vacuum procedures are used to remove floatables and sediments from the unit. This BMP typically does not have to be completely dewatered, which minimizes disposal costs. Quarterly observations are recommended during the first year to determine the frequency of inspection. The units should be cleaned out at least once a year.

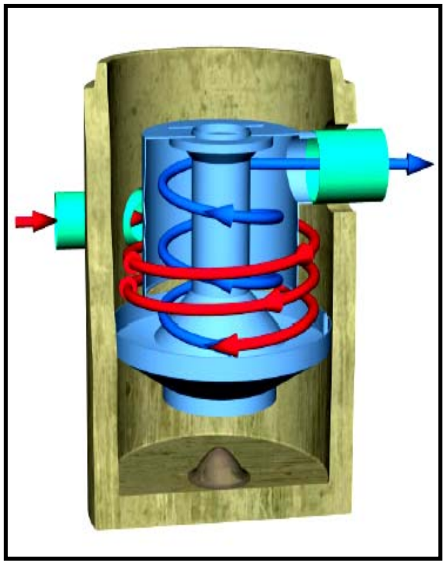

Figure 3.7a

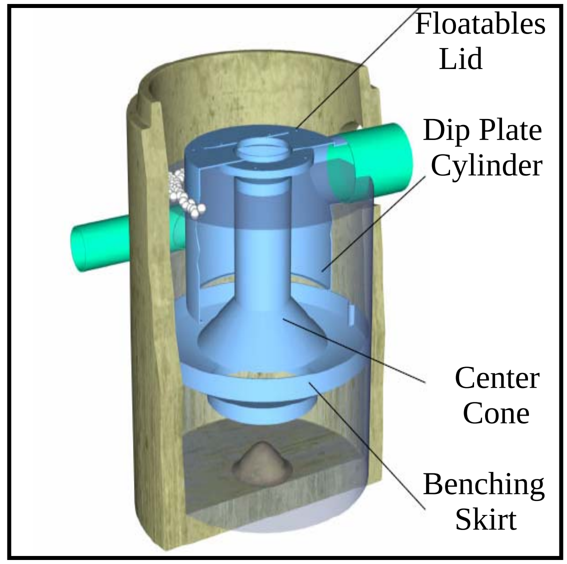

Figure 3.7b

Figure 3.7 Downstream Defender® Flow Path (fig. 3.7a) and Internal Components (fig 3.7b)

3.8.4 Cost Information and Installation Status

The cost of the Downstream Defender® ranges from $10,200 to $38,000 and installation costs typically are 50% to 75% of the product price. Currently, over 1,000 units are installed nationwide and are located primarily in the states of New Hampshire, Maine, Vermont, Connecticut, Rhode Island, Massachusetts, New York, New Jersey, Minnesota, Michigan, Virginia, Oregon and Washington.

3.8.5 Patented Component of System

A number of international patents and one US patent are held by the Downstream Defender®. The US patent number is 5,188,238 and claims the following:

- A separator comprising:

- a vessel having a cylindrical outer wall and base at one end
- a conical body which is provided within the vessel and which defines with the base an annular opening spaced from the outer wall, the lower peripheral edge of the conical body terminating at a position approximately halfway between the central axis of the vessel and the outer wall
- an annular dip plate, disposed in an upper region of the vessel, extending downwardly towards the base and spaced from the outer wall of the vessel, for stabilizing flow patterns in the vessel
- an inlet for introducing the liquid carrying the particulate material into the vessel
- an axially unobstructed outlet in an upper region of the vessel interiorly of the annular dip plate for removing from the vessel liquid carrying a component of the particulate material having a settlement velocity below a predetermined level
- a solids collection region centrally disposed on the base for collecting particulate material having a settlement velocity above a predetermined level
- a means for promoting a rotational movement of liquid and suspended particulate material within the vessel, the arrangement of the vessel being such that liquid flows upwardly to the top of the vessel towards the outlet in a substantially axially direction

3.9 ecoStorm™

3.9.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The ecoStorm™ consists of 2 circular concentric precast structures: an outer structure forms the swirl-chamber, the inner cylinder serves as a floatables collection chamber and outlet chamber (Figure 3.8). The inlet pipe has a deflection bend of 90 degrees which initiates the counterclockwise, circular flow of the storm water. The circular flow pattern extends the detention time of the storm water before it flows to the weir opening and proceeds to the equalization chamber. Floating pollutants such as oil, litter and organics are pushed through the weir into the floatable containment chamber, or inner cylinder (ecoStorm: Working Principle, webpage).

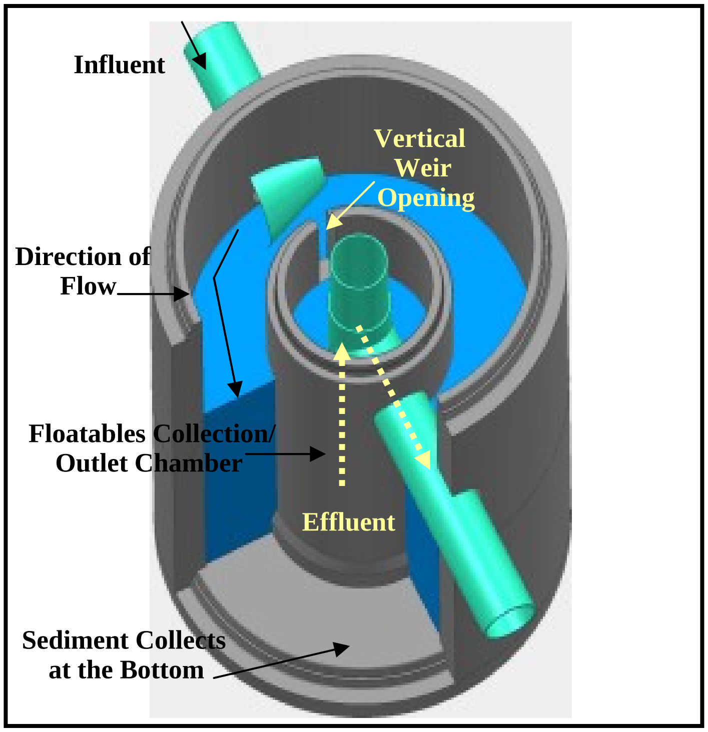

Figure 3.8 ecoStorm™ Schematic

3.9.2 General Configuration and Treatment Capacities

The ecoStorm™ consists of a single circular manhole vault that ranges in size from 6 ft to 12 ft in outer diameter and has a depth of 10 ft. This BMP is designed to treat water flows ranging from 2.0 cfs to 7.0 cfs, and has a hydraulic capacity range of 8.0 cfs to 28.0 cfs. Five flow size models are available.

3.9.3 Maintenance Schedule

The frequency of clean-out is based on site loading, periodic monitoring and measurements of captured pollutant levels in the sediment and floatable containment chambers.

3.9.4 Cost Information and Installation Status

The cost of the ecoStorm™ ranges from $7,500 to $15,000. Installation costs were not given. Over 90 ecoStorms™ been installed nationwide, and approximately ten percent of the installations are department of transportation projects.

3.9.5 Patented Component of System

The ecoStorm™ is currently patent pending.

3.10 Stormceptor®

3.10.1 Description of Treatment Technology

The Stormceptor® is comprised of a round precast concrete tank and fiberglass partition and replaces a maintenance hole in the storm sewer (Figure 3.9). Under normal operating conditions, storm water flows into the upper bypass chamber and is diverted down a pipe into the treatment chamber. Fine sediment and grit settle to the floor of the chamber, while oil and floatables rise and become trapped underneath the fiberglass insert. During periods of intense rain when the treatment chamber is full, influent water flows over the bypass chamber and through the outlet (Stormceptor Single/Multi Inlet, webpage).

3.10.2 General Configuration and Treatment Capacities

The Stormceptor® consists of a single circular manhole, ranging in diameter from 4 ft to 12 ft with a depth ranging from 5.0 ft to 15.5 ft.

Treatment capacities range from 0.28 cfs to 2.4 cfs. Hydraulic capacities can be calculated based on the available height over the weir and the storm drain. Nine flow size models are available.

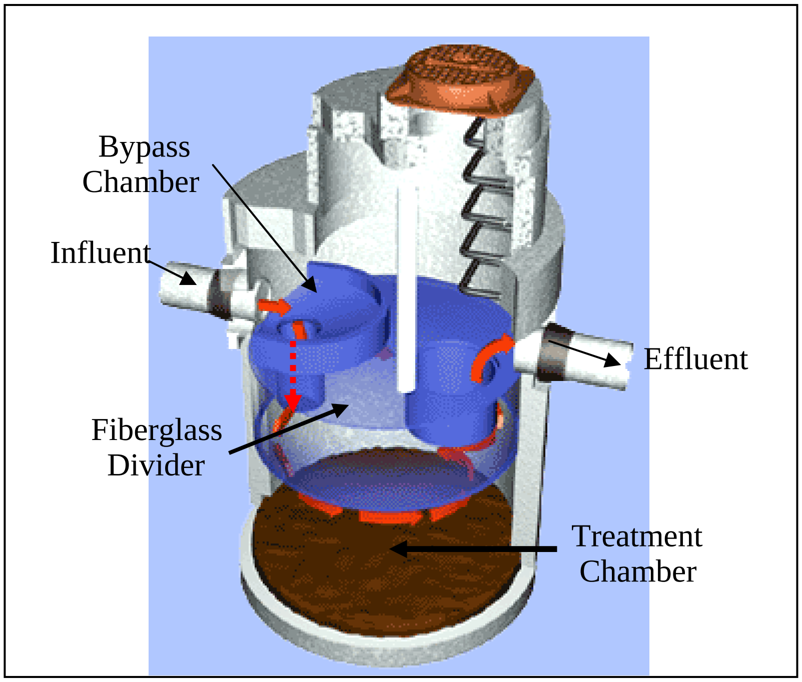

Figure 3.9 Stormceptor® Schematic

3.10.3 Maintenance Schedule

It is recommended that inspection of the system be performed frequently during the first year to establish the maintenance schedule. Approximately 15% of the Stormceptor® total sediment capacity will be reduced each year based on the maximum impervious drainage areas. Removal of the sediment is recommended when the depth is approximately 15% of the total sediment capacity. Maintenance is performed using a vacuum truck. Inspections can be made using a dipstick tube to determine oil accumulation and a dipstick tube with a ball valve to determine sediment depth.

3.10.4 COST INFORMATION AND INSTALLATION STATUS

Stormceptors® range in price from $4,500 to $65,000 and installation costs typically are one-third of the capital cost. Over 11,500 units have been installed nationwide, including 12 units that are TxDOT projects. 50 units have been installed as department of transportation projects in the following states: Ohio, Connecticut, Washington, Texas, Oregon, and Massachusetts.

3.10.5 PATENTED COMPONENT OF SYSTEM

Six U.S. patents are held by Stormceptor Corporation. The numbers are 4,985,148; 5,725,760; 5,498,331; 5,849,181; 5,753,115 and 6,068,765. The patent number that describes the Stormceptor® is US 6,068,765. The claims are:

- a separator tank comprising:
  - a divider dividing the tank into a treatment portion and a bypass portion, the

    divider comprising:
    - a first opening proximal to the inlet and enabling communication between the bypass portion and the treatment portion
    - a second opening proximal to the outlet and enabling communication between the treatment portion and the bypass portion
    - a weir disposed between the first opening and the second opening and operative to create a hydraulic head between the first opening and the second opening
    - a drop pipe having a first end and a second end, the first end of the drop pipe having a size and configuration for forming a friction fit with said first opening, the second end of the drop pipe comprising a T-shaped configuration, the T-shaped configuration being sized to fit through the first opening

- an orifice plate sized to cover the first opening, the orifice plate having a central opening sized appropriately for the environmental conditions within which the separator tank will be used

- the first opening is oval
- the drop pipe comprises an elongated tapered position extending between the first end and the second end
- the drop pipe is removable
- the second end of the drop pipe comprises a handle connected to the bottom of the T-shaped configuration, said handle enabling the drop pipe to be removed from the bypass side of the divider
- the inlet is located in a top wall of the tank (i.e. grate inlet)
- the inlet is located in a side wall of the tank (i.e. pipe inlet)
- the separator tank further comprises:
    - a drop pipe portion integral with the first opening of the divider and having a distal end, where in the first end of the drop pipe has a size and configuration suitable for forming a friction fit with the distal end of the drop pipe portion
    - a riser pipe portion integral with the second opening of the divider
    - a riser pipe having a first end and a second end, the first end of the riser pipe sized for connection to the second opening, the second end of the riser pipe being sized to fit through the second opening

3.11 Stormwater Management Inc. – StormFilter®

3.11.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The StormFilter® consists of a concrete rectangular vault with three chambers (Figure 3.11). The first chamber allows for settling of large particles and spreads the flow evenly into the second chamber, or filtration bay. The filtration bay contains media-filled cartridges that treat the polluted storm water.

The last chamber collects the effluent from the cartridges and directs the water to the outlet pipe.

The StormFilter® works by first introducing storm water into the pretreatment chamber where large particulates and floatables are detained. The water then flows over a weir into the filtration bay and fills the vault containing the media-filled cartridges (See Figure 3.10). Each cartridge treats a maximum of 0.033 cfs, and the number of cartridges needed is determined by the characteristics of the runoff. The cartridges used in the StormFilter® are the same as those used in the StormScreen™ (Section 3.13).

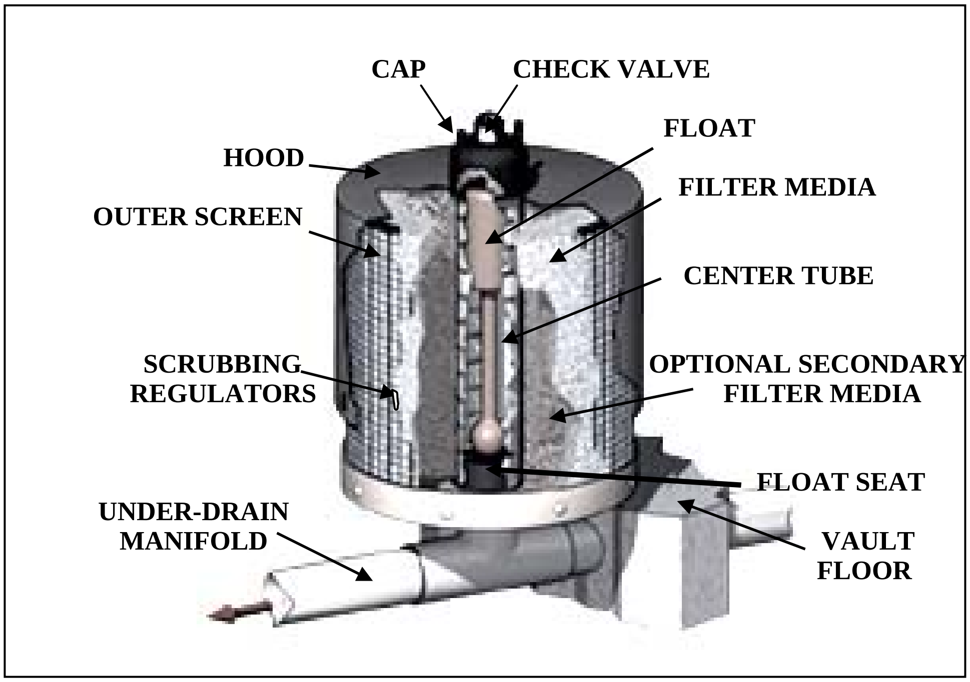

Figure 3.10 StormFilter® Treatment Cartridge

The filtration cartridge is a cylindrical device that consists of a central tube that houses a float, a check valve at the top of the cylinder that allows air to escape, filtration media that targets specific pollutants, and an underdrain pipe that carries the treated water to the third chamber where it is discharged. As storm water enters the filtration bay, it flows under the hood of each cartridge, through the filtration media, and into the center tube. The water level in each cartridge rises with the water level of the vault, forcing the float in each cartridge to rise as well. The upward motion of the float draws air from the filtration media out of the check valve located at the top of the cartridge, essentially creating a siphon through the center tube. The siphon draws in more water from the vault and through the filtration media. The treated water flows down the center tube, through the opening in the float seat, and into the under-drain manifold. Once the water level in the filtration bay drops below the scrubbing regulator openings, air enters the cartridge and the siphon breaks. The float drops back down onto the float seat and creates only a partial seal so treated water can still drain from the cartridge into the under-drain manifold. The air bubbles flow up through the filtration media and cause accumulated sediment to fall to the vault floor. The filtration bay is designed to treat and release all water; approximately 1 inch of water remains in the bay between storms.

The different types of filter media include perlite, CSF® leaf media, zeolite, iron infused, granular activated carbon (GAC), and pleated fabric. These materials can be used in any combination to remove sediments, trash, TSS, oil and grease, soluble metals, total nitrogen, phosphorus and other organic substances.

3.11.2 General Configuration and Treatment Capacities

The StormFilter® is offered in four different configurations: cast-in-place, precast, linear, and catch basin. The precast, linear and catch basin models use pre-manufactured vaults. The cast-in-place units are customized for larger flows and may be either uncovered or covered underground units.

The precast unit has a treatment capacity range of 0.033 cfs to 4.22 cfs. Its dimensions range from 7 ft x 9 ft x 4.5 ft (1 cartridge) to 10 ft x 64 ft x 18 ft (128 cartridges). The linear unit has a treatment capacity range of 0.033 cfs to 0.27 cfs. Its dimensions range from 3 ft x 10 ft x 3.5 ft (1 cartridge) to 3 ft x 20 ft x 5.5 ft (8 cartridges). The catch basin unit has a treatment capacity range of 0.033 cfs to 0.13 cfs. Its dimensions range from 4.75 ft x 2.42 ft x 2.33 ft (1 cartridge) to 10.66 ft x 2.42 ft x 3.33 ft (4 cartridges). The cast-in-place unit has a treatment capacity range of 0.8 cfs to greater than 8.0 cfs. Its dimensions range from 12 ft x 41 ft x 6 ft (24 cartridges) 21.5 ft x 85 ft x open to design (320 cartridges). All dimensions stated above are overall footprint dimensions.

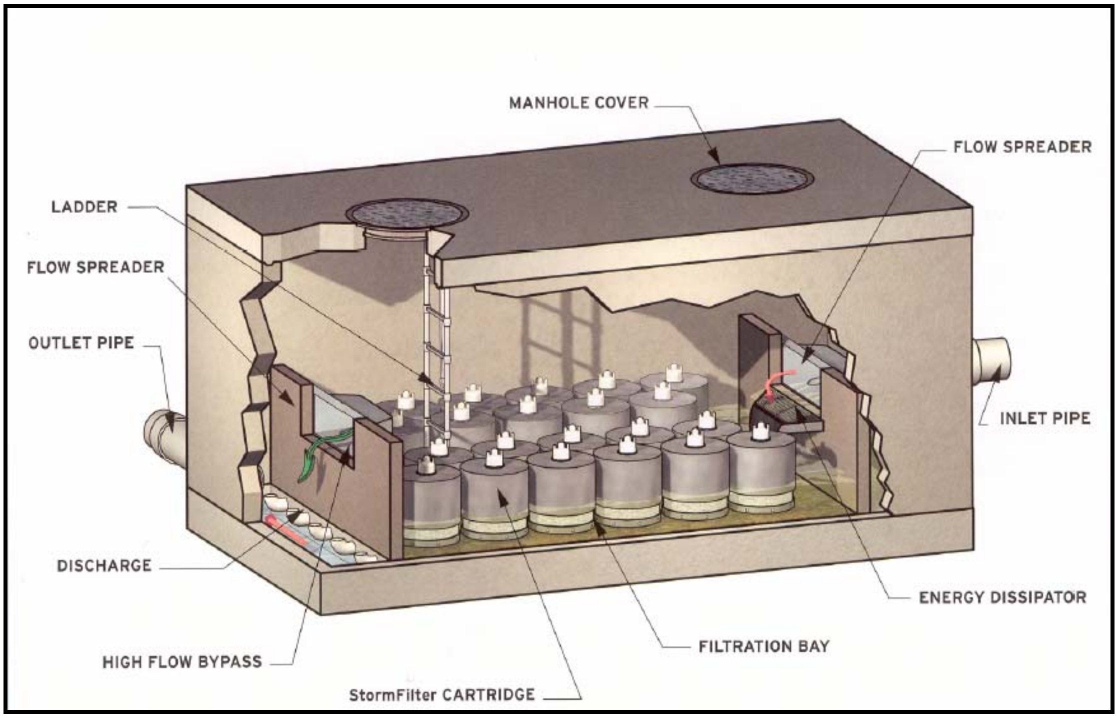

Figure 3.11 StormFilter® Schematic

3.11.3 MAINTENANCE SCHEDULE

Maintenance is recommended once every one to two years, depending on the amount of rainfall and pollutant loading conditions. Complete StormFilter® maintenance is defined by the company as “removing and disposing of the accumulated debris, sediments and other target pollutants from the unit as well as removing and disposing of the spent media from the used cartridges and exchanging them for new cartridges." Disposal of the accumulated pollutants and spent media is typically sent to a locally permitted landfill while the empty cartridges are sent back to the manufacturer and recycled. Stormwater Management provides maintenance services as an option to all StormFilter® owners for a fee (Stormwater Management Product Costs and Maintenance).

3.11.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a StormFilter® ranges from $4,000 to $350,000 and installation costs average 20 percent of the capital cost. More than 2,500 units have been installed nationwide as of June 2004.

3.11.5 PATENTED COMPONENT OF SYSTEM

Four U.S. patents are held by Stormwater Management, Inc and describe the components of the StormFilter® system. The patent numbers are 5,624,576; 5,707,527; 6,027,639 and 6,649,048 B2. Patent number 5,624,576 describes the type of pellet materials that may be used the StormFilter® cartridges. Patent number 5,707,527 was issued in January 1998 and describes the filtration technology and how the water flows through the system. Patent number 6,027,639 was issued in February 2000 and describes the filtration technology in greater detail than in the previous patent. Patent number 6,649,048 B2 was issued in November 2003 and is the most up-to-date version of the filter design. This patent addresses and fixes some of the flaws in the patent number 6,027,639 filter design.

The patent number 6,649,048 B2 claims are:

- A filter assembly for removing pollutants from storm water, comprising:
    - a cylindrical hood having a lower edge, the hood incorporating a horizontally-aligned array of voids near the lower edge

- a cylindrical drainage space disposed concentrically within the hood
- a filter, located between the hood and the drainage space, and in fluid communication with the drainage space
- an inlet configured below the hood for incoming storm water to be filtered
- a check valve in the hood, configured to permit air to escape the filter assembly in response to rising storm water within the hood, but to prevent air from entering the filter assembly

- The filter assembly is configured such that a siphon can be established that draws additional storm water through the filter and into the drainage space, the siphon continuing until air entering the hood via the array of voids disrupts the siphon
- The filter surrounds the drainage space in an annular fashion
- The filter comprises a cylindrical screen that physically filters the storm water
- The filter further comprises a granular filter medium selected to remove contaminants by physical filtration, chemical action, biological action, of by a combination thereof
- The filter further comprises a fabric filter
- Each void in the filtration system is vertically elongate with rounded edges and does not overlap the lower edge of the hood
- The filter assembly, further comprising:
  - a drain manifold that is in fluid communication with the drainage space
  - a drain valve located between the drainage space and the drain manifold, the drain valve configured to partially or completely restrict water flow from the drainage space into the drain manifold and thereby moderate the water flow through the filter
  - a float assembly comprising a buoyant float within the drainage space and a linkage connecting the float to the drain valve, the float assembly configured so that when the drainage space fills with water to a determined depth, the float assembly rises and fully opens the drain valve

to permit increased water flow from the drainage space into the drain manifold

- The filter assembly, where the increased water flow from the drainage space into the drain manifold establishes a siphon effect that draws additional storm water through the filter and into the drainage space, the siphon effect continuing until air entering the hood via the array of voids disrupts the siphon effect, lowers the float assembly, and restricts water flow from the drainage space into the drain manifold
- The filter assembly, where air entering the hood via the array of voids creates turbulence in a region between the hood and the filter, dislodging particulate matter that has accumulated on the filter

Patent number 5,707,527 claims the following about the StormFilter® vault and filter:

- A method of treating storm water runoff, comprising:
    - allowing the runoff water to infiltrate through a water-permeable outer surrounding wall of a basket containing a bed comprising material able to remove pollutants from the storm water
    - controlling a flow rate of the storm water through the basket to a lower rate than an initial infiltration capacity of the bed, the controlled lower rate allowing sufficient contact between the storm water runoff and the bed to remove a substantial proportion of at least one pollutant from the storm water runoff
    - allowing the storm water to flow horizontally through the bed, the bed disposed in a space between the water-permeable outer wall of the basket and an inner water-permeable wall of the basket
- The method wherein the controlling of flow rate is by a flow restrictor in a water outlet of the basket downstream of the bed

- The method wherein the controlling of flow rate is by an orifice plate having an orifice of predetermined diameter, the orifice plate located in a treated water outlet conduit of the basket, the outlet downstream of the bed

3.12 Stormwater Management Inc. – StormGate Separator^{TM}

3.12.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The StormGate Separator^{TM} is a rectangular vault that consists of four chambers (Figure 3.12). Storm water runoff enters the first chamber and flows through next two in series. The plug flow-like flow pattern lengthens the residence time of the storm water, allowing particulates more time to settle out. Water leaves the third chamber through an exit baffle with an opening located on the bottom of the baffle. The exit baffle is placed so the opening is submerged and floatables cannot leave the system. Water enters the fourth chamber and is discharged through a pipe.

The StormGate Separator^{TM} maintains a permanent pool throughout the vault. The first chamber contains an overflow weir that directs high flows into the fourth chamber and out of the system quickly during storm events when the hydraulic flow capacity of the first chamber is exceeded. Floatables are contained in the first three chambers.

3.12.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The StormGate Separator^{TM} is a rectangular vault that consists of four chambers. The dimensions range from 6 ft x 10 ft x 5.5 ft to 8 ft x 18 ft x 6.5 ft. Treatment capacities are based on an estimated 80% removal rate of TSS and range from 0.86 cfs to 2.89 cfs. Hydraulic capacities range from 1.68 cfs to 4.03 cfs. Five flow size models are available.

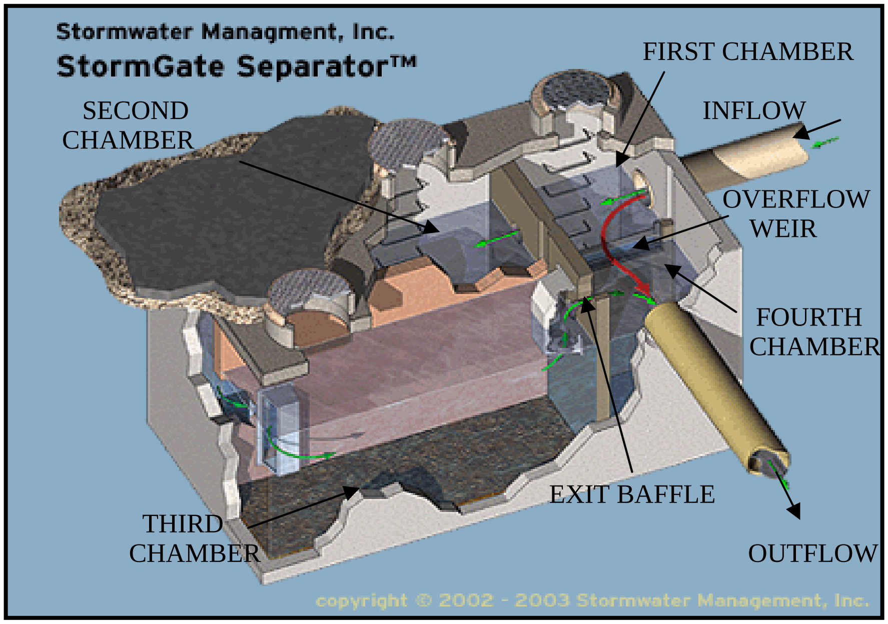

Figure 3.12 StormGate Separator^{TM}

3.12.3 MAINTENANCE SCHEDULE

Maintenance is recommended once every four to six months, depending on the amount of rainfall and pollutant loading conditions. Pollutant loading conditions include the type of sediments (gravel, fine silt, etc) and pollutants (metals, nutrients, TSS, etc) that will be entering the system. The manufacturer recommends the StormGate Separator^{TM} be inspected after major storm events and maintenance provided as needed. Complete maintenance includes removing and disposing of the accumulated debris and sediment from the unit using a shop vacuum or vactor truck. Disposal of the accumulated pollutants are typically sent to a locally permitted landfill.

3.12.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a StormGate Separator^{TM} ranges from \$9,000 to \$40,000 per unit. Installation costs are generally 20% of the capital costs. As of June 2004, 100 units have been installed in 15 states. 6 units are installed in Texas.

3.12.5 PATENTED COMPONENT OF SYSTEM

No patents are held for this product.

3.13 Stormwater Management Inc. – StormScreen™

3.13.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The StormScreen™ is a rectangular vault consisting of two chambers. The first chamber, or the inlet bay, contains cylindrical cartridges on a raised bed that work using the same principle as the cartridges used in the StormFilter® (See Section 3.11.1 for a description of how the cartridge works). A permanent pool is maintained in the first section of the inlet bay, so influent water must rise to the top of the raised bed before the cartridges will be activated. The second chamber, or the outlet bay, collects the treated effluent from the cartridges via an elevated discharge flume located below the raised bed and discharges it through a pipe (Figure 3.13). All captured solids are collected in a sump located below the elevated discharge flume. The sump may be equipped with a dewatering device to aid in vector control.

The system operates in the same basic way as the StormFilter®. Storm water enters the first chamber, fills the vault, activates the cartridges, and is discharged to the elevated discharge flume. However, the StormScreen™ cartridge has an operating flow rate of 225 gpm (0.5 cfs) and utilizes an aluminum screen as opposed to specialized media to treat the water. Therefore, the StormScreen™ does not provide as high a level of treatment as the StormFilter®; the StormScreen™ system is designed to remove sediment, trash and debris as well as limited TSS and oils, but not soluble metals and nutrients.

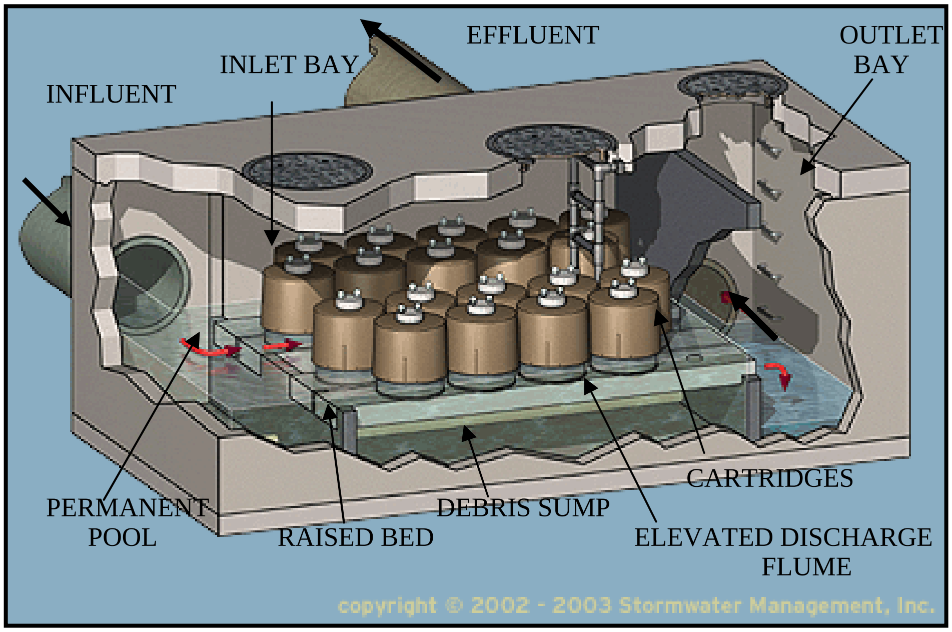

Figure 3.13 StormScreen™

3.13.2 General Configuration and Treatment Capacities

The StormScreen™ consists of cylindrical cartridges placed in a rectangular vault. This treatment system is offered either as a prefabricated catchbasin or cast-in-place. The precast version treats flows ranging from 0.5 cfs to 10.0 cfs and has a minimum dimension of 6 ft x 12 ft x 5 ft. This design contains up to eight cartridges. The maximum dimension is 8 ft x 16 ft x 20 ft and can hold 9 to 20 cartridges. The cast-in-place version can treat flows greater than 10.0 cfs. Dimensions will vary based on site-specific constraints.

3.13.3 Maintenance Schedule

Maintenance is recommended once every one to two years, based on the amount of rainfall and pollutant loading conditions. Complete StormScreen™ maintenance consists of removing and disposing the accumulated debris and sediments from the unit as well as cleaning or replacing the used screen cartridges and exchanging them for new cartridges. Disposal of the accumulated pollutants and spent media is typically sent to a locally permitted landfill (Storm water Management Product Costs and Maintenance).

3.13.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a StormScreen™ ranges from $7,000 to $150,000 and installation costs are approximately 20% of the capital cost. 27 units have been installed nationwide with 2 of those units being in Texas, as of June 2004.

3.13.5 PATENTED COMPONENT OF SYSTEM

The same treatment technology is used for both the StormFilter® and the StormScreen™ filtration mechanisms, so patent numbers and descriptions are the same.

3.14 StormTreat™

3.14.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The StormTreat™ consists of two circular chambers; a closed inner chamber that detains sediments and floatables, and an open outer chamber that is filled with wetland vegetation supported in gravel (Figure 3.14). Pretreatment of the storm water is necessary, as the StormTreat™ is not equipped to handle large floatables such as debris and trash.

Storm water enters the system by flowing through a pipe from the pretreatment area into the inner chamber and through a grit-filter bag that traps the larger floatables and particulates. Next, the storm water flows through a series of sedimentation chambers that contain skimmers. The skimmers continually draw water from just below the surface and transport the water via a tube to the next chamber. This setup prevents floatables such as oil from being transported to subsequent chambers and allows particulates time to settle. After flowing through the last sedimentation chamber, the treated water is transported to the outer chamber and released into the gravel substrate through corrugated pipe. The water then flows downward through the gravel which serves as a substrate for a constructed wetland. Larger-diameter particulates are trapped inside the sedimentation chambers while smaller (silt and clay-sized) particles are filtered in the gravel wetland substrate. If the smaller particles are predominantly organic in composition, they can be decomposed by bacteria which reside within the wetland plant root zone.

The treated storm water may then be infiltrated into 3/4-inch stone which is used for backfill in the excavation around and under the StormTreat™ tanks. This stone is highly permeable and serves to transmit the treated water downward until it encounters the parent soils. During peak flow periods, the infiltration rate may exceed the permeability of the parent soils and the stone backfill area serves as a temporary storage reservoir (StormTreat™ System Overview). The StormTreat™ will slowly drain in 5 to 10 days.

3.14.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The StormTreat™ consists of two circular chambers; a closed inner chamber for settleables and floatables, and an open outer chamber for filtration. The system is offered in one size, 9.5' diameter by 4’ depth. The unit operates off-line and provides 7,000 gallons of storage and treatment, with a live volume of 1,490 gallons. Up to two StormTreat™ units treats one acre of impervious surface area and units may be placed in series to treat the maximum design flow. The manufacturer uses native vegetation for the wetland in the outer chamber whenever possible.

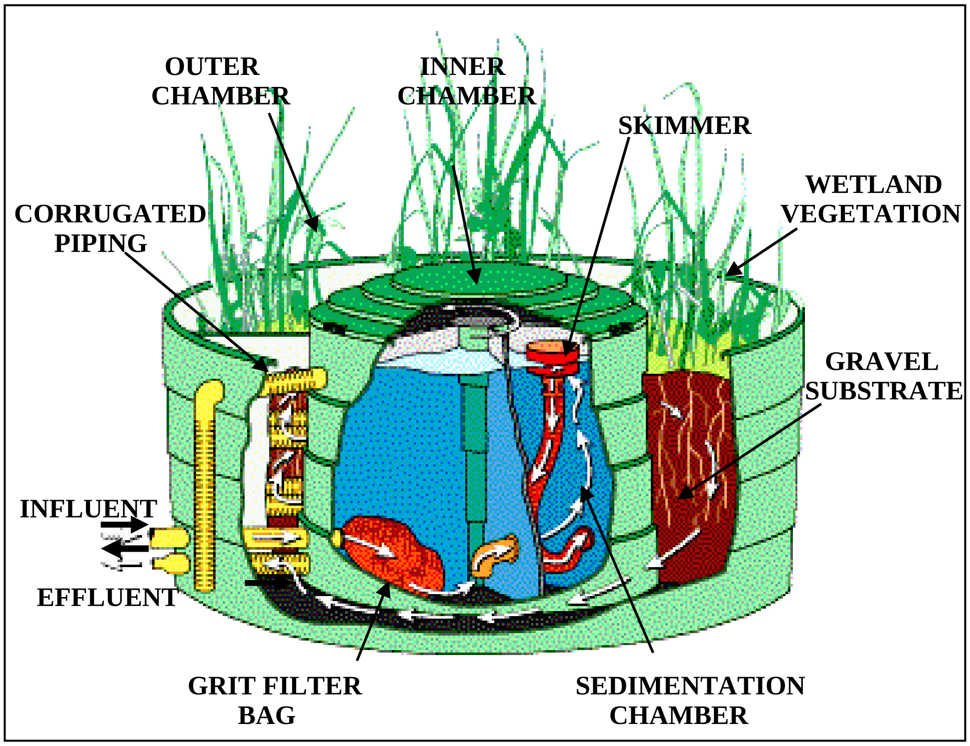

Figure 3.14 StormTreat™

3.14.3 MAINTENANCE SCHEDULE

Maintenance consists of annual inspections and removal of sediment when the depth of sediment in the sedimentation chambers reaches 6 inches. Grit filter bags should be replaced on an as-needed basis. The manufacturer suggests major suction or vacuum pumping of solids every 3 to 5 years.

3.14.4 COST INFORMATION AND INSTALLATION STATUS

The cost of one StormTreat™ is $6,700 per unit with installation costs ranging from $2,000 to $3,000. Approximately 200 units are installed in 18 states. The Massachusetts, Maine and New Hampshire Departments of Transportation have StormTreat™ systems installed for storm water projects.

3.14.5 PATENTED COMPONENT OF SYSTEM

The patent number held by the StormTreat^{TM} system is US 5,549,817. It claims the following:

- A storm water treatment apparatus comprising:
    - a lightweight watertight integrated sedimentation tank module having a central sedimentation tank with an open top within it, formed integrally with an annular perimeter basin
    - the central sedimentation tank having a removable watertight cover
    - the annular perimeter basin having an open top and a wetland formed of sand and gravel deposited within it. Included are wetland plants, having roots that extend downwardly into the sand and gravel.
    - the central sedimentation tank includes an inlet port from outside the basin for carrying storm water into the covered central sedimentation tank and having an infiltration section in the wall between it and the annular perimeter basin, the infiltration section being transmissive of water, but generally not transmissive of particulate materials, and located to pass water into the perimeter basin in the subsurface area of the wetland plant roots.
    - the central sedimentation tank being formed with a plurality of bulkheads, each extending radially from the center of the central sedimentation tank to the perimeter thereof, the bulkheads dividing the central sedimentation tank into a series of adjacent chambers. The first bulkhead being adjacent to the infiltration section and formed to be water impermeable, a second bulkhead adjacent to the inlet port being water impermeable except for an oil and grease trap which passes water into the next chambers while blocking oil and grease from passing, the first and second bulkheads forming a first chamber coupled to the inlet port, at least one additional water impermeable bulkhead forming at least one additional chamber.

- a flexible tube positioned in at least one of the additional chambers, the flexible tube having a float attached to one end for floating on the surface of any water within the chamber with an inlet opening provided in the flexible tube adjacent to the float, below the water surface. The other end of the flexible tube penetrating an adjacent wall common to the chambers and the next adjacent chambers near the bottom of the sedimentation tank, the flexible tube other end having an outlet, whereby water from the surface where the float is located passes to the next compartment near the bottom
- an outlet port located near the bottom of the annular perimeter basin, the outlet port including valve means which can be preset to control the throughput of water entering the sedimentation tank and exiting the annular perimeter basin at the outlet port

- A third bulkhead is formed with filter panels therein in the plane of the bulkhead to permit flow of water through the bulkhead while screening particulate material.
- The bulkheads divide the central sedimentation tank into at least six adjacent chambers, where at least three of the chambers include one of the flexible tubes.
- The annular perimeter basin includes a water impermeable bulkhead extending from the outer perimeter of the annular perimeter basin inwardly to the perimeter of the central sedimentation tank, the water impermeable bulkhead being positioned between the infiltration section and the inlet port.
- The infiltration section is formed of one or more perforated wall tubes positioned near the bottom of the central sedimentation tank and connected through the sedimentation tank wall between the wetlands and the central sedimentation tank, with the perforated walls lying within the wetland.
- The perforations are slots.
- The inlet port has affixed to it a rough biodegradable filter for screening solid objects from entering the central sedimentation tank.

- The float includes a ring spaced below the float and attached to it by struts, and where the flexible tube threads into the ring.
- Each of the adjacent walls penetrated by a flexible tube provide no other passageway for water from one of the chambers to the next.

3.15 Stormvault™

3.15.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The Stormvault™ is a rectangular vault that consists of three chambers and a series of weirs and baffles (Figure 3.15). The first chamber contains a baffle (the inlet baffle) that forms the back wall of the chamber. This inlet baffle is placed in front of the inlet pipe to dissipate the energy of the influent water and to collect floatable trash and debris. The influent water flows into the inlet chamber, under the baffle wall and into the settling chamber. Angled baffles are placed in series in the settling chamber to provide a storage area for settled particles and to prevent resuspension of particles. Hydrocarbon sorbent mats, which float on top of the water, may be placed in the settling chamber to absorb oils and greases. Water then flows under a trapezoidal baffle, or the exit baffle, into the third chamber. The exit baffle prevents floatables, oils and greases from leaving the system. In the third chamber, the outlet is in the form of a tee fitting connected to a pipe that is positioned vertically and is surrounded by a metal screen. The tee fitting provides two means for draining the vault; water flows through the lower end of the tee during normal storm events, and through the top end of the tee (as well as through the lower end) during high-intensity storm events when the vault is full of water. The inlet and outlet pipes are positioned directly inline, creating a permanent pool within the Stormvault™. The outlet is sized to provide a drain down time of 6 hours.

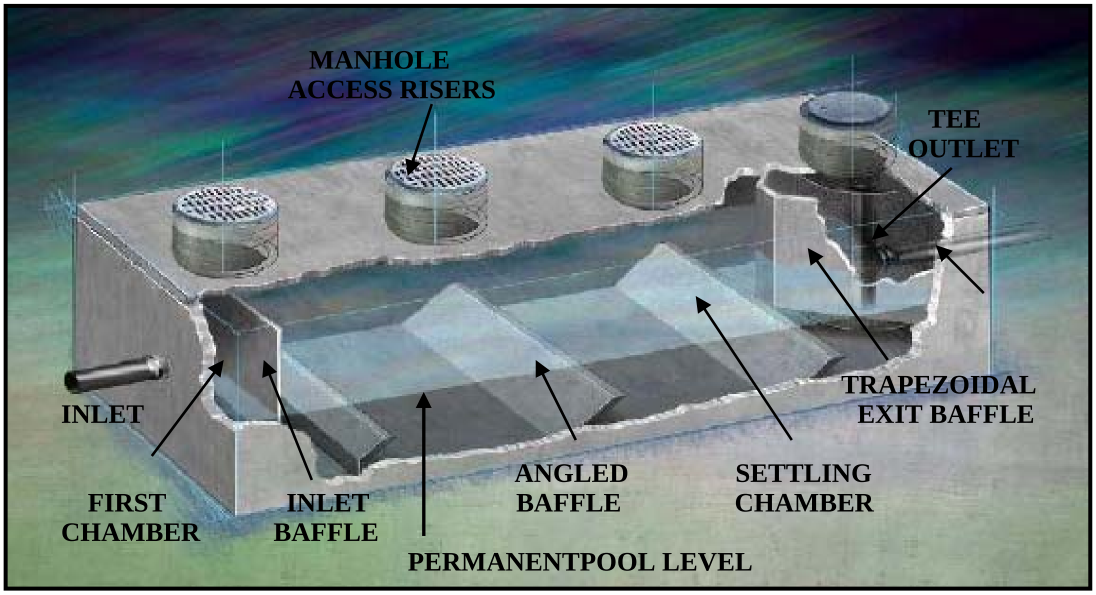

Figure 3.15 Stormvault™

3.15.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The Stormvault™ is configured as a precast rectangular vault. The manufacturer claims they do not have standard models because they base each design on site-specific constraints; however, the minimum dimensions of the Stormvault™ are 12 ft x 24 ft x 6 ft. The vault's length can be increased in 8-foot increments. The slanted bottom baffles are spaced at 8- to 16-foot intervals and are added as the vault's length is increased. Hydraulic and treatment capacities do not pertain to this system because the Stormvault™ is designed to hold storm water from an entire storm event and slowly drain down.

3.15.3 MAINTENANCE SCHEDULE

The manufacturer recommends twice yearly observation of the Stormvault™ and inspection of the hydrocarbon mats on a yearly basis. Sediment must be removed when it reaches 6 inches of depth. The mats may collect some surface sediment (mud), however, only when the mats change to a solid dark color uniformly throughout the granular medium do they need to be replaced.

3.15.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a Stormvault™ begins at $25,000 and increases with size. Installation costs vary with each site. Thirty Stormvaults™ are installed in California, Nevada, Washington, and Virginia.

3.15.5 PATENTED COMPONENT OF SYSTEM

The patent number held by the Stormvault™ system is US 6,350,374 B1. It claims the following:

- A storm water treatment apparatus comprising:
    - a concrete vault having a top, a bottom, a left side wall and a right side wall, an inlet end wall and an outlet end wall, also comprising an inlet section, an outlet section and a midsection between the inlet section and the outlet section
    - the inlet is located in the inlet section above the bottom and the outlet is located in the outlet section above the bottom, defining a permanent pool water surface elevation level
    - a first baffle is positioned in front of the inlet, extending from the permanent pool water surface elevation level to below the permanent pool water surface level, but being spaced above the bottom
    - a second baffle is placed between the first baffle and the outlet having an upstream side and a downstream side, the second baffle connected to the bottom and extending upward no higher that the permanent pool, the upstream side including at least a portion angled upward from the bottom toward the outlet

- a third baffle between the second baffle and the outlet having an upstream side and a downstream side, the third baffle connected to the bottom and extending upward no higher than the permanent pool, the upstream side of the third baffle including at least a portion angled upward from the bottom and toward the outlet
- a fourth baffle between the third baffle and the outlet, the fourth baffle extending from the top to below the permanent pool, but being spaced from the bottom
- at least four baffles positioned within the receptacle between the inlet and the outlet, with all of the baffles attached to both sides of the receptacle, with at least two baffles attached to the bottom of the receptacle and not attached to the top, at least one baffle attached to the top of the receptacle and not attached to the bottom, and at least one baffle that is not attached to the bottom and top of the receptacle
- an inlet section for receiving water, for decreasing energy of the flowing water, and for uniformly distributing water across the width of the receptacle
- an outlet section for discharging water at a controlled rate and for excluding materials more and less dense than water being discharged

- the apparatus has a volume of at least 500 cubic feet
- the angle formed between the first portion of the second baffle and the bottom of the receptacle is between about 30 and 60 degrees
- the second baffle includes a second portion, the second portion of the baffle extending from the bottom of the receptacle and forming an angle with the bottom of the receptacle, the angle being roughly 90 degrees
- the angle formed between the first portion and the second portion of the baffle is roughly 135 degrees

- the fourth baffle defines a horizontal leading edge longer than the horizontal distance between the right side wall and the left side wall along a line tangent to an upstream side of the fourth baffle
- the fourth baffle further comprises a center section and at least one outer section which extends toward the outlet from the center section
- the vault includes a plurality of mid-sections, every other mid-section including at least one additional baffle extending from the bottom of the vault
- both the angle between the receptacle bottom and the first portion of the second baffle and the angle between the bottom and the first portion of the third baffle is approximately 45 degrees
- the first baffle is spaced from the top
- additional baffles are regularly spaced at specified distances along the bottom of the midsections
- mesh screening from the bottom to the top of the apparatus is attached in a removable fashion to the outlet end wall to form a half cylinder through which any water that discharges through the opening must pass prior to discharge
- access to the inlet section, the outlet section, and all midsections is provided by manholes that are of sufficient size to allow cleaning of the vault via pump out or another vacuum removal process
- a collar of width equivalent to the diameter of the manhole opening extends down from the top of the apparatus for several inches into the apparatus for all manholes associated with midsections
- the inlet section, outlet section and midsection are separable
- the inlet section, outlet section and midsection are integral
- the outlet flow rate is less than the inlet flow rate
- the apparatus further comprises an overflow structure upstream to the inlet section
- the receptacle is rectangular

- the angle formed between all baffles between the second baffle and the fourth baffle and the bottom of the receptacle is between about 30 and 60 degrees

3.16 Suntree Technologies - Nutrient Separation Baffle Box

3.16.1 Description of Treatment Technology

The nutrient separation baffle box is a rectangular vault with a horizontal screen that extends almost the entire length of the vault to catch and retain vegetation and trash (Figure 3.16). Incoming storm water flows along the horizontal screen. Trash and debris remain in the screen and fine sediments pass through to three chambers that are located below the screen. The top of each chamber wall is level with the invert of the inlet and outlet pipes so water and sediment are retained in each chamber between storms, but vegetation that collects on the screen remains above the water level and dries out, thus inhibiting decomposition and anaerobic conditions. An oil boom is placed after the screen to absorb hydrocarbons.

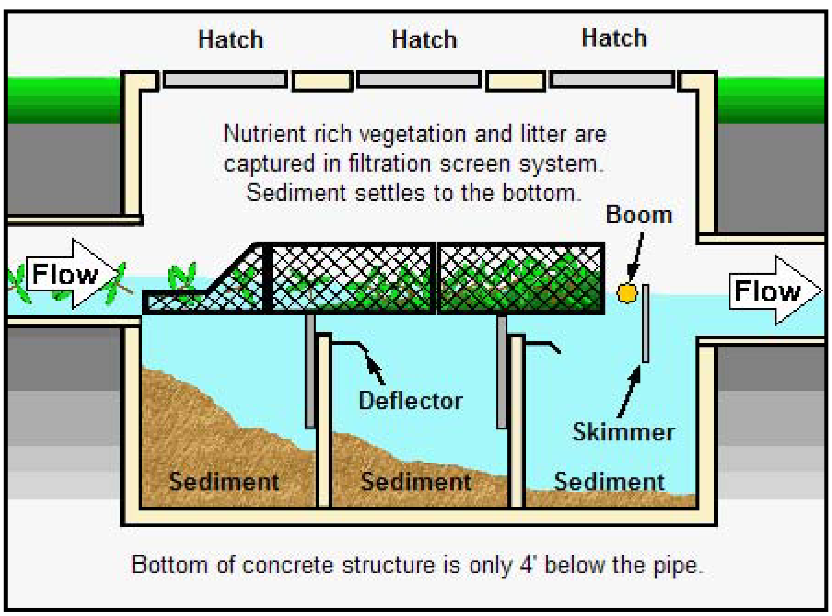

Figure 3.16 Nutrient Separation Baffle Box

3.16.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The Nutrient Separation Baffle Box consists of a rectangular vault constructed of concrete or fiberglass with three chambers. The entire flow of the storm event is treated and head loss is minimal; therefore determining the appropriate size of the Baffle Box for a project is more a function of pipe size than flow rate. Seven models are offered that treat flows ranging from 12.0 cfs to 97.2 cfs. The minimum size available is 4 ft x 8 ft x 7 ft and the maximum size is 8 ft x 14 ft x 8 ft.

3.16.3 MAINTENANCE SCHEDULE

No information was received from the manufacturer regarding maintenance. Information on the website indicates that the screen system hinges off to the side to provide access to the sediment collected in the lower chambers.

3.16.4 COST INFORMATION AND INSTALLATION STATUS

None available.

3.16.5 PATENTED COMPONENT OF SYSTEM

The system is patented but the number has not been provided by the manufacturer and sales representatives.

3.17 Vortechnics – Vortechs®

3.17.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The Vortechs® System is a rectangular vault comprised of a series of baffles and weirs (Figure 3.17). Storm water enters tangentially into a cylindrical grit chamber, which creates a vortex that forces larger particles to settle out. The effluent flows over a weir into the next chamber where an oil baffle wall retains floatables such as trash, oil and grease. The water flows under the oil baffle wall and into the next chamber where a low flow control orifice meters out the treated water. A high flow control orifice is located above the low flow orifice to allow larger volumes of water to leave the system during highly intense storm events. A permanent pool is maintained in the system.

3.17.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The Vortechs® System consists of a rectangular vault that contains a grit chamber, oil baffle wall, and flow control weirs. The flow rates treated range from 1.6 cfs to 25.0 cfs. Hydraulic capacities are the same as the treatment capacities. Nine models are available. The minimum dimensions are 3 ft x 9 ft x 7 ft and the maximum dimensions are 12 ft x 18 ft x 8 ft.

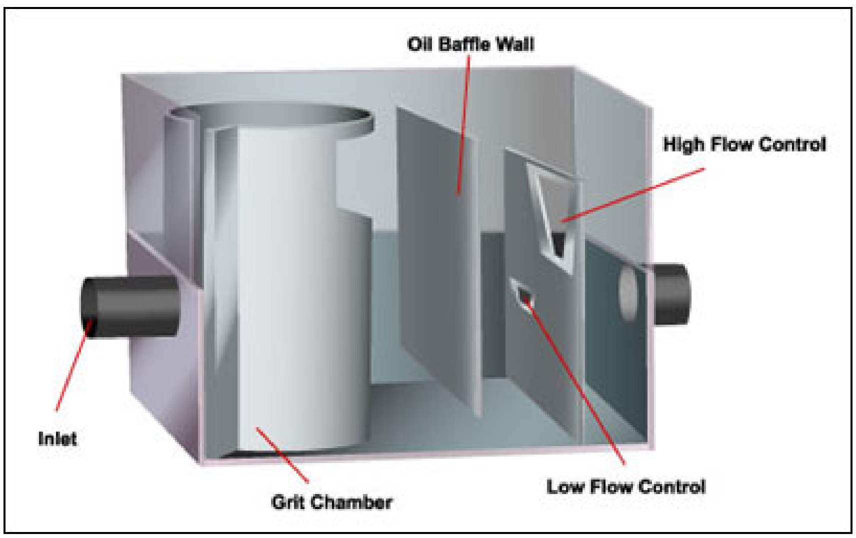

Figure 3.17 Vortechnics Vortechs® System

3.17.3 MAINTENANCE SCHEDULE

Pollutant deposition and transport may vary from year to year and quarterly inspections will help insure that systems are cleaned out at the appropriate time. The Vortechs® System is to be cleaned when inspection reveals that the tank is nearly full; specifically, when sediment depth has accumulated to within six inches of the dry-weather water level. This determination can be made by taking two measurements with a stadia rod or similar measuring device: one measurement is the distance from the manhole opening to the top of the sediment pile and the other is the distance from the manhole opening to the water surface. If the difference between the two measurements is less than six inches the system should be cleaned out (Vortechs Inspection and Maintenance, webpage).

3.17.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a Vortechs® system ranges from $10,500 to $40,000 and installation costs range from 25% to 50% of the capital cost. Currently, over 3,000 units are installed in 17 states as department of transportation projects.

3.17.5 PATENTED COMPONENT OF SYSTEM

The patent number held by Vortechs® is 5,759,415. The claims are:

- An apparatus for separating floating and non-floating particulates from drain water. The apparatus comprising:
  - a tank including inlet means for introducing the drain water into the tank and tank outlet means for discharging the drain water.
  - a first containment means for receiving the drain water and for trapping non-floating particulates under relatively higher drain water flow rates and relatively lower drain water flow rates in a manner that restricts the non-floating particulate from exiting one or more openings of the first containment means
  - a second containment means for trapping floating particulates under the relatively higher drain water flow rates in a manner that restricts the floating particulate from exiting one or more openings of the second containment means

- a means for controlling water level in the tank, where the means for controlling water level is designed to operate as a function of a flow rate of the drain water through the inlet means into the tank such that when the flow rate is relatively higher, the water level in the first containment means is greater than a level of the inlet means

- The means for controlling the water level in the tank includes a low-level outlet device and a high-level outlet device.
- The first containment means is a substantially cylindrical non-floating particulate containment chamber and the inlet means is an inlet pipe for delivering the drain water to the chamber, and where the inlet pipe is tangential to the chamber. This shall cause a swirling motion of the drain water within the containment chamber.
- The first containment means is a substantially cylindrical bulkhead section extending from the floor of the tank. One or more openings of the bulkhead section include one or more slots therein.
- One of the "one or more slots" has a top level that substantially matches a bottom level of the inlet pipe.
- No slot is directly opposite the inlet pipe.
- At least one of the "one or more slots" is oriented essentially parallel with the floor of the tank.
- The second containment means is a baffle extending from the top of the tank to a point spaced above the floor of the tank and below a low-level outlet device of the means for controlling water level.
- The means for controlling the water level in the tank includes an orifice plate having one or more apertures for discharging the drain water and means for adjusting the position of the orifice plate with respect to the position of the tank outlet pipe.
- Output receiving means including one or more distribution tubes.

- The output receiving means where at least one of the distribution tubes is perforated.
- Where each of the distribution tubes is positioned in a sand filter or peat filter bed.
- Where the output receiving means includes a controlled-outlet means for controlling direction of flow of the drain water from the tank outlet means, and a fluid-detention basin. The controlled outlet means is a one-way valve.
- A separator means for separating oil from the drain water, where the separator means is located between the low-level outlet device and the output receiving means.
- The tank outlet means is a tank outlet pipe and the means for controlling water level in the tank includes a removable screen.
- The screen includes a fine mesh section and a coarse mesh section for filtering the drain water, where the coarse mesh section is located above the fine mesh section.

3.18 Vortechnics – VortSentry™

3.18.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The VortSentry™ is a vertically cylindrical manhole (Figure 3.18). Storm water runoff enters the unit tangential to a baffle wall which creates a vortex. Settleable solids fall into the sump and are retained. Floatables such as buoyant debris and oil and grease are retained in the treatment chamber by the baffle wall. Treated water exits the treatment chamber through a flow control orifice located behind the baffle wall. A high permanent pool remains in the system because of the placement of the inlet and outlet pipes.

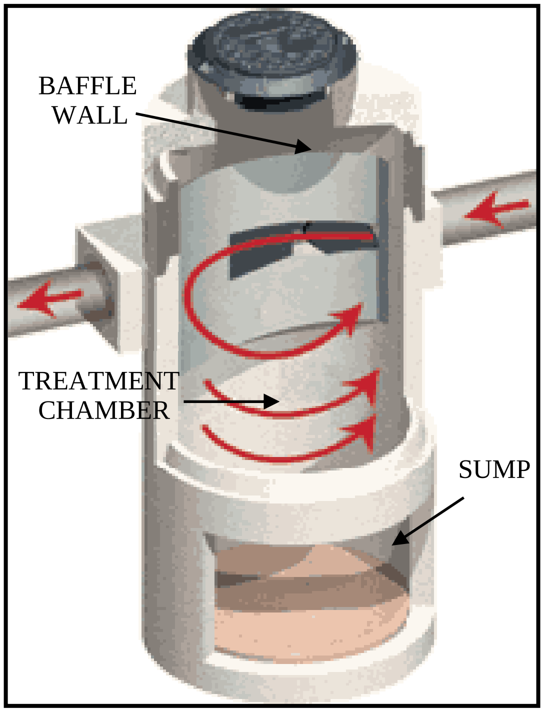

Figure 3.18 VortSentry™

3.18.2 General Configuration and Treatment Capacities

The VortSentry™ consists of a single circular manhole ranging in diameter from 3 ft to 12 ft. Depths are measured from below the invert and range from 5.4 ft to 16.5 ft. This system treats flows ranging from 0.3 cfs to 11.9 cfs. The hydraulic capacities of the system range from 1.2 cfs to 47.6 cfs. Typically, the hydraulic capacity is four times the treatment flow rate, but that can be adjusted to meet site-specific requirements. Eight models are available.

3.18.3 Maintenance Schedule

Vortechnics recommends ongoing quarterly inspections of the accumulated sediment. Pollutant deposition and transport may vary from year to year and quarterly inspections will help ensure that systems are cleaned out at the appropriate time. Inspections should be performed more often during winter months in climates where sanding operations may lead to rapid accumulations, or in equipment wash down areas. The VortSentry™ should be cleaned when inspection reveals that the sediment depth has accumulated to 3 ft in the treatment sump. This determination can be made by taking two measurements with a stadia rod or similar measuring device; one measurement from the manhole opening to the top of the sediment pile and the other from the manhole opening to the water surface. If the distance measured is less than the distance given in the following table, the VortSentry™ should be maintained to ensure effective treatment (VortSentry Maintenance).

3.18.4 COST INFORMATION AND INSTALLATION STATUS

The cost of a VortSentry™ ranges from $5,000 to $30,000 and installation costs typically are 25% to 50% of the capital cost. Currently, over 50 units are installed nationwide. The Maine department of transportation uses a VortSentry™ for at least one of its projects.

3.18.5 PATENTED COMPONENT OF SYSTEM

The VortSentry™ is patent pending

3.19 V2B1 Storm Water Treatment System

3.19.1 DESCRIPTION OF TREATMENT TECHNOLOGY

The V2B1 Storm Water Treatment System provides primary treatment of storm water using precast concrete manholes (Figure 3.18). The tangential inlet pipe provides swirl distribution for sediment removal, and the 4 to 5 ft deep sump provides sediment storage. Treated water enters a floatables chamber where floating oil and organic debris are trapped by a baffle wall. An underflow opening in the bottom of the baffle wall directs flow to the system outlet pipe.

3.19.2 GENERAL CONFIGURATION AND TREATMENT CAPACITIES

The V2B1 consists of two precast manholes in series, with inner diameters ranging from 4’ to 12’. The sump depth ranges from approximately 7’ to 11’. V2B1's treatment sizing is based on the impervious acreage of the site and a peak flow rate (PFR) of 0.70 cfs per impervious acre. This PFR is based on 1979 EPA studies of sediment scour of pavement. As such, the company offers seven models that treat flows ranging from 0.21 cfs to 8.19 cfs. The hydraulic capacities range from 1.0 cfs to 38.0 cfs.

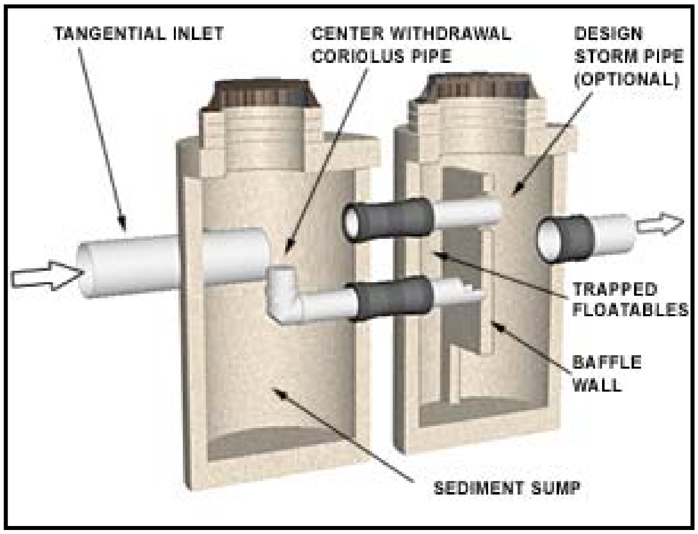

Figure 3.19 V2B1 Schematic

3.19.3 MAINTENANCE SCHEDULE

During the first year of operation, Environment 21 recommends inspections in February, May, and October. This inspection schedule can be modified in subsequent years according to experience and/or to meet specific storm water permit requirements. A cast iron manhole frame with vented cover is provided in the manhole roof to make the sediment pile readily accessible for measurement and cleaning. Sediment should be removed when the top of the pile is within one foot of the normal water surface elevation in the 4-5 ft deep sump of the sediment chamber. The depth of oil sheen and floating debris can be estimated using visual inspection while gently stirring the water surface in the floatables chamber. This depth will typically be less than two inches and floatables can be skimmed from the surface. Organic debris that has become waterlogged and settled to the floor of the chamber can be assumed to be present in relatively small quantities that may need to be removed annually (V2B1 Operation and Maintenance, webpage).

3.19.4 Cost Information and Installation Status

The V2B1 Storm water Treatment System ranges in price from $7,500 to $40,000. Installation costs are site specific and therefore cannot be estimated. Over 400 units are installed nationwide. The Montana, Illinois, and Connecticut departments of transportation have all installed V2B1s.

3.19.5 Patented Component of System

Environment 21 holds one patent for the V2B1 Storm water Treatment System. The patent number is 6,120,684 and claims the following:

- An apparatus for separating floating and non-floating particulates from drain water where the apparatus includes a first chamber for collecting non-floating particles, a second chamber for collecting floating particles, and a third chamber through which treated drain water can be discharged from the apparatus.
    - The improvement where an inlet pipe for introducing drain water into the first chamber is tangential to the first chamber to provide a vortex flow of drain water, and an outlet pipe providing flow of drain water from the first chamber to the second chamber has an inlet at the vortex of drain water flow in the first chamber.
    - Where an outlet from the first chamber to the second chamber is positioned near the bottom of the second chamber and a flow deflection

means is positioned adjacent the outlet from the outlet pipe to deflect floating pollutants in the drain water flowing into the second chamber in an upwardly direction to segregate floating pollutants during peak storm flows.

- An additional pipe is provided near the top of the first chamber to allow a portion of the drain water during peak storm flows to bypass the second chamber and pass directly from the first chamber to the third chamber.

CHAPTER 4: EVALUATION OF TESTING MATERIAL

4.1 Introduction

Very few municipalities have set requirements for the removal of total suspended solids (TSS) from storm water; those that have requirements commonly call for the removal of 80% TSS in influent storm water. A BMP's pollutant removal efficiency can be determined based on the results of lab tests, computer simulations, or field studies.

Lab tests are conducted using controlled flows and a known amount of sediment and grain size. This technique provides consistent results, but does not give a true representation of the performance of the BMP under varying conditions, e.g. excess sand in the system due to sanding during winter weather, pipes backing up downstream of the BMP (i.e. the receiving wetland/detention pond floods) thus forcing water backwards through the system, and a 2-year storm occurring when the system is only designed to treat average-sized storms. In order for a lab test to correctly simulate storm water, the sediment distribution and the densities of the sediments used in the test must be the same as that of storm water.

Computer simulations are useful in determining the hydraulics of a system, but again may not accurately predict how a system will perform after installation. Field studies give the most accurate portrayal of how a BMP will operate once installed. They also identify problems that a controlled lab study and a computer simulation cannot predict. Problems might include a large amount of trash and debris clogging up the filters, or a large amount of sediment from a construction site entering the system and filling up the sedimentation vault; thus limiting the detention time of the storm water flowing through it.

Some companies claim their BMP provides a high level of pollutant removal efficiency, but field studies conducted on the BMP indicate otherwise. This report attempts to determine each product's "true" TSS removal efficiency by analyzing completed field studies based on the following guidelines: field tests, composite samples, mass balances, typical storm water TSS concentration, and representative storm size. The field studies analyzed in this report were obtained through written or verbal requests to the manufacturer or were found on the company webpage.

4.2 Evaluation Guidelines

Composite samples are preferred over grab samples. Composite samples are flow-weighted while grab samples are time-based. A composite sample is prepared by taking flow-based samples, or *aliquots*, after a predetermined volume of water passes by at the inlet and outlet sampling ports. At the end of a storm event all aliquots are combined to generate an "inflow" sample from the influent stream and an "outflow" sample from the effluent stream. Each composite sample is then analyzed to find each constituent's event mean concentration (EMC) of the inflow and outflow.

Composite sampling, however, typically underestimates the amount of mass in the influent stream. Influent aliquots are generally taken using a device that captures water from the bottom of the pipe. The influent stream contains a wide range of particle sizes (and densities) and floatables, such as leaves, and all loadings are not accounted for. This makes the composite influent sample have a seemingly low concentration. The composite effluent sample is considered to be accurate because the larger particles and floatables have been retained in the BMP and only small particles leave the system.

A mass balance is calculated using equation 4.1. M*sump* is the mass of sediment collected in the sump of the BMP, EMC_{out} is the effluent event mean concentration and V_{out} is the volume of water that left the BMP.

$$Min = Msump - EMC_{out} * V_{out} \tag{4.1}$$

The mass balance approach is a more accurate means of calculating the influent mass during a storm event than using composite sampling alone.

A typical influent TSS concentration for storm water runoff is between 100 mg/L and 200 mg/L. This range was determined by evaluating a number of studies conducted nationwide that measured average TSS influent values. The average influent TSS concentration for storm water in Austin, Texas is 150 mg/L. Representative storm depths must be greater than 0.1 inch. Most storm water BMPs are designed to retain water between storms, ideally to allow particles more time to settle. For storm depths smaller than 0.1 inch, the storm water that enters the BMP displaces water that has been sitting in the system since the last storm event. The water that leaves the BMP has had ample time for particulates to settle out, so the removal efficiency appears to be extremely high when in reality it is not.

The pollutant removal efficiency of a BMP may be calculated using one of a variety of equations. For this report, removal efficiency will be calculated using an equation suggested by Urbonas (1995) as “the basic equation for calculating the percent removal of any sampled constituent”

$$\%\ Removal\ Efficiency = \frac{V_{in} * EMC_{in} - V_{out} * EMC_{out}}{V_{in} * EMC_{in}} * 100 \qquad (4.2)$$

in which V_{in} = storm runoff inflow into the BMP; EMC_{in} = event mean concentration of inflow volume; V_{out} = storm runoff volume outflow from the BMP; and EMC_{out} = event mean concentration of outflow volume.

Many factors can affect the overall removal efficiency during a field study. If only small rain events occur (< 0.1 inch) during the testing period, the amount of pollutant removal will appear to be high. The type of sampling equipment and the methods used for analyzing the samples can skew data. A good example of sampling and methodology error is the previous discussion on composite sampling. The composite influent value may be measured low compared to what it actually is based on sampling procedures. The soil type can either aid or hinder removal efficiencies. Larger grained soil, such as sand, will settle more readily than finer grained soils such as silt and clay. Extraneous factors such as construction near the testing site and excessively large storm events can also affect the removal efficiency of a BMP. The goal of a field study is to monitor how a BMP performs under a wide variety of conditions, and to determine what removal efficiencies are achieved under these conditions.

4.3 Summary of Field Studies

4.3.1 Advanced Drainage System (ADS) Water Quality Structure

The makers of the ADS Water Quality Unit claim that test laboratory data indicates the treatment unit provides 80% removal efficiency of TSS (ADS Water Quality Units, 2003). ADS hired Gayle Mitchell, Ph.D., P.E., and Yuming Su, Graduate Student, of Ohio University to perform a laboratory study and a field study of the ADS Water Quality

Structure. A 42-inch HDPE "treatment pipe" unit was fabricated by ADS for the field study and installed at the downstream end of a storm water collection site at Ohio University, which received runoff from 2.62 acres. Automated samplers were installed and detailed monitoring throughout the rainfall/runoff events. To supplement automated sampling, composite manual sampling was continued for specific sources, such as rainfall, roof runoff, and parking lot runoff to determine the amount of TSS that was contributed by each source. No detailed storm event data was reported. Thus, there is no indication of the storm event sizes and individual storm mass balances. A bar chart is given that shows the minimum, maximum and average TSS "in" and TSS "out" for the entire nine-storm testing period. The average TSS "in" concentration ranged from 20 mg/L to 300 mg/L. The average TSS "out" concentration ranged from 15 mg/L to 100 mg/L. The reported data indicate that the concentration of most constituents was reduced by 40% to 50%. No constituent's concentration was reduced by more than 60%.

4.3.2 AQUASHIELD STORM WATER TREATMENT SYSTEMS – AQUA-SWIRL CONCENTRATOR ™

Field studies are underway in Georgia, New Hampshire, Washington & Michigan. Results will be available over the next 4-8 months.

4.3.3 AQUASHIELD STORM WATER TREATMENT SYSTEMS – AQUA-FILTER ™

Field studies are underway in Georgia, New Hampshire, Washington & Michigan. Results will be available over the next 4-8 months.

4.3.4 BAYSAVER® SEPARATION SYSTEM

A letter from Richard Jetton, BaySaver® representative, dated February 10, 2004 states that "the largest standard unit treats 21.8 cfs at an 80% TSS removal rate with a peak design of 100 cfs…" The University of Maryland was contracted to conduct a field study of the BaySaver® 3K Separation System. The study site was a 3.67 acre Montgomery county school bus depot in Rockville, Maryland. Storm water samples were taken using two ISCO® 6700 Compact Portable samplers. At the beginning of each storm event, samples were taken at two-minute intervals. The sampling interval was increased after the first eight samples. The testing period was stated to be from June 30, 1998 to June 14, 1999; however, only three storm events are reported in the summary with dates occurring in April, May and June of 1999. The mass balance of each storm event showed TSS "in" average concentrations to be greater than 100-200 mg/L. The highest TSS "in" concentration was 2,019 mg/L and the lowest TSS "in" average concentration was 503 mg/L. The storm size for each event was not reported, but the peak flow rate was. For the first storm event, the peak flow rate was 0.47 cfs. The reported removal efficiency of the product was 91.28%. The second storm event had a peak flow rate of 6.31 cfs and a removal efficiency of 97.29%. The third storm event had a peak flow rate of 24.33 cfs and a removal efficiency of 75.56%. The full report was not available; these three events appear to be just a sample from all the storm events monitored. Evaluating all the storm events may prove the efficiency of this product to be less than what is claimed.

The BaySaver® 3K model has a maximum treatment capacity of 7.8 cfs and a maximum hydraulic flow rate of 30 cfs. The third storm event recorded a peak flow rate of 24.33 cfs, which is close to the maximum hydraulic flow rate. Even though the maximum treatment capacity of the model was greatly exceeded, the unit still provided close to 80% removal of TSS.

4.3.5 CONTINUOUS DEFLECTIVE SEPARATION (CDS®) – STORM WATER TREATMENT

The makers of the CDS® Storm Water Treatment Unit claim "a properly sized CDS unit is capable of removing more than 80% of the TSS (in storm water)" (CDS Storm Water Treatment Review, 2003). Three field studies have been conducted on the CDS® Storm Water Treatment Unit. See Table 4.1 for a summary of the field studies. The first study, was conducted over a catchment area of approximately 123.55 acres of the inner city suburb of Coburg, Melbourne, Australia. The testing period was from November 1996 to February 1998. Water samples were collected from fifteen storm events and were analyzed for TSS. Flow depth and velocity measurements were recorded every two minutes during storm events. Automatic samplers collected water samples every ten minutes, and passed the water through a filter which limited the sample to particles less than 1mm. Analysis showed that only six of the fifteen storm events had sufficient inflow and outflow samples for an adequate assessment of the change in water quality. For each of the eight storm events, inflow and outflow TSS (mg/L) data points were plotted, as well as the rainfall (mm) and discharge rate (mm/hr). Most of the events had peak rainfalls above the 0.1 inch requirement; the largest peak rainfall depth was approximately 5 mm or 0.19 inches. The influent TSS concentrations ranged from approximately 100 mg/L to 300 mg/L with one storm event having an influent TSS concentration of approximately 420 mg/L. The effluent TSS concentrations ranged from approximately 5 mg/L to 200 mg/L.

The stated conclusion from the test report was that “the CDS unit is relatively effective in reducing TSS for concentrations above approximately 75 mg/L (Walker et.al., 1999).” It was estimated in the report that the TSS removal efficiency was 70% for concentrations above the background concentration of 75 mg/L. “The TSS removal efficiency of the CDS® unit is thus expected to be low when the inflow TSS concentration is within the range of the background concentrations and the efficiency is approximately 70% with higher concentrations (Walker et.al., 1999).” By analyzing the given data, the CDS® treatment unit reduced influent TSS concentrations by at least 50% for five of the six storm events.

The second study consisted of five storm events sampled from April 1998 to March 1999 over a 62.45 acre drainage basin of mixed industrial, commercial and vacant land in Brevard County, Florida. Composite samples were collected for three of the storm events, and mass balances were developed for each event. The rainfall depth was greater than 0.1 inches for all but one storm. Many problems were encountered during this testing period, with most problems relating to inexperienced personnel performing the storm water sampling. “The storm water samples showed a wide range of removal efficiencies; most of which could be explained by problems with equipment failure or improper equipment set up (Strynchuk et.al., 1997).” The average influent TSS concentration for the first three storm events was 290 mg/L and the average effluent TSS concentration was 203 mg/L. This results in an average TSS removal efficiency of 30% using equation 4.2. The average influent TSS concentration for the fourth storm event was 686 mg/L and the average effluent TSS concentration was 582 mg/L, which results in a 15% removal efficiency (using equation 4.2). The average influent TSS concentration for the fifth storm event was 41 mg/L and the average effluent TSS concentration was 16 mg/L, which results in a TSS removal efficiency of 61%, again using equation 4.2. The average removal efficiency, as estimated by the authors of the report, was 52% for TSS. The average removal efficiencies for TSS, as stated above in each storm analysis, do not reflect the efficiency found by the authors.

The third study was conducted by the California Department of Transportation (CalTrans) Department of Environmental Analysis, and was performed as part of a larger study comparing the effectiveness of a variety of structural storm water BMPs at removing gross pollutants and sediments from storm water. For the study, two CDS® units were installed along highway I-210 in the Los Angeles area. One unit was placed on the west-bound side of highway I-210 near Orcas Avenue and received storm water from a drainage area of 1.09 acres. The second unit was placed on the west-bound side of highway I-210 near Filmore Street and received storm water from a drainage area of 2.52 acres. The testing period was from January 2000 through April 2002. No data was reported on the number or depths of the storms used in the analysis. During the first year of study, BMP constituent removal performance was calculated using "the standard analysis procedure for the Pilot Program based upon the Event Mean Concentration (EMCs) measured at the influent and effluent points of each BMP" (BMP Retrofit Pilot Program Final Report, 2003). Some concern was raised that the removal rates determined from the EMC calculations would be biased low because automatic samplers do not capture high-density particles, lending the influent TSS concentrations to be low. Therefore, a mass balance approach was taken during the second year of evaluation. This approach involves quantifying the amount of sediment retained in each device as well as the amount discharged. Knowing the amount of sediment captured in the unit and the amount discharged allowed computation of the influent load and the load removal efficiency.

The TSS removal efficiency for the CDS® unit located at Orcas Avenue was 0.75% and the removal efficiency for the unit located at Filmore Street was 3.56%, based on the mass balance approach. It was noted in the report that the difference in removal efficiency between the two units is most likely because the watershed that drains to the Orcas Avenue unit has a large number of trees, so the amount of vegetative matter that entered the Orcas unit and filled up the sump was quite high compared to that of the Filmore Street unit. No theory was provided in the report as to why each unit provided little to no removal of TSS.

Table 4.1 Summary of CDS® Field Testing

FIELD STUDY TITLE	SITE DRAINAGE AREA	TESTING PERIOD	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
"Removal of suspended solids and associated pollutants by a CDS gross pollutant trap"	123.55 acres inner city suburb	Nov 1996 - Feb 1998 16 months	15	~60%
"The Use of a CDS Unit for Sediment Control in Brevard County"	61.45 acres mixed industrial, commercial, and vacant land	Apr 1998 - March 1999 12 months	5	~50%
"BMP Retrofit Pilot Program Final Report"	1.09 acres along highway I-210/Orcas Ave. 2.52 acres along highway I-210/Filmore St	Jan 2000 - Apr 2002	NA	0.75% 3.56%

4.3.6 CRYSTALSTREAM™ TECHNOLOGIES

Field studies are underway and will be completed in 2005.

4.3.7 DOWNSTREAM DEFENDER®

The makers of the Downstream Defender® claim that "removal efficiencies of greater than 80% can be achieved (depending on site conditions) with a selection of models being available to cater for a broad range of design flows (Stormwater Products – Downstream Defender)." One field study was conducted in Onondaga County, New York. The catchment area primarily encompassed a 1,000-foot length of the East Seneca Turnpike and is approximately 1.2 acres in size. A 4-foot diameter Downstream Defender® with a design flow of 0.75 cfs and a maximum capacity of 3.0 cfs was used for the study. The testing period was from March 2001 to May 2002, and encompassed six storm events. A US DH-81A sampler, which is specifically designed for sampling sediment in flowing water, was used for the first five storm events. Concern was raised that the US DH-81A sampler was not taking representative samples of the sediment load, so a Van Dorn sampler was used to sample during the last event. Grab samples from each location were taken at approximately 15-minute intervals throughout each rain event and attempts were made to collect the first flush of storm water.

The laboratory procedures for analyzing TSS concentrations were changed for the last two storm events to reflect the industry's new understanding of laboratory bias with respect to heavy solids and the TSS analysis. Traditionally, the original TSS analysis allowed the laboratory to split the primary sample for the purpose of performing the analysis with a single filter of size 24 or 42 mm in diameter. Research has shown that splitting storm water samples that contain solids larger than 62 microns can bias the TSS results downward by as much as 50%. The new TSS method (also known as ASTM 3977 Suspended Sediment Concentration) requires the laboratory to filter the entire sample and not take a split or sub-sample (Downstream Defender Report Sections, 2002).

Influent versus effluent comparisons were only made for the sixth storm event when both the Van Doran sampler and the ASTM 3977 solids analysis were used because of the previous discrepancy in samplers and in the testing procedures of the TSS samples. The sixth storm lasted 5 hours and three samples were taken. The first sample was taken during the first observed flows. The next sample was taken as the flow peaked to near the design flow of the BMP (0.75 cfs), and the last sample was taken once the flow lessened. All three samples were taken during a 15-minute time period. The influent TSS measurements ranged from 2,217 mg/L to 12,544 mg/L with an average influent TSS concentration of 5,716 mg/L. The effluent TSS measurements ranged from 785 mg/L to 1,765 mg/L with an average effluent TSS concentration of 1,268 mg/L. The overall removal efficiency for this storm was calculated to be 77.8% using equation 4.2.

The influent TSS concentrations measured in this study are all too high compared to the given national average influent TSS concentration of 100-200 mg/L to be considered for evaluation. Even though the Downstream Defender® provided near 80% removal of TSS during the sixth storm event, the effluent TSS concentrations were well over 200 mg/l. One possible explanation for the high TSS concentrations is that sand was laid down on the East Seneca Turnpike during bad weather, and was thus washed into the BMP during storm events.

4.3.8 EcoStorm™

No field studies have been done for the EcoStorm™

4.3.9 STORMCEPTOR®

The makers of the Stormceptor® claim this BMP removes 80% of annual influent TSS (Stormceptor Benefits, 2003). Seven field studies were conducted between June 1996 and November 2002 with testing periods ranging from two months to fourteen months. See Table 4.2 for a summary of the studies. The three rows highlighted in Table 4.2 are studies that are not included in further analysis for reasons noted in the following paragraphs.

All studies used composite sampling and automatic samplers. The majority of storm events that occurred during the testing periods produced more than 0.1 inch of rain in depth. The Madison, Wisconsin study, entitled “Evaluation of Stormceptor® and Multi-Chamber Treatment Train as Urban Retrofit Strategies”, was disregarded for this analysis because the testing site was a public works yard that contained sand piles for use during the icy winter months. These sand piles can create extremely high influent TSS concentrations that are not representative of normal storm water, and thus may skew the removal efficiencies.

Two of the studies were conducted at the same location, with one study being a continuation of the other one (Como Park, Phase I and II). The first study was conducted from August to October 1998, and three storm events were tested. The second study, entitled “Stormceptor Monitoring Study, Como Park,” was conducted from August 1998 to September 1999 and contained the storm event data from the first study plus data from five additional storm events for a total of eight storm events; therefore the second study will be used in this evaluation and not the first study. Influent TSS concentrations ranged from 13.3 mg/L to 318 mg/L, with an average influent TSS concentration of 90 mg/L. Effluent TSS concentrations ranged from 3.3 mg/L to 59 mg/L, with an average effluent TSS concentration of 29 mg/L. The influent TSS loading was calculated in the report to be 43.14 kg and the effluent TSS loading was calculated to be 10.46 kg. The removal efficiency of TSS was calculated to be 76% using equation 4.2.

The Greenwood Village study, entitled “The Effects of Backwater on Stormceptor® Treatment Systems, Denver, Colorado Area,” found that the Stormceptor® provided a TSS removal efficiency of 50.3%. This study was conducted in 2002 and was plagued with problems associated with backwater. The Stormceptor® was installed directly upstream of a slow draining detention pond, and became susceptible to severe backwater effects even during moderate runoff events.

The City of Edmonton, Alberta study was conducted from June to July 1996 and contained data from four storm events. The drainage area encompassed 9.9 acres of a commercial shopping plaza. The average influent TSS concentration was 405 mg/L, and the average effluent TSS concentration was 199 mg/L. The average TSS removal efficiency was 52.7%. It was noted in the field study report that the Stormceptor® model used was undersized compared to the 50% TSS removal criteria and the testing techniques that were used are now antiquated.

Table 4.2 Summary of Stormceptor® Field Studies

FIELD STUDY	SITE DRAINAGE AREA	TESTING PERIOD	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
Field Monitoring Results, City of Edmonton, Alberta	9.9 acre commercial shopping plaza	June - July 1996 2 months	4	52.7%
Preliminary Field Monitoring Results Madison, Wisconsin	4.3 acre public works yard	Aug 1996 - Apr 1997 9 months	45	22.0%
Field Monitoring Results Westwood, Massachusetts	0.65 acre loading/unloading area at a local manufacturing facility	July - Oct 1997 4 months	3	93.0%
Como Park, Minnesota Phase I	1.03 acre parking lot	Aug to Oct 1998 3 months	3	80.0%
Como Park, Minnesota Phase II	1.03 acre parking lot	Aug 1998 - Sept 1999 14 months	8	76.0%
Seatac, Washington	1 acre Texaco gas station	Mar - Oct 1999 8 months	4	87.0%
Greenwood Village, Colorado	3.5 acre hotel complex	Aug - Nov 2002 4 months	12	50.3%

The Westwood, Massachusetts study was conducted from July to October 1997 and contained data from five storm events. The STC 1200 was installed at a loading/unloading trucking area at a local manufacturing facility; the drainage area was 0.65 acres of impervious surface area. The average influent TSS concentration was 135 mg/L and the average effluent TSS concentration was 6 mg/L. The overall average TSS removal efficiency was 92%. The largest storm event produced a flow rate of 250 gallons per minute (gpm) and the maximum treatment flow rate of the STC 1200 is 285 gpm.

The Seatac, Washington study was conducted from March to October 1999 and included four storm events. The STC 900 was installed at a 1-acre Texaco gas station and convenience store. Composite samples were completed for two of the four storm events. The average influent TSS concentration was 200 mg/L and the average effluent TSS concentration was 30 mg/L. The total influent TSS loading was 13.5 kg and the total effluent loading was 1.46 kg, resulting in a TSS removal efficiency of 89%.

4.3.10 STORMWATER MANAGEMENT, INC - STORMFILTER®

Stormwater Management, Inc. claims that the StormFilter® "removes high levels of pollutants such as suspended solids, heavy metals, oil and grease and organics (The Stormwater Management StormFilter®, 2004)." Six field studies were conducted using the StormFilter® with different types of filter media to determine the pollutant removal efficiencies associated with each media type. See Table 4.3 for a summary of the field studies.

Four field studies were evaluated in a combined report (Lake Stevens, Giles Street, McDonalds and the Southwest Bible Church) entitled "Total Suspended Solids Removal Using StormFilter® Technology". These studies all used composite sampling, and the influent TSS concentrations were either well below 100 mg/L or well above 200 mg/L. The filtration media used in the StormFilter® cartridges for these four reports was either CSF Leaf media or Perlite. The storm sizes were not reported. The Giles Street study included six storm events for analysis of TSS, the Southwest Bible Church study included two storms for analysis, and the Lake Stevens study and the McDonald's study both contained one storm event for analysis. The sum of all influent TSS concentrations (from all four studies) using the StormFilter® with CSF Leaf media was 816 mg/L and the sum of all effluent TSS concentrations was 243 mg/L. The weighted average TSS removal efficiency for CSF® leaf media, calculated using equation 4.2, was 70%. The sum of all influent TSS concentrations using the StormFilter® with Perlite media was 802 mg/L and the sum of all effluent TSS concentrations was 177 mg/L. The weighted average removal for the Perlite media was 78% and was calculated using equation 4.2. The testing methods used to determine pollutant removal efficiency in these four reports are now antiquated;

these studies were performed to get an idea of the removal efficiencies of the different media types.

The fifth field study was located in Clark County, Washington at the Heritage Marketplace shopping center. A StormFilter® system using CSF Leaf media was installed and tested from March to July 2002. Three storm events were used for sampling, and all storm depths were greater than 0.1 inch. All storm events had influent TSS concentrations close to the 100 mg/L – 200 mg/L requirement, and all samples were composites. The total influent TSS concentration (sum of all three storm events) was 570 mg/L and the total effluent TSS concentration (sum of all three storm events) was 81 mg/L. The average weighted TSS removal efficiency for these three storms was 85.8%, and was calculated using equation 4.2.

The last study was conducted by the California Department of Transportation (Caltrans) and involved evaluating a variety of storm water BMPs to determine which was most cost-effective and most efficient at removing TSS. The StormFilter® did not perform well, as it only achieved 40% removal of TSS. No storm or testing data was included except for one mass balance. It was noted that one potential reason for the modest pollution removal may be the very short residence time within the device. It was clear from comparisons of influent versus effluent hydrographs for a typical storm that there is no attenuation of peak flows in the device and consequently little time for particles to be filtered or to settle out of the runoff.

Table 4.3 Summary of StormFilter® Field Studies

FIELD STUDY TITLE	SITE DRAINAGE AREA	TESTING PERIOD	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
"Lake Stevens"[3]	30,000 ft^2 roadway runoff prior to bridge	Oct 1996	1	76.0%
"Monitoring of the Giles Street StormFilter"[3]	200 acres mature commerical and resedential developments and roadways	Oct 1996 - March 1999	6	59.5%
"Monitoring of McDonald's, Vancouver"[3]	1 acre	Oct 1996 - July 1999	1	79.4%
"Particle Size Distribution and Suspended Solids Removal at the Southwest Bible Church StormFilter"[3]	25 acres	Sept 1997 - Feb 2000	2	84.5%
"Heritage Marketplace Field Evaluation: Stormwater Management StormFilter with CSF Leaf Media"	4 acres Heritage Place Shopping Center	March - July 2002	3	87.0%
"BMP Retrofit Pilot Program Final Report"	1.48 acre Maintenance Station	Feb 2002	3	40.0%

4.3.11 STORMGATE SEPARATOR™

There are no field studies at this time for the StormGate Separator™.

4.3.12 STORMSCREEN™

There are no field studies at this time for the StormScreen™.

4.3.13 STORMTREAT™

The makers of the StormTreat™ claim the system "meets EPA's recommended 80% removal rate for Total Suspended Solids (TSS), and can be configured to meet more stringent state standards in critical water resource areas (StormTreat System – Home)." Two field studies have been conducted in Massachusetts and are summarized in a report entitled "The Massacuhsetts Strategic Envirotechnology Partnership Technology (STEP) Assessment of StormTreat™ System, Inc."

The first study was conducted in Kingston, Massachusetts along an environmentally sensitive portion of the Jones River. The testing period was from November 1994 to October 1996, and six storm events were sampled for analysis. Storm water was collected from approximately 73,000 ft^2 of impervious area. The only data presented concerning the storm events is in the form of one table with the influent and effluent range of concentrations and the mean concentration for various storm water constituents. It was stated in the STEP report that "sampling was conducted when a one-half inch rainfall was likely to occur." The influent TSS concentrations ranged from 4 mg/L to 344 mg/L, with an average influent concentration of 77 mg/L. The effluent TSS concentrations ranged from 0.5 mg/L to 12 mg/L, with an average effluent TSS concentration of 1.75 mg/L. The TSS removal efficiency was 98%.

There is little information reported concerning the second field study in Greenfield, Massachusetts. "The site received storm water from a parking area and roadway associated with a municipal sewage treatment plant. Data from a single storm event was reported to have a TSS removal efficiency of 85% with influent and effluent concentrations at 6.0 mg/L and 0.4 mg/L, respectively. Additional data from this study may become available at a later time." (The Massachusetts STEP Technology Assessment of StormTreat™ Systems, Inc, 1997)

The two field studies were performed by an independent party and the information from the studies was provided to the Massachusetts Strategic Envirotechnology Partnership (STEP) for assessment of the product. The STEP technical assessments attest only that, through the screening process, the reviewers feel the StormTreat™ may be of benefit to the Commonwealth of Massachusetts. The following is a footnote from the STEP evaluation of the StormTreat™:

> The sizing information presented by StormTreat system (STS) in the initial submission lacked adequate justification based on existing experimental data. In particular, the sizing data for 89% and 90% removal efficiency, based on soil type, did not consider details such as: storm duration, soil water permeability, and potential for reduced efficiency of the StormTreat system at higher flow rates. The STS claimed that the closed mode installations should be capable of treating the first one-half inch of storm water from 8,920 ft^2 of impervious surface. Our analysis of the treatment potential for a given drainage area suggests that the sizing should be based on the holding capacity of the unit and any conveyance pipes that are full at the end of the storm event. It is important to note that the mean interval between storm events in the Northeast is 73 hours. This period is shorter that the claimed system

> process time of 120 hours and only 40% of the process time for the volume of runoff from 8,080 ft^2. This suggests that the total volume treated by the system, on an annual basis, may be lower than predicted. Shorter process times may be achieved by adjusting the outflow rate; however, shortening the process time may potentially reduce performance. Without additional field data, the performance capability at higher flow rates cannot be verified.
>
> (The Massachusetts STEP Technology Assessment of StormTreat™ Systems, Inc, p. 11, 1997)

4.3.14 STORMVAULT™

The makers of the Stormvault™ Mitigation System claim the BMP provides an "effluent discharge of TSS concentration of less than 20 mg/L, independent of influent concentrations of inflow volume. The detention time promotes sedimentation of particles less than 70 microns (Wright Waters Engineering, Albemarle, 2002)." Two studies have been conducted to analyze the performance of the Stormvault™.

The first study was located in Sacramento, California at a Paratransit bus yard. The Stormvault™ received runoff from an area of 2.0 acres with an imperviousness of approximately 90%. Ten storms were sampled over a period of twelve months, from January to December 2001. All storm depths were greater than 0.1 inch, with the largest storm being 1.23 inches in depth. The water samples from each storm event were combined to form influent and effluent composites. All storm events produced influent TSS concentrations of less than 100 mg/L; the influent TSS concentrations ranged from <10 mg/L to 54 mg/L with an average concentration of 42.1 mg/L. The effluent TSS concentrations ranged from <10 mg/L to 36 mg/L. The removal efficiency of the Stormvault™, based on total mass loads, was 51%.

The second field study was located at the Albemarle County Office Building parking lot in Charlottesville, Virginia, and was conducted in two phases. The plan outlined monitoring two different Stormvault™ configurations at the site, permitting examination of two different capture volumes and drawdown times. The Stormvault™ was designed as a SV68x2 (two midsections) with a 6-hour drawdown time. In order to create the Phase I test model, a false wall was constructed to limit the effective midsection size to that of a SV68x1 (one midsection). The wall was designed so that is could be removed once Phase I was complete to create the SV68x2 for the second phase of testing. For the SV68x1, a 4.5-inch orifice was installed to control the outflow resulting in a drawdown time of 15 minutes. When the unit was converted to a SV68x2, the 4.5-inch orifice plate was replaced with a 1.0-inch orifice to provide a 6-hour drawdown time.

The testing period for Phase I went from January to April 2001, and eight storm events were used for sampling. All storm events during this period generated depths greater than 0.1 inch, with the range being 0.17 to 2.0 inches in depth. One storm event cannot be counted because the precipitation was snowmelt, not rainfall. The samples from each storm event were combined to form influent and effluent composites. All influent TSS concentrations were well below the 100 mg/L requirement for typical storm water, with a range of 6.9 mg/L to 20.4 mg/L and an average of 13.6 mg/L. The effluent TSS concentrations ranged from 3.1 mg/L to 22.5 mg/L. The last storm event in this period produced a negative removal efficiency (-88%). It must be noted that this storm intensity was the highest of the testing period and a storm depth of 2.0 inches was measured. It is possible that sediment in the vault was resuspended into the water during the highly intense portions of the storm, thus causing more TSS to leave the system than to enter it. The average removal efficiency based on total mass loads was 25% for Phase I. Therefore, a 15-minute drawdown time is not long enough for sufficient removal of TSS. It should also be noted that the influent TSS concentrations were not large enough to provide true removal efficiencies under normal flows.

Phase II involved the monitoring of seventeen storm events from May to August 2001. All storm depths but one were greater than 0.1 inch and ranged from 0.08 to 1.86 inches. The samples from each storm event were combined to form influent and effluent composites. Three of the seventeen storm events had influent TSS concentrations greater than 100 mg/L (889.5, 185.3, and 171.5 mg/L); the influent concentrations for all seventeen storm events ranged from 10.4 mg/L to 889.5 mg/L. The average influent TSS concentration was calculated to be 68.7 mg/L by disregarding the highest value, 889.5 mg/L, based on its abnormal appearance in the data, and averaging the rest of the concentrations. The influent TSS concentrations for two storms were not reported, possibly due to equipment malfunctions. The effluent TSS concentrations ranged from 4.9 mg/L to 44.1 mg/L, and the average effluent concentration was 15.4 mg/L. The removal efficiency based on total mass loads for Phase II was 80%. The large difference in efficiency between this study (Phase II) and the other two studies could be due to the large number of storms analyzed and the higher influent TSS concentrations. It could also be due to the system being sized better for its treatment area as opposed to the California site and the Phase I test.

4.3.15 SUNTREE TECHNOLOGIES – NUTRIENT SEPARATION BAFFLE BOX

No information has been provided by the manufacturer.

4.3.16 VORTECHNICS – VORTECHS®

The makers of Vortechs® claim that "annual TSS removal efficiencies have been shown to be 80% for typical urban runoff particle distributions (Vortechs® System)." One field study has been conducted at the DeLorme Publishing Company in Yarmouth, Maine. The test site drainage area included a 4-acre parking lot and unpaved tributary areas totaling approximately 3 acres. The testing period was from May to November 1999 and twenty storm events were evaluated. Composite samples were taken for the study. Ten of the twenty storm events had influent TSS concentrations less than 100 mg/L (37.2 to 93.3 mg/L, average 59.5 mg/L) , and seven storm events had influent TSS concentrations much greater than 200 mg/L (367.6 to 1364.9 mg/L, average 779.5 mg/L). The effluent concentrations ranged from 12.6 mg/L to 149.2 mg/L with an average effluent TSS concentration of 56.8 mg/L. The net removal efficiency for this testing period was 81.6%. No data was given on the storm sizes during the testing period.

4.3.17 VORTECHNICS – VORTSENTRY™

There are no field studies of the VortSentry™ at this time.

4.3.18 V2B1

There are no field studies of the V2B1 at this time.

4.4 Analysis of Selected Field Studies

Field studies may be conducted and the data analyzed in a variety of ways. The field studies that most accurately characterize a BMP contain data from a large number of storm events and a large range of storm depths in the testing period, a total flow volume for each storm event, an influent and effluent EMC for constituents of interest, and a description of the test site (drainage area, impervious surface area, etc.). The field studies conducted on the Stormceptor®, Stormvault™, and Vortechs® all contain ample data to provide additional analysis.

Field studies conducted using the aforementioned BMPs were evaluated based on the criteria outlined in Section 4.2. Storm events that produced depths less than 0.1 inch were disregarded and not used in further calculations. Precipitation caused by means other than a storm event (e.g. snow melt) was also discounted from further calculations.

The data from each field study is presented in a table, and then the data is subdivided to create two tables. One table shows all storm events in the testing period with influent TSS concentrations less than 100 mg/L and the other table shows all storm events with influent TSS concentrations greater than 100 mg/L. The removal efficiency associated with each data set is calculated using equation 4.2. The goal of this exercise is to determine if each BMP is more effective at treating high concentration waters or low concentration waters, or if there is a distinction at all.

4.4.1 STORMVAULT™

Two studies were conducted using the Stormvault™ Mitigation System. The storm events analyzed in the first study all produced influent TSS concentrations less than 60 mg/L and the storm events analyzed during the first part of the second study (Phase I testing period) all produced influent TSS concentrations less than 20 mg/L. Therefore, only Phase II of the second study will be used for further analysis. Table 4.4 shows the storm event data from Phase II. Three of the rows that are highlighted were disregarded because not all of the data was reported. The fourth row that is highlighted was disregarded because the storm depth was less than 0.1 inch.

Table 4.4 Stormvault™ Phase II Field Study Summary

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
5/26/01	0.35	10.4	4.9	11437.97	0.12	0.06
6/1/01	0.52	39.6	7.4	17100.33	0.68	0.13
6/5/01	0.50	889.5	24.6	14439.02	12.84	0.36
6/7/01	0.55	185.3	23.0	16194.35	3.00	0.37
6/15/01	0.36	53.0	11.1	10248.87	0.54	0.11
6/16/01	0.32	25.4	5.5	8833.28	0.22	0.05
6/20/01	0.59	79.8	12.2	17496.69	1.40	0.21
6/21/01	0.56	62.5	17.3	18430.98	1.15	0.32
~~6/30/01~~	~~0.44~~	~~NR~~	~~19.8~~			
7/1/01	0.10	78.6	6.1	3482.35	0.27	0.02
~~7/5/01~~	~~0.08~~	~~43.4~~	~~4.9~~			
~~7/8/01~~	~~0.29~~	~~NR~~	~~4.4~~			
7/26/01	1.86	171.5	44.1	61181.80	10.49	2.70
7/28/01	1.82	35.0	6.1	60360.76	2.11	0.37
8/10/01	0.80	66.5	21.8	26584.78	1.77	0.58
~~8/11/01~~	~~NR~~	~~73.1~~	~~41.4~~	~~NR~~	~~NR~~	~~NR~~
8/13/01	0.21	37.5	7.5	7134.57	0.27	0.05
				Total:	34.87	5.33

NR - Not Reported

Removal Efficiency: 84.7%

Table 4.5 Stormvault™ Field Study Data with Influent TSS Concentrations < 100 mg/L

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
7/1/01	0.10	78.6	6.1	3482.35	0.27	0.02
8/13/01	0.21	37.5	7.5	7134.57	0.27	0.05
6/16/01	0.32	25.4	5.5	8833.28	0.22	0.05
6/15/01	0.36	53.0	11.1	10248.87	0.54	0.11
5/26/01	0.35	10.4	4.9	11437.97	0.12	0.06
6/1/01	0.52	39.6	7.4	17100.33	0.68	0.13
6/20/01	0.59	79.8	12.2	17496.69	1.40	0.21
6/21/01	0.56	62.5	17.3	18430.98	1.15	0.32
8/10/01	0.80	66.5	21.8	26584.78	1.77	0.58
7/28/01	1.82	35.0	6.1	60360.76	2.11	0.37
				Total:	8.53	1.90

Removal Efficiency: 77.7%

Table 4.6 Stormvault^{TM} Field Study Data with Influent TSS Concentrations > 100 mg/L

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]	
6/5/01	0.50	889.5	24.6	14439.02	12.84	0.36	
6/7/01	0.55	185.3	23.0	16194.35	3.00	0.37	
7/26/01	1.86	171.5	44.1	61181.80	10.49	2.70	Removal Efficiency
				Total:	26.34	3.43	87.0%

A comparison of the removal efficiencies associated with Tables 4.5 and 4.6 show that the Stormvault^{TM} provides better removal efficiencies for flows that have a high influent TSS concentration, but still provides almost 80% removal of TSS for flows that have low influent TSS concentrations.

Regardless of the influent TSS concentration, the effluent concentration was less than 45 mg/L for all storm events monitored. The makers of the Stormvault^{TM} Mitigation System claim the BMP provides an "effluent discharge of TSS concentration of less than 20 mg/L, independent of influent concentrations of inflow volume (Wright Waters Engineering, Albemarle, 2002)." While the study does not prove the claim to be right, it does show the Stormvault^{TM}

4.4.2 STORMCEPTOR®

Seven field studies were conducted using the Stormceptor®. Four of the studies were disregarded for reasons previously mentioned; the three remaining studies (Westwood, MA, Como Park II, and Seatac, WA) are used for further analysis. The data from each of the three studies is combined in Table 4.7 to get an overall removal efficiency for the BMP.

Table 4.7 Stormceptor® Combined Field Study Summary

Study	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
Westwood, MA	NA	8.0	5.8	1434.60	0.01	0.01
	0.18	400.0	5.3	462.00	0.18	0.00
	0.25	86.0	6.8	1152.00	0.10	0.01
	0.22	47.0	5.0	2545.00	0.12	0.01
Como Park II	0.77	64.0	16.0	81406.25	5.21	1.30
	0.40	318.0	59.0	61214.81	19.47	3.61
	0.12	196.0	58.0	6900.06	1.35	0.40
	0.53	26.0	31.0	54712.18	1.42	1.70
	0.19	33.0	41.0	21763.75	0.72	0.89
	0.11	22.7	19.3	10961.36	0.25	0.21
	1.96	48.0	7.6	303924.15	14.59	2.31
	0.11	13.3	3.3	9466.29	0.13	0.03
Seatac, Washington	0.80	23.0	8.0	82296.00	1.89	0.66
	0.17	40.0	18.0	17488.00	0.70	0.31
	0.18	16.0	5.0	18517.00	0.30	0.09
	0.30	240.0	10.0	30861.00	7.41	0.31

	Composite TSS In [kg]	Composite TSS Out [kg]	Removal Efficiency
Total:	53.84	11.86	78.0%

Table 4.8 Stormceptor® Field Study Data with Influent TSS Concentrations > 100 mg/L

Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
0.18	400.0	5.3	462.00	0.18	0.00
0.40	318.0	59.0	61214.81	19.47	3.61
0.12	196.0	58.0	6900.06	1.35	0.40
0.30	240.0	10.0	30861.00	7.41	0.31

	Composite TSS In [kg]	Composite TSS Out [kg]	Removal Efficiency
Total:	28.41	4.32	84.8%

Table 4.9 Stormceptor® Field Study Data with Influent TSS Concentrations < 100 mg/L

Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]	
0.25	86.0	6.8	1152.00	0.10	0.01	
0.22	47.0	5.0	2545.00	0.12	0.01	
0.77	64.0	16.0	81406.25	5.21	1.30	
0.53	26.0	31.0	54712.18	1.42	1.70	
0.19	33.0	41.0	21763.75	0.72	0.89	
0.11	22.7	19.3	10961.36	0.25	0.21	
1.96	48.0	7.6	303924.15	14.59	2.31	
0.11	13.3	3.3	9466.29	0.13	0.03	
0.80	23.0	8.0	82296.00	1.89	0.66	
0.17	40.0	18.0	17488.00	0.70	0.31	
0.18	16.0	5.0	18517.00	0.30	0.09	Removal Efficiency
			Total:	25.42	7.53	70.4%

A comparison of the TSS removal efficiencies associated with Tables 4.8 and 4.9 shows that removal of TSS is greater when the influent storm water has TSS concentrations greater than 100 mg/L. Effluent TSS concentrations are consistently less than 60 mg/L regardless of influent TSS concentration and storm size.

The makers of the Stormceptor® claim that this BMP removes 80% of annual influent TSS (Stormceptor Benefits, 2003). The field study data proves this claim not to be true in all cases; it is true for storm water that contains influent TSS concentrations greater than 100 mg/L. The overall removal efficiency of TSS was calculated to be 78% for the Stormceptor® and this value comes close to the claimed 80% removal.

4.4.3 VORTECHS®

Twenty storms were sampled for one field study located at the Delorme Publishing Company in Yarmouth, Maine. All storm depths during the testing period were greater than 0.1 inch, and a wide range of storm sizes was sampled.

Table 4.10 Vortechs® Field Study at Delorme Publishing Company

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
5/24/99	0.30	65.9	50.3	594547.8	39.2	29.9
6/24/99	0.52	1010.7	149.2	180487.7	182.4	26.9
6/28/99	0.32	1364.9	63.6	127403.1	173.9	8.1
7/6/99	0.32	857.6	49.4	276040.1	236.7	13.6
7/18/99	0.52	367.6	145.9	233572.4	85.9	34.1
7/24/99	0.46	533.2	57.8	191104.7	101.9	11.0
8/7/99	0.55	43.0	31.0	318507.8	13.7	9.9
8/14/99	0.75	1088.8	52.0	424677.0	462.4	22.1
8/29/99	0.10	37.2	33.6	63701.6	2.4	2.1
9/7/99	0.17	61.0	38.0	127403.1	7.8	4.8
9/15/99	5.45	88.8	59.1	441664.1	39.2	26.1
9/30/99	0.48	111.6	47.3	113247.2	12.6	5.4
10/4/99	0.53	46.2	19.8	198182.6	9.2	3.9
10/9/99	0.13	69.2	14.7	67948.3	4.7	1.0
10/14/99	0.43	33.1	12.6	226494.4	7.5	2.9
10/23/99	1.91	164.1	93.2	226494.4	37.2	21.1
11/2/99	1.02	233.6	102.4	452988.8	105.8	46.4
11/11/99	0.27	93.3	25.5	186857.9	17.4	4.8
11/14/99	0.25	57.4	21.0	181195.5	10.4	3.8
11/20/99	0.30	188.4	70.3	209507.3	39.5	14.7
				Total:	1589.7	292.7

Removal Efficiency: 81.6%

Table 4.11 Vortechs® Field Study Data with Influent TSS Concentrations < 100 mg/L

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]
5/24/99	0.30	65.9	50.3	594547.8	39.2	29.9
8/7/99	0.55	43.0	31.0	318507.8	13.7	9.9
8/29/99	0.10	37.2	33.6	63701.6	2.4	2.1
9/7/99	0.17	61.0	38.0	127403.1	7.8	4.8
9/15/99	5.45	88.8	59.1	441664.1	39.2	26.1
10/4/99	0.53	46.2	19.8	198182.6	9.2	3.9
10/9/99	0.13	69.2	14.7	67948.3	4.7	1.0
10/14/99	0.43	33.1	12.6	226494.4	7.5	2.9
11/11/99	0.27	93.3	25.5	186857.9	17.4	4.8
11/14/99	0.25	57.4	21.0	181195.5	10.4	3.8
				Total:	151.4	89.2

Removal Efficiency: 41.1%

Table 4.12 Vortechs® Field Study Data with Influent TSS Concentrations > 100 mg/L

Storm Date	Total Storm Depth [in]	Composite TSS In [mg/L]	Composite TSS Out [mg/L]	Total Flow Volume [L]	Composite TSS In [kg]	Composite TSS Out [kg]	
6/24/99	0.52	1010.7	149.2	180487.7	182.4	26.9	
6/28/99	0.32	1364.9	63.6	127403.1	173.9	8.1	
7/6/99	0.32	857.6	49.4	276040.1	236.7	13.6	
7/18/99	0.52	367.6	145.9	233572.4	85.9	34.1	
7/24/99	0.46	533.2	57.8	191104.7	101.9	11.0	
8/14/99	0.75	1088.8	52.0	424677.0	462.4	22.1	
9/30/99	0.48	111.6	47.3	113247.2	12.6	5.4	
10/23/99	1.91	164.1	93.2	226494.4	37.2	21.1	
11/2/99	1.02	233.6	102.4	452988.8	105.8	46.4	
11/20/99	0.30	188.4	70.3	209507.3	39.5	14.7	Removal Efficiency
				Total:	1438.3	203.5	85.9%

The Vortechs® BMP provides a high level of treatment during storm events when influent TSS concentrations are over 100 mg/L, and not nearly as good a level of treatment when the influent TSS concentrations are less than 100 mg/L. The Vortechs® effluent TSS concentrations are not as low as the other two BMP's effluent concentrations; the highest TSS concentration to leave the Vortechs® system was 149.2 mg/L. Yet the Vortechs® provided the best overall removal efficiency of TSS of the three analyzed.

Urbonas (1995) suggests there is evidence "that TSS and other constituent removal efficiencies can be significantly affected by the initial concentrations of the constituent. Laboratory and field data using stormwater show that it is easy to remove 80-90% of TSS when its initial concentration is high (e.g. >400 mg/L) and difficult to remove even 20% when the initial concentrations are low (e.g. < 20 mg/L)." The analysis of the three BMPs in Section 4.4 proves this to be true. The removal efficiencies were much higher when influent TSS concentrations were greater than 100 mg/L than when they were less than 100 mg/L.

The effectiveness of a BMP at removing constituents cannot be measured by removal efficiency alone. Several storm events produce influent concentrations that are relatively low and therefore produce low removal efficiencies; however, effluent quality is not degraded appreciable during these events and the removal of TSS does occur. It is also worth evaluating how well the increased flows due to urbanization are mitigated.

CHAPTER 5: SUMMARY AND CONCLUSION

The quality of water in our nation's lakes and rivers has improved dramatically since the adoption of the NPDES program in the 1970's and the subsequent implementation of Phase I and Phase II in the 1980's. However, urbanization is spreading in cities across America, and impervious surface area is increasing dramatically. The amount of water entering streams and rivers from urban sources (such as parking lots and strip malls) during storm events is increasing and thus more pollutants are being carried into these water bodies.

In order to mitigate the increasing storm water pollution into receiving water bodies, many local and state agencies have begun developing and implementing storm water management plans. Many of these plans call for the use of storm water best management practices (BMPs), which may be either structural or nonstructural in nature. Structural small-footprint storm water BMPs are manufactured products that replace some part of the storm sewer system and provide primary treatment of storm water. The BMPs may or may not be patented, and are offered in a variety of shapes and sizes. They are designed to treat a wide range of flow sizes and to provide removal of TSS and other pollutants typically founding storm water.

This report focused on the comparison and evaluation of small-footprint structural BMPs specifically designed to remove sediment and floatables from storm water. The main objectives were identification of manufactured storm water BMPs currently on the market, identification of the main characteristics of each BMP, assessment of the pollutant removal efficiency of each product, and establishing which parts of each product, if any, are patented.

Small-footprint storm water BMP configurations fall in one of three categories: vertically cylindrical manhole, rectangular vault, and filter combinations. Although most companies offer a series of models that treat a pre-determined range of flow, the majority of the companies evaluated in this report prefer to design their systems on a case-by-case basis in order to provide the most efficient model for a given site. A total of well over 22,000 small-footprint storm water BMPs are installed nationwide and that number continues to grow. The overall cost of the BMPs range from $4,800 to $420,000. The majority of companies evaluated for this report claim their BMP product provides high removal efficiency of TSS from storm water, but through analysis of field studies, very few BMPs were found to consistently provide high pollutant removal efficiency.

The following sections are more in-depth analyses and observations of data from this report.

5.1 Efficiency Summary

Of the eighteen small-footprint storm water BMPs evaluated for this report, eight were cylindrical manhole configurations, six were horizontal vaults, and four were filter combinations. Nine BMPs were evaluated using field studies, and seven of those nine products are claimed to provide 80% removal of TSS. Seven BMPs did achieve 80% removal of TSS at the conclusion of at least one field study (some companies conducted several field studies). Tables 5.1 through 5.3 show each BMP in its respective configuration category and a summary of the field studies that were conducted.

Table 5.1 Vertically Cylindrical Manhole BMPs and Field Study Results

SYSTEM	FIELD STUDY TITLE	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
AquaSwirl	NA	NA	NA
BaySaver	"University of Maryland TSS Removal Study Review"	3	>80%
CDS	"Removal of suspended solids and associated pollutants by a CDS gross pollutant trap"	15	60.0%
	"The Use of a CDS Unit for Sediment Control in Brevard County"	5	50.0%
	"BMP Retrofit Pilot Program Final Report"	NA	0.75% 3.56%
Downstream Defender	"Downstream Defender Report Sections from Final Report for Onondaga Lake Nonpoint Source Environmental Benefit Project"	6	80.0%
EcoStorm	NA	NA	NA
Stormceptor	"Field Monitoring Results, City of Edmonton, Alberta"[1]	4	52.7%
	"Preliminary Field Monitoring Results Madison, Wisconsin"[2]	45	22.0%
	"Field Monitoring Results Westwood, Massachusetts"	3	93.0%
	"Como Park, Minnesota" Phase I[3]	3	80.0%
	"Como Park, Minnesota" Phase II	8	76.0%
	"Seatac, Washington"	4	87.0%
	"Greenwood Village, Colorado"[4]	12	50.3%
VortSentry	NA	NA	NA
V2B1	NA	NA	NA

The four highlighted rows in the Stormceptor® Field Study section were disregarded for analysis based on reasons discussed in Section 4.3.9.

Table 5.2 Horizontal Vault BMPs and Field Study Results

SYSTEM	FIELD STUDY TITLE	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
ADS Water Quality Unit	"Using a Pipe as a Storm Water Treatment Device" Ohio University Study	9	60.0%
CrystalStream Technologies	NA	NA	NA
Nutrient Separation Baffle Box	NA	NA	NA
StormGate Separator	NA	NA	NA
Stormvault	"Paratransit Bus Lot, Sacramento, CA"	8	51.0%
	"Albermarle County Office Building Parking Lot, Charlottesville, VA" Phase I[1]	5	25.0%
	"Albermarle County Office Building Parking Lot, Charlottesville, VA" Phase II	15	80.0%
Vortechs	"Vortechs Stormwater Treatment System"	20	81.6%

The Albemarle County field study was disregarded for further analysis because the influent TSS concentrations in this study were all less than 20 mg/L. Concentrations this low do not reflect how the BMP truly performs in the field.

Table 5.3 Filter Combination BMPs and Field Study Results

SYSTEM	FIELD STUDY TITLE	NO. OF STORM EVENTS	STUDY TSS REMOVAL EFFICIENCY
AquaShield - AquaFilter	NA	NA	NA
StormFilter	"Lake Stevens"[1]	1	76.0%
	"Monitoring of the Giles Street StormFilter"	6	59.5%
	"Monitoring of McDonald's, Vancouver"[1]	1	79.4%
	"Particle Size Distribution and Suspended Solids Removal at the Southwest Bible Church StormFilter"	2	84.5%
	"Heritage Marketplace Field Evaluation: Stormwater Management StormFilter with CSF Leaf Media"	3	87.0%
	"BMP Retrofit Pilot Program Final Report"	3	40.0%
StormScreen	NA	NA	NA
StormTreat	"Massachusetts (STEP) Technology Assessment, Kingston Site"	6	98.0%
	"Massachusetts (STEP) Technology Assessment, Greenfield Site"[1,2]	1	85.0%

The two studies highlighted in the StormFilter® section and the one study highlighted in the StormTreat™ section were all disregarded for further analysis because each study contained only one storm event. One storm event does not provide sufficient data for a complete analysis of a BMP and its pollutant removal efficiency.

As can be seen by the field study removal efficiencies, no one configuration works better than another one. The field study removal efficiencies in each category range from barely containing any sediment to removing over 80% of TSS in the influent storm water. Therefore, removal efficiency is more a function of BMP size than of inner components. In order to achieve removal efficiencies of 80% and greater, the BMP unit (regardless of configuration) must be large enough to provide an adequate detention time to allow the maximum number of particles to settle out. Many BMPs are sized just large enough to treat the average storm event for a given area when in reality, storm events with a wide range of intensities occur throughout the year. Therefore, the BMP must be sized big enough to hold larger storm events and to bypass as little influent as possible. In general, the larger the system, the greater the removal efficiency will be.

5.2 Field Study Reporting Requirements

Field studies may be conducted in a variety of ways to assess the ability of a BMP to reduce pollutant concentrations and loadings in storm water. However, in reviewing the field studies for this report, it is clear that inconsistent study methods, lack of information (about the product being tested, the test site, storm event data, etc), and reporting protocols make overall assessments difficult. Field data will be collected and analyzed in a variety ways, using different monitoring techniques, reporting styles, sampling methods, etc depending on the given conditions of the study. "The selection of techniques used at each site will be determined by local conditions, budgets, expertise of the investigators, and other factors impossible to predict in advance. Some level of consistency in how this data is reported will be needed if we hope to make any sense of it or hope to draw generalized conclusions over time (Urbonas, 1995)." One of the main goals of a field study is to determine the removal efficiency of the BMP, but the data from the study may also be used for comparison with other types of storm water BMPs to determine which characteristics of a BMP, if any, are more effective than others.

There is a need for a standard protocol that outlines what exactly needs to be measured, how it should be measured, and how it should be reported. The following is a list of minimum requirements of what should be reported in a field study:

1. Tributary watershed area, total percent imperviousness, and land use
2. Date and duration of storm events
3. Peak 1-h intensity, total depth and total runoff volume for each event
4. Number of bypassed flows during testing period
5. Type and frequency of maintenance
6. Type and location of monitoring instruments
7. BMP model used and hydraulic and treatment capacities of the model

8. Influent and effluent concentrations for constituents of concern
9. Pretreatment description if necessary
10. Method of determining percent removal
11. Problems encountered that may skew data

Inconsistencies also occur in the calculation and reporting of constituent removal efficiencies. Table 5.4, taken from a report written by Strecker, et.al. entitled "Determining Urban Storm Water BMP Effectiveness," shows three different approaches to calculating removal efficiency and the resultant variance in efficiency. The first approach ("Statistical Characterization of Inflow and Outflow Concentrations") is based upon individual storm pollutant concentration reductions and assumes all storms are equal in size. It is apparent this is not the case, as all storm volumes and their associated constituent concentrations are rarely equal. In Table 4.11, an evaluation of the influent concentrations and resulting loads shows the first storm event dated 5/24/99 and the second to last storm event dated 11/11/99 both contribute a large portion of the loading, yet their influent TSS concentrations are not very high.

"Based upon a national characterization of rainfall, if a basin were sized to have a permanent pool equal to the average storm volume from the watershed, about 60-70% of the storms would be less than this volume. Therefore, due to many storms not being large enough to displace the permanent pool volume, storm-by-storm comparisons are probably not valid (Strecker et.al. 2001)." It is more appropriate to utilize storm volumes when determining the overall loading into and out of the system, and base removal efficiency on loading calculations. The middle column of Table 5.4 entitled "Inflow and Outflow Pollutant Loads" uses this method to calculate removal efficiency. A comparison of removal efficiencies in Table 5.4 shows the first two to be almost equal; however, the efficiency associated with loadings in more accurate because it takes volume into account. The removal efficiency associated with the "Percent removal by storm" column is different by 17 percentage points and is clearly not accurate. The removal efficiency is calculated by averaging the removal efficiencies associated with each storm in the testing period.

Table 5.4 Comparison of BMP Pollutant Removal Efficiency Estimation Techniques (Strecker et.al. 2001)

Storm	Volume of flow (ft^3) [m^3(ft^3)] inflow = outflow	Pollutant Removal Estimation Technique: Statistical Characterization of Inflow and Outlfow Concentrations [mg/l]			Inflow and Ouflow Pollutant Loads [kg(lb_m)]		Percent removal by storm
			In	Out	In	Out	
1	12,609 (445,300)		352	24	4,436 (9,780)	304 (670)	93
2	18,400 (649,800)		30	25	553 (1,220)	458 (1,010)	17
3	12,915 (456,100)		99	83	1,279 (2,820)	1,070 (2,360)	16
4	9,857 (348,111)		433	141	4,268 (9,410)	1,388 (3,060)	67
5	20,678 (730,261)		115	63	2,376 (5,240)	1,302 (2,870)	45
		Median	139	65	Total In	Total Out	
		Coefficient of variation	1.48	0.86	12,914 (28,470)	4,522 (9,970)	
		Mean	249	85			
Pollutant Removal Estimation			66%		65%		48%

Note: 1 lb_m = 2.2046 kg and 1 ft^3 = 0.028317 m^3.

5.3 Conclusion

Storm water BMPs are manufactured products installed underground to remove TSS and other constituents from influent storm water. They are useful in urban environments where land is a commodity, and storm water is high in pollutant concentration. BMPs are designed either as a vertically cylindrical vault, a horizontal vault, or a filter combination. No one configuration provides better removal of TSS over another one. BMPs may have design components that target specific contaminants such as metals, nutrients, and microbes.

Field studies are the best means of determining how a BMP will perform once installed, and what removal efficiencies will be achieved under varying storm sizes and other unforeseen conditions. For a field study to be deemed complete, it must contain information that effectively characterizes the study site. The storm event data must be reported in a way that can be understood and used for additional analysis. A good field study will incorporate a large number of storm events (> 10) over a long testing period with a wide range of influent TSS concentrations, intensities and volumes. The BMP will also be better characterized if multiple field studies are conducted at different sites (across the nation).

It is best if researchers adopt a standard protocol for conducting field studies. The desire to fully understand storm water BMPs draws people to study and compare field studies; if studies have no similarities in approach and style, they are impossible to compare. The components listed in Section 5.2 are the minimum necessary items to be reported in a field study. Samples should be taken and composited into one EMC "in" and one EMC "out" per storm. The loading on the BMP can then be calculated by multiplying the EMC by the measured volume of runoff. The removal efficiency can be calculated using equation 4.2.

Overall, the field of storm water management is a necessary one that is designed to protect our nation's water bodies from the destructive nature of urbanization and increased population. Structural storm water BMPs are one of a number of best management practices utilized to mitigate the debilitating effects storm water pollution can have on receiving water bodies. Although not all BMP products meet the requirement of 80% removal of TSS, they do provide a definite amount of pollutant removal that would otherwise not occur if the BMP were not present.

Appendix A

Data Tables

Table A.1 Contact Information

Company Name	Web address	Contact Name	Phone Number	Email Address
ADS Water Quality Unit	http://www.ads-pipe.com	Brad Hunemuller	512-246-2966	brad.hunemuller@ads-pipe.com
AquaShield - AquaFilter	http://www.aquashieldinc.com/aquafilter.html	Shea Kent Eric Rominger	409-866-6702 888-344-9044	shea@mkmsales.com erominger@aquashieldinc.com
AquaSwirl	http://www.aquashieldinc.com/aquaswirl.html	Eric Rominger	888-344-9044	erominger@aquashieldinc.com
BaySaver	http://www.baysaver.com	Austin Meyermann	301-829-6470	ameyermann@baysaver.com
CDS	http://www.cdstech.com	Thomas Fletcher	1-866-272-0290	tfletcher@cdstech.com
CrystalStream Technologies	www.crystalstream.com	John Moll	800-748-6945	johnmoll@crystalstream.com
Downstream Defender	http://www.hydrointernational.biz/nam/ind_storm.html	Pamela Deahl	207-756-6200	pdeahl@hil-tech.com
EcoStorm	http://www.royalenterprises.net/ecoT/products/ecoStorm.html	Jeff Sievers	800-817-3240	jeffs@royalenterprises.net
Nutrient Separation Baffle Box	http://www.biocleanenvironmental.net		321-637-7552	
Stormceptor	http://www.stormceptor.com/index.php	Ken Waite	832-590-5405	kwaite@rinker.com
StormFilter	http://www.stormwaterinc.com/	Scott Love	214-734-9109	scottl@stormwaterinc.com
StormGate Separator	http://www.stormwatermgt.com/products/stormfilter.shtml	Sean Darcy	800-548-4667 x105	seand@stormwaterinc.com
StormScreen	http://www.stormwatermgt.com/products/stormfilter.shtml	Sean Darcy	800-548-4667 x105	seand@stormwaterinc.com
StormTreat	http://www.stormtreat.com/home.htm	Roy Perry	877-787-6426	royperry63@aol.com
Stormvault	http://www.stormvault.com	Steven Phelps Scott Aston	775-352-6329 800-526-3999	SPhelps@jensenprecast.com saston@con-span.com
Vortechs	http://www.vortechnics.com/products/vortechsystem.html	Vaikko Allen	207-885-9830 x275	vallen@vortechnics.com
VortSentry	http://www.vortechnics.com/products/vortsentry.html	Vaikko Allen	207-885-9830 x275	vallen@vortechnics.com
V2B1	http://www.env21.com/	Mike Patterson	585-762-8314	envengr@env21.com

Table A.2a: General Description of Treatment Technology and Patent Number, ADS thru ecoStorm^{TM}

SYSTEM	SYSTEM DESCRIPTION	PATENTED PART	POLLUTANTS POTENTIALLY REMOVED	POLLUTANT REMOVAL MECHANISMS
ADS Water Quality Unit	HDPE horizontal cylinder with three chambers and two manhole access risers. In the first chamber, water enters and particles settle out. The water must rise over a weir to get into the second chamber which contains the floatables and oil/grease. Water must travel under a third weir to leave the system. 16 flow sizes.	NA	Sediments, floatables, and oil/grease	Gravity settling, weirs to prevent floatables from leaving system
AquaShield - AquaFilter	Two chamber system. First chamber utilizes Aqua-Swirl technology to collect floatables and to settle out heavy particles. Vortex separation accelerates gravitational separation. A pipe takes the water from the first chamber to the second. The Aqua-Filter in the second chamber removes finer sediment and water-borne pollutants with media filtration technology. 8 flow sizes	US 6,190,545	hydrocarbons (i.e. light and heavy oils and grease); phosphorus, and various heavy metals (i.e. copper, zinc).Fine sediments and water-borne pollutants.	Vortex separation to accelerate gravitational separation, bypass to prevent resuspension of sediments, followed by second chamber to remove fine sediment.
AquaSwirl	Circular manhole, utilizes swirl-flow technology to settle out small particles. Baffle wall separates floatables from the outlet pipe. Treated water exits the treatment chamber through a flow control orifice located behind the baffle wall. 9 flow sizes	US 6,524,473	TSS, sediments, oil and grease, and trash debris	Swirl technology to enhance removal of sediments in small space, baffle wall to contain floatables.
BaySaver	Consists of two standard manholes. The first is for removal of sediment and separation of floatables, which are diverted by a special device into the second manhole for storage. Diversion device also passes extreme flows to bypass through the unit. Five flow sizes.	US 5,746,911	Floatables including oil/grease and trash, particulate pollutants.	Gravity settling, bypass to prevent resuspension of sediments, protection of floatables by movement to a second manhole.
CDS	Circular device; flow is directed to create circular flow like a vortex, but removal occurs as the water passes through a screen around the outer perimeter. Removal induced by countercurrent flows on opposite sides of the screen, which also prevents clogging of the screen. 19 flow sizes, 27 models	US 5,788,848 US 6,511,595 B2	TSS, sediments, oil and grease, and trash debris	Trapping of floatables and sediments by differential velocities created by a countercurrent flow next to a screen
CrystalStream Technologies	Rectangular box . The tank stays full of water at all times, water flows trhough a series of baffles to slow water and ensure oil gathers at top. Removal at entrance pipe by a mesh basket to collect debris. Water passes through a filter on exit to remove the smaller floating materials.	Patent Pending - will be issued fall of 2004	Floatables including oil/grease and particulate pollutants	Gravity settling, wire baskets to remove the large debris, coconut fiber filter to remove the small particles.
Downstream Defender	Single manhole with inner cylindrical chamber. Flow is introduced tangential into the side of the vessel, spirals down around inner chamber wall, then spirals up inner chamber and out through outlet pipe. Particulates settle out by means of vortex action and gravity. Floatables and oils are trapped between manhole wall and chamber wall. 4 model sizes. Designed for removal efficiency of 90% for all grit particles down to 150 microns and specific gravity of 2.65.	US 5,188,238	Floatables including oil/grease and particulate pollutants	Advanced swirl technology to enhance removal of fine sediments in small space and prevent pollutant washouts over a wide flow range.
ecoStorm	Consists of 2 circular concentric precast structures: An outer structure forms the swirl-chamber/vortex separator, the inner cylinder serves as a floatables collection chamber and outlet chamber. 5 model sizes	Patent Pending	Floatables including oil/grease and particulate pollutants	Swirl technology to enhance removal of sediments in small space.

Table A.2b General Description of Treatment Technology and Patent Number, Stormceptor® thru StormScreen™

SYSTEM	SYSTEM DESCRIPTION	PATENTED PART	POLLUTANTS POTENTIALLY REMOVED	POLLUTANT REMOVAL MECHANISMS
Stormceptor	Comprised of a round precast concrete tank and fibreglass partition, it replaces a maintenance hole in the storm sewer. Treatment is based on gravity separation and an oil-grit separator. Water flows in and is directed down into the chamber. Gravity settles out particles and oil/grease floats to top and is blocked by a fibreglass partition from going higher. The outlet riser pipe is submerged ~400mm below the level of insert pipe to keep oil and grease from escaping into the effluent.	US 4,985,148 US 5,725,760 US 5,498,331 US 5,849,181 US 5,753,115 US 6,068,765	Floatables including oil/grease and particulate pollutants	Gravity settling enhanced by improved hydraulic conditions in what is essentially a large manhole.
StormFilter	Vertical cylinder with media of various types placed in rectangular vault. Composed of three bays: the inlet bay, the filtration bay, and the outlet bay. Water enters laterally through the filter, the treated water then goes through the vertical center well which exits to an underdrain system. One standard size cylinder (15 gpm, 0.033cfs). Number of cylinders is a function of design peak flow. Pretreatment desirable under circumstances as defined by the manufacturer. It is offered in five basic configurations: precast, linear, catch basin, manhole, and cast-in-place.	US 5,322,629 US 5,624,576 US 5,707,527 US 6,027,639 US 6,649,048	Varies with the filter media used. Removes: sediments, oil/grease, soluble metals, organics, total and dissolved phosphorous, total nitrogen, dissolved ammonium. All reduce particulate pollutants down to 10-15 um range.	Gravity settling, variety of filtration media to treat TSS, dissolved metals and nutrients
StormGate Separator	Rectangular vault divided to create an inlet chamber, two settling chambers and an outlet chamber. An overflow weir is placed between the inlet and outlet chamber to control flows in excess of peak design flow. Baffle system in the vault allows for longer settling times. Works offline.	No patents held	Sediments and grease/floatables	Gravity settling to remove solids. Grease and floatables stay at top of water.
StormScreen	Vertical cylinder with stainless steel screen assembly placed in rectangular vault. Water enters laterally through the filter, the treated water then goes through the vertical center well which exits to an underdrain system. One standard size cylinder (0.5cfs). Number of cylinders is a function of design peak flow.	US 5,322,629 US 5,624,576 US 5,707,527 US 6,027,639 US 6,649,048 ** Patents same as StormFilter. The same technology is used for both filtration mechanisms	Trash, debris and some fine sediment. The cartridge screen has a pore opening of 2.5 mm (2400 microns) which ensures the capture of all solids of greater size.	Gravity settling, filtration of trash and debris by stainless steel screen assembly

Table A.2c General Description of Treatment Technology and Patent Number, StormTreat™ thru V2B1

SYSTEM	SYSTEM DESCRIPTION	PATENTED PART	POLLUTANTS POTENTIALLY REMOVED	POLLUTANT REMOVAL MECHANISMS
StormTreat	Circular device consisting of two circular chambers; a closed inner chamber for settleables and floatables, and an open outer chamber with wetland vegetation that is supported in gravel. One size, about 9.5' diameter, off-line unit with live volume of 1,490 gallons. Fills during each storm, slowly drains after storm in 5 to 10 days. Several units placed together with flow manifold to match design flow. Pretreat to remove gross solids is required. Up to 2 units treats one acre of impervious surface.	US 5,549,817	Particulate and dissolved pollutants, oil/grease, and bacteria.	Gravity settling, filtration of TSS by screens and soil that supports wetland vegetation that also removes dissolved metals and phosphorus by adsorption or ion exchange. Nutrient uptake by the vegetation.
Stormvault	Rectangular vault designed to mitigate downstream erosion and watershed degradation through volume-control-based treatment that retains and slowly meters out the flow from each storm event. Design is based on size of drainage area and volume of storm events for that area.	US 6,350,374	Trash, debris, oil/grease, detention time is optimized to promote sedimentation of particles less than 100 microns	Sedimentation
Suntree Technologies - Nutrient Separation Baffle Box	Rectangular vault with a screen that extends almost entire length of vault to catch and contain vegetation and litter; series of three chambers below screen that accumulate sediment. The top of each chamber wall is level with the bottom invert of the inlet and outlet pipes so water and sediment are retained in each chamber between storms, but vegetation on screen is above water level so it dries out.	Could Not Find	Trash, debris, oil/grease, sediments	Gravity settling for particulates, long screen located above chambers to contain trash and vegetation and prevent decay
Vortechs System	Rectangular vault with swirl-flow device to contain sediment followed by oil baffle wall to contain oil, followed by baffle for low- and high-flow control. Comes in nine standard sizes.	US 5,759,415	Floatables including oil/grease and particulate pollutants	Swirl technology to enhance removal of sediments in small space, oil baffle wall to contain floatables.
VortSentry	Circular manhole, utilizes swirl-flow technology to settle out small particles. Baffle wall separates floatables from the outlet pipe. Treated water exits the treatment chamber through a flow control orifice located behind the baffle wall. Eight models	patent pending	Trash, debris, oil/grease, sediments	Swirl technology to enhance removal of sediments in small space, oil baffle wall to contain floatables. Includes an internal bypass.
V2B1	Two manholes in series. Swirl flow concentration removes particulates and floatables in first manhole. Floatables move to chamber in second manhole for storage. Diverter in first manhole bypasses high flows from first to second manhole. This product is designed based on Peak Flow Rate (PFR) of 0.70 cfs per impervious acre and the impervious acreage of the site, not on cfs alone. Seven models.	US 6,120,684	Floatables including oil/ grease and particulates	Swirl technology and gravity settling for removal of particulates, containment of floatables and oils

Table A.3a Engineering Data, ADS thru StormGate Separator™

SYSTEM	SURFACE OR SUBSURFACE	TREATMENT FLOW CAPACITIES [cfs]	HYDRAULIC FLOW CAPACITIES	GENERAL CONFIGRUATION	SPACE USED (+)[2] Dia x D or W x L x D
ADS Water Quality Unit	Subsurface	0.7, 0.86, 1.13, 1.47, 1.5, 1.6, 1.73, 1.83, 2.26, 2.39, 2.95, 3.12, 3.2, 3.66, 4.78, and 6.23 cfs 16 models	Same as treatment flow capacities.	Horizontal cylinder with three chambers. 3' to 5' diameters	Min: 3' x 20' Max: 5' x 40'
AquaShield - AquaFilter	Subsurface	0.5, 1, 1.5, 2.5, 3.0, 4.0, 5.0 and 6.0 cfs	1.8, 3.0, 4.25, 6.25, 8.5, 11.0, 14.0 and 17.5 cfs	Two chambers. Swirl chamber 2.5' to 12' diameter. Filter chamber 6.7' dia x 9.6' to 36' length	Min: 6.7' x 9.6'[15] Max: 6.7 x 36'[15]
AquaSwirl	Subsurface	1.0, 3.0, 4.5, 6.5, 8.5, 11.0, 14.0, 17.5 and 25.2 cfs offline	Same as treatment flow capacities.	Circular manhole	Min: 2.5' x 3' Max: 12' x open
BaySaver	Subsurface	1.1, 2.4, 7.8, 11.1, and 21.8 cfs	8.5, 10, 30, 50, and 100 cfs	Two circular manholes, 4' to 6' diameters	Min: 10 x 14 x 4 Max: 13 x 18 x 8
CDS	Subsurface	0.7 to 6 cfs online 2 to 64 cfs offline 148 to 300 cfs offline and cast in place 27 total models	varies with each site-specific project	Circular manhole	Min: 4.8' dia Max: 17.5' dia precast 41' dia cast in place
CrystalStream Technologies	Subsurface	1.2, 2.5, 3.5, 4.8, 6.0, 7.2 cfs 6 models[14]	6.0, 12.5, 17.5, 9.6, 30.0, 36.0 cfs[14]	Rectangular vault	Min: 5' x 6' x ? Max: 8' x 14' x ?
Downstream Defender	Subsurface	3, 8, 15, and 25 cfs.	3, 8, 15, and 25 cfs	One circular manhole vault, 4' to 10' diameters	Min: 6' x 8' Max: 12' x 15'
EcoStorm	Subsurface	2, 3, 4, 5.5, and 7 cfs	8, 12, 16, 22, and 28 cfs	One circular manhole vault, 6' to 12' outside diameters	Min: 6' x 10' Max: 12' x 10'
Stormceptor	Subsurface	0.28, 0.64, 1.06, 1.8, 2.4 cfs 9 models	Available height over weir and the storm drain	One circular manhole vault, 4' to 12' diameters	Min: 4' x 5' to 5.75' Max: 12' x 15.5'
StormFilter	Subsurface	Precast: 0.033 to 4.22 cfs Linear: 0.033 to 0.27 cfs Catch Basin: 0.033 to 0.13 cfs Manhole: 0.10 cfs Cast in place: 0.8 cfs to >8 cfs ** each cartridge treats 0.033 cfs. Calculations are given to determine the # of cartridges needed	Precast: NA Linear: 1.3 cfs Catch Basin: 1.0 cfs Manhole: 1.0 cfs Cast in place: NA	Cylinder cartridges placed in rectangular vault	Precast Min: 7'x 9'x 4.5'(1) ** Max: 10'x 64'x INF (128)** Linear Min: 3' x 10' x 3.5' (1)** Max: 3' x 20' x 5.5' (8)** Catch Basin Min: 4'9"x 2'5"x 2.3' (1)** Max: 10'8" x 2'5" x 3.3' (4)** Manhole: 48" dia x 5' and up Cast in Place Min: 12'x41'x 6' (24)** Max: 21.5' x 85' x INF (320)**
StormGate Separator	subsuface	0.86, 1.17, 2.03, 2.46, and 2.89 cfs[8]	1.68, 2.01, 3.14, 3.58, and 4.03 cfs	Rectangular vault with baffles to lengthen detention time	Min: 6' x 10' x 5.5' Max: 8' x 18' x 6.5'

Table A.3b Engineering Data, StormScreen™ thru V2B1

SYSTEM	SURFACE OR SUBSURFACE	TREATMENT FLOW CAPACITIES [cfs]	HYDRAULIC FLOW CAPACITIES	GENERAL CONFIGRUATION	SPACE USED (+)[2] Dia x D or W x L x D
StormScreen	Subsurface	Precast: 0.5 to 10 cfs Cast-in-Place: > 10cfs 0.5 cfs / cartridge	NA	Cylinder cartridges placed in rectangular vault	Precast Min: 6' x 12' x 5' (<8)** Max: 8' x 16' x 20' (9-20)** Cast-in-place; Multiple precast units: size varies (WxL) x 4' (>20)**
StormTreat	Surface	7,000 gallons/unit	NA (offline)	Circular	9.5' x 4'
Stormvault	Subsurface	Each configuration holds the entire storm runoff and slowly meters it out	NA (offline)	Rectangular Vault	Min: 12' x 24' x 6' Max: open[17]
Suntree Technologies - Nutrient Separation Baffle Box	Subsurface	12, 31.2, 46.2, 61.2, 64.8, 97.2 cfs. Seven models.[10, 11]	Same as treatment flow capacities.	Rectangular Vault	Min inside dimensions: 4' x 8' x 7' Max inside dimensions: 8' x 14' x 8'
Vortechs	Subsurface	1.6 to 25 cfs nine models	1.6 to 25 cfs[7]	Rectangular vault	Min: 3' x 9' x 7' Max: 12' x 18' x 8'
VortSentry	Subsurface	0.3 to 11.9 cfs eight models	1.2 to 47.6 cfs[12]	Circular manhole	Min: 3' x 5.4' [13] Max: 12' x 16.5' [13]
V2B1 [16]	Subsurface	0.21 to 8.19 cfs[16] seven models	1.0 to 38.0 cfs	Two circular manhole vaults, 4' to 12' inner diameter	Min Sump Depth: 4' x 7' +/- Max Sump Depth: 12'x 11' +/-

1. Some of the enclosed information provided by personal communication and is not present in the manufacturer's brochure material.
2. For subsurface product, excludes riser to surface, which is variable, excludes ballast.
3. Of the heaviest component of each model delivered to the site, which in many cases is the entire unit preassembled. Excludes ballast.
4. Range of maximum heads required by the various models of each product.
5. Variable depth for the 3 largest units which are cast in place.
6. Assuming 24" pipe.
7. This is the capacity at 100 gpm/ft2. However, each model is able to pass a somewhat higher, unstated, flow as the water is able to rise an additional 3 inche top of the flow control wall.
8. Flow rate at 80% removal
9. Based on Hydraulic Loading Rate (HLR) of 0.028cfs/ft2
** (#) number of cartridges in vault
INF - infinity, no limit on vault depth
10. Because the entire flow is always treated and head loss is so minimal, determining the appropriate size of Nutrient Separating Baffle Box for a project is more an element of pipe size than treated cfs.
11. Flow rate based on 6 feet per second flow multiplied by the minimum bypass available.
12. Typical hydraulic capacities for the systems will be four times theWater Quality Flow Rate but can be adjusted to meet specific site requirements.
13. Depth is measured from below the invert
14. Crystal Stream Technologies are designed based on local water quality criteria. These numbers are national averages.
15. Length of cylinder on its side
16. V2B1's treatment sizing is based on the impervious acreage of the site and a Peak Flow Rate (PFR) of 0.70 cfs per impervious acre. This PFR is based or
17. The vault's length can be increased in 8-foot increments. Slanted bottom baffles are spaced at 8- to 16-foot intervals and are added as the vault's length is

Table A.4 Installation Status

SYSTEM	# INSTALLED	TXDOT PROJECT?	OTHER DOTs	OTHER ROAD SYSTEMS
ADS Water Quality Unit	32 in place, over 200 units specified	X	X	8 in Texas, most in the Houston area - most are commerical applications - apartment complexes, car dealerships, etc.
AquaShield - AquaFilter	more than 100 systems	0	X	"several are in the design stages in Texas"[1]
AquaSwirl	more than 450	X	X	209 are in the design stage or are ready to be installed
BaySaver	1000	0	X	12 in Texas - airport in Houston, resedential, commercial and schools. Approved by TxDOT
CDS	>1900	2 are considering it (Rockwall and Houston Districts)	CA, FL, MN, NV, NY, NC, OR, VA	X
CrystalStream Technologies	400	0	N and S Carolina Tennessee	resedential, subdivisions
Downstream Defender	1000 +	0	NH, ME, VT, CN, RI, MA, NY, NJ, MN, MI, VA, OR, WA	Numerous
EcoStorm	90 +	0	10%	X
Nutrient Separation Baffle Box	NA	NA	NA	NA
Stormceptor	11,500	12	50 Ohio, Connecticut, Washington Texas, Oregon, Massachusetts	yes
StormFilter[2]	2,500	0	0	78
StormGate Separator[2]	100	0	0	CA, CO, CN, NJ, OH, NV, MD, MA, GA, DE, OR, PA, VA, WA 6 in Tx
StormScreen[2]	27	0	0	2 in TX, CA
StormTreat	~ 200 systems[3]	0	yes Massachusetts, New Hampshire, Maine	yes, installed in 18 states
Stormvault	30	0	0	CA, NV, WA, VA
Vortechs	3000+	0	17 Connecticut, Maine, Minnesota, New Hampshire, New Jersey, New York, Ohio, Washington etc.	yes
VortSentry	50+	0	Maine	yes
V2B1	over 400	0	NT, IL, CN, and others	yes

1. Quoted per email dated 4/23/04 from Shea Kent, Regional Sales Rep 2. Numbers current as of 6/11/04 3. Estimation per conversation with Roy Perry, Distributor 4. Quoted per email from Steven Phelps, Stormwater Project Manager

Table A.5a Maintenance Information, ADS thru StormScreen™

SYSTEM	TREATMENT FLOW CAPACITY RANGES	MANUFACTURER'S RECOMMENDATIONS	STORAGE CAPACITIES[1]		CLEANOUT AT % OF SUMP CAPACITY[4]
			SEDIMENT ft^3 [2]	FLOATABLES gallons	
ADS Water Quality Unit	0.7 to 6.23 cfs	Frequent observations during first year to determine frequency. Clean sump when depth of sediment has reached approximately 25% of the diameter of the structure.	22.97 to 384.44 ft^3	8.66 ft^3 to 205.15 ft^3	20%
AquaShield - AquaFilter	0.5 to 6.0 cfs	Frequent observations during first year to determine frequency.	10 to 180 ft^3	37 to 1,130 gallons	50%
AquaSwirl	1.0 to 25.2 cfs	Frequent observations during first year to determine frequency.	10 to 270 ft^3	37 to 1,698 gallons	50%
BaySaver	1.1 to 21.8 cfs	Inspection of the system is recommended quarterly for the first year or more to determine the appropriate cycle based on site characteristics.	50 to 200 ft^3 [5]	280 to 1,110 gallons	25%
CDS	0.7 to 300 cfs.	Clean sump seasonally four times per year and inspect screen annually. Clean sump when 85% full or if floatables exceed 2' thickness	29.7 to 350 ft^3	101 to 28,836 gallons	75%
CrystalStream Technologies	1.2 to 7.2 cfs	Inspect quarterly and clean out at most every six months through a locked access lid on top of the device. Company does their own maintenance on products.	24 to 144 ft^3	300 to 2,000 gallons	20%
Downstream Defender	3 to 25 cfs.	Quarterly observations during first year to determine frequency, then at least once a year cleanout.	19 to 235 ft^3	70 to 1050 gallons	100%
EcoStorm	2 to 7 cfs	The frequency of pump-out is based on the site loading, periodic monitoring and measurements of captured pollutant levels in the sediment and floatable containment chambers.	X	X	X
Nutrient Separation Baffle Box	12 to 97.2 cfs	X	68 to 400 ft^3	11.8 to 123.7 ft^3 [7]	X
Stormceptor	0.28 to 4.94 cfs	Annual with observation as to whether frequency should change. Remove when sediment exceeds 15% of sump	45 to 828 ft^3	85 to 1,096 gallons	0.14 to 0.28[7]
StormFilter	0.033 cfs to >8 cfs	Replace cartridges annually	NA as maintenance frequency driven by cartridges rather than sediment accumulation in vault. Generally, the hydraulic action of the cartridge will tend to prevent accumulation of sediment immediately around the cartridge base (Lenhart, pers. comm.)		
StormGate Separator	0.86 to 2.89 cfs	Remove when 6" of sediment has accumulated	60 to 288 ft^3	225 to 759 gallons	cleanout when sediment volume reaches 6" height
StormScreen	0.5 to >10 cfs	Replace cartridges annually	NA as maintenance frequency driven by cartridges rather than sediment accumulation in vault. Generally, the hydraulic action of the cartridge will tend to prevent accumulation of sediment immediately around the cartridge base (Lenhart, pers. comm.)		

Table A.5b Maintenance Information, StormTreat™ thru V2B1

SYSTEM	TREATMENT FLOW CAPACITY RANGES	MANUFACTURER'S RECOMMENDATIONS	STORAGE CAPACITIES[1]		CLEANOUT AT % OF SUMP CAPACITY[4]
			SEDIMENT ft^3, [2]	FLOATABLES gallons	
StormTreat	7,000 gallons/unit	Annual inspection, remove sediment from the StormTreat when it reaches 6" in depth. Manufacturer suggests major suction or vacuum pumping of solids every 3 to 5 years.	Storage volume not defined. There is about 25 ft^3 in the bottom of the center well beneath the invert of the inlet that can serve as sediment storage. The unit should be preceded by a manhole with sump to remove coarse sediments, as suggested in manufacturer's specification sheet.		
Stormvault	NA	Twice yearly observation, inspection of the hydrocarbon mats on a yearly basis. Remove sediment when it reaches 6" depth. The mats may collect some surface sediment (mud) however, only when they change to a solid dark color uniformly throughout the granular medium do they need to be replaced.	min: 120 ft^3 max: open	X	6" depth
Vortechs	1.6 to 25 cfs	Make quarterly inspections during first year and set frequency accordingly	20 to 189 ft^3	110 to 840 gallons	0.5 to 0.95[6]
VortSentry	0.3 to 3.9 cfs	Make quarterly inspections during first year and set frequency accordingly	22 to 340 ft^3	75 to 4480 gallons	20 - 50%
V2B1	0.21 to 8.19 cfs	During first year, inspect in February, May and October. Set frequency accordingly.	37.8 to 513 ft^3	X	30%

1. Some of the enclosed information provided by personal communication and is not present in the manufacturer's brochure material.
2. The capacity at the point of recommended maintenance. Total capacity is determined by dividing the volume in this column by the % value in the last column in the table.
3. Unit capacities do not necessarily increase with increasing capacity depending on the particular product; most decrease with increasing model size.
4. When the unit is cleaned as a percentage of the total sump volume.
5. Based on data from Tables A2 and 3.4, not D2, in the Technical and Design Manual, and letter to RPA of 1/26/99 with recommendation that unit be clean when 2' of sediment has accumulated.
6. Storage area is below the vortex unit.
7. These numbers represent basket storage volumes, which can hold trash and vegetation. Oil/grease will float atop the water.

Table A.6 Cost Information

SYSTEM	TREATMENT FLOW CAPACITIES	RANGE OF PRODUCT COST	RANGE OF INSTALLATION COST OR PERCENTAGE	TOTAL COST (with Construction)
ADS Water Quality Unit	0.7 to 6.23 cfs	$5,000 to $10,000	product cost x 1.8	$9,000 to $18,000
AquaShield - AquaFilter	0.50 to 6.0 cfs	$25,000 to $110,000	$5,000 to $10,000	$30,000 to $115,000
AquaSwirl	1.0 to 25.2 cfs	$5,000 to $40,000	$5,000 to $10,000	$10,000 to $50,000
BaySaver	1.1 to 21.8 cfs	$4,350 to $16,040	approx 100%	$10,700 to $35,040
CDS	0.7 to 300 cfs	$6,900 to $128,000 (64cfs)	$2,400 to $115,000 (offline unit, includes diversion structure)	$9,300 for smallest unit; $243,000 for the largest unit.
CrystalStream Technologies	1.2 to 7.2 cfs	$9,000 to $20,000	< $1,500	$10,000 to $48,000
Downstream Defender	3 to 25 cfs.	$10,200 to $38,0003	50% to 75%	$15,000 for smallest unit; $57,000 for the largest unit.
EcoStorm	2.0 to 7.0 cfs	$7,500 to $15,000	NA	
Nutrient Separation Baffle Box	12 to 97.2 cfs	NA	NA	
Stormceptor	0.28 to 2.4 cfs	$4,500 to $65,000	1/3 of purchase price	$5,985 to $86,450
StormFilter	0.033 cfs to >8 cfs	$4,000 to $350,000	20%	$4,800 to $420,000
StormGate Separator	0.86 to 2.89 cfs	$9,000 to $40,000	20%	$10,800 to $48,000
StormScreen	0.5 to >10 cfs	$7,000 to $150,000	20%	$8,400 to $180,000
StormTreat	7,000 gallons/unit	$6,700/unit	$2,000 to $3,000	$8,000-$10,000/unit
Stormvault	NA	$25,000 and up	Site Specific	
Vortechs	1.6 to 25 cfs	$10,500 to $40,000	25% to 50%	$13,125 to $60,000
VortSentry	0.3 to 11.9 cfs	$5,000 to $30,000	25% to 50%	$6250 - $45,000
V2B1	0.21 to 8.19 cfs	$7,500 to $40,000	Site Specific	

1. Excludes costs associated with excessive excavation depths, non-normal construction problems, and other than normal ballast requirements; some of the enclosed information provided by personal communication and is not present in the manufacturer's brochure material.
2. Costs for retrofits; installations in new drainage systems may be less.
3. Standard delivery costs
4. Excludes delivery costs.
5. Delivery to California.
6. A general average provided by Storm water Management.

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