NJCAT TECHNOLOGY VERIFICATION

FloGard Dual-Vortex Hydrodynamic Separator

KriStar Enterprises, Inc.

August 2007

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1. INTRODUCTION

1.1 New Jersey Corporation for Advanced Technology (NJCAT) Program

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

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

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

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

The PPA also requires that:

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

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

1.2 Technology Verification Report

In April 2007, KriStar Enterprises, Inc. (P.O. Box 6419, Santa Rosa, CA 95406) submitted a formal request for participation in the NJCAT Technology Verification Program. The request (after pre-screening by NJCAT staff personnel in accordance with the technology assessment guidelines) was accepted into the verification program. The technology proposed by KriStar, the FloGard® Dual-Vortex Hydrodynamic Separator, is an enhanced gravity separator used for the control of sediments and their associated pollutants, oil and floatables in stormwater.

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

This verification project included the evaluation of assembled company's manuals, literature, and laboratory testing reports to verify that the FloGard® Dual-Vortex satisfies the performance claim made by KriStar.

1.3 Technology Description

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

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

The nature of pollutants emanating from differing land uses is very diverse. KriStar has developed a technology for separating and retaining floating and sinking pollutants including sediment, hydrocarbons and debris under rapid flow conditions using a dual-vortex hydrodynamic separator. Between maintenance events, pollutants accumulate within the system and are therefore removed from the natural environment. Maintenance is performed from above by a vacuum truck and without interference from internal components.

The FloGard® Dual-Vortex Hydrodynamic Separator provides enhanced gravity separation of suspended stormwater pollutants in a compact configuration. Particle settling or floatation is accelerated by centripetal forces induced by the tangential flow pattern augmented by a highly circuitous flow path (a vendor-provided statement). The unit uses two independent cylindrical separators: Low flow is diverted by the inlet to the first separator, while moderate flow begins to overflow the first control weir and enters the second separator. Settled particles collect in the bottom storage area of the unit which is isolated from the fluid outlet, minimizing resuspension. Floating debris and oils are temporarily held at the top of each separator and deposited in the upper storage area by peak storm events. Once the unit treatment capacity is exceeded, excess flow breaches a second control weir at the inlet and passes through the bypass pipe without decreasing the treatment flow or re-entraining captured pollutants.

1.3.2 Specific Applicability

The FloGard® Dual-Vortex Hydrodynamic Separator 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

1.3.3 Range of Contaminant Characteristics

The FloGard® Dual-Vortex Hydrodynamic Separator has been shown to capture a wide range of pollutants of concern. These include: trash and debris, total suspended solids (TSS), sediments, and oil and grease.

1.3.4 Range of Site Characteristics

The FloGard® Dual-Vortex Hydrodynamic Separator is designed to accommodate a wide range of flows and volumes (Table 1). The FloGard® Dual-Vortex is a primary treatment device, which requires no pretreatment. However, it can be used as a pretreatment device before detention systems, mitigating wetlands or other polishing systems.

Table 1. FloGard DUAL-VORTEX Hydrodynamic Separator Models and Dimensions

Model No.	Diameter		Depth (below invert)		Maximum inlet pipe size	
	ft	mm	ft	mm	in	mm
DVS-36	3	914	3.5	1067	12	305
DVS-48	4	1219	4.5	1372	18	457
DVS-60	5	1524	5.4	1646	24	610
DVS-72	6	1829	6.8	2225	30	762
DVS-96	8	2438	8.0	2438	42	1067

1.3.5 Material Overview, Handling and Safety

The FloGard® Dual-Vortex offers full access manhole opening for ease of maintenance and offers removable internal components for full and complete clean-outs. During regular maintenance, an industrial vacuum with an extension can be used to remove collected floating debris and hydrocarbons from surface and remove sediment from the bottom of the tank through separators tubes.

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

1.4 Project Description

This project included the evaluation of assembled reports, company manuals, literature, and laboratory testing reports to verify that the FloGard® Dual-Vortex meets the performance claim of KriStar Enterprises, Inc.

1.5 Key Contacts

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2. EVALUATION OF THE APPLICANT

2.1 Corporate History

KriStar Enterprises, Inc. was founded in 1993 to develop stormwater pollutant removal products for use in catch basins. Since that time, KriStar has created innovative solutions for the stormwater management industry and today has one of the broadest product lines covering issues ranging from sediment and erosion control during construction to a multitude of manufactured best management practices for both standard and unique, custom applications to a full-service

BMP maintenance operation. Ten patents have been issued to KriStar covering stormwater management product items in that time frame.

2.2 Organization and Management

KriStar's senior management, Doug Allard, Chief Executive Officer, and Craig Beatty, President, have over 60 years combined of experience in the underground stormwater industry. They are ably supported by Jonathan McDonald, PE, Engineering Services Manager, Gary Jones, Vice President- Field Operations, and Skip Short, Eastern Regional Sales Manager. The company headquarters is in Santa Rosa, CA with additional sales/warehouse locations in Southern California and Atlanta, Georgia.

2.3 Operating Experience with respect to the Proposed Technology

The FloGard® Dual-Vortex Hydrodynamic Separator was developed during 2004 to provide improved maintenance access for this class of BMP's as well as providing footprint relief for building sites with area restraints. Over 150 units have been installed throughout the United States since that time. The majority of these units are under contract with KriStar's maintenance operations division which allows the continual monitoring and inspection of these units.

2.4 Patents

The design of the FloGard® Dual-Vortex Hydrodynamic Separator received a US Patent (# 7,182,874) in February 2007.

2.5 Technical Resources, Staff and Capital Equipment

KriStar employs 60 persons including three members in the engineering department and five sales persons.

As part of its continuing commitment to providing innovative solutions in this field, KriStar works on product development in a full-scale test loop in its main facility. In addition, regional universities are contracted regularly to perform independent laboratory evaluations of new products and applications as well as any enhancements to existing product lines.

3. TREATMENT SYSTEM DESCRIPTION

A schematic diagram of the FloGard® Dual-Vortex Hydrodynamic Separator is shown in Figure 1. The technology generally relates to a novel, in-line hydrodynamic treatment system for stormwater runoff in which dual vortex separators are used to remove sediments from runoff. The separators are designed to function in stages, to treat the lowest flows in one separator, with diversion of increasing flows to a second separator. At peak flow, an in-line bypass allows any excess flow to pass through the treatment system, thereby preventing backup of stormwater, while at the same time leaving accumulated materials undisturbed.

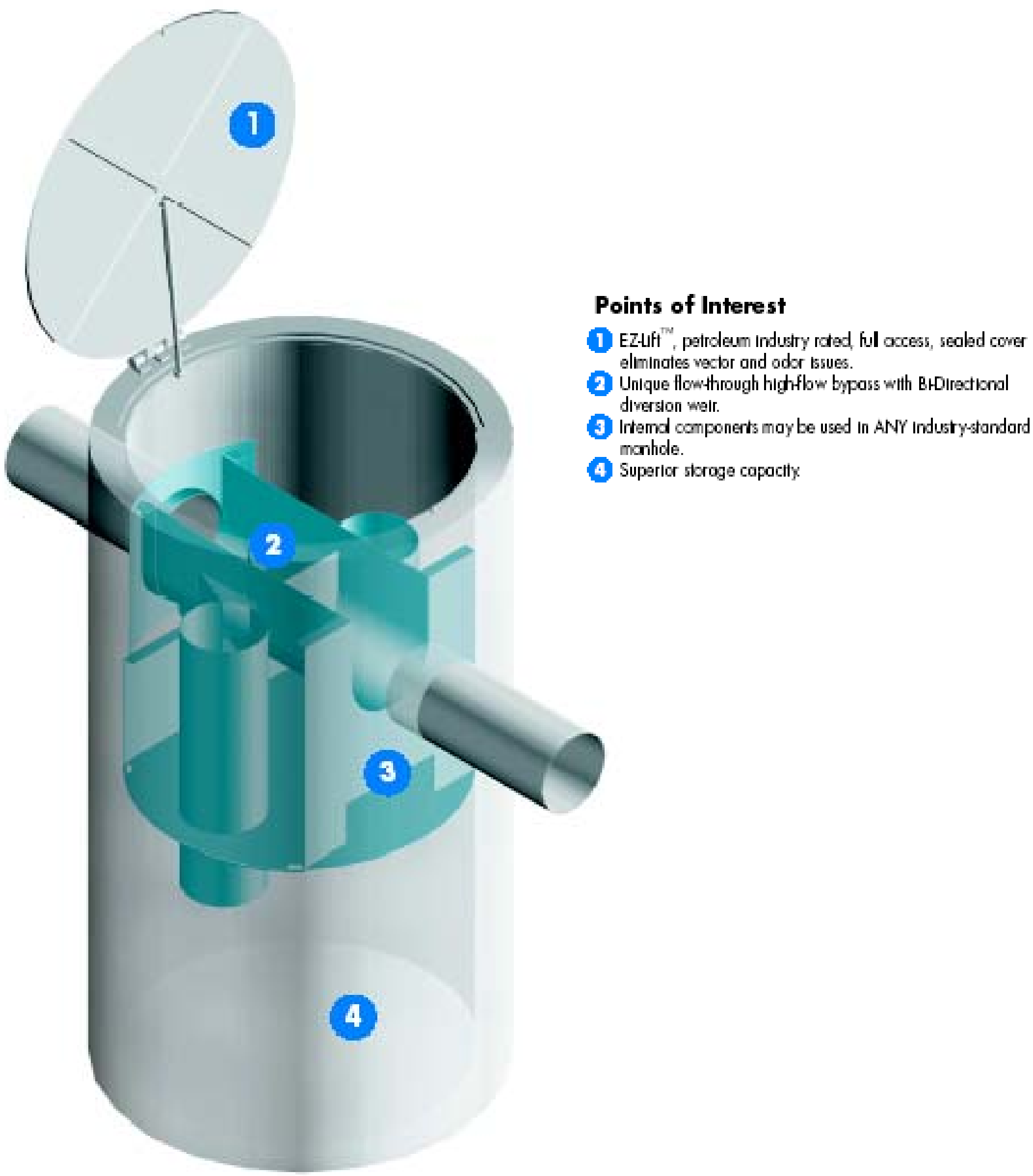


Figure 1. Schematic of the FloGard® Dual-Vortex Hydrodynamic Separator

A removable assembly unit (Figure 2) is provided including a directional pass-through member, one vortex separator positioned to each side of the pass-through member, with a separate passageway or inlet extending from the wall of the passthrough member to the wall of each of the separators. The passageways direct the flow of fluids tangentially to the inner wall of the separator to impart a downwardly spiraling, vortex type flow to the introduced water. In one embodiment, the pass-through member is a closed wall through-pipe. In another embodiment, the pass-through member comprises an open-top bypass chute (shown in Figures 1 and 2).

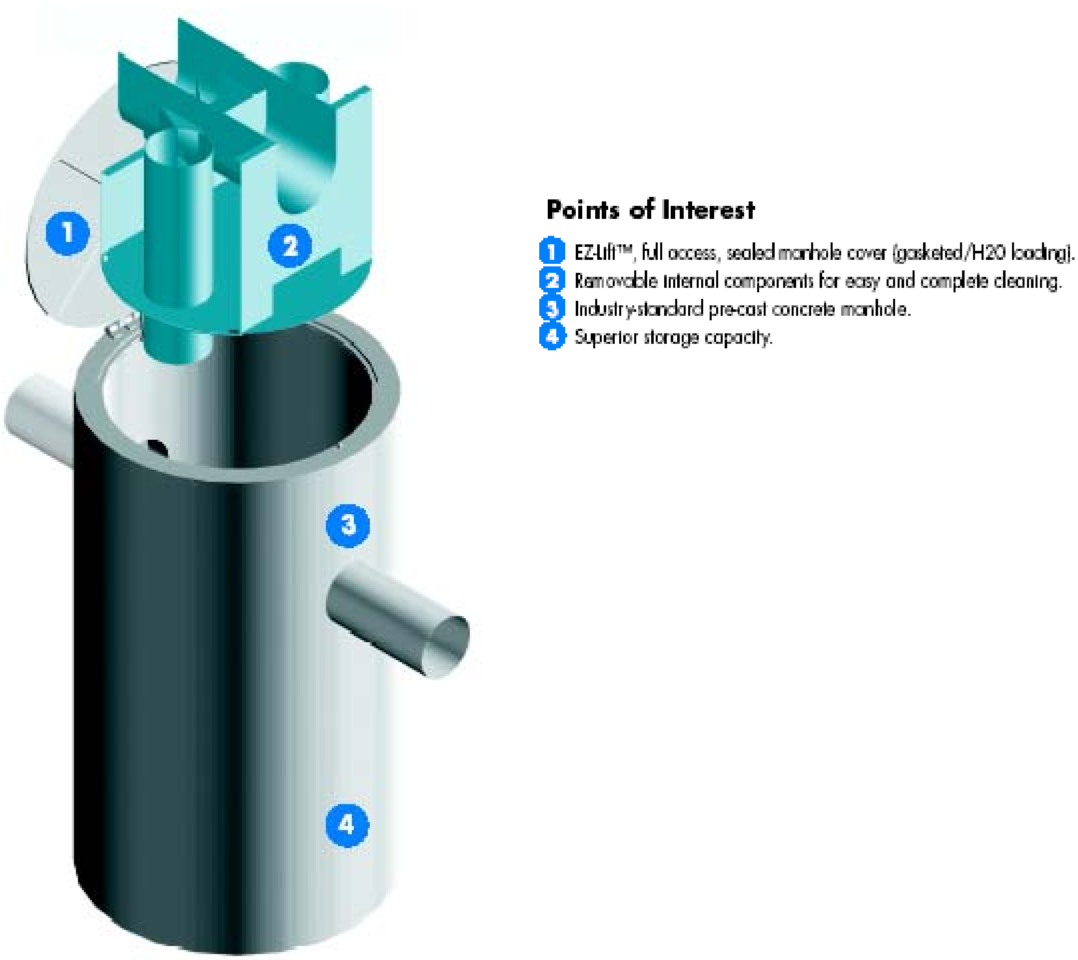


Figure 2. Removable Assembly Unit of the FloGard® Dual-Vortex Hydrodynamic Separator

The vortex separators themselves comprise cylindrical tubes, extending downwardly from the pass-through member through a central platform, to a debris holding reservoir below the platform. A first weir disposed internal to the pass-through member at its base directs the initial, low flow to the first passageway, carrying first flow stormwater to the first of the two vortex separators, each oriented vertically relative to the through-pipe. That is, the central, longitudinal axis of each separator is disposed substantially orthogonally relative to the longitudinal axis of the through-pipe. A second weir, disposed within the pass-through member downstream from, and taller than the first weir, directs overflow from the first weir to a second transport passageway to carry this second stage flow to the second, vertically oriented vortex separator.

The flow paths at three different stages are shown in Figure 3. In most cases, the flows are directed to either the first or second separator for treatment. When flows from storm runoff increase beyond the capacity of the two separators, water will flow over the second weir, thereby continuing through the assembly to exit into the storm drain system for later discharge or treatment. The capacity of the pass-through member should be equal to or larger than that of the drainage pipe supplying the system, to prevent the possibility of backup. Having such an inline, high flow capability, the need for a secondary unit, or placement of the unit offline, to accommodate a condition of high flow is eliminated.

As important as treatment capability is, it is also vital that treatment units be easily maintainable, and provide access to allow for complete cleanout. In the embodiment wherein the pass-through member comprises a closed wall through-pipe (shown in Figure 3), the through-pipe is provided with an opening at its top (not shown in Figure 3) to permit access to the weirs disposed there-within. Such a design allows for visual inspection of weirs and access for necessary cleanout to assure debris, which could block flow to either of the vortex separators, or over the second weir to outfall the unit, is not allowed to accumulate. In the embodiment where the pass-through member comprises an open-top bypass chute (shown in Figures 1 and 2), inherent in this design is full access to the weir structures for easy inspection and cleanout. As a further feature of either embodiment, the treatment unit can exist as an integrated assembly which can be easily disconnected from the walls of the basin into which it has been secured, and sized to be completely removed from the manhole via the manhole cover, thus allowing full access to all areas of the basin for cleaning and removal of accumulated sludge and debris.

Installation

The installation sequence is: (1) install internal support ring, (2) install base plate (with vortex tubes), and (3) install weir plate mounting guides, inlet weir plate and lower half of outlet weir plate, (4) install “through pipe” with inlet flange adapter, and (5) install upper half of outlet weir plate.

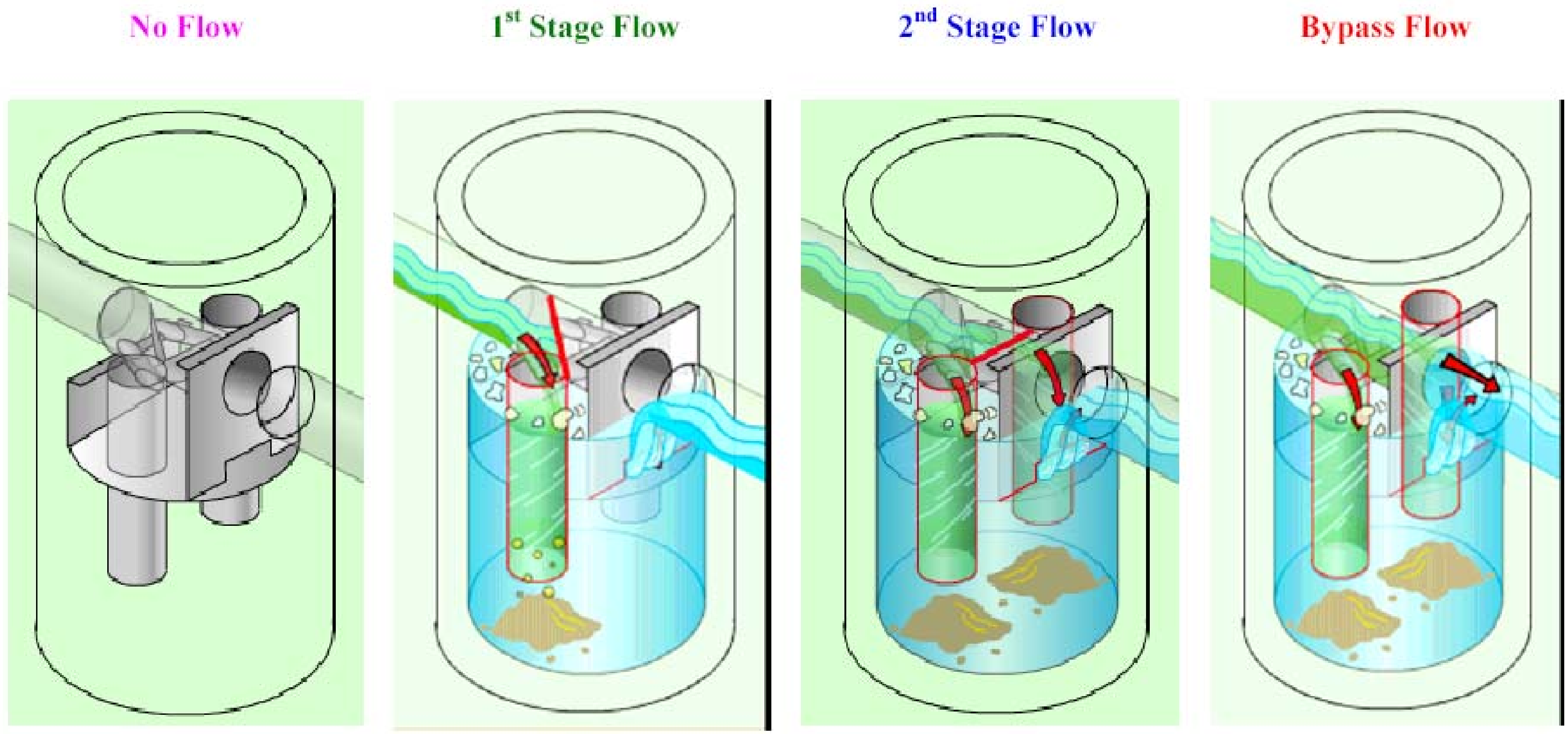


Figure 3. Three Flow Stages of the FloGard® Dual-Vortex Hydrodynamic Separator

4. TECHNICAL PERFORMANCE CLAIM

Claim: The FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, at a flow rate of 280 gpm (0.63 ft^3/s), has been shown to have a 60% total suspended solids (TSS) removal efficiency, measured as suspended solids concentration (SSC) (as per the NJDEP methodology for calculation of treatment efficiency) using NJDEP specified material with an average d_{50} particle size of 70 microns, an average influent concentration of 202 mg/L and 100% initial sediment loading in laboratory studies using simulated stormwater.

5. TECHNICAL SYSTEM PERFORMANCE

5.1. NJDEP Total Suspended Solids Laboratory Test Procedure

NJDEP has prepared a TSS laboratory testing procedure to help guide vendors as they prepare to test their stormwater treatment systems prior to applying for NJCAT verification. The testing procedure has three components:

1. Particle size distribution
2. Full scale laboratory testing requirements
3. Measuring treatment efficiency

<u>1. Particle size distribution:</u>

The following particle size distribution will be utilized to evaluate a manufactured treatment system (See Table 2) using a natural/commercial soil representing the United States Department of Agriculture (USDA) definition of a sandy loam material. This hypothetical distribution was selected as it represents the various particles that would be associated with typical stormwater runoff from a post construction site.

<u>2. Full Scale lab test requirements</u>

A. At a minimum, complete a total of 15 test runs including three (3) tests each at a constant flow rate of 25, 50, 75, 100, and 125 percent of the treatment flow rate. These tests should be operated with initial sediment loading of 50% of the unit's capture capacity.
B. The three tests for each treatment flow rate will be conducted for influent concentrations of 100, 200, and 300 mg/L.
C. For an online system, complete two tests at the maximum hydraulic operating rate. Utilizing clean water, the tests will be operated with initial sediment loading at 50% and 100% of the unit's capture capacity. These tests will be utilized to check the potential for TSS re-suspension and washout.

D. The test runs should be conducted at a temperature between 73-79 degrees Fahrenheit (°F) or colder.

Table 2. NJDEP Particle Size Distribution

Particle Size (microns)	Sandy loam (percent by mass)
500-1,000 (coarse sand)	5.0
250-500 (medium sand)	5.0
100-250 (fine sand)	30.0
50-100 (very fine sand)	15.0
2-50 (silt)	(8-50 µm, 25%) (2-8 µm, 15%)*
1-2 (clay)	5.0

Notes:
1. Recommended density of particles ≤2.65 g/cm^3

*The 8 µm diameter is the boundary between very fine silt and fine silt according to the definition of the American Geophysical Union. The reference for this division/classification is: Lane, E. W., et al. (1947). "Report of the Subcommittee on Sediment Terminology," Transactions of the American Geophysical Union, Vol. 28, No. 6, pp. 936-938.

3. Measuring treatment efficiency

A. Calculate the individual removal efficiency for the 15 test runs.
B. Average the three test runs for each operating rate.
C. The average percent removal efficiency will then be multiplied by a specified weight factor (See Table 3) for that particular operating rate.
D. The results of the 5 numbers will then be summed to obtain the theoretical annual TSS load removal efficiency of the system.

Table 3. NJDEP Weight Factors for Different Treatment Operating Rates

Treatment operating rate	Weight factor
25%	.25
50%	.30
75%	.20
100%	.15
125%	.10

Notes:

Weight factors were based upon the average annual distribution of runoff volumes in New Jersey and the assumed similarity with the distribution of runoff peaks.

This runoff volume distribution was based upon accepted computation methods for small storm hydrology and a statistical analysis of 52 years of daily rainfall data at 92 rainfall gauges.

5.2 Laboratory Testing

5.2.1 Introduction

Verification testing of a 4 ft diameter FloGard Dual-Vortex Hydrodynamic Separator (DVS–48) was conducted at Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts, under a contract from KriStar Enterprises, Inc. (Mailloux 2007). Testing was conducted according to the protocols set forth by the New Jersey Department of Environmental Protection (NJDEP), as described above. Testing consisted of establishing the unit's hydraulic capacity, determining the sediment removal efficiencies (using NJDEP specified particle distribution) and evaluating the re-entrainment conditions for various flows.

The DVS–48 is a cylindrical separating device measuring 4 feet in diameter by approximately 8 feet high. The unit has a 12-inch diameter inlet and outlet, with the inverts located 60.5 inches above the floor. The pipes are oriented horizontally and centered within the unit. The DVS-48 contains two (2) internal overflow weirs, 8-in and 14-in high, respectively, as well as two (2) vertical drop tubes, approximately 12-inches in diameter, connecting the upper and lower chamber. Figure 4 shows a layout drawing of the DVS–48 test unit and Figure 5 shows the unit installed in Alden's test facility. The test unit supplied by KriStar included two (2) 12-inch viewing windows, located approximately 36 inches above the floor, to facilitate visual observations and documentation.

5.2.2 Test Facility Description

Figure 6 shows the closed test loop, located in Alden's laboratory/test facility, which was used to test the DVS–48. The test loop consisted of two pumps (20HP and 50HP with flow capacities of 3 and 9cfs, respectively) drawing water from a laboratory sump, five calibrated flow meters (2, 4, 6, 8 and 12-inch) connected by a manifold to a 12-inch influent pipe, test unit and 12-inch effluent pipe to return the water to the laboratory sump. Isokinetic sampling-tube arrays were located within the influent and effluent piping, approximately 8 ft upstream and 2 ft downstream of the test unit, to collect the influent and effluent sediment concentration samples. As seen on Figure 7, each array consisted of one (1) to three (3) vertically adjustable sampling tubes (water level dependent), containing a flow-control shut-off valve. Sediment was injected into the crown of the influent pipe through a vertical pipe connected to a tee. The tee was located 10 influent pipe diameters upstream of the influent sampling ports. The influent pipe diameter from the injector to downstream of the sampling ports varied from 3 inches to 6 inches (depending on the test flow), in order to produce a sufficiently high velocity to maintain sediment suspension at the samplers.

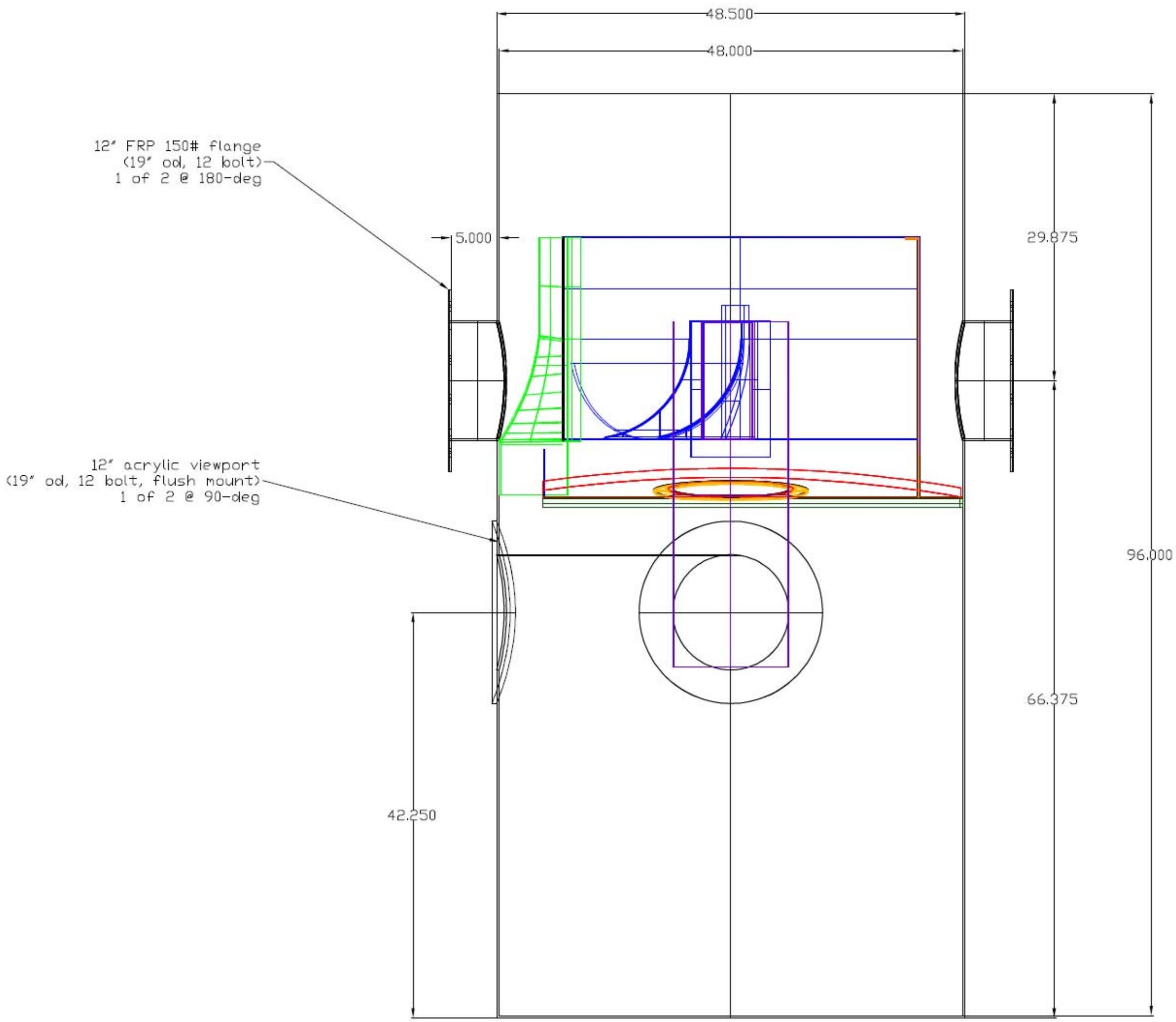


Figure 4. FloGard DVS-48 Test Unit

Figure 5. Photograph of the DVS-48 in Alden's Test-Loop

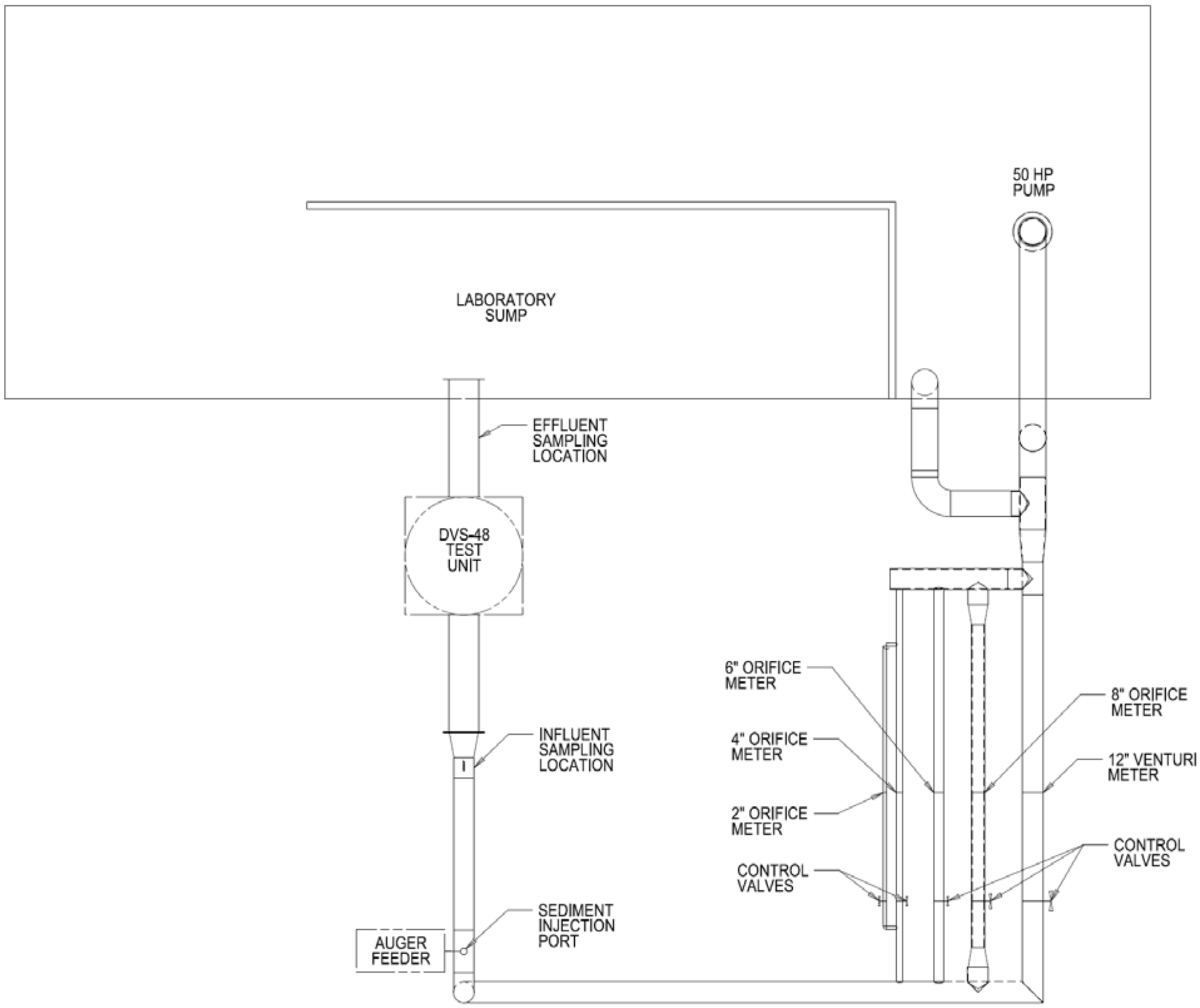


Figure 6. Alden's Stormwater Laboratory Flow Loop

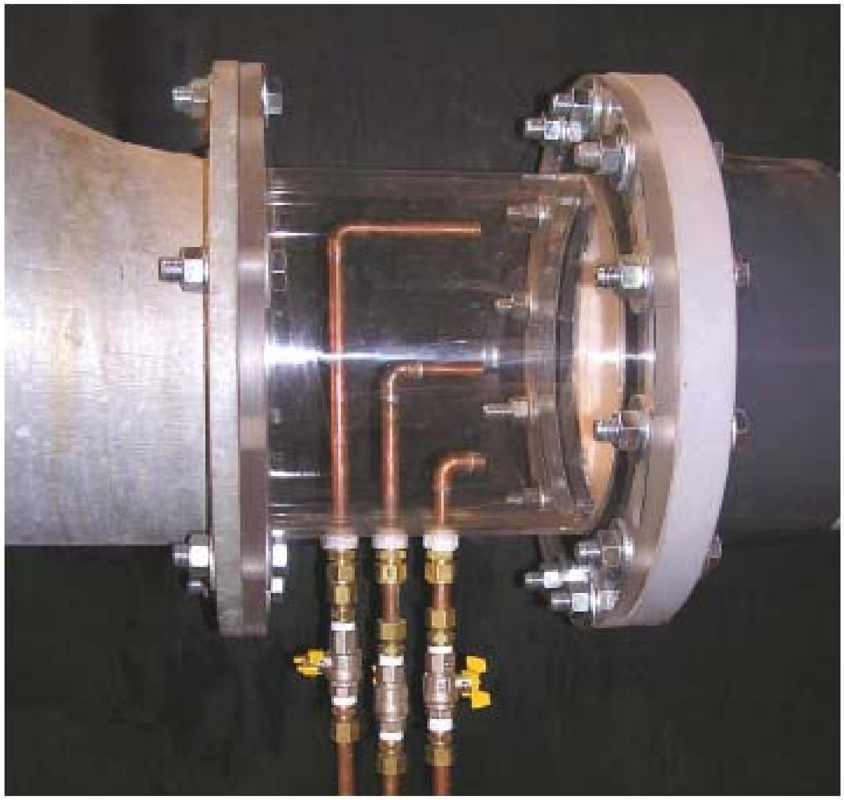


Figure 7. Photograph of Influent Sampling Tube Array

5.2.3 Instrumentation and Measuring Techniques

Flow

The inflow to the test unit was measured using one of five calibrated flow meters. Each meter was fabricated per ASME guidelines and calibrated in Alden's Calibration Department prior to the start of testing. Flows were set with a butterfly valve and the differential head from the meter was measured using a Rosemount® 0 to 250-inch Differential Pressure Cell, also calibrated at Alden prior to testing. The test flow was averaged and recorded every 5 seconds throughout the duration of the test, using a computerized data acquisition (DA) program. The accuracy of the flow measurement is estimated at ±2%.

Temperature

Water temperature measurements were obtained using a calibrated Omega® DP41 temperature probe and readout device. The calibration was performed at the laboratory prior to testing. The temperature reading was entered into the DA program at the start of each test for use in the flow measurement calculations.

Pressure Head

The pressure head within the WQ unit was measured using a Druck®, 2-psi single-ended pressure cell. The pressure cell was calibrated at Alden prior to testing. Pressure readings were averaged and recorded every 5 seconds throughout the duration of the test, using a computerized DA program.

Sediment Injection

NJDEP protocol sediment, with a Specific Gravity of 2.65, was used to test the DVS-48 unit. The test sand was introduced into the influent pipe using an Auger® volumetric screw feeder, model VF-1. The Auger feed screws used in testing ranged in size from 0.75 to 1.0 inches, depending on the test flow. The auger screw, driven with a variable speed drive, was calibrated with the test sediment prior to testing, in order to establish a relationship between screw RPM and feed rate in mg/minute. The feeder has a 1.5 cubic foot hopper at the upper end of the auger to provide a constant supply of dry test sand.

Sample Collection

As described in Subsection 5.2.2, isokinetic sampling tubes were located within the influent and effluent piping to collect the sediment concentration samples. The tubes ranged from 0.375 to 0.75 inches in diameter, depending on the pipe diameter, test flow and location within the pipe. Each tube array was vertically adjusted and calibrated to match the velocities for each flow condition, prior to testing. A typical sampling array is shown on Figure 7.

Sample Concentration Analyses

Sample concentrations can be analyzed using one of two analytical methods: Suspended Solids Concentration (SSC), or Total Suspended Solids (TSS). SSC methodology utilizes the entire sample in the analysis, as opposed to the TSS method, which requires the sample to be split prior to processing. Two sets of samples (approximately one liter each) were collected to allow both analytical methods to be used for the present study. The SSC samples were processed at Alden as described below and the TSS samples were processed at Alpha Analytical Labs per EPA method 160.2.

SSC Analysis:

Collected samples were filtered and analyzed by Alden in accordance with Method B, as described in ASTM Designation: D 3977-97 (Re-approved 2002), "Standard Test Methods for Determining Sediment Concentration in Water Samples". The required silica sand used in the sediment testing did not result in any dissolved solids in the samples and therefore, simplified the ASTM testing methods for determining sediment concentration.

Samples were collected in graduated 2-Liter beakers which were cleaned, dried and weighed to the nearest 0.1-gram (using an Ohaus® 4000g x 0.1g digital scale, model SCD-010), prior to sampling. Collected samples were also weighed to the nearest 0.1-gram using the Ohaus® digital scale. Each sample was filtered through a Whatman® 934-AH, 47 mm, 1.5-micron, glass microfiber filter paper, using a laboratory vacuum-filtering system. Each filter was placed in a designated dish and dried prior to filtering, in an Oakton® StableTemp gravity convection oven, model 05015-59, at 225 degrees F for a minimum of 2 hours. Each dried filter/dish set was then weighed to the nearest 0.0001 gram, using an AND® analytical balance, model ER-182A. Once filtered, each sample and dish was dried at a temperature between 175 and 220 degrees F (below boiling) for 20 to 30 minutes until visually dry. The oven temperature was increased to 225 degrees F and the samples were dried for an additional 2-½ to 3 hours. The dry samples and dishes were then weighed to the nearest 0.0001 gram, using the AND® balance. Net sediment weight (in mg) was determined by subtracting the dried filter weight from the dried sample weight and multiplying the result by 1,000. The net sample volume, in liters, was determined by subtracting the beaker and net sediment weight from the overall sample weight and dividing by 1,000. Each sample sediment concentration, in mg/liter, was determined by dividing the net sediment weight by the net sample volume.

Test Sediment Mix and Particle Size Distribution

NJ#00N, OK110 and Min-U-Sil 40 silica sand, available from US Silica, was used to produce the test sediment as required by the NJDEP testing protocol. Table 4 shows the theoretical PSD of each grade of sand, as well as the mix ratios and resulting percentages. The D_{50} size for the mix, as seen in Figure 8, was approximately 70 microns, which matched well with the NJDEP estimated D_{50} of 67 microns.

Table 4. Test Sediment mix using commercially available US Silica sand

Range	**Target**	Mesh	Microns	NJ #00N	OK-110	Min-U-Sil 40	%	%	%	**Total**
	NJDEP			11%	46%	43%				
		20	850							
500-1000	**5%**	30	600	45			4.95			**4.95**
		40	425	52			5.72			
250-500	**5%**	50	300	3			0.33			**6.05**
		70	212					0.46		
		100	150		1			6.9		
		120	125		15			22.08		
100-250	**30%**	140	106		48					**29.44**
		170	88		24.2			11.13		
		200	75		9.7			4.46		
50-100	**15%**	270	53		1.9			0.87		**16.47**
8-50	**25%**				0.2	60		0.09	25.8	**25.89**
2-8	**15%**					28			12.04	**12.04**
1-2	**5%**					12			5.16	**5.16**
		Total		100	100	100				**100.00**

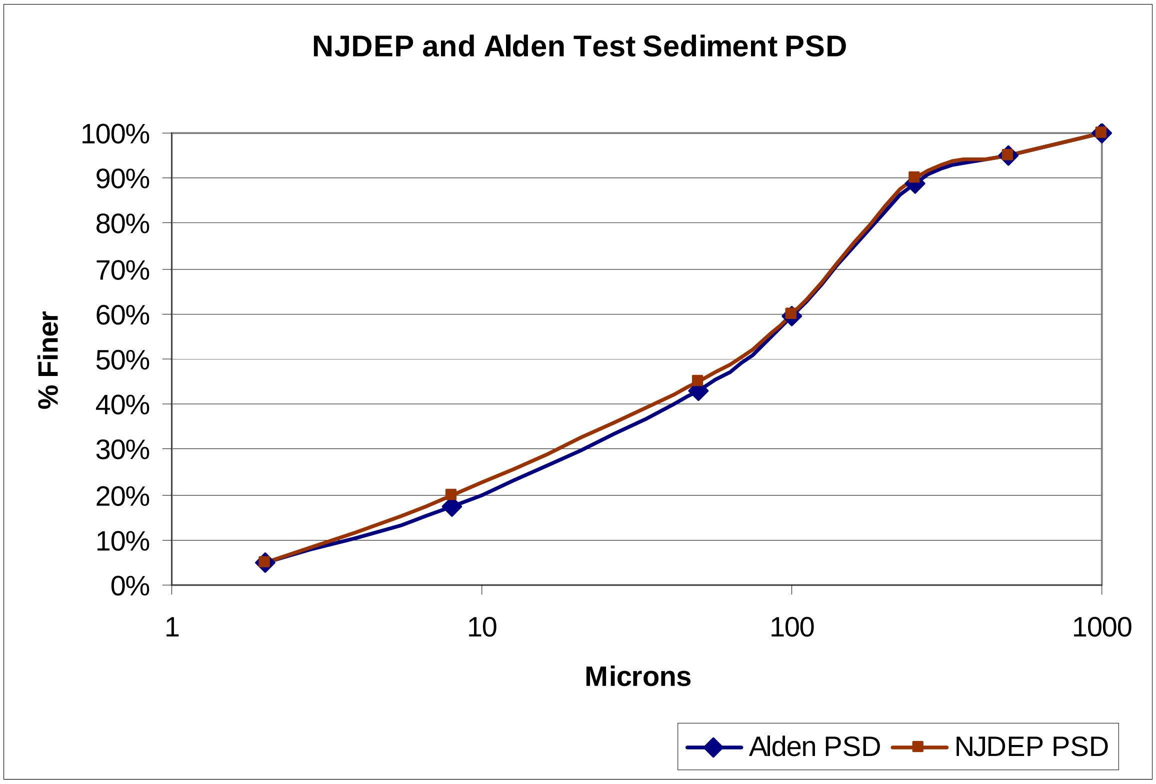


Figure 8. Test Sediment mix using commercially available US Silica sand

5.3 Test Procedures

The DVS–48 was tested in accordance with the NJDEP testing protocol for Stormwater Treatment Devices (see Section 5.1). The guideline requires, at a minimum, documentation showing the capture efficiency of particles ranging from 1 to 1000 microns, for five (5) flows, at 100, 200 and 300mg/L concentration per flow. Re-entrainment testing was conducted with the unit preloaded to 50% and 100% of the stated loading capacity (by KriStar). The test matrix was expanded to include suspended sediment concentration (SSC) analysis.

Testing of the DVS–48 was conducted in three phases, as described below:

5.3.1 Phase 1 - Hydraulic Capacity

The unit was tested without sediment to determine its maximum hydraulic capacity (MHC). Flow and pressure head measurements within the unit were recorded for 5 conditions. Each test flow was set and allowed to reach steady state, at which time a minimum of 3 minutes of flow and pressure data were recorded and averaged. Observations were documented throughout the test, including conditions at the floatables and bypass weirs, as well as water elevations in the influent and effluent pipes.

5.3.2 Phase 2 - Sediment Removal Efficiency Testing

The unit was pre-loaded with the NJDEP sediment to a volume corresponding to 100% of the stated capacity (19 ft^3 in volume and 18 inches in depth). Consequently, the results will be conservative when compared to 50% loading data. Sediment removal efficiency testing was performed using the indirect method (sampling), as described below.

The test flow was set and allowed to reach steady state. The test sediment was introduced into the inflow line and three (3) system volumes were allowed to pass through the test-loop prior to the collection of samples. A minimum of 5 pairs of influent/effluent samples, of approximately 1 Liter each, were collected during each test, with each effluent sample taken one residence time after the influent sample. At the completion of the sample collections, sediment injection was stopped and the system continued to operate for a duration of time necessary to assure that all the sediment had entered the unit. Background samples were taken throughout the test at a location upstream of the injection point, to establish the sediment concentration level of the influent flow. Each collected sample was processed as described in Subsection 5.2.3.

5.3.3 Phase 3 - Re-entrainment and Washout

Re-entrainment tests were conducted at sediment loadings corresponding to 50% and 100% (9.5 and 19.0 ft^3, respectively) of the unit's capture capacity as claimed by KriStar. The sediment trapped from the removal efficiency tests was used to cap the bed load. The unit was slowly filled to the invert of the effluent pipe and the system remained idle for a minimum of 24 hours prior to testing.

Testing was conducted by incrementally increasing the flow of clean water (no sediment) into the unit while continuously obtaining flow data and video documentation of sediment retention and/or re-entrainment. Effluent samples, for SSC and PSD analyses, were obtained at the first sign of sediment bed movement, and/or at the targeted flows (25, 50, 75, 100 and 125%), at which time four (4) samples were collected incrementally over a period of 15 minutes.

5.4 Verification Procedures

All the data provided to NJCAT were reviewed to fully understand the capabilities of the FloGard® Dual-Vortex Hydrodynamic Separator. To verify KriStar's claim, the FloGard® Dual-Vortex laboratory procedures and data were reviewed and compared to the NJDEP TSS laboratory testing procedure.

Claim: The FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, at a flow rate of 280 gpm (0.63 ft^3/s), has been shown to have a 60% total suspended solids (TSS) removal efficiency, measured as suspended solids concentration (SSC) (as per the NJDEP methodology for calculation of treatment efficiency) using NJDEP specified material with an average d_{50} particle size of 70 microns, an average influent concentration of 202 mg/L and 100% initial sediment loading in laboratory studies using simulated stormwater.

5.4.1 Laboratory Testing Results

Results of the tests are summarized below. The detailed results are presented in the lab testing report prepared by the Alden Lab (Mailloux 2007).

Hydraulic Capacity

Flow (gpm) and water level (inches) within the unit were measured for 5 flows ranging from 0 to 700 gpm (1.56 cfs). The maximum flow attained prior to breaching the first weir was 240 gpm (0.53 cfs) and the maximum flow attainable prior to washing out the bypass weir (MHC), was 560 gpm (1.25 cfs). The Hydraulic Characteristics graph, seen on Figure 9, shows two curves describing the flow and water elevations in the unit referenced to the influent pipe invert. The first (top) curve shows the water elevations at the overflow weirs and presents a general picture of the overall elevation changes with respect to flow. However, the lack of elevation data between 240 gpm and 561 gpm prevents the development of the S-shaped curve that is expected due to the free-discharge over the first weir. The second curve shows the change in elevation measured at a location upstream of the downstream outlet orifice. The Delta-H curve shows the elevation differential between the influent and effluent pipes, measured 1.5 ft upstream and downstream of the unit. The discharge coefficient (or the loss coefficient) curve (Cd) is calculated using the flow, water elevation upstream of the outlet orifice and the fully submerged orifice area.

Sediment Removal Efficiency

The removal efficiency reported for each test represents the mean suspended solids load reduction for that test and is calculated using the following equation:

$$\text{Removal Efficiency} = 100\left(\frac{\text{Influent Conc.} - \text{Effluent Conc.}}{\text{Influent Conc.}}\right)$$

Removal efficiency tests were conducted at flows ranging from 70 to 350 gpm (0.16 to 0.78 cfs) and influent sediment concentrations of 100, 200 and 300 mg/l. As stated in Subsection 5.2.4, the unit was loaded to 100% of the stated capacity, as opposed to 50%. This was due to Alden's misinterpretation of the maintenance statement supplied by KriStar and consequently, resulted in lower, more conservative efficiency results as discussed in Subsection 5.4.2 below.

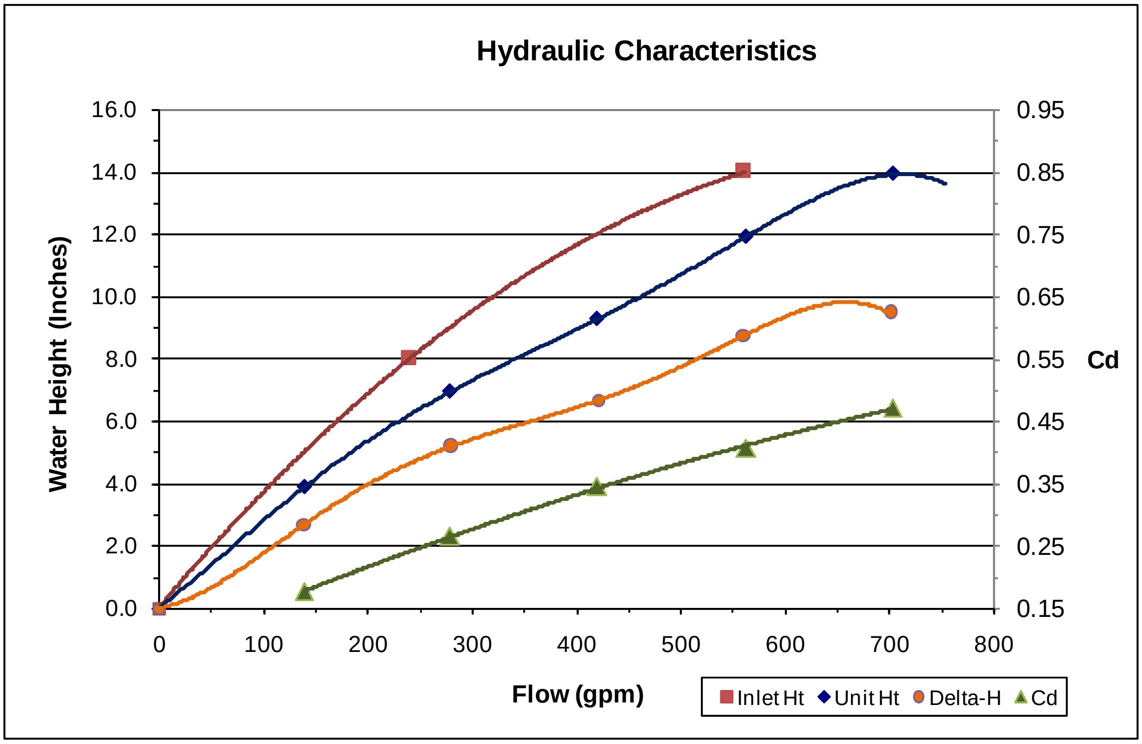


Figure 9. Hydraulic Capacity Flow Curve (Top Two Lines, Height Relative to Invert of Influent Pipe)

In addition to the collected influent samples, verification of the injected sediment concentration was achieved by taking timed dry samples from the auger feeder at regular intervals throughout the test. The additional calculated concentrations are reported in the data sets as "Adjusted Influent Concentrations". The difference between the collected sample concentrations and adjusted concentrations ranged from 0% to approximately 15%.

Figure 10 shows the average sediment removal efficiency curves for both the adjusted and unadjusted SSC analyses, as well as the TSS method, which understated the efficiencies by approximately 50% for all tests conducted. The testing data summary is shown in Table 5, which includes the NJDEP weighted efficiencies.

Water Temperature

Water temperature during the tests varied from 50 to 70.1 degree F.

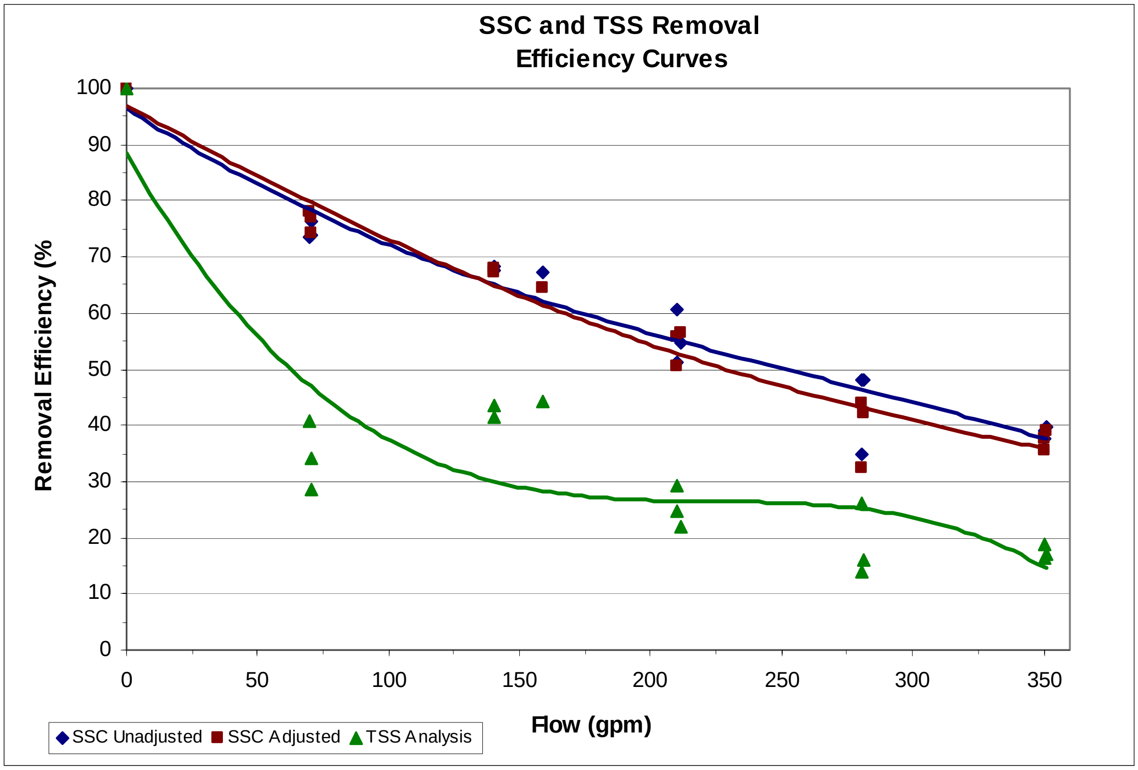


Figure 10. Averaged SSC and TSS Efficiency Curves

Effluent PSD

One effluent sample was collected during each test for particle size distribution (PSD) analysis. Each sample was analyzed by Analytical Services, Incorporated, using a Hiac/Royco 8000A/3000A/MicroCount-05 laser particle counter. The particle counts were determined for the following ranges of micron sizes: (1-2), (2-8), (8-25), (25-50), (50-75), (75-100), (100-175), (175-350), (+350). The percentages of each size range were determined by assuming a spherical particle shape and calculating the corresponding volumes using the average particle size for each range. The size range measured to have the most weight (65.1% to 82.9% by weight) was from 8 to 25 microns. Difference between the measured PSD results is expected when different analysis methods (e.g., using laser particle counter vs. using the likely more accurate Coulter particle counter) are used.

Table 5. Summary of Test Results and Calculated NJDEP Weighted SSC and TSS Removal Efficiencies

			Unadjusted Data				Adjusted Data				TSS Data			
% Revised MHC	Flow gpm	Concentration mg/L	Influent mg/L	Effluent mg/L	Efficiency %	Avg. Efficiency %	Influent mg/L	Effluent mg/L	Efficiency %	Avg. Efficiency %	Influent mg/L	Effluent mg/L	Efficiency %	Avg. Efficiency %
124.6	350.78	300	291.8	176.2	39.6		288.9	176.2	39.0		175.7	145.7	17.1	
124.5	350.54	200	205.0	125.1	39.0		193.8	125.1	35.4		148.6	124.3	16.3	
124.4	350.07	100	103.7	64.9	37.5	38.7	103.8	64.9	37.5	37.3	76.1	61.9	18.8	17.4
99.7	280.65	300	336.4	174.7	48.1		310.9	174.7	43.8		230.0	170.0	26.1	
99.9	281.20	200	226.7	117.4	48.2		202.9	117.4	42.2		140.0	117.7	15.9	
99.8	280.92	100	98.5	64.0	35.0	43.8	94.5	64.0	32.3	39.4	76.3	65.6	14.0	18.7
75.1	211.31	300	289.6	131.1	54.7		301.5	131.1	56.5		120.0	93.9	21.8	
74.6	210.10	200	216.8	85.2	60.7		193.0	85.2	55.9		97.0	68.6	29.3	
74.7	210.17	100	97.1	47.3	51.3	55.6	95.7	47.3	50.6	54.3	54.3	40.9	24.7	25.3
56.4	158.82	300	289.8	95.4	67.1		269.3	95.4	64.6		142.9	79.4	44.4	
49.8	140.32	200	198.7	63.3	68.2		198.4	63.3	68.1		95.0	55.7	41.4	
49.9	140.59	100	99.2	32.1	67.6	67.6	98.1	32.1	67.3	66.7	55.0	31.0	43.6	43.1
24.9	70.19	300	292.4	69.6	76.2		302.6	69.6	77.0		157.1	112.3	28.5	
24.9	70.15	200	196.7	51.1	74.0		197.7	51.1	74.1		124.3	81.9	34.1	
24.9	70.08	100	83.7	22.1	73.6	74.6	101.1	22.1	78.1	76.4	52.0	30.9	40.7	34.4
	0				100.0				100.0				100.0	
						Weighted Eff. **60.5**				**Weighted Eff.** **59.6**				**Weighted Eff.** **31.1**

Re-entrainment and Washout

Re-entrainment tests were performed at flows ranging from 0 to 350 gpm, with initial sediment loadings at 50% (9.5 ft^3) and 100% (19 ft^3) of the unit's capacity (stated by KriStar). The unit flow was incrementally increased, with effluent samples collected for concentration analysis. A series of four (4) samples were collected every 5 minutes at the target flows of 140, 210, 280 and 350 gpm to allow insight into trends and/or anomalies of sediment movement. A single sample was collected at 70 gpm during each test

Fifty Percent (50%) Loading

Movement of suspended material was observed in the lower chamber throughout the duration of the test. However, the quantity of suspended material was minimal and there was no apparent movement of the sediment bed at any point during the test. Measured sediment concentrations were negligible for all flow conditions, with quantities ranging from 0.9 to 4.6 mg/L. The first sample collected at each target flow had the highest concentrations, indicating an initial displacement of fine particles with a sudden increase of flow (approximately 2 minutes elapsed time). A graph of the recorded flow data and corresponding sediment concentration analyses are shown on Figures 11 and 12.

One Hundred Percent (100%) Loading

Movement of suspended material was observed in the lower chamber at 70 gpm. The quantity of material was minimal, with a measured concentration of 0.7 mg/L. Initial movement of the sediment bed was observed at 140 gpm, with particles moving in an outward radial pattern, originating from just below the first drop tube. The continued displacement (scour) of the material resulted in the formation of ripples and dunes, which moved in the same radial pattern. Although the quantity of suspended material increased, the sample concentrations were still minimal, with values ranging from 0.93 to 5.64 mg/L. As expected, the increase in flow to 210 gpm resulted in an increased displacement of the bed and greater amount of suspended material in the lower chamber. The movement of the sediment along the bed was not constant, moving instead in small surges created by the turbulence of the inflow. The measured concentrations were still relatively low, ranging from 6.78 to 25.35 mg/L. However, occasional low-strength vortices of short duration were observed, which periodically carried particles to the outlet. This was made evident by the concentration spike of 53.75 mg/L, measured in the second sample. With the increase in flow to 280 gpm, the radial movement of the sediment bed shifted, due to inflow from the second drop tube. Sediment from the outer ripple and dune formations was observed being carried inward toward the outlet opening from the direction of the second tube. The observed quantity of suspended sediment decreased with time due to the increased depth of the depression under the first drop tube. This was verified by the steady decline in sample concentrations from 38.54 to 27.93 mg/L. This trend of decreased suspended sediment continued at the 350-gpm condition, with sample concentrations dropping from 27.78 to 12.31 mg/L. A graph of the recorded flow data and corresponding sediment concentration analyses are shown on Figures 13 and 14.

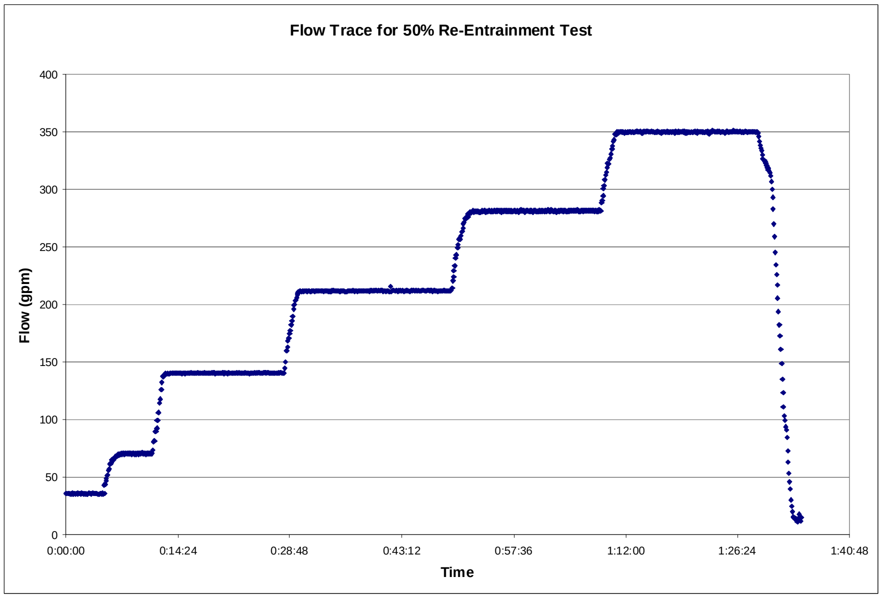
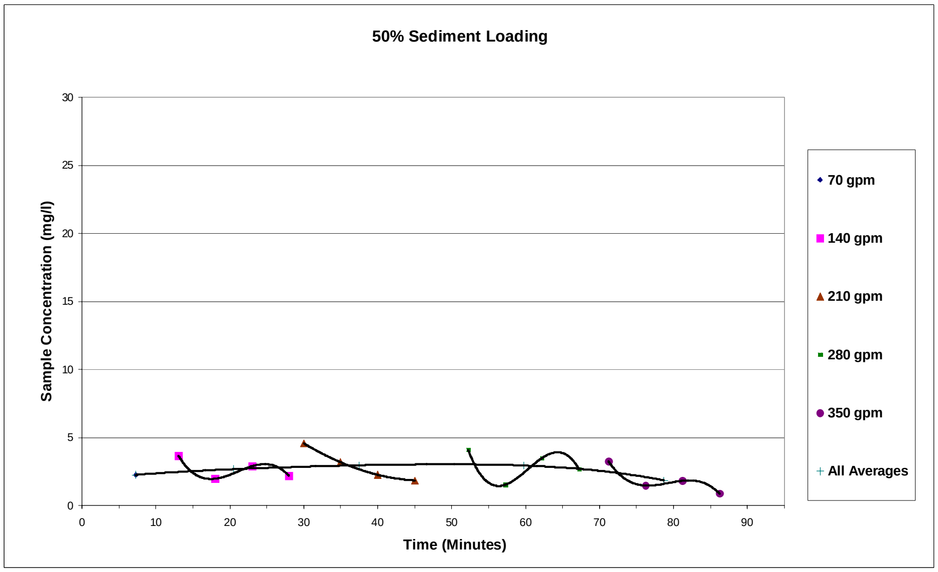


Figure 11. 50% Flow Trace Graph



Time	70 gpm	140 gpm	210 gpm	280 gpm	350 gpm
0	2.28	3.68	4.58	4.09	3.25
5		1.98	3.19	1.54	1.48
10		2.91	2.28	3.51	1.84
15		2.18	1.86	2.69	0.90

Figure 12. Re-entrainment Effluent Sample Concentrations at 50% Flow

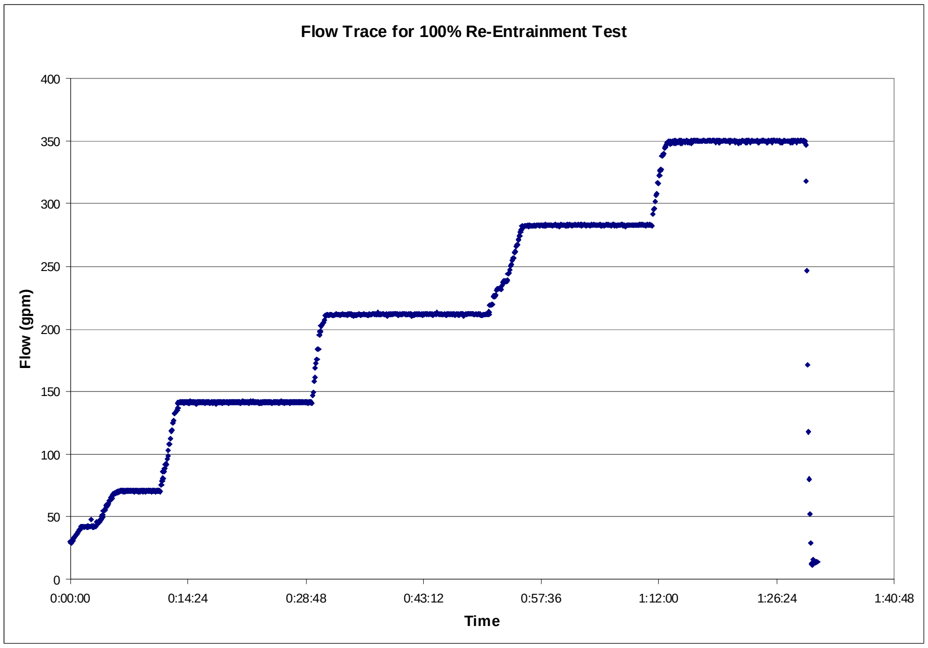
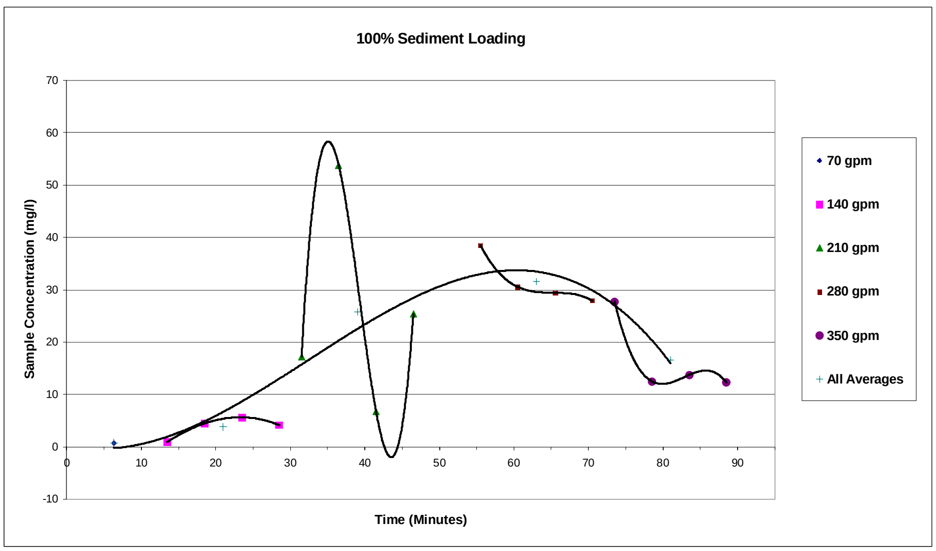


Figure 13. 100% Flow Trace Graph



Time	70 gpm	140 gpm	210 gpm	280 gpm	350 gpm
0	0.71	0.93	17.18	38.54	27.78
5		4.48	53.75	30.57	12.51
10		5.64	6.78	29.44	13.74
15		4.17	25.35	27.93	12.31

Figure 14. Re-entrainment Effluent Sample Concentrations at 100% Flow

5.4.2 Assessment of Test Methods and Results

The lab tests were well controlled as demonstrated by a close agreement between the desired influent concentrations and the actual influent concentrations. Moreover, the SSC removal efficiencies calculated from the measured influent and effluent concentrations followed the physical trend of decreasing with increasing flow.

The large variability of the TSS data and its values been much smaller than the SSC values are not surprising based on a recent study conducted for NJDEP (Guo 2006). The TSS data is provided for informational purposes only. It is not used in the technology verification.

To provide an estimate of the deviations from the calculated average overall SSC removal efficiency, the minimum measured removal efficiency at each tested flow rate (Table 5) was used to calculate the minimum overall removal efficiency, and the maximum measured removal efficiency at each tested flow rate (Table 5) was used to calculate the maximum overall removal efficiency. These were calculated to be 57.8% and 62.8%, respectively, for the unadjusted data, and 56.4% to 61.7%, respectively, for the adjusted data. The deviations from the averages (60.5% and 59.6%) are within 3% and are considered to be acceptable.

It is concluded: The KriStar FloGard DVS-48 Hydrodynamic Separator had a maximum hydraulic capacity of 560 gpm (1.25 cfs). Sediment removal efficiency testing, conducted with the NJDEP-specified PSD test sediment, resulted in an NJDEP weighted TSS (measured as SSC) removal efficiency of 60%. This rating is considered conservative due to the 100% pre-loading of the test unit and subsequent re-entrainment of the sediment bed. Re-entrainment testing indicated negligible re-suspension of the sediment bed at 50% loading capacity, with effluent concentrations below 5 mg/L for flows up to 350 gpm (0.78 cfs). Re-suspension was documented at the 100% loading capacity condition. However, the effluent concentrations were low, with a peak average of 32 mg/L, which diminished to approximately 13 mg/L once the sediment bed stabilized.

5.5 Size Scaling and Design Flow Rates

Model DVS-48 of the FloGard® Dual-Vortex Hydrodynamic Separator was evaluated above for solids removal performance. There is a need to scale the size up or down in order for other units (shown in Table 1) to take a higher or lower treatment flow rate.

The commonly used scaling factor for design of solids settling basins (clarifiers, sedimentation tanks, etc.) is the surface area, that is, the flow rate is scaled by length to the power of 2.0 (if the particle settling velocity remains the same). This is the Hazen law. The scaling factor of 2.0 was determined based on gravitational settling of discrete particles along the straight path in the rectangular sedimentation basin (see, e.g., Peavy et al. 1985). Sullivan et al. (1972) used the Froude law to design the physical model in their laboratory study of the swirl separator, that is, the flow rate was scaled by length to the power of 2.5 and the particle settling velocity was scaled by length to the power of 0.5.

The exact scaling law is not yet known for vortex-type hydrodynamic separators. The flow patterns and particle transport in the dual-vortex separator are even more complex than those of the single-vortex separator. Therefore, an exact scaling law would be even more difficult to determine.

Since the particle size will not change in the actual installation no matter what model is used, application of the Hazen law in the scale-up as well as scale-down appears to be most appropriate at this time. That is, the design flow rate could be expressed in terms of flow rate per unit surface area. That is, the verified flow rate of 280 gpm for the FloGard® Dual-Vortex Model DVS-48 could be expressed as 22 gpm per square foot of the surface area. Applying this verified treatment flow rate to other models yields the treatment flow rates for other models (Table 6).

Table 6. FloGard® Dual-Vortex Treatment Flow Rates

Model	Diameter	Treatment Flow Rate
DVS36	3 ft	160 gpm (0.35 cfs)
DVS48	4 ft	280 gpm (0.63 cfs)
DVS60	5 ft	440 gpm (0.98 cfs)
DVS72	6 ft	630 gpm (1.4 cfs)
DVS96	8 ft	1120 gpm (2.5 cfs)

5.6 Field Studies and Maintenance Records

Field studies of the FloGard Dual-Vortex Hydrodynamic Separator are currently underway in California and Minnesota. There have been no indications of any issues with the mounting mechanisms and/or separator assembly, and the maintenance of these units has been completed by KriStar's crews well within the expectations and budgets set aside for this activity. The ability to access the sump area through either of the vortex tubes and the ability to disassemble and then re-assemble portions of the assembly expedites and enhances the maintenance procedures.

6. TECHNICAL EVALUATION ANALYSES

6.1 Verification of Performance Claim

Based on the evaluation of the results from laboratory studies, sufficient data are available to support the KriStar Claim: The FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, at a flow rate of 280 gpm (0.63 ft^3/s), has been shown to have a 60% total suspended solids (TSS) removal efficiency, measured as suspended solids concentration (SSC) (as per the NJDEP methodology for calculation of treatment efficiency) using NJDEP specified material with an average d_{50} particle size of 70 microns, an average influent concentration of 202 mg/L and 100% initial sediment loading in laboratory studies using simulated stormwater.

6.2 Limitations

6.2.1 Factors Causing Under-Performance

If the FloGard® Dual-Vortex is designed and installed correctly, there is minimal possibility of failure. There are no moving parts to bind or break, nor are there parts that are particularly susceptible to wear or corrosion. Lack of maintenance may cause the system to operate at a reduced efficiency, and it is possible that eventually the system will become filled with sediment up to the lower edge of the vortex tubes, blocking flow.

When a FloGard® Dual-Vortex unit is newly installed, frequent inspection is highly recommended. The design of the FloGard® Dual-Vortex unit permits easy inspection. It is recommended that during the first two years after installation, inspection be performed at least quarterly for the purpose of noting the rate of sediment and floatables accumulation.

6.2.2 Pollutant Transformation and Release

The FloGard® Dual-Vortex will not increase the net pollutant load to the downstream environment. However, pollutants may be transformed within the unit. For example, organic matter may decompose and release nitrogen in the form of nitrogen gas or nitrate. These processes are similar to those in wetlands but probably occur at slower rates in the FloGard® Dual-Vortex due to the absence of light and mixing by wind, thermal inputs and biological activity. Accumulated sediment should not be lost from the system at or under the design flow rate.

6.2.3 Sensitivity to Heavy Sediment Loading

Heavy loads of sediment will increase the needed maintenance frequency.

6.2.4 Mosquitoes

Although the FloGard® Dual-Vortex is a self-contained unit, the design does incorporate standing water in the lower chamber, which can be a breeding site for mosquitoes. It is supplied with a gasketed petroleum industry rated (vandal-proof) access cover to better address vector issues, the only stormwater treatment system with such an access cover. Access covers are supplied in E-Z Lift™ design with hydraulic assistance. ?

7. NET BENEFICIAL EFFECT

The NJDEP encourages the development of innovative environmental technologies (IET) that provide a net beneficial effect (NBE) to the environment and human health. The NBE is calculated as a mass balance of the IET in terms of its inputs of raw materials, water and energy use and its outputs of air emissions, wastewater discharges, and solid waste residues. Overall the IET should demonstrate a significant reduction of the impacts to the environment and human health when compared to baseline conditions for the same or equivalent inputs and outputs.

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

8. REFERENCES

Guo, Q. (2006). *Correlation of Total Suspended Solids (TSS) and Suspended Sediment Concentration (SSC) Test Methods*, Final Report, Prepared for New Jersey Department of Environmental Protection, Division of Science, Research, and Technology, Trenton, NJ, Ravi Patraju, Project Manager, November.

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Peavy, H. S., Rowe, D. R., and Tchobanoglous, G. (1985). Environmental Engineering, McGraw-Hill, Inc., New York, NY.

Sullivan, R. H., Cohn, M. M., Coomes, J. P., and Smission, B. S. (1972). *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*. USEPA-R2-72-008.

NJCAT TECHNOLOGY VERIFICATION
ADDENDUM REPORT

FloGard Dual-Vortex Hydrodynamic Separator

KriStar Enterprises, Inc.

March 2009

1. Introduction

NJCAT published a Technology Verification Report on the FloGard® Dual-Vortex Hydrodynamic Separator manufactured by KriStar Enterprises, Inc. (KriStar), Santa Rosa, CA 95406 in August 2007. The verified performance in that report of the FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, was based on testing using the NJDEP specified material with an average d_{50} particle size of 70 microns, three influent concentrations with an average influent concentration of 202 mg/L and 100% initial sediment loading in laboratory studies using simulated stormwater. The verification was based on an April 2007 laboratory test report by Alden Research Laboratories (Alden), Holden, MA on the performance of the Model DVS-48.

In September 2007 Alden published a second verification testing report on the FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, using OK 110 silica sand. Laboratory testing was conducted at a single influent concentration and with 0% initial sediment loading using simulated stormwater.

Recently, KriStar approached NJDEP requesting an amendment to their January 4, 2008 Conditional Interim Certification (CIC) that was based on removal of NJDEP specified material. Specifically, KriStar requested an amended CIC based on the OK 110 test results. NJDEP requested that NJCAT prepare a Technology Verification Report based on the September 2007 Alden verification test report using OK 110 silica sand in support of KriStar's request.

2. Technical Performance Claim

Claim - The FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, at a flow rate of 449 gpm (1.0 ft^3/s), has been shown to have a 70.7% suspended solids concentration (SSC) removal efficiency (as per the NJDEP methodology for calculation of treatment efficiency) using OK 110 silica sand with a measured d_{50} particle size of 100 microns, an average influent concentration of 203 mg/L and 0% initial sediment loading in laboratory studies using simulated stormwater.

3. Technical System Performance

3.1 Laboratory Testing

Verification testing of a 4 ft diameter FloGard Dual-Vortex Hydrodynamic Separator (DVS–48) was conducted at Alden's laboratory/test facility (Mailloux 2007). Testing consisted of establishing the unit's hydraulic capacity, determining sediment removal efficiencies (using OK 110 silica sand) and evaluating the re-entrainment conditions for various flows.

The DVS–48 is a cylindrical separating device measuring 4 feet in diameter by approximately 8 feet high. The unit has a 12-inch diameter inlet and outlet, with the inverts located 60.5 inches above the floor. The pipes are oriented horizontally and centered within the unit. The DVS-48 contains two (2) internal overflow weirs, 8-in and 14-in high, respectively, as well as two (2) vertical drop tubes, approximately 12-inches in diameter, connecting the upper and lower chamber. Figure 4 (page 14) shows a layout drawing of the DVS–48 test unit and Figure 5 (page 15) shows the unit installed in Alden's test facility. The test unit supplied by KriStar included two (2) 12-inch viewing windows, located approximately 36 inches above the floor, to facilitate visual observations and documentation.

The DVS-48 unit was tested in Alden's laboratory/test facility as described in section 5.2.2 (page 13). Instrumentation and Measurement Techniques as described in Section 5.2.3 (page 17) were the same with the following three exceptions.

- *Sediment Injection* - OK 110 silica sand rather than NJDEP protocol sediment was used to test the DVS-48 unit. The Auger feed screws used in testing ranged from 0.75 to 1.0 inches.
- *Sample Concentration Analysis* – Only the SSC analytical method was used in this study and the samples were analyzed at Alden as described in Section 5.2.3.
- *Test Sediment Mix and Particle Size Distribution* – OK 110 silica sand, available from US Silica, was used to test the DVS-48 unit. The d_{50} particle size was measured at 100 µm, which is smaller than the d_{50} particle size reported by US Silica.

3.2 Test Procedures

The DVS-48 was tested at six (6) flows, with 200 mg/L influent concentration per flow and 0% sediment pre-loaded volume. Re-entrainment testing was conducted with the unit preloaded to 50% and 100% of the stated loading capacity (by KriStar). Testing of the DVS–48 was conducted in three phases, as described below:

3.2.1 Phase 1 - Hydraulic Capacity

As described in Section 5.3.1 (page 20) the unit was tested without sediment to determine its maximum hydraulic capacity (MHC).

3.2.2 Phase 2 – Sediment Removal Efficiency Testing

Sediment removal efficiency testing was performed using the indirect method (sampling), as described below. The test flow was set and allowed to reach steady state. The test sediment was introduced into the inflow line and three (3) system volumes were allowed to pass through the test-loop prior to the collection of samples. A minimum of 5 pairs of influent/effluent samples, of approximately 1 Liter each, were collected during each test, with each effluent sample taken one residence time after the influent sample. At the completion of the sample collections, sediment injection was stopped and the system continued to operate for a duration of time necessary to assure that all the sediment had entered the unit. Background samples were taken throughout the test at a location upstream of the injection point to establish the sediment concentration level of the influent flow.

3.2.3 Phase 3 – Re-entrainment and Washout

Re-entrainment tests were conducted at sediment loadings corresponding to 50% and 100% (9.5 and 19.0 ft^3, respectively) of the unit's capture capacity as claimed by KriStar. The unit was slowly filled to the invert of the effluent pipe and the system remained idle for a minimum of 24 hours prior to testing.

Testing was conducted by incrementally increasing the flow of clean water (no sediment) into the unit while continuously obtaining flow data and video documentation of sediment retention and/or re-entrainment. Effluent samples, for SSC analyses, were obtained at the first sign of sediment bed movement, and/or at the targeted flows (10, 25, 50, 75, 100 and 125%), at which time four (4) samples were collected incrementally over a period of 15 minutes.

3.3 Verification Procedures

All the data provided to NJCAT were reviewed to fully understand the capabilities of the FloGard® Dual-Vortex Hydrodynamic Separator and to verify KriStar's claim. Hydraulic capacity results are summarized in Section 5.4.1 (page 22). Results of the sediment removal efficiency and re-entrainment and washout testing are summarized below. The detailed results are presented in the laboratory testing report prepared by the Alden (Mailloux 2007).

Removal efficiency tests were conducted at flows ranging from 44.8 to 560 gpm (0.10 to 1.25 cfs) and influent sediment concentration of 200 mg/l. Water temperature varied from 67.3 to 68.7 degree F, while the average background concentration varied from 0 to 1.34 mg/L for the six tests.

In addition to the isokinetic collected influent samples (Unadjusted Data), verification of the injected sediment concentration was achieved by taking timed dry samples from the auger feeder at regular intervals throughout the test. The additional calculated concentrations are reported in the data sets as "Adjusted Data". The difference between the collected influent concentrations and adjusted influent concentrations ranged from 2% to approximately 50%, resulting in flow rate efficiency differentials of 0.2% to 8.0% and a weighted efficiency differential of 3%. (Alden opines that greater weight should be placed on the removal efficiencies calculated with the adjusted concentrations, as this methodology has shown to produce a much higher level of consistency and accuracy.) The testing data summary is shown in Table 1.

Table 1 Testing Summary

		Target	Unadjusted Data			Adjusted Data		
% MHC	Flow (cfs)	Concentration mg/L	Influent mg/L	Effluent mg/L	Efficiency %	Influent mg/L	Effluent mg/L	Efficiency %
124.8	560.0	200	199.7	125.2	37.3	203.3	125.2	38.4
99.6	447.1	200	185.3	105.7	43.0	206.0	105.7	48.7
74.9	336.3	200	251.3	74.5	70.4	197.8	74.5	62.3
50.1	224.7	200	301.2	45.8	84.8	198.6	45.8	76.9
25.2	113.0	200	220.6	8.6	96.1	208.5	8.6	95.9
			Weighted Eff. = 73.7			Weighted Eff. = 70.7		

The lab tests were well controlled as demonstrated by close agreement between the desired influent concentrations and the actual influent concentrations. Moreover, the SSC removal efficiencies calculated from the measured influent and effluent concentrations followed the physical trend of decreasing with increasing flow.

Re-entrainment and washout tests were performed at flows ranging from 45 to 560 gpm, with initial sediment loadings at 50% (9.5 ft^3) and 100% (19 ft^3) of the unit's capacity (stated by KriStar). A series of four (4) samples were collected every 5 minutes at the target flows of 45, 112, 224, 337, 449, and 560 gpm to allow insight into trends and/or anomalies of sediment movement.

Fifty Percent (50%) Loading

A small amount of suspended material was observed in the lower chamber at 45 gpm. The quantity of material was negligible, with a measured effluent concentration of 0.6 mg/L. Initial movement of the sediment bed was observed at 112 gpm, with particles moving in an outward radial pattern, originating from just below the first drop tube. The continued displacement of the material resulted in the formation of ripples and dunes, which moved in the same radial pattern. Although the quantity of suspended material increased, the effluent concentrations were still negligible, with values ranging from 0.03 to 1.48 mg/L. The increase in flow to 224 gpm resulted in a slight increase in the amount of suspended material. However, the measured concentrations were still considered low, ranging from 2.72 to 3.59 mg/L. With the increase in flow to 337 gpm, the radial movement of the sediment bed near the center of the chamber slowed, due to inflow from the second drop tube. The observed quantity of suspended sediment showed a slight initial increase with the introduction of flow from the second tube, but decreased with time as the bed stabilized. This was verified by the decline in effluent concentrations from 6.27 to 1.34 mg/L. An increase in suspended sediment was observed during the transition to 449 gpm, which decreased once the flow stabilized. This is once again due to the additional flow through the second tube. The suspended particles steadily increased over time, with effluent concentrations ranging from 6.13 to 10.81 mg/L. A dramatic drop in suspended particles was observed at 560 gpm, with effluent concentrations ranging from 3.08 to 1.49 mg/L. The d_{50} size of the effluent samples ranged from approximately 90 to 120 microns.

One Hundred Percent (100%) Loading

A small amount of suspended material was observed in the lower chamber at 45 gpm. Once again, the quantity of material was negligible, with a measured effluent concentration of 0.87 mg/L. Initial movement of the sediment bed was observed at 112 gpm, with particles moving in an outward radial pattern, originating from just below the first drop tube. The continued displacement of the material resulted in the formation of ripples and dunes, which moved in the same radial pattern. Although the quantity of suspended material increased, the effluent concentrations were low, with values ranging from 1.15 to 3.95 mg/L. The increase in flow to 224 gpm resulted in a significant increase in the amount of suspended material. The measured effluent concentrations ranged from 24.16 to 57.75 mg/L. This was due not only from the increase in flow, but also from the turbulence off the side wall of the chamber, which caused a "peeling" effect of the top layer of sediment. The increase in flow to 337 gpm resulted in a reduction in suspended sediment. This was most likely due to the stabilization of the sediment bed under the first tube. This was verified by the decline in effluent concentrations from 52.89 to 23.69 mg/L. A steady increase in suspended sediment was observed during the transition to 449 gpm, as more flow passed through the second tube. The sediment concentrations steadily decreased once the flow stabilized, with measured quantities ranging from 84.26 down to 59.69 mg/L. A dramatic drop in suspended particles was observed at 560 gpm, with concentrations ranging from 13.04 to 0.15 mg/L. The d_{50} size of the effluent samples ranged from approximately 125 to 150 microns.

4. Verification of Performance Claim

Based on the evaluation of the results from the Alden laboratory studies, sufficient data are available to support the KriStar claim: The FloGard® Dual-Vortex Hydrodynamic Separator, Model DVS-48, at a flow rate of 449 gpm (1.0 ft^3/s), has been shown to have a 70.7% suspended solids concentration (SSC) removal efficiency (as per the NJDEP methodology for calculation of treatment efficiency) using OK 110 silica sand with a measured d_{50} particle size of 100 microns, an average influent concentration of 203 mg/L and 0% initial sediment loading in laboratory studies using simulated stormwater.

5. References

Mailloux, J. T. (2007). Verification Testing of the KriStar 4 ft Diameter FloGard Dual-Vortex Hydrodynamic Separator (DVS-48) Using OK 110 Silica Sand. Submitted to KriStar Enterprises, Inc., by Alden Research Laboratories, Inc., Holden, MA. (September, 2007)