NJCAT TECHNOLOGY VERIFICATION

StormVault^{TM}

Jensen Water Resources

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1. Introduction

1.1 New Jersey Corporation for Advanced Technology (NJCAT) Program

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

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

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

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

The PPA also requires that:

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

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

1.2 Interim Certification

The StormVault^{TM} is a best management practice (BMP) designed to meet federal, state, and local requirements for treating stormwater runoff in compliance with the Clean Water Act. The StormVault^{TM}, a detention and sedimentation vault, is a patented water quality improvement device applicable for treatment of stormwater in a variety of development situations. In June of 2005, the StormVault^{TM} was accepted into the NJCAT Verification Program after completing the initial application and screening process. The performance claims made in the 2005 submittal were supported by field performance data collected during 15 storm events at an office park site in Charlottesville, Virginia. On December 11, 2005 NJCAT issued a verification report indicating that sufficient data was available to support the original performance claims for the StormVault^{TM} (NJCAT 2005). However, since the field testing did not meet all of the requirements of the TARP Tier II Stormwater Protocol and the New Jersey Tier II Stormwater Testing requirements, NJCAT recommended an interim certification thus necessitating additional field monitoring.

In 2005 CONTECH® Construction Products Inc. acquired BridgeTek and CON/SPAN, which resulted in the StormVault^{TM} being added to the CONTECH Stormwater Solutions product portfolio. CONTECH Stormwater Solutions recognized that additional field performance data had become available since the time of the original StormVault^{TM} submittal that would likely create a complete data set satisfying the TARP and NJDEP Tier II testing requirements. Accordingly, CONTECH Stormwater Solutions asked that NJCAT/NJDEP delay the interim certification of the StormVault^{TM} until CONTECH reviewed the additional data to determine if final certification may be warranted. CONTECH Stormwater Solutions has since completed a thorough evaluation of the additional field monitoring data and feels the combined data set satisfies both the TARP (2003) and NJDEP (2006) Tier II requirements.

CONTECH has submitted a document that serves as an amendment to the original submittal to NJCAT in June of 2005 that was subsequently verified in December of 2005. Additional performance data collected in Charlottesville, Virginia during 2002-2003 has been pooled with the data collected in 2001 at the same location. Monitoring at the Charlottesville site was conducted in accordance with the Sacramento Stormwater monitoring guidelines for proprietary devices, which are similar to those in the TARP Tier II Protocol but differ slightly with regard to data qualification. However, the pooled dataset was reviewed by CONTECH against the TARP and NJDEP Tier II data quality objectives, resulting in 34 qualifying storm events. Of the 24 storm events that were deemed non-qualifying, 21 failed to meet the minimum storm coverage criteria and 3 failed to meet the minimum event depth criteria. Therefore, CONTECH has decided to submit the data sets for NJCAT verification.

1.3 Applicant Profile

CONTECH offers a range of stormwater treatment products including filtration, hydrodynamic separation, volumetric separation, detention/retention, screening, oil/water separation, and flow control technologies. A knowledgeable team of 200 professionals across the U.S. provide the engineering and customer service support to determine a project's most appropriate stormwater treatment system that meets the requirements of the relevant permitting jurisdiction.

At CONTECH's state-of-the-art laboratories, engineers and scientists conduct ongoing research to further the understanding of non-point source pollution and develop practical product solutions. CONTECH helps its customers achieve their water quality goals by providing treatment technologies that remove a variety of pollutants from stormwater runoff. These stormwater treatment products are specifically designed to meet federal, state, and local regulations.

Former CONTECH subsidiaries Vortechnics (2004) and Stormwater Management, Inc. (2005) combined to form Stormwater360 (2006), and later became CONTECH Stormwater Solutions, Inc., a division of CONTECH Construction Products Inc. In December 2006, CDS Technologies, Inc. was added into CONTECH Stormwater Solutions product offerings.

CONTECH Stormwater Solutions has four primary regional offices that service their customers.

Ohio (Headquarters)
9025 Centre Pointe Drive, Suite 400
West Chester, OH 45069
800-395-0608

Maryland
521 Progress Drive, Suite H
Lithicum, MD 21090
866-740-3318

Maine
200 Enterprise Drive
Scarborough, ME 04074
877-907-8676

Oregon
12021-B NE Airport Way
Portland, OR 97220
800-548-4667

California
16360 S. Monterey Rd, Suite 250
Morgan Hill, CA 95037
800-469-7162

The managers of CONTECH Stormwater Solutions, Inc. are Rick Stepien – President, James Lenhart – Chief Technical Officer, and Tom Slabe – Vice President of Marketing.

1.4 Key Contacts

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2. StormVault™

2.1 Technology Description

2.1.1 Technology Status

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

The nature of pollutants emanating from differing land uses is very diverse. The StormVault™ is a multi-baffled vault structure designed to remove sediment, oil and grease and various other contaminants from stormwater runoff. It is a detention and sedimentation vault, which makes use of a permanent pool. Between maintenance events, pollutants accumulate within the system and are therefore removed from the natural environment. These pollutants may otherwise become a human health hazard, an aesthetic issue or may be cycled within the food chain or water table even if trapped in a land based treatment system. Maintenance is performed from above by lowering a nozzle and hose into each chamber and pumping the collected materials into a vacuum truck.

General

In 1998, Jensen Precast, a manufacturer of concrete vaults and other precast concrete products, decided to pursue the development of a stormwater treatment vault that would produce effluent quality comparable to surface extended detention basins and retention ponds (WWE, 2002). Jensen was aware of the limitations inherent in the competing product lines offered at that time and wanted to address them directly. Their first step was to hire four independent consulting teams. Ben Urbonas, P.E., of Denver, Colorado was contracted to act as the senior advisor and reviewer of various concepts and technical products that would emerge during the vault's development. Wright Water Engineers, Inc. was contracted to work out the design details and to develop user software for sizing and selecting the product. Dr. Steve Abt and Thomas Brisbane of Colorado State University (CSU) and their team of hydraulic specialists were contracted to build and test scale models of the concepts that emerged. Dr. Shaw Yu and Elizabeth Fassman of the University of Virginia (UVA) provided periodic peer review, commented on the model testing at CSU and assisted with preparation of a monitoring program for field prototypes and field testing in Virginia. All of the researchers were cognizant of the desirable characteristics of underground treatment vaults, including:

- Provision of adequate residence time for dynamic settling.
- Minimization of re-suspension of trapped sediments.
- Provision of adequate storage volume to provide treatment for a majority of runoff events.
- Attenuation of peak flows associated with urbanization.

Based on these considerations, the developers' objective was to accomplish both pollutant removal (primarily for settleable solids and petroleum hydrocarbons) and peak flow attenuation.

At the CSU hydraulics laboratory, 14 test runs were made with a model of a vault that had a 16-foot distance (prototype dimension) between the inlet and the outlet bottom baffles. These test runs were used to optimize the hydraulic performance, including maximizing energy dissipation at the entrance, converting point inflow to uniform flow downstream of the first bottom baffle and minimizing flow velocities and turbulence near the bottom of the vault by adjusting other features (modifying the shape of the downstream skimmer baffle, for example) which created currents that tended to re-suspend sediment off the bottom. Figure 1 shows the vault configuration that was finally adopted. Initial testing focused on dye tracing and three-dimensional acoustic velocity probe data.

After the initial tests, the unit was enlarged to have a length of 32 feet (prototype dimension) between the inlet and outlet bottom baffles, and a slanted baffle was added to the middle. Another 20 test runs were made. Fine dusts (i.e., 1 to 50 microns in size) were positioned 1.0 foot above the bottom to simulate accumulated sediment during six of these runs. The effectiveness of the basic configuration shown in Figure 1 was confirmed, and the test with fine dust on the bottom showed that the unit had practically zero sediment re-suspension, even under worst-case loading conditions considered for design.

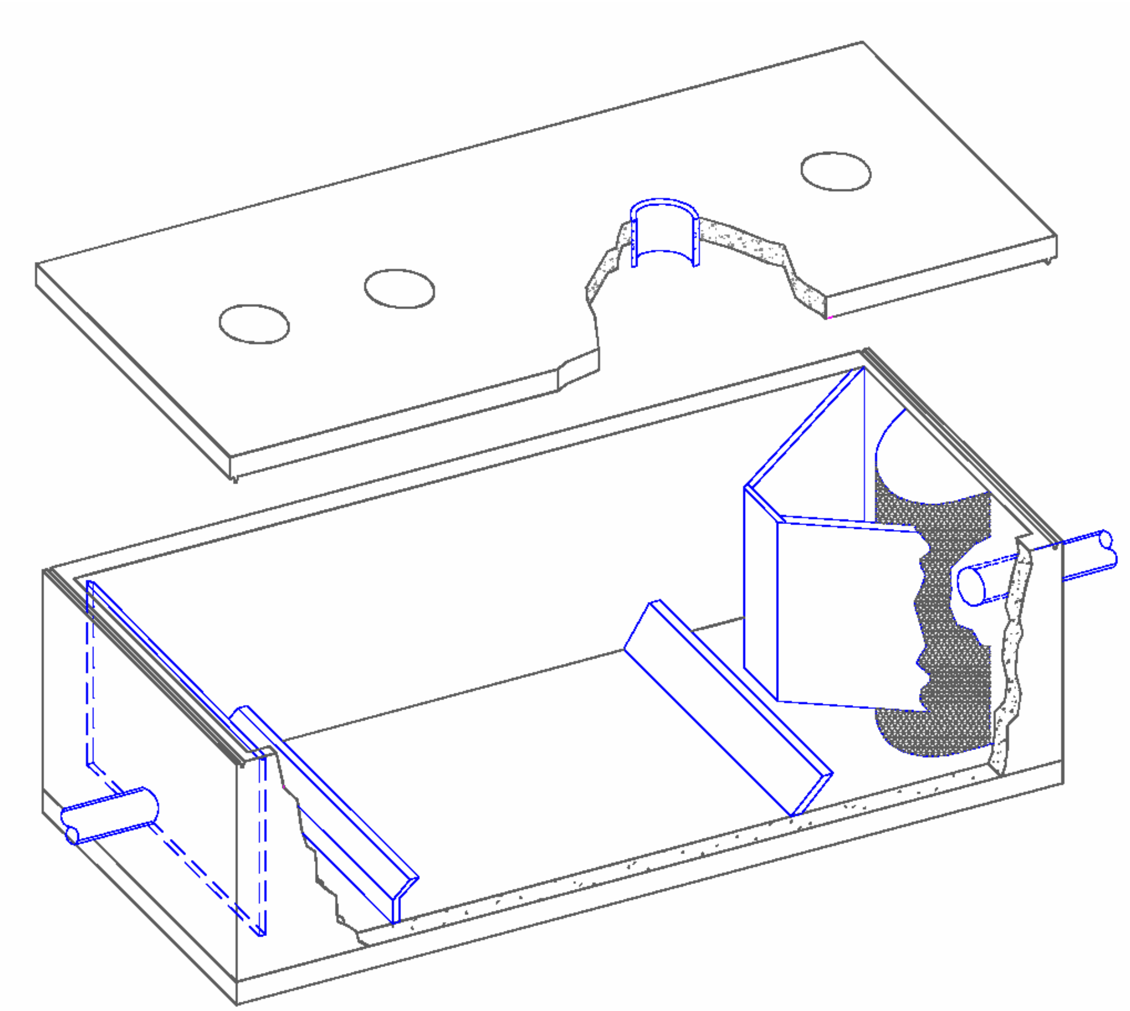

Figure 1. Final StormVault™ Configuration Showing a Single 16-Ft Bay Between Baffles.

In January of 2004, CON/SPAN® Bridge Systems and Jensen Precast entered into an alliance to expedite the marketing and future development of the StormVault™ System throughout the country. Under that alliance, the system was known as the StormVault™ by CON/SPAN®. The system was previously known as the Jensen Precast StormVault™. Under the partnership and new naming, the treatment system and its pollutant removal capabilities remain intact. The only difference is that the system is now contained within an underground vault made up of CON/SPAN® precast units. ***The product is no longer licensed to Contech and is fully owned by Jensen Water Resources.***

2.1.2 Specific Applicability

The StormVault^{TM} is a water quality improvement device applicable for treatment of stormwater in a variety of development situations including:

New developments and retrofits
Construction sites
Streets and roadways
Parking lots
Vehicle maintenance wash-down yards
Industrial and commercial facilities
Wetlands protection

2.1.3 Range of Contaminant Characteristics

The StormVault^{TM} has been shown to capture a wide range of pollutants of concern. These include: trash and debris, TSS, sediments, oil and grease, hydrocarbons and other pollutants such as phosphorus, nitrogen, and metals associated with the solid particles.

2.1.4 Range of Site Characteristics

The StormVault^{TM} is designed to accommodate a wide range of flows and volumes. It was envisioned that typical site characteristics for the StormVault^{TM} would include a drainage area ranging from as little as 0.25 acre up to 100 acres that are heavily developed, potentially with 100-percent impervious area. (Note: This drainage-area range applies to most areas in the United States and includes a range of drawdown times and capture volume combinations.)

The StormVault^{TM} recommended mean storm depth sizing methodology follows the method prescribed by ASCE/WEF in their Urban Runoff Quality Management Manual of Practice (WEF 1998). The system has been refined to allow sizing of the capture volume using the mean runoff volume (as defined by Driscoll, et al., 1989), and to accommodate a six-hour drain down time. This "mean storm event capture volume" will result in the capture of roughly 75-83% of all runoff-producing events in their entirety. In addition, this mean event provides the most economical storage volume.

A minimum overall length of the unit is 26 feet. The modular vault's length can be increased to any desired length. Slanted bottom baffles are spaced at 8- to 16-foot intervals and are added as the vault's length is increased.

2.1.5 Material Overview, Handling and Safety

In order to insure efficient operation and achieve the desired pollutant removal rates, several important inspection and maintenance functions must periodically be performed.

The removal of collected sediments is to be performed once an average sediment depth of 6 inches has been reached in the vault. The hydrocarbon sorbent mats are to be replaced once the mats turn completely dark in color and can no longer absorb any free oils and greases.

The contractor must verify proper disposal with the local jurisdiction. An analysis of the materials may be required before disposal. The used mats should be disposed of as directed by the local authority. Generally this is in a similar manner used to dispose of drain oil or similar materials.

2.2 Treatment System Description

2.2.1 System Summary

A schematic of the StormVault™ is shown in Figure 2.

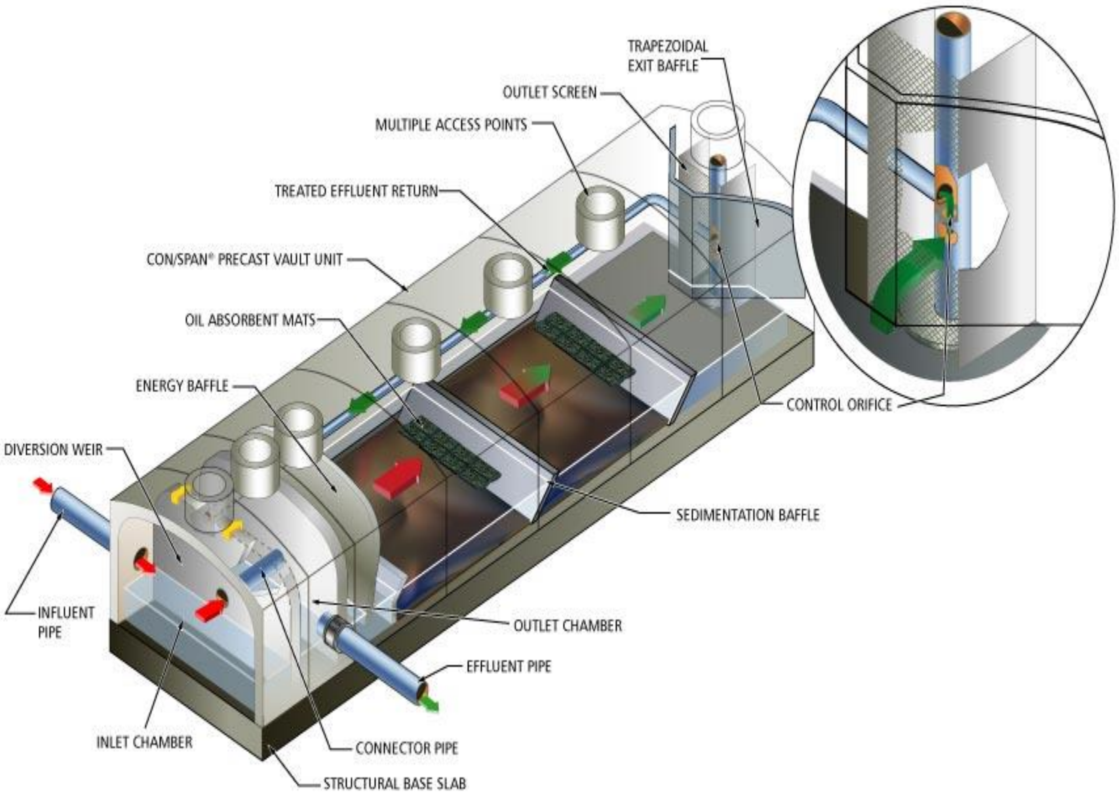

Figure 2. Schematic of the StormVault™.

System Overview (per CON/SPAN®)

- Below Grade Detention and Sedimentation Vault
- Internal bypass places structure off-line
- Provides stormwater treatment for a specified Water Quality Capture Volume
- Laminar (low-velocity) flow in sediment chamber allows for settling of very small particles
- Effluent discharge TSS concentration of less than 20 mg/L with a 95% level of confidence, independent of influent concentrations or inflow volume
- Detention time promotes sedimentation of particles less than 70 microns
- Oils and greases captured through the use of hydrocarbon absorbent mats
- Maintenance Cycle
    - Hydrocarbon absorbent mat replacement approximately 3-5 years
    - Sediment chambers cleanout approximately 3-5 years
- Structure can be designed for any loading condition

System Features

Energy Baffle:	Dissipates energy of inflow, creates laminar (low-velocity) flow in sediment chamber, and collects floatable trash and debris. (Along with influent chamber, serves as a pre-treatment area)
Sediment Baffles:	Promote laminar (low-velocity) flow within the vault, provide storage area for settled particles, and prevent re-suspension of particles.
Multiple Accesses:	Provide easy observation and maintenance.
Trapezoidal Exit Baffle:	Provides stable exit velocity and prevents floatables, oils and greases from reaching control orifice.
Control Orifice:	Sized to provide optimal drain down time (6 hour recommended)
Large Outlet Screen:	Installed around orifice to prevent blockage.
Diversion Weir:	Adequate weir length to pass maximum flows from inlet pipe in case of an overflow event (key feature of internal bypass).
Permanent Pool:	Aids in sedimentation process.

2.2.2 Treatment Objectives

The StormVault™ is designed to meet a set of objectives that an ideal underground stormwater treatment vault should address (WWE, 2002). These objectives are:

- Provide for sufficient residence time during wet-weather periods to settle out small particulates and to float up to the surface small oil droplets and marginally buoyant particles.

- Minimize the re-suspension of deposited sediment by limiting flow velocities near the bottom.

- Provide for the aeration of the water stored in the vault during dry weather periods to further reduce pollutant remobilization due to anoxia (dissolved oxygen depletion).

- Be of sufficient size to capture and treat the total amount of storm runoff from the large majority of runoff events and capture and treat the "first flush" of events that exceeds the maximum design storm.

- Attenuate the peak flow rates from the majority of storm runoff events to levels that minimize adverse physical impacts (channel degradation) on receiving waters such as streams, lakes and wetlands.

Figure 3 shows a diagram of the StormVault™ with the various components numbered for reference. Numbers noted in the text below correspond to the features labeled in Figure 3.

2.2.3 Sufficient Residence Time for Dynamic Settling

The need for extended residence time is driven by the fact that much of the pollutant load in stormwater is associated with very small (i.e., slow-settling) particulates (Grizzard, et. al. 1986; Randall, 1982; Whipple and Hunter, 1981). During wet weather, the sedimentation of these particles takes place under dynamic settling conditions. The fraction of any sized sediment particle removed from the water column is a function of its settling velocity and the hydraulic surface loading rate (*Q/A*) of the flow (Fair, et al. 1958; Kuo, 1976).

The lower the surface loading rate (*Q/A*), the larger the fraction of particles having a given settling velocity (V_s) removed. This can be achieved by building a vault with a very large surface area and/or by reducing the peak flow-through rate through the vault by increasing the residence time. If the goal is to remove smaller fractions of suspended sediment (which typically have large associated concentrations of heavy metals, organics, oxygen-demanding substances and nutrients), the structural BMP should have a relatively low surface loading rate and long residence time during wet-weather periods. This can only be accomplished by providing a capture volume[1] [(1)] that, in combination with a slow release outlet[2], buffers the flow-through rate for stormwater runoff rates that can vary tremendously during any storm event.

2.2.4 Minimize Re-suspension of Deposited Sediment

An ideal vault limits flow velocities and turbulence near its bottom as close as practicable to zero. The goal is to keep the smallest sediment particles from being scoured back into the water column. Low turbulence increases the fraction of suspended sediment removed. Thus, the vault's design has to provide for very low bottom velocities, little short circuiting and minimal turbulence. To accomplish this, it is necessary to:

[(1)] The superscript number refers to the StormVault component labeled in Figure 3.

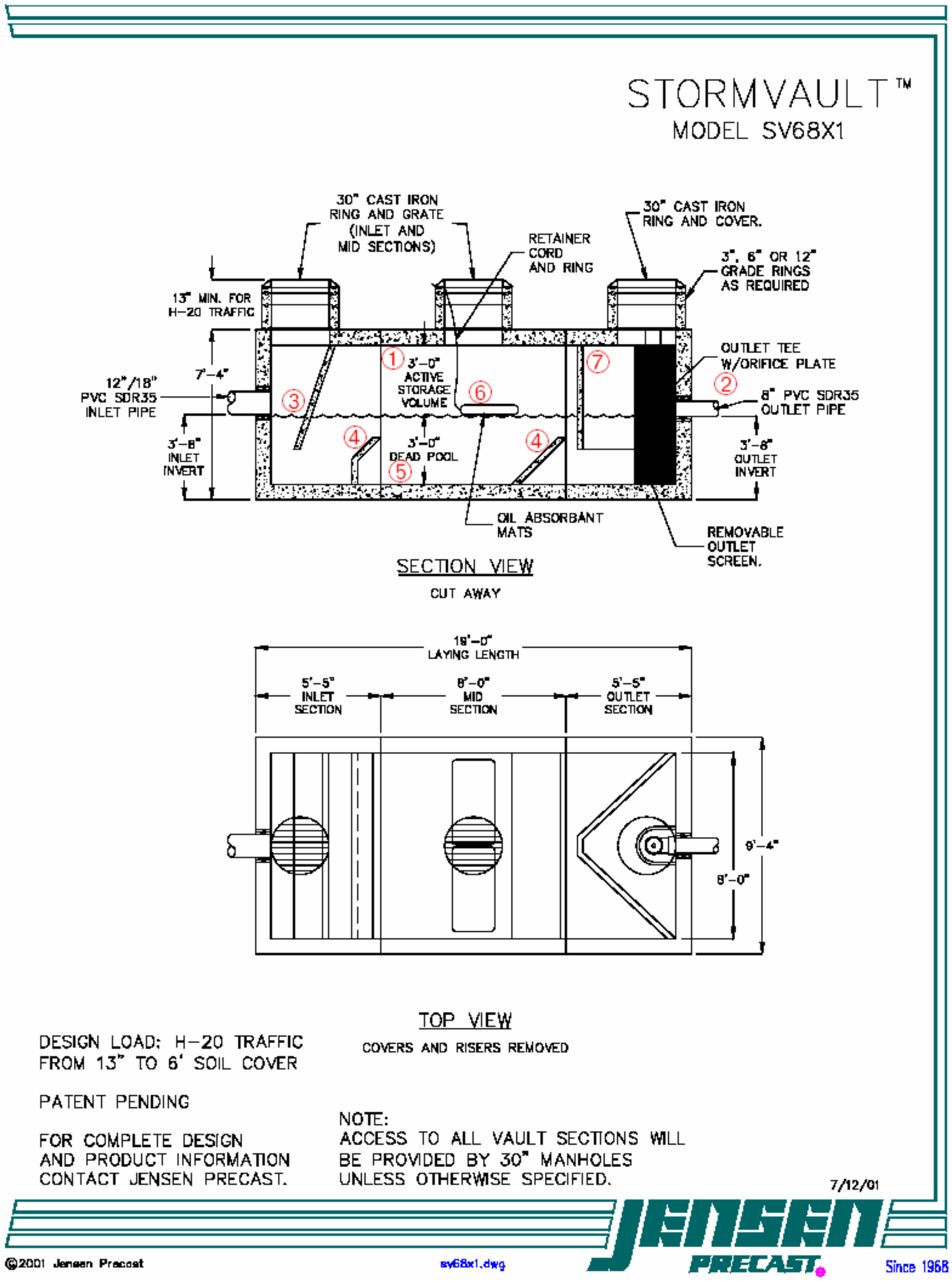

Figure 3. Stormvault^{TM} Components.

- Dissipate the energy of flow as it enters the vault. This is accomplished with the energy dissipation baffle[3].
- Spread inflow uniformly across the vault. This is accomplished with bottom baffles that promote laminar (low-velocity) flow[4].
- Maintain uniform flow through the length of the vault. Bottom baffles[4] serve this purpose by spreading inflow uniformly across the vault.
- Keep velocities from "diving" to the vault's bottom during its filling and emptying phases. This is accomplished by maintaining a permanent pool[5] in the vault that buffers the impact of inflows on bottom sediments. In addition, the specially designed bottom baffles[4] have been shown in the laboratory to produce very low bottom velocities.

2.2.5 Provide for the (Passive) Aeration of Water in the Vault

Anoxic conditions (the absence of dissolved oxygen) can develop in stormwater if it is stored for an extended time without adequate aeration, because urban runoff normally contains elevated levels of oxygen-demanding substances. For a vault to achieve the above-stated goal of low bottom velocities and to provide space for sediment storage, it has to store some of the runoff[5]. In order to maximize the amount of dissolved oxygen, a number of grated manholes are provided to introduce oxygen into the system. The water surface also has to be relatively free of oil or other substances that may interfere with diffusion of oxygen. This is accomplished by providing floating sorption pillows[6] that adsorb insoluble oil and other organic materials floating on the surface.

2.2.6 Sufficient Volume to Capture in Full the Majority of Runoff Events

The available surcharge volume in the vault needs to be of sufficient size, in combination with the outlet control that releases the volume at a low rate of flow, to capture and treat the majority of storm runoff in total and the first flush of the larger events. This volume, according to WEF (1998) recommendations, should be between the "mean" event and the "maximized" event (90 percent of all events completely captured).). When local regulations do not prescribe a specific sizing methodology for volume capture devices Jensen Precast (and now CONTECH Stormwater Solutions as well) recommends using the WEF sizing methodology. Depending on treatment objectives and selection of sizing parameters, the StormVault™ sized per the WEF method will completely capture from 70 to 90 percent of storm events and will provide treatment of the first flush for the other 10 to 30 percent.

The design peak inflow capacity of the system is limited only by the size of the inflow pipe. The outlet is controlled by an orifice.

2.2.7 Attenuate the Effects of High Flow Rates for Urban Runoff

Providing capture volume[1] and sufficiently low release rates[2] helps attenuate the effects of high and rapidly rising runoff flow rates on streams. As lands urbanize, depression storage decreases, the runoff coefficient increases and the time of concentration decreases. These effects are most pronounced for smaller storms. Comparison of a 1.0-acre parking lot versus a 1.0-acre meadow in good condition, as presented by Scheuler (1994), illustrates the effects of urbanization. The runoff coefficient for the meadow is approximately 0.06; for the parking lot, a runoff coefficient of 0.95 is appropriate. The time of concentration of the parking lot would be roughly one-third of the time of concentration of the meadow, and the peak rate of runoff would increase by a factor of 10 or more for the most frequent events. The volume of runoff from a 1.0-inch storm would increase by a factor of more than 15. In addition to dramatic changes in peak rates and volumes, urbanization increases the frequency of runoff. As imperviousness increases, more events that formerly generated no runoff (i.e., all precipitation infiltrated) will begin to yield runoff.

2.2.8 Oil Removal Mechanisms

As discussed above, the minimization of turbulence provided by the StormVault™ is conducive to separating oil and grease (O&G) and other immiscible hydrocarbons from stormwater via gravitational settling. This is a factor of the storage[1] and controlled release[2]. The free O&G removal is enhanced by extended contact with floating absorbent pads[6]. Oil and grease are kept in the treatment chamber by the trapezoidal underflow baffle[7] that separates the midsection of the StormVault™ from the outlet section. The trapezoidal design creates more surface area than a straight baffle (in the horizontal plane) for water to pass through as it moves from the midsection to the outlet section. This reduces the velocity of the water passing through the plane, thereby minimizing entrainment of trapped O&G.

2.2.9 Installation

The unit should be installed in a location that is easily accessible for the maintenance vehicle, preferably in a flat area close to a roadway or parking area. Off-site fabrication ensures tight adherence to specs, less on-site work and quality control of modular units. Installation can be accomplished fast - usually in hours. Road closings and detours are minimized, resulting in significant reductions in maintenance of traffic costs.

3. Technical Performance Claim

In light of the additional qualifying data, CONTECH Stormwater Solutions revised the performance claim for the StormVault™.

Revised Claim

StormVault™, with a minimum permanent pool depth of 3-feet, sufficient active storage to capture the water quality volume and a minimum brim-full drain down time of 6-hours, has demonstrated a total suspended solids (TSS Standard Method 2540D) removal efficiency of 86%

with 95% confidence intervals of 81% and 91% for a sandy loam texture sediment in the field using the NJDEP TARP/Tier II Protocol.

4. New Jersey Tier II Stormwater Test Requirements

The purpose of the Technology Acceptance and Reciprocity Partnership (TARP) Tier II Stormwater Protocol is to provide a uniform method for 1) demonstrating stormwater treatment technologies, and 2) developing field test quality assurance plans for verification and certification of performance claims in accordance with individual state regulatory standards. The protocol reduces the requirements for a stormwater Best Management Practice (BMP) demonstration to a common set of standard criteria, acceptable to all participating states. However, the protocol also recommends that state specific requirements must be considered when a technology vendor is pursuing certification or verification of a stormwater BMP in that state. In addition, the protocol does not completely eliminate all state review or approval of construction projects proposing to use the stormwater technology, nor does it require any state to "rubber stamp" the approval or permit of another state or regulator (TARP Tier II Protocol, p.4).

The main focus of the TARP states' technology verification and certification programs is the independent validation of data supporting specific technology performance claims. An advisory work group, comprising the technology vendors active in the NJ verification program and representatives from the New Jersey Corporation for Advanced Technology (NJCAT) and the New Jersey Department of Environmental Protection (NJDEP), determined that certain requirements of the TARP Tier II Stormwater Protocol were potentially very difficult to achieve and recommended revisions to these requirements. While other criteria described in the TARP Tier II Stormwater Protocol remain in effect, the **Site Selection** and **Stormwater Data Collection** sections have been revised as follows:

Site Selection

1. TSS influent characteristics such as influent loading and particle size distribution will be the determining factors for site selection as follows:

   i. The **mean influent concentration** of the sediments must be in the range of 100- 300 mg/L.

   ii. The **mean particle size** must not exceed 100 μm.

   Since published studies conclude that contaminants such as heavy metals and nutrients partition against very small particles, the NJDEP final certification of the performance claims for the manufactured treatment devices will be strongly influenced by PSD. This decision by the NJDEP results from the fact that permitting of manufactured treatment devices is not based on soil types or PSD, and, consequently, permitted devices must be able to operate at the certified performance level anywhere in New Jersey. Therefore, the final certification of the Total Suspended Solids

(TSS) removal efficiency claim would be based to a significant extent on the size of particles that the device is capable of removing from stormwater runoff. To effectively demonstrate the efficient removal of the targeted PSD, the NJDEP strongly recommends that soil types at the chosen sites (verified through influent sampling) should be similar to the PSD characteristics described in the NJDEP Laboratory Protocol, which is 55% sand, 40% silt and 5% clay.

iii. At least three (3) influent samples from the overall 15 to 20 storms (as described in the **Stormwater Data Collection** section) must be tested to establish the particle size distribution for the site. Also, for the same reason described above regarding future NJDEP policy changes, it is recommended that the effluent from the same three (3) influent samples be tested to establish the PSD of the sediments exiting the manufactured treatment device. It is recommended that the test method used be one of the following; any other proposed method must be approved by NJCAT:

- Laser Diffraction
- Visual Accumulator
- Pipette Method
- Coulter Counter
- Wet Sieve
- Serial Filtration

iv. Only one of the recommended analytical methods described above must be used for all influent and effluent samples tested for PSD characterization.

2. Selected sites can be within or outside New Jersey providing that the influent concentrations and particle size distribution criteria are satisfied.

Stormwater Data Collection

1. A qualifying storm event must exceed 0.1 inch of total rainfall.

2. The minimum inter-event period must be 6 hours.

3. Sampling one hundred percent (100%) of the storm flow should be the goal. However, flow-weighted composite samples covering a minimum of 60% of the total storm flow will be accepted.

4. A minimum of 6 water quality samples (i.e., 6 influent and 6 effluent samples) must be collected for each storm event. However, the goal should be an average of 10 samples per storm event.

5. The number of water quality sampling events must be representative of the storm events in the respective climatic regions, with the following criteria:

   - The total sampled rainfall must be a minimum of 15 inches of precipitation.

   - At least 15 storms, but preferably 20 storms, must be sampled.

6. The Tier II Stormwater Protocol sampling requirement during adverse weather conditions is not applicable.

7. At least two storms must exceed 75% of the design treatment capacity.

8. Scouring tests must be completed (either in the laboratory or field) for the manufactured treatment devices at 125% of the treatment flow rate. These tests should be operated with initial sediment loading of 50% and 100% of the unit's capture capacity.

9. Both Total Suspended Solids (TSS) (EPA Method 160.2 or APHA et al. Standard Method 2540 D) and Suspended-Sediment Concentration (SSC) (ASTM Method D3977) test methods must be used to establish the TSS removal efficiency of the manufactured treatment devices.

Since the NJDEP requirements described above differ from the standard TARP Tier II Stormwater Protocol, there is a possibility that reciprocity of certified manufactured treatment devices may not be achievable in the other TARP states. However, the NJDEP will attempt to defend the basis for the amendments and work with the other TARP states to have these requirements replace those in the present TARP Tier II document.

5. Technical System Performance

In general, it is a good practice to submit the project plan for review and approval by the verification/certification agency before its implementation. As indicated in the Introduction section, the field monitoring programs were planned and implemented following the City of Sacramento protocol (1999) rather than the TARP (2003) and NJDEP (2006) Tier II requirements. Nevertheless, CONTECH has decided to submit the data sets for NJCAT verification since they feel that a sufficient number of qualified storm events have been sampled.

5.1 Site Description

The site used for this study was chosen based upon suitability for a long-term monitoring project. The system was not maintained during the 3 ½ year investigation.

The StormVault^{TM} system in Albemarle County was installed during the first week of October, 2000 in the parking lot of the Albemarle County office building (COB), located in

Charlottesville, Virginia (Figure 4). The site is subject to heavy traffic ranging from police cars, public works vehicles, and employee and visitor parking. The StormVault™ treats runoff from 1,349-m^2 (1/3 acre), consisting primarily of an impervious asphalt parking lot. Primary sources of pollution within this drainage area include solids, metals and trash and debris from automobiles, site maintenance activities, seasonal activities and atmospheric deposition.

Figure 4. Site Drainage Area (from Yu and Fassman, 2001).

5.2 Descriptions of Monitored System

The monitored StormVault™ unit is composed of three bays: the fore bay (inlet section), sediment compartment (two modular midsections) and outlet structure (outlet section). Stormwater first enters a fore bay and trash compartment through an inlet pipe, which is plumbed to catch basins throughout the drainage area. Stormwater in the fore bay is then directed into an inlet baffle which collects floatable trash and dissipates energy and diverts a laminar (low-velocity) flow into the sediment compartment. Once in the sediment compartment, stormwater enters a permanent pool that contains two sediment baffles that minimize resuspension potential. The water level in the vault rises to become active storage with a 6 hour drain-down period before emptying into an outlet structure with a screened flow control orifice. The treated water is discharged from the system through an outlet pipe.

The Model SV68x2 StormVault^{TM} system installed at Albemarle COB test site has a floor dimension of 7.7 m x 2.4 m (25.5 ft x 8 ft) including that of midsections and end sections. The active storage has two 8.0 ft x 8.0 ft x 3.0 ft vault midsections as well as two 4.75 ft x 8.0 ft x 3.0 ft vault end sections (WWE, 2002). Depth of both the permanent storage/pool and the active storage (the temporary pool) is 3 ft. A 1.0-inch screened outlet orifice regulates flow resulting in a brim-full emptying time (a draining time for the 3-ft deep active storage) of slightly more than 6 hours.

In design of the monitored unit, number of vault midsections was calculated by setting total volume of the vault midsections equal to the desired water quality control volume (WQCV). The ASCE/WEF sizing methodology was used to determine WQCV as 370 ft^3 (2,726 gallons) (WWE, 2002). The volume provided by end sections was not considered as a part of the WQCV for the Virginia facility; however, sizing routines have since been modified, and volumes of end sections are now counted as a part of the WQCV (WWE, 2002). Depth of the permanent pool was set to be 3 ft. Bottom area of the lower permanent pool is the same as surface area of the upper temporary pool (the active storage).

5.3 Water Quality Sampling and Analysis Methods

The first stage of the field investigation was conducted by Professor Shaw L. Yu, Ph.D. and Elizabeth A. Fassman, M.S., EIT, a graduate research assistant within the Department of Civil Engineering at the University of Virginia located in Charlottesville, VA (Yu and Fassman, 2001). The second stage of the investigation was conducted by Professor Shaw L. Yu, Ph.D. and Jing Li who was also a graduate research assistant within the Department of Civil Engineering at the University of Virginia (Yu and Li, 2004).

Two American Sigma 900MAX automatic samplers were used to collect inlet and outlet samples at points over the hydrograph at pre-set time intervals. For characterization of overall system performance, samples were analyzed as flow-weighted composites. Other data collected includes on-site rainfall data and level measurements to determine flow. Precipitation was measured using a tipping bucket rain gauge. Change in water level at the outlet was used to determine flow through the system from the mass conservation (storage) relationship. Outflow rate was determined using the orifice equation. Figure 5 shows the site with monitoring equipment.

In the second stage of the monitoring project (Yu and Li, 2004), two additional samplers (mid1 and mid2 in Figure 6) were installed in one of the mid-vaults at two different depths to collect samples from the active and permanent pools, respectively, for providing data on the transport path of sediment through the system.

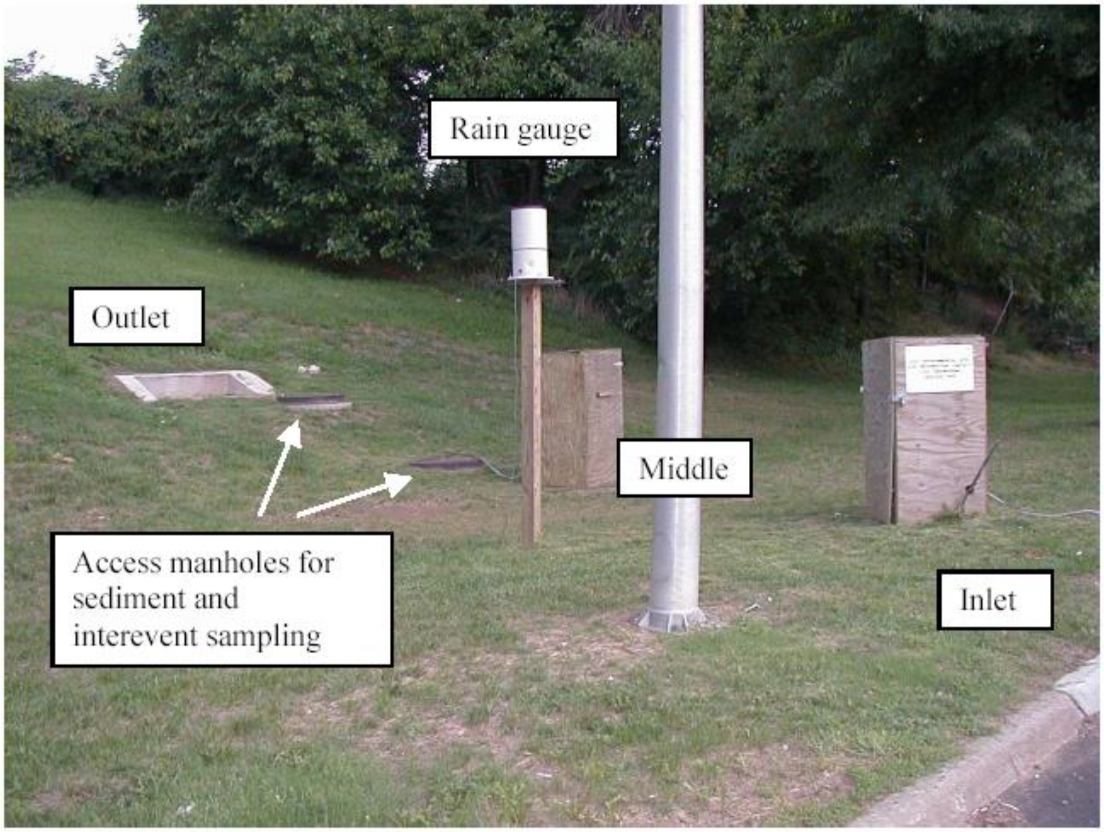

Figure 5. Site Monitoring Equipment: Plywood Boxes Protect Equipment (from Yu and Fassman, 2001).

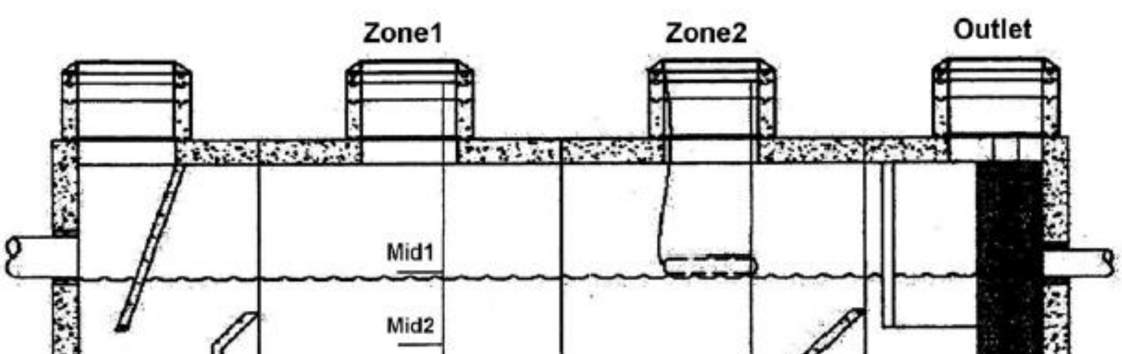

Figure 6. Sampling Locations Inside of the StormVault™ (from Yu and Li, 2004).

One of the fundamental design objectives of the StormVault™ is to provide effective removal and immobilization of settleable solids in stormwater runoff. As a result, a primary pollutant of interest in that study was TSS. TSS, as required by the Sacramento Stormwater monitoring guidelines, was analyzed in the University of Virginia laboratory using the Standard Method-2540D (APHA et al., 1995).

5.4 Monitoring Results

A total of 58 storm events were sampled between 2001 and 2003 at the Charlottesville site and CONTECH determined that 34 of those storms meet the TARP/NJDEP Tier II data quality objectives. All 58 storm events monitored during the project are summarized in Appendix A.

A summary of the qualifying storms is presented in Table 1. Both influent TSS and effluent TSS concentrations are included to demonstrate the effectiveness of TSS removal by the monitored treatment system.

An example of measured inflow and outflow hydrographs are shown in Figure 7. A significant attenuation of the inflow peak through the treatment system, a water detention system, is clearly demonstrated. Measured peak inflow and outflow rates for all the monitored storms are shown in Appendix B.

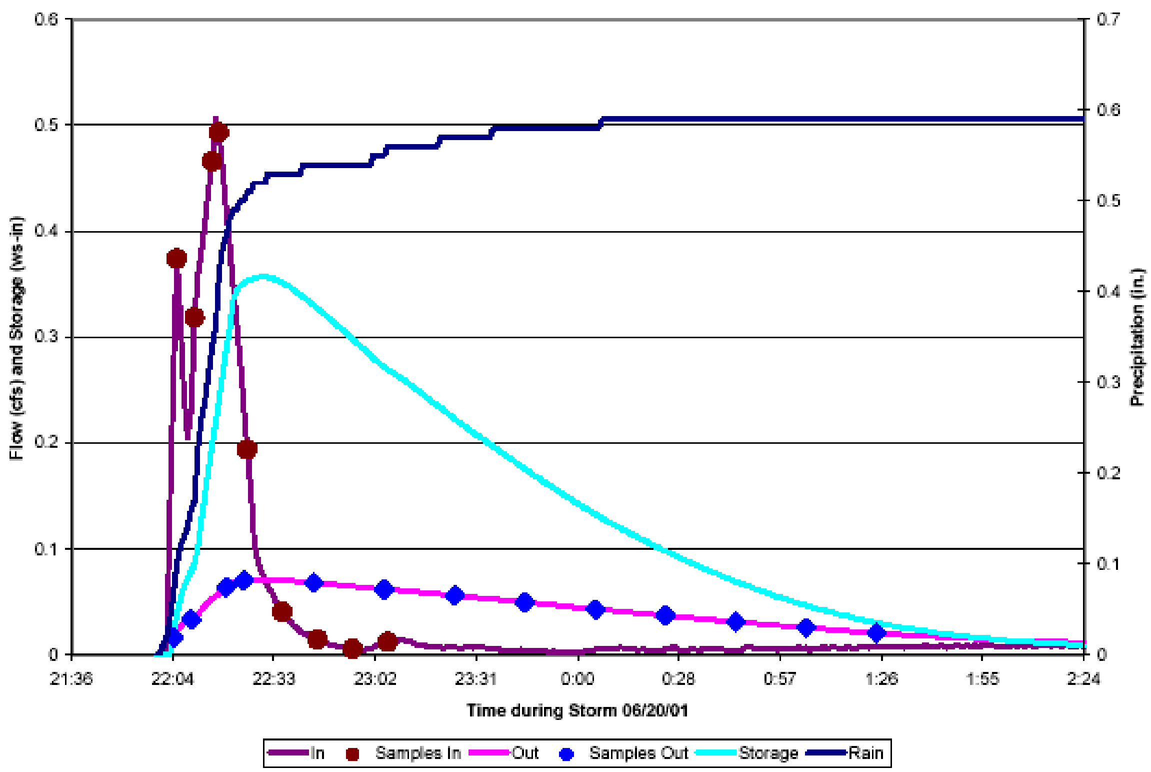

Figure 7. Example Hydrograph: Storm 06/20/2001 (from Yu and Fassman, 2001).

Table 1. Summarized Event Characteristics for All Qualifying Events

Event ID	Data Quality Objectives (DQOs)				Other Event Characteristics						
	Event Depth (in) [minimum 0.10]	Antecedent Dry Period (hr) [minimum 6-hrs <0.04-in] estimated	Number of Aliquots [minimum of 6 (Inf:Eff)]	Avg. Vol. Coverage (nearest 10%) [minimum of 60 (Inf:Eff)]	Qualification based upon Best Professional Judgement	Influent Volume (gal)	Runoff Duration	Average Intensity in/hr	Dead Storage Volume (DSV) (gal)	Influent TSS EMC (mg/l)	Effluent TSS EMC (mg/l)
PhII-052601	0.35		13-14	>80	✓	3042	5.9	0.06	4578	10	5
PhII-060101	0.52	120	8-10	70	✓	4523	2.9	0.18	4578	40	7
PhII-060701	0.55	144	15-12	>90	✓	4778	1.7	0.32	4578	185	23
PhII-061501	0.36	192	17-15	>70	✓	3127	2.1	0.17	4578	53	11
PhII-061601	0.32	24	11-12	>70	✓	2778	1.4	0.23	4578	25	6
PhII-062001	0.59	96	9-13	>80	✓	5125	2.1	0.28	4578	80	12
PhII-062101	0.56	23	8-18	>85	✓	4866	2.1	0.27	4578	63	17
PhII-070101	0.10	24	11-10	>60	✓	869	0.2	0.6	4578	79	6
PhII-072601	1.86	192	20-20	>70	✓	16166	9.2	0.2	4578	172	44
PhII-081001	0.80	312	17-24	>80	✓	6952	0.9	0.91	4578	67	22
PhIII-081702	0.41	264	11-24	100	✓	3673	4.8	0.09	4578	66	23
PhIII-091502	0.15	336	14-24	100	✓	1346	6.7	0.02	4578	50	3
PhIII-092202	0.35	168	9-24	100	✓	3134	5.5	0.06	4578	132	14
PhIII-102102	0.23	144	12-24	>90	✓	2064	10.2	0.02	4578	42	3
PhIII-102502	0.97	96	24-24	>80	✓	8692	12.4	0.08	4578	16	3
PhIII-102802	0.22	72	24-24	100	✓	1975	2.9	0.08	4578	38	3
PhIII-111102	0.95	96	21-24	100	✓	8512	6.7	0.14	4578	86	38
PhIII-032603	0.40	96	24-24	100	✓	3583	3.7	0.11	4578	90	15
PhIII-040703	1.06	48	24-24	100	✓	9500	10.3	0.10	4578	26	6
PhIII-042503	0.23	72	24-24	100	✓	2064	13.2	0.02	4578	37	7
PhIII-043003	0.97	96	15-24	>90	✓	8692	9.5	0.10	4578	272	36
PhIII-050503	0.10	24	7-24	100	✓	898	2.4	0.04	4578	83	5
PhIII-050903	0.51	24	16-24	80	✓	4570	16.7	0.03	4578	126	44
PhIII-051503	1.40	120	24-24	90	✓	12544	16.1	0.09	4578	69	14
PhIII-052103	0.60	48	10-24	>90	✓	5378	12	0.05	4578	56	11
PhIII-052603	0.49	12	12-24	100	✓	4391	6.8	0.07	4578	32	9
PhIII-052703	0.40	24	24-24	100	✓	3583	10	0.04	4578	34	11
PhIII-052903	0.45	34	19-24	>90	✓	4032	13.9	0.03	4578	32	10
PhIII-053103	0.17	41	24-24	60	✓	1526	12.5	0.01	4578	40	6
PhIII-060303	0.25	62	24-24	100	✓	2237	3.4	0.07	4578	26	7
PhIII-060403	0.18	24	24-24	100	✓	1616	4.3	0.04	4578	114	9
PhIII-060703	2.07	48	24-24	>90	✓	18550	27.3	0.08	4578	40	18
PhIII-061103	0.27	72	9-24	100	✓	2416	1.3	0.21	4578	175	23
PhIII-061203	0.20	22	24-24	100	✓	1795	2.3	0.09	4578	46	16
Sum	19.04	-	-	-	34	168996	-	-	-	-	-
Median	0.41	72.00	17-24	90	-	3627.80	5.70	0.08	-	55	11

Shading = DQO Met

Unit of the runoff duration is hour.

Measured depths of the bottom sediment accumulation throughout the monitoring period are shown in Appendix C. A net accumulation of the bottom sediment, that is, a net removal of solids from the stormwater runoff, is clearly demonstrated.

5.5 Performance Summarization

Unlike other CONTECH products participating in the NJCAT Certification program, the StormVault^{TM} has not previously obtained interim certification based on laboratory data, so field performance cannot be measured against a prior performance claim. The performance claim is based solely on the results of the field testing conducted in Charlottesville, VA. A regression of EMC analysis shown in Figure 7 demonstrates a linear relationship between influent and effluent TSS EMCs that is significant at the >99.9% confidence level. Use of the regression statistics suggests a mean TSS removal efficiency for the 34 qualifying events of 86% with 95% confidence intervals of 81% and 91%.

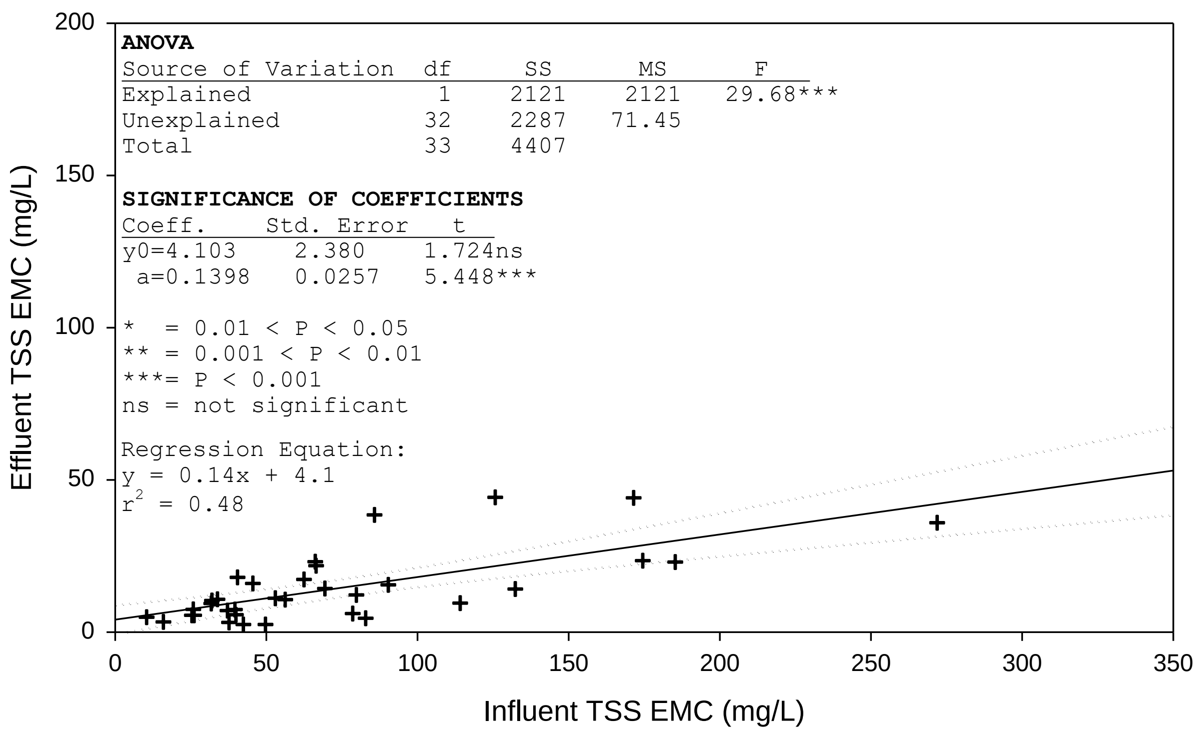

Figure 8. Regression Analysis of the Observed TSS Data.

Table 2 provides a summary of the qualifying TSS performance data as well as the mean TSS removal efficiency estimate calculated using the aggregate load reduction method for the 34 qualifying events.

Table 2. Summarized TSS performance for Charlottesville StormVault™

Analyte	Descriptive Statistics			Regression of EMC				Aggregate Load Reduction	
	n	Range of Influent EMCs (mg/L)	Median Influent EMC (mg/L)	Mean Removal Efficiency Estimate (%)	95% Confidence Interval for the Mean Removal Efficiency Estimate (%)	Median Effluent EMC Estimate (mg/L)	95% Confidence Interval for the Median Effluent EMC Estimate (mg/L)	Mean Removal Efficiency Estimate (%)	One-Tailed Sign Test* (H0=H1=0.5)
TSS (mg/L)	34	10.4 to 271.94	54.6	86***	81 to 91	11.7	8.6 to 14.9	77	R

*** = P < 0.001
** = 0.01 > P > 0.001
* = 0.05 > P > 0.01
--- = undeterminable due to insufficient data quantity
R = removal is significant at the 5% level or less
~ = no significant difference
A = addition is significant at the 5% level or less

6. Performance Claim Verification

All the data provided to NJCAT were reviewed to fully understand the capabilities of the StormVault™. To verify CONTECH Stormwater Solutions' claims, the StormVault™ field data were reviewed and compared to the TARP field monitoring protocol (TARP, 2003) and New Jersey Tier II Stormwater Test Requirements – Amendments to TARP Tier II Protocol (NJDEP, 2006).

As indicated above, the StormVault™ monitoring project was executed in compliance with the City of Sacramento's stormwater monitoring guidelines which deviate from the TARP and NJDEP Tier II requirements. However, the Sacramento guidelines are sufficiently similar to the TARP/NJDEP Tier II requirements to allow comparison of the resulting data set and sampling methodology to the TARP/NJDEP Tier II requirements.

Claim - StormVault™, with a minimum permanent pool depth of 3-feet, sufficient active storage to capture the water quality volume and a minimum brim-full drain down time of 6-hours, has demonstrated a total suspended solids (TSS Standard Method 2540D) removal efficiency of 86% with 95% confidence intervals of 81% and 91% for a sandy loam texture sediment in the field using the NJDEP TARP/Tier II Protocol.

6.1 Comparison with the NJ Field Monitoring Requirements

6.1.1 Site Selection

Influent Solids Concentration Representativeness

The median influent concentration was 55 mg/L (Table 1). This is less than the 100 mg/L to 300 mg/L range in the NJDEP guidance. This is a conservative site for BMP testing due to the low influent concentration. If the median influent concentration were larger than 55 mg/L, the removal efficiency would most likely have been larger than that measured.

Suspended Solids Size Representativeness

The graduated filtration method (the serial filtration method) was utilized to assess the particle size distribution (PSD) of inflow samples throughout the multi-year study. However, this analysis did not yield sufficient data to allow a reliable determination of the median particle size in the inflow samples. Furthermore, Yu and Li warn that the data itself is suspect due to the limitations of the methodology and recommend it be used with caution (Yu and Li 2004). Yu and Li feel there is a high degree of uncertainty with the graduated filtration method because of potential filtration clogging, which potentially results in underestimating the amount of fine particles.

During the first stage of the study, sediment samples were collected from each of the 3 chambers within the StormVault™, combined and subjected to PSD analysis. The PSD of the combined samples indicate that the captured material was 52.8% sand, 40.0% silt, and 7.2% Clay (Yu and Fassman 2001). This PSD is consistent with sandy loam material and past studies have demonstrated that the d_{50} of a similar material was likely <100 microns (CONTECH 2006b). Also, the sandy loam material represents what was captured in the vault, and the device likely captures the coarsest fraction of sediment entering the system, so it seems logical to hypothesize that the influent PSD contained a greater proportion of fine material. This further supports the evidence suggesting that the influent d_{50} is <100 microns and in compliance with NJDEP Tier II requirements.

Near the end of the second stage of the monitoring period, accumulated sediment was collected from the bottom of Zone 1 and Zone 2 to test its composition (Yu and Li, 2004). Items tested include moisture content, particle size distribution, metals, and toxicity characteristics leaching procedure (TCLP) test. PSD of the combined sediment samples showed that “49.26% sediment samples passed 10 mesh (2 mm), and 34.61 % passed 270 mesh (53 μm).” The PSD in the second stage appears to be similar to that of the first stage.

6.1.2 Stormwater Data Collection

Table 1 shows comparison of the data quality objectives with what actually achieved, resulting in 34 qualified storm events. Failure to meet minimum storm coverage criteria excluded 21 storms and failure to meet the minimum event depth criteria disqualified 3 additional storm events (Appendix A).

The 34 qualifying events represent 19.04 inches of precipitation, exceeding the 15 inch threshold established in the TARP Tier II guidance.

Since the design of StormVault™ is volume-based rather than flow (rate) based, the NJDEP flow-monitoring requirement should probably be translated into a volume-monitoring requirement, that is, “at least two storms must exceed 75% of the design treatment volume.”

Using the ASCE/WEF sizing methodology, the treatment volume for the StormVault monitored in Virginia was calculated as 370 ft^3 (2,726 gallons) (WWE, 2002). Then, among the 34 qualifying storms submitted (Table 1), 28 storms had an influent volume larger than 75% of the calculated treatment volume. That is, most of the storms monitored were comparable to the design storm, and the NJDEP's 75% monitoring flow (volume) requirement was met.

The NJDEP has identified a water quality storm defined as 1.25 inches of rainfall non-uniformly distributed over two hours (NJDEP, 2004). Use of the NJDEP water quality storm in combination with the modified rational method or NRCS method [Per NJ Stormwater BMP Manual (NJDEP, 2004)] to calculate the water quality volume for a 1/3 acre impervious site would yield a larger water quality volume than the ASCE/WEF method. If the Modified Rational Method were used, the calculated treatment volume for a 1/3 acre, highly impervious site in New Jersey would be 1,425ft^3 (10,660 gallons). For comparison purposes, if we use the larger volume to determine if the system monitored in Virginia met the 2 storms >75% of design criteria, then, the requirement would still be met. Of the 34 storms submitted (Table 1), 3 storms had an influent volume (Table 1) larger than 75% of the NJDEP treatment volume.

6.1.3 Scour Tests

As indicated above, the system was designed to minimize sediment re-suspension (scour). For the monitored site, the NJ water-quality design peak inflow rate would have been 1.07 cfs (= 1.0 * 3.2 in/hr* 1/3 acre). In this estimate using the Rational Method, the maximum possible rainfall intensity of 3.2 in/hr (for the time of concentration equal to or less than 10 minutes) and the maximum possible runoff coefficient of 1.0 (for the completely impervious area) are used. Among the qualified storm events, the maximum peak inflow rate was 1.33 cfs on May 9, 2003, and the next largest peak inflow rate was 1.011 cfs on July 26, 2001 (Appendix B). These two peak flow rates are about 100% to 125% of the NJ design peak flow rate, but no obvious sediment re-suspension (scour) was observed based on the measured effluent concentrations (Table 1). Moreover, depth of the sediment accumulation on May 9, 2003 (Appendix C) was more than 100% of the required maintenance depth (6 inches).

The inflow larger than that from the 2-year storm (UVA-estimated from the IDF curve) was bypassed from the monitored treatment system upstream of the inlet on July 26, 2001 and August 11, 2001 respectively (Yu and Fassman, 2001). Therefore, the maximum treatment flow rate is similar to the maximum hydraulic capacity of the treatment system. No additional scour test under the maximum hydraulic capacity is necessary.

6.1.4 TSS and SSC Measurements

Solids concentrations in the influent and effluent were measured only as the total suspended solids (TSS) concentration, as required by the Sacramento Stormwater monitoring guidelines, using the Standard Method 2540 D (APHA et al., 1995). They were not additionally measured as suspended sediment concentration (SSC) using the ASTM Method D3977 (ASTM, 1997) in accordance with the NJ requirements.

Although a good correlation between TSS and SSC measurements (with the known particle characteristics) could be obtained in a well-controlled laboratory by well-trained personnel (SMI, 2004; Guo, 2006), many studies suggest uncertainties in the TSS measurement (Gray et al., 2000; Guo, 2006). Moreover, different labs may use different procedures since specifics are not provided in the Standard Method.

6.1.5 Unit Sizing Methodology

As indicated above, the monitored unit was sized based on the method prescribed by ASCE/WEF in their Urban Runoff Quality Management Manual of Practice (WWE, 2002). As also described above, if the NJDEP sizing methodology were applied, the treatment volume would have been much larger (1,425 cubic feet vs. 370 cubic feet). All else equal, had the monitored unit been sized to provide storage for the New Jersey treatment volume, the measured TSS removal efficiency may have been even higher.

6.2 Conclusion

The Charlottesville (VA) StormVault field test has demonstrated that: **StormVault™, with a minimum permanent pool depth of 3-feet, sufficient active storage to capture the water quality volume and a minimum brim-full drain down time of 6-hours, has demonstrated a total suspended solids (TSS Standard Method 2540D) removal efficiency of 86% with 95% confidence intervals of 81% and 91% for a sandy loam texture sediment in the field using the NJDEP TARP/Tier II Protocol.**

7. Net Environmental Benefit

The StormVault™ requires no input of raw material, has no moving parts, and therefore uses no water or energy other than that provided by stormwater runoff.

After approximately three years of operation, approximately 120 cubic feet of solids were trapped within the treatment system (estimated from approximately 7 inches of sediment depth over the floor area of 25.5 ft x 8 ft). The moisture content, zinc and copper contents of the trapped sediment were found to be 92.00%, 88.23 mg/kg, and 8.88 mg/kg, respectively. Once the trapped sediment is removed at the time of maintenance, a substantial, net amount of pollutants would be removed from the stormwater runoff.

According to the TCLP results (Yu and Li, 2004), the bottom sediment was not found to be toxic. Therefore, for the test site sediment handling and disposal can be made in a "regular waste" manner.

Mosquito breeding is a potential problem. The mosquito dunks were found to be effective for mosquito larvae control although some adult mosquitoes were still present. If used, they should be replaced at least once a month during warm seasons for best efficiency.

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Appendix A: Summary of All Storm Events Sampled during StormVault™ Monitoring Project

	Data Quality Objectives (DQOs)					Other Event Characteristics					
Event ID	Event Depth (in) [minimum 0.10]	Antecedent Dry Period (hr) [minimum 6-hrs <0.04-in] estimated	Number of Aliquots [minimum of 6 (Inf:Eff)]	Avg. Vol. Coverage (nearest 10%) [minimum of 60 (Inf:Eff)]	Qualification based upon Best Professional Judgement	Influent Volume (gal)	Runoff Duration	Average Intensity in/hr	Dead Storage Volume (DSV) (gal)	Influent TSS EMC (mg/l)	Effluent TSS EMC (mg/l)
PhII-052601	0.35		13-14	>80	✓	3042	5.9	0.06	4578	10.4	4.9
PhII-060101	0.52	120	8-10	70	✓	4523	2.9	0.18	4578	39.6	7.4
PhII-060501	0.50		6-9	>80		4342			4578	889.5	24.6
PhII-060701	0.55	144	15-12	>90	✓	4778	1.7	0.32	4578	185.3	23
PhII-061501	0.36	192	17-15	>70	✓	3127	2.1	0.17	4578	53	11.1
PhII-061601	0.32	24	11-12	>70	✓	2778	1.4	0.23	4578	25.4	5.5
PhII-062001	0.59	96	9-13	>80	✓	5125	2.1	0.28	4578	79.8	12.2
PhII-062101	0.56	23	8-18	>85	✓	4866	2.1	0.27	4578	62.5	17.3
PhII-063001	0.44		nd	nd			0.5	0.94	4578		
PhII-070101	0.10	24	11-10	>60	✓	869	0.2	0.6	4578	78.6	6.1
PhII-070501	0.08	96	8-7	>60		694	0.2	0.37	4578	43.4	4.9
PhII-070801	0.29		nd	nd			1.9	0.15	4578		
PhII-072601	1.86	192	20-20	>70	✓	16166	9.2	0.2	4578	171.5	44.1
PhII-072801	1.82	48	24-24	>5		15816	20.4	0.09	4578	35	6.1
PhII-081001	0.80	312	17-24	>80	✓	6952	0.9	0.91	4578	66.5	21.8
PhII-081101	1.86	24	23-24	>50		16206	7.9	0.23	4578	73.1	41.4
PhII-081301	0.21	48	24-22	>50		1882	0.6	0.36	4578	37.5	7.5
PhIII-081702	0.41	264	11-24	100	✓	3673	4.8	0.09	4578	66.21	23.13
PhIII-082802	1.40	264	0-24	30		3403	1.4	0.04	4578		
PhIII-090102	0.08		0-24			718	21.1	0.00	4578		
PhIII-091502	0.15	336	14-24	100	✓	1346	6.7	0.02	4578	49.73	2.5
PhIII-092202	0.35	168	9-24	100	✓	3134	5.5	0.06	4578	132.35	14.13
PhIII-092602	2.49	96	24-24	30		22313	31.9	0.08	4578	16.17	3.05
PhIII-101002	1.66	96	8-24	10		14878	23.2	0.07	4578	43.44	2.91
PhIII-101502	1.72	96	24-24	50		15409	16.9	0.10	4578	27.96	2.85
PhIII-102102	0.23	144	12-24	>90	✓	2064	10.2	0.02	4578	42.42	2.5
PhIII-102502	0.97	96	24-24	>80	✓	8692	12.4	0.08	4578	15.95	3.34
PhIII-102802	0.22	72	24-24	100	✓	1975	2.9	0.08	4578	37.66	3.19
PhIII-102902	1.28	24	17-24	>30		11467	24.6	0.05	4578	103.32	6.03
PhIII-110402	0.13	144	0-24			1167	5.5	0.02	4578		
PhIII-110502	0.87	12	24-24	50		7794	14.9	0.06	4578	14.92	2.83
PhIII-111102	0.95	96	21-24	100	✓	8512	6.7	0.14	4578	85.8	38.49
PhIII-111202	1.61		0-0			14429	9.7	0.17	4578		
PhIII-111602	1.82	96	21-24	>40		16306	28.1	0.07	4578	21.59	4.76
PhIII-111702	0.37		0-0			3314	6.3	0.06	4578		
PhIII-032603	0.40	96	24-24	100	✓	3583	3.7	0.11	4578	90.38	15.49
PhIII-032903	1.17		0-24			10479	37		4578		
PhIII-040703	1.06	48	24-24	100	✓	9500	10.3	0.10	4578	26.14	5.54
PhIII-040803	0.97		0-0			8692	14.1	0.07	4578		
PhIII-041803	0.58		0-0			5199	24.9	0.02	4578		
PhIII-042503	0.23	72	24-24	100	✓	2064	13.2	0.02	4578	37.18	7.06
PhIII-043003	0.97	96	15-24	>90	✓	8692	9.5	0.10	4578	271.94	35.89
PhIII-050303	0.08	48	15-24	100		718	2.1	0.04	4578	47.37	6.12
PhIII-050503	0.10	24	7-24	100	✓	898	2.4	0.04	4578	82.9	4.56
PhIII-050703	0.09	24	8-24	100		808	2.4	0.04	4578	57.63	6.2
PhIII-050903	0.51	24	16-24	80	✓	4570	16.7	0.03	4578	125.74	44.25
PhIII-051503	1.40	120	24-24	90	✓	12544	16.1	0.09	4578	69.39	14.34
PhIII-051703	1.78	24	24-24	>10		15947	33.3	0.05	4578	25.63	9.65
PhIII-052103	0.60	48	10-24	>90	✓	5378	12	0.05	4578	56.28	10.66
PhIII-052203	0.65		24-24	90	✓	5827	31.5	0.02	4578		
PhIII-052503	0.19		0-0			1705	2.7	0.07	4578		
PhIII-052603	0.49	12	12-24	100	✓	4391	6.8	0.07	4578	31.8	9.4
PhIII-052703	0.40	24	24-24	100	✓	3583	10	0.04	4578	33.86	10.8
PhIII-052903	0.45	34	19-24	>90	✓	4032	13.9	0.03	4578	32.01	10.36
PhIII-053103	0.17	41	24-24	60	✓	1526	12.5	0.01	4578	39.95	5.69
PhIII-060303	0.25	62	24-24	100	✓	2237	3.4	0.07	4578	25.84	7.46
PhIII-060403	0.18	24	24-24	100	✓	1616	4.3	0.04	4578	114.15	9.49
PhIII-060703	2.07	48	24-24	>90	✓	18550	27.3	0.08	4578	40.46	17.95
PhIII-060803	0.25		0-0			2237	3.8	0.07	4578		
PhIII-061103	0.27	72	9-24	100	✓	2416	1.3	0.21	4578	174.56	23.47
PhIII-061203	0.20	22	24-24	100	✓	1795	2.3	0.09	4578	45.56	15.99
Sum	43.43	-	-	-	58	370746	-	-	-	-	-
Median	0.49	72.00	-	-	-	4342.44	6.70	0.07	4577.76	46.47	8.45

Shading = DQO Met. Unit of the runoff duration is hour.

Appendix B. Hydrologic Characteristics of StormVault™

Storm Date	Precipitation Total (in)	Precipitation Ave. Intensity (in/hr)	Peak Flow In (cfs)	Peak Flow Out (cfs)	Peak Flow Attenuation (%)	Vault Peak Storage (ws-in)
5/17/01	0.05	0.050	0.011	0.004	63.6%	0.010
5/18/01	0.07	0.026	0.036	0.006	83.3%	0.026
5/19/01	1.60	0.018	0.859	0.025	97.1%	0.270
5/24/01	0.03	0.003	0.011	0.001	90.9%	0.013
5/26/01	0.35	0.06	0.056	0.018	67.9%	0.044
6/01/01	0.52	0.14	0.178	0.051	71.3%	0.161
6/05/01am	0.5*	0.50*	0.920	0.062	93.3%	0.234
6/05/01pm	0.08	0.04	0.022	0.008	63.6%	0.016
6/07/01	0.55	0.44	0.618	0.072	88.3%	0.361
6/15/01	0.36	0.23	0.153	0.039	74.5%	0.115
6/16/01	0.32	0.23	0.324	0.047	85.5%	0.131
6/20/01	0.59	0.37	0.513	0.079	84.6%	0.357
6/21/01	0.56	0.35	0.582	0.068	88.3%	0.425
6/22/01	0.35	0.11	0.310	0.036	88.4%	0.129
6/30/01	0.44	0.94	0.428	0.062	85.5%	0.316
7/01/01	0.10	0.60	0.104	0.019	81.7%	0.050
7/05/01	0.08	0.32	0.100	0.020	80.0%	0.030
7/08/01	0.29	0.15	0.061	0.034	44.3%	0.097
7/18/01	0.08	0.04	0.021	0.013	38.1%	0.016
7/26/01	1.86	0.57	1.011	0.166	83.6%	0.585
7/28/01	1.82	0.09	0.363	0.075	79.3%	0.496
8/10/01	0.8	0.96	0.722	0.084	88.4%	0.540
8/11/01	1.86	1.8	1.146	0.135	84.9%	0.594
8/13/01	0.21	0.36	0.165	0.03	81.8%	0.096
Average	0.56	0.35	0.364	0.050	78.7%	0.213

* Approximate: no hyetograph recorded.

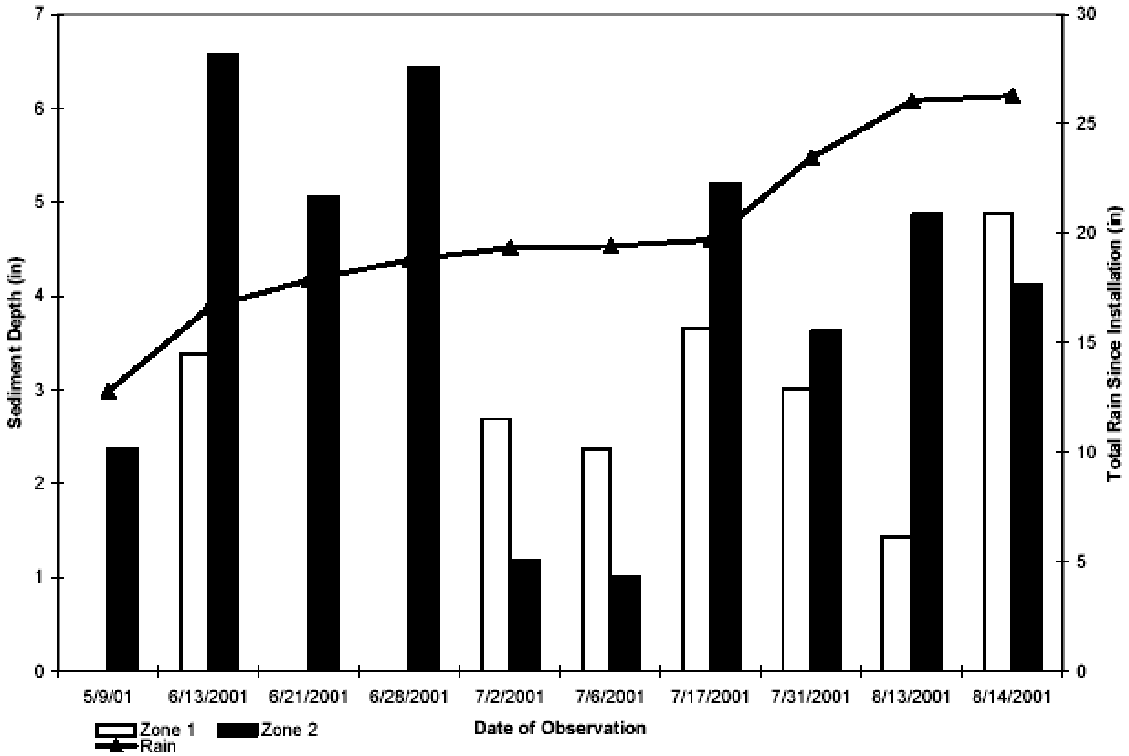
(From Yu and Fassman, 2001)

Appendix B. Hydrologic Characteristics of StormVault™ (Continued)

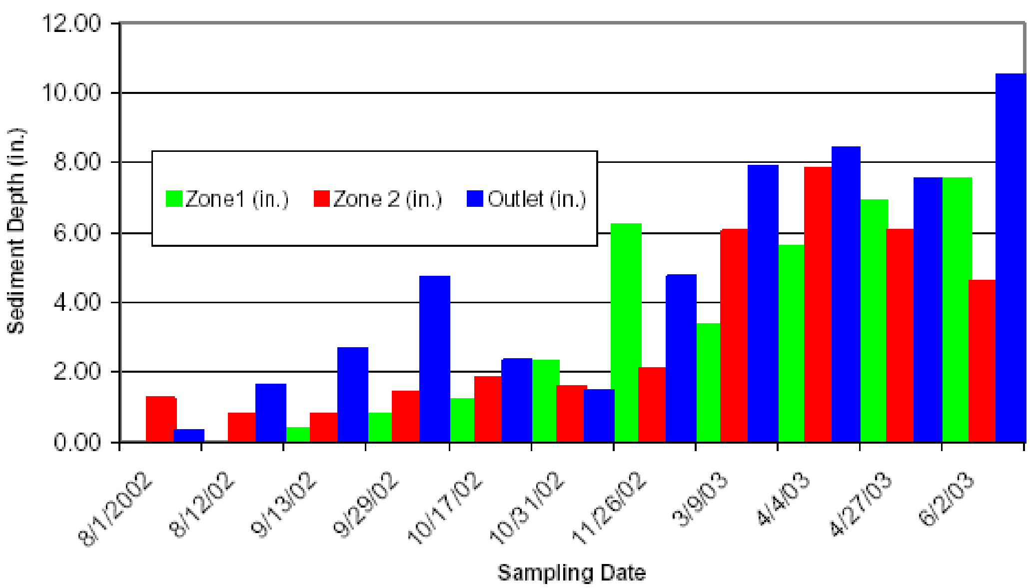
Storm Date	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Flow Attenuation (%)	Maximum Vault Storage (ws-in.)
8/17/02	0.384	0.057	85.2	0.240
8/28/02	0.147	0.024	83.7	0.109
9/1/01	0.027	0.006	77.8	0.037
9/15/02	0.062	0.009	85.5	0.035
9/22/02	0.171	0.031	81.9	0.094
9/26/02	0.121	0.054	55.4	0.250
10/10/02	0.247	0.050	79.8	0.215
10/15/02	0.082	0.053	35.4	0.177
10/21/02	0.050	0.015	70.0	0.040
10/25/02	0.138	0.067	51.4	0.220
10/28/02	0.045	0.017	62.2	0.049
10/29/02	0.128	0.036	71.9	0.140
11/4/02	0.013	0.008	38.5	0.017
11/5/02	0.123	0.032	74.0	0.097
11/11/02	0.787	0.063	92.0	0.287
11/12/02	0.183	0.061	66.7	0.453
11/16/02	0.114	0.036	68.4	0.161
11/17/02	0.029	0.012	58.6	0.080
3/26/03	0.055	0.034	38.2	0.111
3/29/03	0.076	0.026	65.8	0.129
4/7/03	0.080	0.046	42.5	0.218
4/8/03	0.052	0.024	53.8	0.120
4/18/03	0.064	0.036	43.8	0.122
4/25/03	0.029	0.010	65.5	0.024
4/30/03	0.626	0.066	89.5	0.443
5/3/03	0.022	0.017	22.7	0.013
5/5/03	0.031	0.011	64.5	0.020
5/7/03	0.018	0.006	66.7	0.023
5/9/03	1.330	0.039	97.1	0.410
5/15/03	0.302	0.054	82.1	0.543
5/17/03	0.066	0.031	53.0	0.224
5/21/03	0.086	0.020	76.7	0.087
5/22/03	0.031	0.013	58.1	0.061
5/25/03	0.039	0.018	53.8	0.042
5/26/03	0.081	0.028	65.4	0.154
5/27/03	0.088	0.022	75.0	0.067
5/29/03	0.043	0.020	53.5	0.062
5/31/03	0.139	0.012	91.4	0.044
6/3/03	0.030	0.019	36.7	0.055
6/4/03	0.109	0.019	82.6	0.073
6/7/03	0.363	0.058	84.0	0.545
6/8/03	0.162	0.021	87.0	0.112
6/11/03	0.255	0.029	88.6	0.132
6/12/03	0.057	0.018	68.4	0.058

(From Yu and Li, 2004)

Appendix C. Sediment Accumulation in the StormVault™



(From Yu and Fassman, 2001)



(From Yu and Fassman, 2004)