

# **NJCAT TECHNOLOGY VERIFICATION**

## **Dual Vortex Separator (DVS) Stormwater Treatment Device**

### **Oldcastle Stormwater Solutions**

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## 1. Description of Technology

A 48-inch diameter Dual Vortex Separator (DVS) stormwater treatment device manufactured by Oldcastle Stormwater Solutions was independently tested at the University of Minnesota St. Anthony Falls Laboratory (SAFL) to assess removal efficiency and scour of total suspended solids in accordance with a testing protocol developed by the New Jersey Department of Environmental Protection (NJDEP). **Figure 1** shows a graphic of the DVS unit.



**Figure 1 – Graphic of Typical Inline DVS Unit with Internal Components**

The DVS is a hydrodynamic stormwater treatment device used to remove pollutants from urban runoff. Impervious surfaces and other urban and suburban landscapes generate a variety of contaminants that can enter stormwater and pollute downstream receiving waters. The DVS is designed to capture and retain sediment as well as floating trash, debris, and oils. The concentration of metals and other constituents associated with the sediment or floating pollutants may also be reduced.

Stormwater runoff enters the DVS unit through an inlet pipe. Influent flow is split evenly between two vortex tubes by a V-shaped weir. The shape and diameter of the vortex tubes promotes circular motion of the incoming stormwater at increased velocities to enhance particle settling through centrifugal force. The system is also designed with an extended flow path to

maximize hydraulic residence time which allows increased time to settle out solids. Settled pollutants are collected in an isolated storage area or sump at the bottom of the structure, while floating trash, debris, and petroleum hydrocarbons are retained behind baffles that contain the vortex chambers. During peak runoff events, flow in excess of design treatment flow overtops the bypass weir and exits the system without entering the treatment chambers to interrupt the treatment process or re-entrain captured pollutants.

The internal components of the DVS system are fabricated from stainless steel and mounted in a concrete manhole or vault structure (See **Figure 2** for a schematic of the test unit.). The system is typically delivered as a complete unit for installation by the contractor. Installation includes excavation, preparation of the base rock, setting the unit, plumbing the inlet and outlet piping, backfill, and placement of the finished surface.

## **2. Laboratory Testing**

Testing was conducted independently by the University of Minnesota St. Anthony Falls Laboratory (SAFL) between October 2014 and January 2015. SAFL is an interdisciplinary fluid mechanics laboratory located on the Mississippi River that focuses its research on major societal questions addressing renewable energy, human health, and the environment. SAFL also provides engineering services including third-party testing and physical modeling.

Testing was performed in accordance with “New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device”, dated January 25, 2013 (NJDEP 2013b) and the project-specific Quality Assurance Project Plan (QAPP) submitted to and approved by the New Jersey Corporation for Advanced Technology (NJCAT).

### **2.1 Test Setup**

The test setup was located on the lowest level of the laboratory at SAFL which allowed ample water flow and head for testing, space for construction of the test setup, and an overhead hoist to facilitate movement of equipment (**Figure 3**).

#### *Test Cylinder and Piping*

A DVS-48, provided by Oldcastle Stormwater Solutions, was used for testing. The DVS-48 is designed to be installed in a typical 48-inch diameter cylindrical manhole. In the laboratory, a 48-inch diameter cylindrical fiberglass tank was used to simulate a typical manhole structure.

The internal components of the test unit had to be removable so that the test cylinder could be cleaned after each test run. The internal components were provided as a complete assembly with a support flange to allow the assembly to hang from the top flange of the test cylinder. The assembly was equipped with a lifting bar to facilitate installation and removal. Each time the assembly was reinstalled in the test tank, it was aligned, clamped in place, and all gaps between the assembly and the test cylinder were temporarily re-sealed.

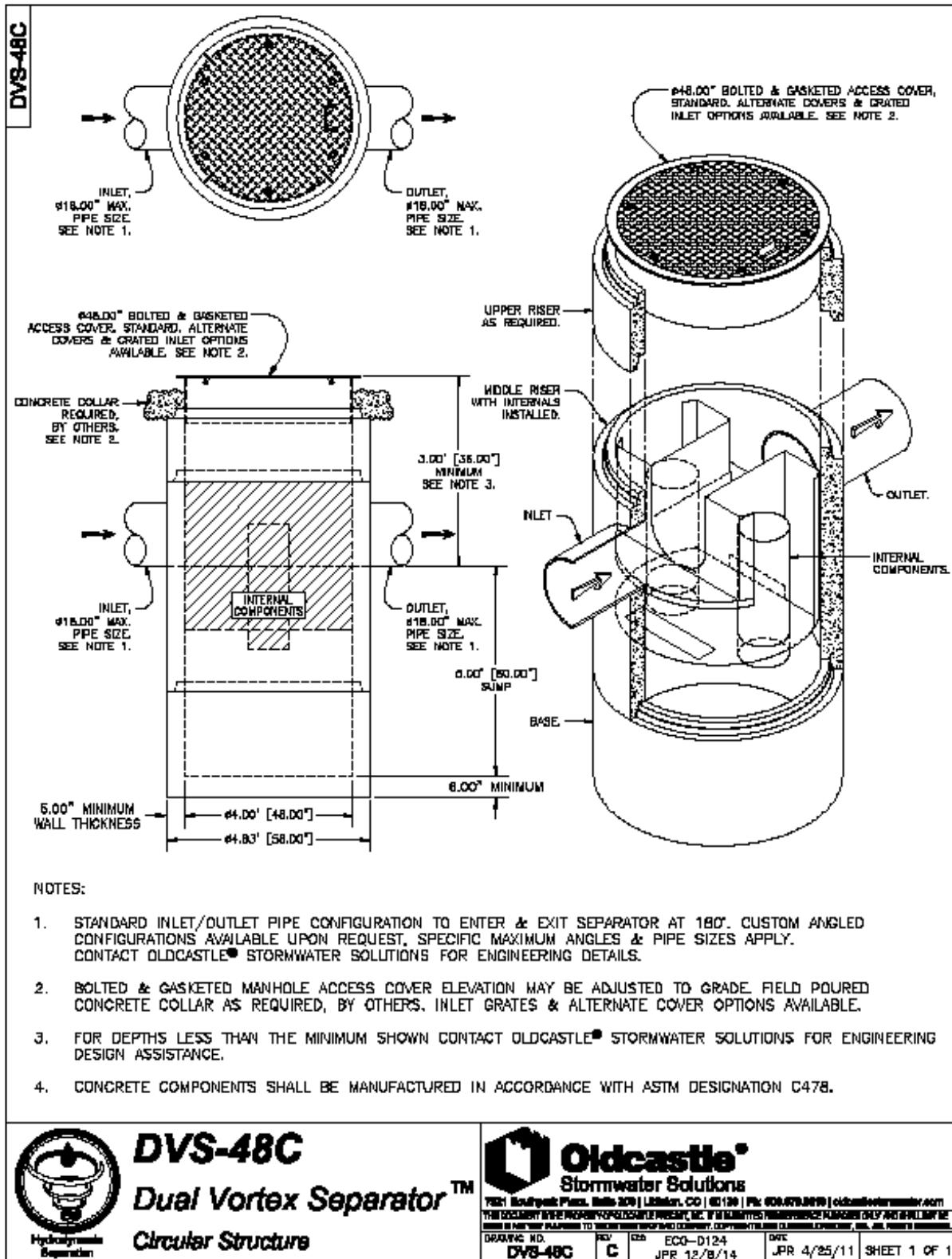
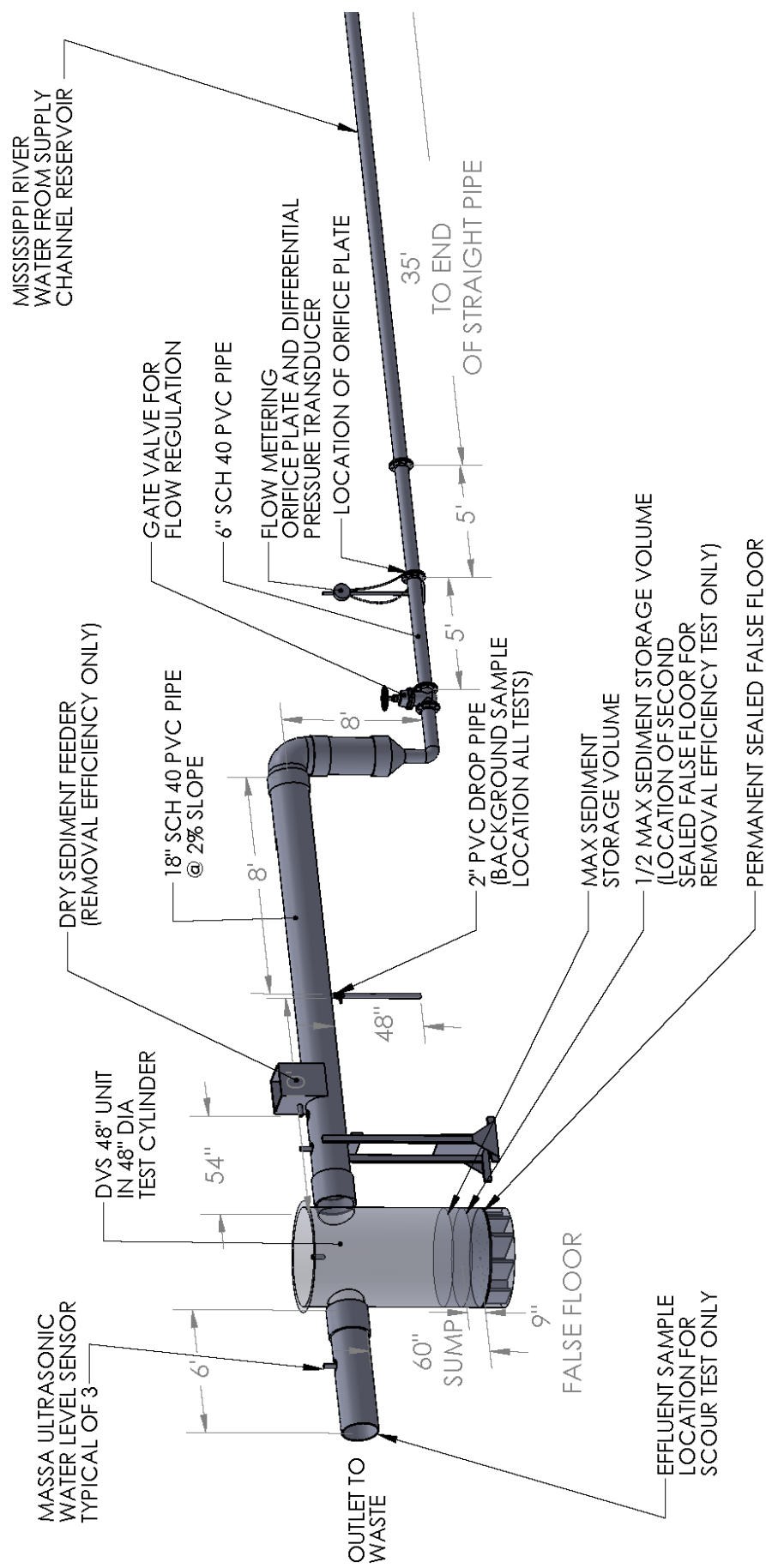


Figure 2 – Schematic of Test Unit





**Figure 3 – Schematic of Laboratory Test Setup**

The standard sump in a DVS-48 is 60 inches deep as measured from the inlet and outlet pipe inverts and the bottom of the structure. This dimension was 72 inches on the cylindrical tank used in the performance testing. Therefore, a “permanent” watertight false floor made of plywood and dimensional lumber was installed 12 inches from the bottom of the test cylinder. The false floor was filled with water to prevent buoyancy and fully sealed to the tank. The false floor remained in place throughout the duration of the performance tests.

The test cylinder was fitted with one 18-inch diameter Schedule 40 PVC pipe inlet stub, and one identical outlet stub located directly opposite the inlet. The test cylinder had been used for other unrelated testing in the past and had other pipe stubs from those tests. These stubs remained on the outside of the tank but were plugged flush with the inside of the test cylinder. Upstream of the cylindrical tank was an 18-inch diameter Schedule 40 PVC inlet pipe at a slope of 2.0%, resting on supports constructed of dimensional lumber and plywood. The 18-inch diameter schedule 40 PVC outlet pipe was set at 0% slope to discharge freely onto an outlet structure for return to the river.

#### *Water Supply and Flow Control*

Water used for testing was natural river water from the Mississippi River. Approximately 40 feet of gravity head was available at the test setup location so pumps were not required to provide flow. Typical background TSS concentrations are well below the maximum 20 mg/L allowed under the test protocol.

Flow was measured using a calibrated brass orifice plate with D and D/2 pressure taps installed per ASME PTC 19.4-2004. Differential pressure across the orifice plate was registered by a Rosemount® 3051 differential pressure transducer. A nominal 4.5” diameter orifice plate was used for flows 0.5 cfs and greater and a nominal 3.0” diameter orifice plate was used for the 0.25 cfs flow rate. Differential pressure measurements were converted to discharge measurements via calibration relationship measured in the Lab and implemented in LabVIEW 6i, a PC-based data acquisition system. Discharge measurements were recorded at a minimum sampling rate of 1 recording per minute. The flow rate was controlled with a gate valve.

#### *Other Instrumentation*

A temperature probe was installed in the cylindrical tank to measure water temperature during all tests. The probe was connected to the data acquisition computer and set to log once every 60 seconds. A manual thermometer was used to validate the temperature probe. The temperature of the source water during testing was well below 80 degrees Fahrenheit. Typical temperatures ranged from 1 to 3 °C (33 to 37 °F) during testing.

Three MassaSonic M-300 stage recorders were installed in the test setup to monitor head-loss through the DVS-48 over the range of flow conditions. The first stage recorder was located in the inlet pipe three feet upstream of the cylindrical tank. The second stage recorder was located within the cylindrical tank and the third stage recorder was located three feet downstream of the cylindrical tank in the outlet pipe. The three stage recorders were connected to a data acquisition computer and were typically set to log at 60 second intervals. Factory calibration of the stage

recorders was validated prior to testing by blocking the outlet pipe to pond water in the system to verify that all three sensors output the same water surface elevation. This validation was performed at three different elevations.

### *Sample Collection Locations*

Influent water samples for TSS background concentration were taken from a sample collection point located 10 feet upstream of the cylindrical tank. A short nipple was tapped into the bottom of the 18-inch inlet pipe at this location and a 2-inch ball valve was installed with a 2-inch PVC pipe extending vertically downward a total of 4 feet below the bottom of inlet pipe.

The Mass Balance method was used to determine TSS Removal Efficiency. Thus, effluent sampling and a corresponding effluent sampling location were not required for TSS removal efficiency testing.

Effluent samples for the scour test were collected at the downstream end of the outlet pipe using a grab sample method. A 5-gallon pail was swept through the discharging flow stream to collect a representative sample.

### *TSS Removal Efficiency vs. Scour Test Setup*

The test setup for total suspended solids removal efficiency testing was identical to the setup used for scour testing except for the following modifications:

- A second “temporary” false floor was constructed at half of the maximum sediment depth (9 inches) above the “permanent” false floor. The “temporary” false floor was fully sealed to the test cylinder and was only used for TSS removal efficiency testing.
- An Accurate Model 602M dry sediment feeder was used to introduce the dry sediment mix for the TSS removal efficiency testing. The feeder uses a rotating helix to move sediment from a hopper to discharge through a stainless steel nozzle tube. The sediment feeder was installed on a platform mounted to the top of the inlet pipe a distance of 4.5 feet (three 18-inch pipe diameters) upstream of the inlet side of the cylindrical tank. During TSS removal efficiency testing, sediment exiting the feeder nozzle dropped vertically through a 6-inch diameter hole cut in the crown of the inlet pipe.

## **2.2 Test Sediment**

SAFL developed sediment mixtures for removal efficiency and scour testing that met the particle size distribution (PSD) requirements of the NJDEP protocol. Particle size distribution data were collected following the ASTM 422-63 procedure for particle analysis for soils and employed both hydrometer and sieve analyses.

### *Removal Efficiency Test Sediment*

The sediment mix for removal efficiency testing was a mixture of five commercially available sediments whose particle size distribution, when mixed in the correct proportion, satisfies the NJDEP requirement within the stated tolerances. The sediment mixture was oven-dried prior to mixing and weighing and used methods outlined in ASTM Method D 4959-07. An approximate dry mass of 37 pounds of the mixture was used for each test. Sediment components were mixed in single-batches in a small rotating drum cement mixer. Mixed sediment was stored in 5-gallon buckets with sealing lids for transfer to the sediment feeder.

### *Scour Test Sediment*

The sediment mix for scour testing was a mixture of two commercially available sediments whose PSDs, when mixed in the correct proportion, satisfied the NJDEP requirement within the stated tolerances. The mixture did not deviate more than 2% below the target minimum percent-less-than value at the given sizes. The specific gravity of the scour mixture is 2.65. Sediment for the scour test was dried, proportioned by weight, thoroughly mixed in a cement mixer several days prior to the test, and stored in clean, covered 32-gallon plastic bins.

## **2.3 Removal Efficiency Testing Procedure**

Removal efficiency testing was conducted in accordance with Section 5 of the NJDEP Laboratory Protocol for HDS MTDs. Testing was conducted at flow rates of 25%, 50%, 75%, 100%, and 125% of the MTFR and a TSS influent sediment concentration of 200 milligrams per liter (mg/L). The equivalent flow rates based on a MTFR of 1.00 cubic feet per second were 0.25, 0.50, 0.75, 1.00, and 1.25 cfs, respectively. Flow rates were measured continuously throughout the tests.

### *Sediment Feed Rate*

The sediment feed rate required to achieve a concentration of 200 mg/L of TSS was calculated for each test run in accordance with the flow rate. For example, for the 1.00 cfs flow rate, the feed rate was calculated as follows:

$$1.0 \frac{ft^3}{s} \times \frac{28.31685 L}{ft^3} \times \frac{200 mg}{L} \times \frac{1 g}{1000 mg} \times \frac{60 s}{1 min} = 339.8 \frac{grams}{minute}$$

The sediment feed rate was adjusted by a dial potentiometer on the feeder control panel until the required feed rate within a tolerance of +/- 10% was reliably achieved over a number of trial samples weighed on the scale used for the actual test. All sediment used in feed rate testing was dumped back into the hopper. Just prior to the test run, the full sediment feeder and lifting apparatus was weighed with a hanging scale suspended from the overhead hoist, and lifted into position on top of the pipe. In preparation for a test run, the DVS-48, cylindrical tank, and inlet pipe were cleaned of any sediment. The DVS-48 was inserted into the test cylinder, aligned, clamped, and sealed as described in the test setup. Then the test cylinder was slowly filled with river water up to the pipe inverts. The data acquisition computer was set to begin recording flow, temperature, and water levels.

At the beginning of the test run, once the water flow was adjusted to the correct rate,  $t=0$  was called, a stopwatch was started, the sediment feeder was powered on by a toggle switch, and the first background water sample was taken. The sampling of background (influent) river water was as described in the Scour Test procedure, Section 4.3.2. Eight background samples were taken, evenly spaced over the duration of the test. The duration of each test was determined beforehand by calculating to ensure the feed rate multiplied by the test duration would yield at least 25 lb of sediment input.

The first sediment feed sample was begun at  $t=30$  seconds to allow the feed rate to stabilize from the instantaneous feeder start. Several seconds prior to the scheduled sample time, the short vertical shield pipe was removed. At the scheduled sample time as noted on a running stopwatch, a pre-weighed sample container was quickly moved into the sediment stream directly under the sediment feeder nozzle. Prior to actual testing, a time in seconds to approximately fill the sample container to the correct volume was determined. The container was quickly pulled away from the sediment stream when the pre-determined sample time on the stopwatch was reached, and the shield pipe was put back into position. Each sample was brought to a scale to be weighed in milligrams. Once the weight was recorded in the notebook, the weighed sediment sample was returned back into the hopper of the sediment feeder. The data was immediately input to a spreadsheet to automatically calculate the feed rate in order to confirm it was within  $\pm 10\%$  of 200 mg/L. Six feed rate samples were taken using this procedure, evenly distributed over the duration of the run.

Immediately after the last sediment sample was finished, the sediment feeder was switched off and another team member concurrently shut the gate valve to stop water flowing into the test setup. The sixth and final sediment sample was weighed and recorded and dumped back into the inactive feeder. The sediment feeder and lifting apparatus was then lifted off the pipe and weighed again to determine a post-run weight, to be subtracted from the pre-run weight to yield the mass of sediment fed into the system during the test run. The stage sensor mount and temperature probe were removed from the top of the test cylinder, and the lifting bar was reinstalled on the DVS-48. The top of the test cylinder was covered with plastic sheeting and allowed to settle.

After the settling period of at least 40 hours, a siphon constructed of  $\frac{3}{4}$ -inch rigid PVC tube inside the tank and flexible clear tube on the discharge side was used to slowly and carefully decant the clarified water above the settled sediment in the test cylinder. Clear water was directed to waste. The siphon was clamped to the DVS-48 and progressively moved downward over a period of several hours as water level dropped. When the water surface was approximately one to two inches from the bottom, the siphon was allowed to stop so as to not entrain any sediment from the bottom. In several cases when the water reached a low level, the siphon discharge was directed into a clean 5-gallon pail for mass-balance processing. In this case, the siphon tube was moved around the bottom to remove sediment until the siphon was broken, at which point the siphon tube was thoroughly rinsed with clean water back into the test cylinder.

In accordance with the Mass Balance test method in the NJDEP Laboratory Protocol, all sediment was removed from the DVS-48 and test cylinder for oven drying and weighing to

quantify the mass of sediment removed during each TSS Removal Efficiency test run. Sediment deposited in the inlet pipe and on the upper surface of the DVS-48 was manually removed and placed in pre-weighed aluminum pans for oven drying. The temporary sealing materials between the DVS-48 and the test cylinder walls were removed and any sediment clinging on was rinsed to the bottom of the test cylinder. The DVS-48 and inlet pipe were thoroughly rinsed down with a squirt bottle of tap water, and with a hose. The clean DVS-48 was lifted out using the overhead hoist and placed beside the test cylinder. A pre-cleaned wet/dry shop vacuum with filter removed was used to suck out the sediment and water in the bottom of the test cylinder. The shop vacuum contents were emptied into a clean 5-gallon pail for transfer to aluminum drying pans. This process was repeated, rinsing the test cylinder as necessary, until all sediment was removed. Then the shop vacuum was thoroughly cleaned of all sediment into the 5-gallon transfer pails.

#### *Sample Processing – Removal Efficiency Testing*

The eight background (Influent) water samples were processed according to ASTM D3977-97, in the same manner as for the Scour Test. The six sediment feed rate samples were weighed to the nearest milligram on a Denver Instruments P-4002 balance as previously described.

The retained sediment and water mixture collected from the test cylinder was dried in pre-weighed aluminum (non-ferrous) pans in a large vented oven until dry. Due to the large volume of water and sediment mix generated in each test run, the collected material did not all fit in the drying pans at one time. Additional sediment water mixture was added from the transfer pails when sufficient water had evaporated from a pan, until the entire collected amount was in the pans. The transfer pails were thoroughly rinsed down into the drying pans. This process typically lasted several days until all water had evaporated and only dry sediment remained in the pans. Each pan was removed from the oven, allowed to cool to room temperature, and weighed on the Denver Instruments P-4002 balance. In accordance with the NJDEP Test Protocol, the pans were then returned to the oven for at least two hours and the process was repeated until there was less than 0.10% difference in weight between the sums of net weights of the pans.

## **2.4 Scour Testing Procedure**

Scour testing was conducted at a flow rate of 200% of the MTFR with the DVS sump preloaded with scour test sediment to 50% of the maximum sediment storage volume. The equivalent flow rate based on an MTFR of 1.00 cubic feet per second was 2.00 cfs. The flow rate was measured continuously throughout the test.

#### *Sediment Pre-Load*

For the typical installation, the maximum sediment storage volume of the cylindrical tank is 18 inches deep, measured from the floor. 50% of the maximum sediment storage volume is 9 inches from the floor. Prior to the start of the scour test, the dry cylindrical tank was loaded with the scour sediment mixture up to 50% of maximum sediment storage volume - 9 inches of sediment. A lumber screed and carpenter's level were used to smooth and level the surface of the sediment. The sediment surface elevation was measured at five locations in the cylindrical

tank from the top to an accuracy of 0.125 inches to confirm level. Once the sediment was loaded into the tank and the surface was leveled and measured, the cylindrical tank was slowly filled with clear water up to the inlet and outlet inverts at 60" depth or its normal, dry weather operating depth. The testing was carried out within 24 hours of loading sediment into the cylindrical tank.

### *Test Run Procedure and Sampling*

For online installation of the Manufactured Treatment Device, NJDEP requires scour testing at a minimum of 200% of the maximum treatment flow rate (MTFR). The MTFR for the DVS-48 is 1.0 cubic feet per second. On the test date (February 27, 2015), the gate valve was initially opened to start the flow at 10:36 am. The gate valve was adjusted to regulate the flow rate to 2.0 cfs, or 200% of the MTFR. At four minutes the target flow was consistent and  $t_0$  was called 10:40 am.

For the scour test, influent clear water was sampled eight times in evenly spaced intervals throughout the duration of the target maximum flow rate, starting at  $t = 2$  minutes. Influent (background) samples were collected by opening the 2-inch sample valve approximately half way and allowing a "flush" of approximately five gallons of water to flow out into a designated 5-gallon pail, which was later discarded. A clean pre-labeled 5-gallon pail was immediately placed under the flowing water to collect a sample of approximately two gallons in volume. The valve was then closed until the next influent background sampling time. The sample was then placed to the side and allowed to settle. To quickly and accurately measure the sample volume, a measuring device consisting of a ruler with divisions of millimeters affixed to an aluminum rod was created. Known volumes of water in a standard "Home Depot" 5-gallon pail (all pails were the same type) were used to develop a volume vs. depth relationship. To determine the sample volume, the rod was placed into the sample pail, the water surface depth was recorded, and the bucket calibration relationship used to calculate sample volume. After the test the influent sample pails were processed to determine TSS. Pails not processed immediately were loosely covered with plastic sheeting to keep out dust from the lab environment and limit evaporation.

The grab sampling method was used for scour test effluent samples. Samples were taken by passing a sample vessel (5-gallon pail) through the effluent water stream flowing from the end of the 18" outlet pipe. The 5-gallon pails were labeled E1-E15 and thoroughly cleaned and dried before use. The 15 samples were evenly spaced every two minutes over the 30 minute scour test duration. At the designated sampling time, a sample vessel was moved in a sweeping motion through the stream to acquire a representative sample of 3-4 gallons. Each sample was placed to the side and allowed to settle. Three additional effluent samples were taken at 32, 34, and 36 minutes, but were not processed.

After the completion of the test, the volumes of the effluent samples were determined in the same manner as described above for the influent samples, and processed to determine TSS. Run data was recorded on a data collection sheet, and in computer files. In general there was no visible sediment in either influent or effluent samples.

### *Sample Processing*

The captured water and sediment samples for both influent (background) and effluent samples were analyzed for TSS per ASTM D3977-97, using Test Method C, “Wet-Sieving-Filtration”. The full sample volume was poured through a 63 micron, 8” sieve (US Std Sieve #230) into a clean container and any sediment retained was designated as the coarse fraction. The coarse fraction was oven dried in non-ferrous pans and weighed on an OHAUS Adventurer Model AR1140 laboratory balance. The dry weight of the coarse fraction was divided by the total sample volume to obtain the coarse fraction concentration in mg/L. The water and sediment passing the sieve was designated as the fine fraction. The fine fraction was thoroughly mixed and three 1-liter aliquots were collected in a process analogous to a churn sample splitter method. The three 1-liter aliquot bottles with samples were weighed on a Denver Instruments P-4002 balance, and bottle pre-weights were subtracted to obtain net aliquot mass.

Each aliquot was processed through a pre-weighed 1.5 micron glass fiber filter using a vacuum pump setup. The filters were oven dried in aluminum dishes and pre-weights subtracted to obtain the mass of sediment contained on each filter, which was divided by the aliquot volume to yield a solids fine fraction concentration. Results of the three aliquots were averaged to determine a fine fraction concentration for each sample. The coarse fraction and fine fraction concentrations were combined to determine a total TSS concentration for each sample.

### **3. Performance Claims**

Per the NJDEP verification document, Oldcastle Stormwater Solutions makes the following performance claims for the DVS system (all claims are supported by third-party testing at the University of Minnesota St. Anthony Falls Laboratory, as reported in this verification report).

#### *Verified TSS Removal Rates*

Based on the laboratory testing conducted and reported by the St. Anthony Falls Lab the DVS achieved greater than 50% Total Suspended Solids (TSS) removal.

#### *Maximum Treatment Flow Rate (MTFR)*

The hydraulic loading rate used to calculate the MTFR for all commercially available DVS sizes is 35.7 gallons per minute per square foot (gpm/sf).

#### *Maximum Sediment Storage Depth and Volume*

The maximum sediment storage depth is 18” for all DVS models. The total volume of sediment storage varies depending on the footprint or diameter of a particular model. The model tested, a DVS-48, has 18.85 cubic feet of available storage volume.



### *Effective Treatment Area*

The effective treatment area is dependent on the size of the DVS model used and is the surface area or footprint of the model selected. The effective treatment area of the model tested, a DVS-48, is 12.57 square feet (sf).

### *Detention Time and Volume*

Detention time is determined by dividing the effective treatment volume by the maximum treatment flow rate. The effective treatment volume does not include the volume dedicated to sediment storage. The detention time for the DVS-48 is 44 seconds at the tested MTFR (1.0 cfs).

### *Effective Sedimentation Area*

The effective sedimentation area is the same as the effective treatment area for all DVS models.

### *Online or Offline Installation*

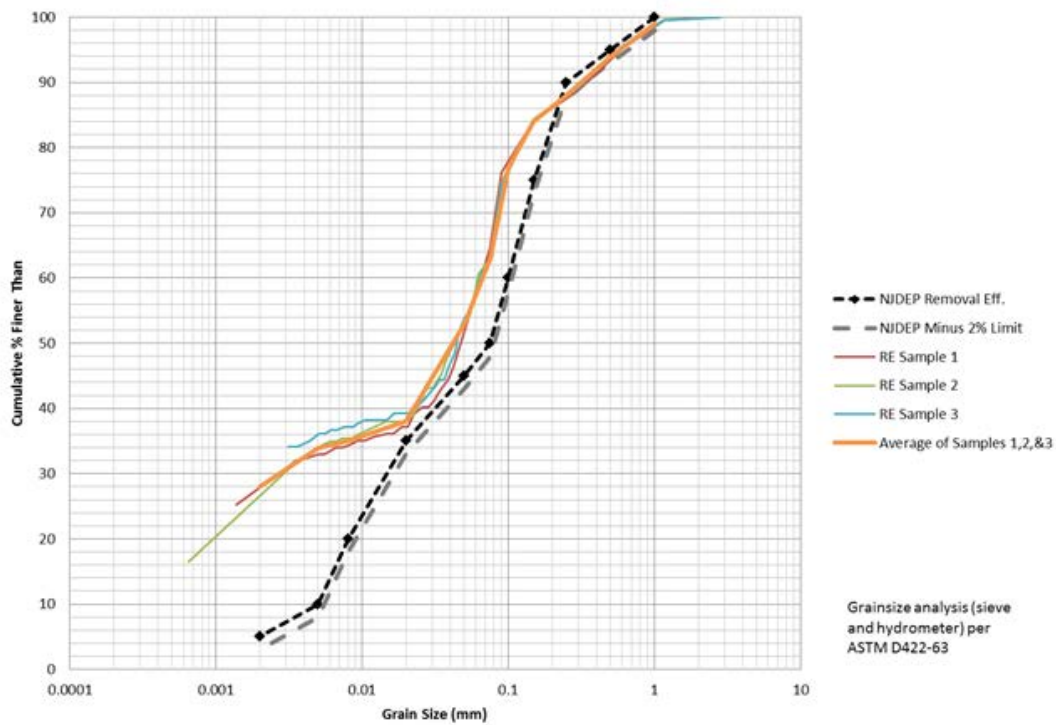
Based on the results of the scour test, the DVS stormwater treatment system qualifies for online installation.

## **4. Supporting Documentation**

The NJDEP Procedure (NJDEP, 2013a) for obtaining verification of a stormwater manufactured treatment device (MTD) from the New Jersey Corporation for Advanced Technology (NJCAT) requires that “copies of the laboratory test reports, including all collected and measured data; all data from performance evaluation test runs; spreadsheets containing original data from all performance test runs; all pertinent calculations; etc.” be included in this section. This was discussed with NJDEP and it was agreed that as long as such documentation could be made available by NJCAT upon request that it would not be prudent or necessary to include all this information in this verification report.

### **4.1 Test Sediment PSD Analysis – Removal Efficiency Testing**

**Figure 4** shows the distribution of particles from the average of samples taken from three separate batches of the removal efficiency mixture. The data were collected following the ASTM 422-63 procedure for particle analysis for soils and employed both hydrometer and sieve analyses. The mixture satisfied tolerances since it did not deviate more than 2% below the target minimum percent-less-than value at the given sizes, nor did the measured  $D_{50}$  exceed 75 microns. The  $D_{50}$  of the SAFL Removal Efficiency Mix was 43 microns. Specific gravity for the coarsest two components and the finest component was measured at 2.65. Specific gravity for the two remaining middle components (10-88 micron) was measured at 2.5 which is slightly lower density than the limit specified in the NJDEP protocol. The lower specific gravity of these two components has an extremely minor impact on test results and is, in fact, a more conservative mixture than allowed under the protocol. This material meets the requirements of the specification since it is a more conservative material. **Table 1** provides a tabular summary of protocol PSD versus measured.



**Figure 4 - TSS Removal Efficiency Test Sediment Particle Size Distribution**

**Table 1 - Particle Size Distribution - TSS Removal Efficiency**

Particle Size ( $\mu\text{m}$ )	Target Minimum % Less Than	Average of 3 Samples % Less Than	Acceptable?
1000	100	99	Yes*
500	90	94	Yes
250	55	63	Yes
150	40	53	Yes
100	25	43	Yes
75	10	22	Yes
50	0	5	Yes
20	0	3	Yes
8	0	2	Yes
5	0	2	Yes
2	0	2	Yes

Target Minimum From: "Scour Test Pre-Load PSD", Table 1, Test Sediment Particle Size Distribution in NJDEP Laboratory Protocol for HDS MTDs, 2013 [1]

\* Per footnote 2 of the referenced table, a measured value may be lower than a target minimum %less than value by up to two percentage points.

## 4.2 Removal Efficiency Testing

In accordance with the NJDEP HDS Protocol, removal efficiency testing was executed on the DVS-48 laboratory unit in order to establish the ability of the DVS to remove the specified test sediment at 25%, 50%, 75%, 100% and 125% of the target MTFR. Prior to the start of testing Oldcastle reviewed existing data and decided to utilize a target MTFR of 1.00 cfs. This target was chosen based on the ultimate goal of demonstrating greater than 50% annualized weighted solids removal as defined in the NJDEP HDS Protocol.

All results reported in this section were derived from test runs that fully complied with the terms of the protocol and QAPP. The system removal efficiency was determined using the mass balance method described in Section 5C of the NJDEP Test Protocol. TSS removal efficiency was computed from measurements of sediment mass input to the system and collected mass of sediment retained in the test tank, using the following equation:

$$\text{Removal Efficiency(\%)} = \left( \frac{\text{Total Mass Collected}}{\text{Total Mass Input During Run}} \right) \times 100$$

Mean influent concentrations reported were calculated from the mean feed rate and the mean flow rate during dosing.

### *25% MTFR Results*

To establish the performance of the DVS-48 at 25% MTFR a test was conducted in accordance with the criteria in the NJDEP HDS Protocol at a target flow rate of 0.25 cfs. **Table 2** provides an overview of the test conditions and a summary of the results for the 25% MTFR test. The feed rate calibration sample results are provided in **Table 3**. Background and effluent sampling results are presented in **Table 4**. A summary of the mass balance TSS removal efficiency is shown in **Table 5**. The DVS-48 removed 58.2% of the test sediment at an operating rate of 0.250 cfs. Each of the QA/QC parameters that pertain to sampling and flow measurement are presented in **Table 6** and are in compliance with the thresholds defined in the NJDEP HDS Protocol.

**Table 2 – Summary of DVS-48 25% MTFR Laboratory Test**

<b>DVS-48 / 25% MTFR Trial Summary</b>					
<b>Trial Date</b>	<b>Target Flow (cfs)</b>	<b>Detention Time (sec)</b>	<b>Target Sediment Concentration (mg/l)</b>	<b>Target Feed Rate (mg/min)</b>	<b>Test Duration (min)</b>
1/9/2015	0.25	176	200	84,950	151
<b>Measured Values</b>					
<b>Mean Flow Rate (cfs)</b>	<b>Mean Influent Concentration (mg/l)</b>	<b>Maximum Water Temperature (°F)</b>	<b>Mean Adjusted Effluent Conc.* (mg/l)</b>	<b>Average Removal Efficiency</b>	<b>QA/AC Compliance</b>
0.2504	193	34	81	58.2%	Yes

\* Mean adjusted effluent concentration calculated from mass balance removal efficiency

**Table 3 – Summary of DVS-48 25% MTFR Feed Rate Calibration Sample Results**

<b>DVS-48 / 25% MTFR Feed Rate Calibration Sample Results</b>					
<b>Target Concentration, (mg/l)</b>			<b>Target Feed Rate, (mg/min)</b>		
<b>200</b>			<b>84,950</b>		
<b>Sample ID</b>	<b>Sample Time (min)</b>	<b>Sample Weight (mg)</b>	<b>Sample Duration (sec)</b>	<b>Feed Rate (mg/min)</b>	<b>Calc'd Influent Concentration (mg/l)</b>
Feed Rate 1	15:15	83,038	60	83,038	195
Feed Rate 2	15:45	81,728	60	81,728	192
Feed Rate 3	16:15	81,648	60	81,648	192
Feed Rate 4	16:45	82,138	60	82,138	193
Feed Rate 5	17:15	82,328	60	82,328	194
Feed Rate 6	17:45	81,798	60	81,798	192
			<b>Mean</b>	<b>82,113</b>	<b>193</b>

**Table 4 – Summary of DVS-48 25% MTFR Background Results**

<b>DVS-48 / 25% MTFR Background Sample Results</b>		
<b>Sample ID</b>	<b>Time (min)</b>	<b>Concentration (mg/l)</b>
Background 1	15:15	1.87
Background 2	15:36	4.52
Background 3	15:57	3.58
Background 4	16:19	3.87
Background 5	16:41	5.35
Background 6	17:02	3.73
Background 7	17:22	2.89
Background 8	17:45	2.91
	<b>Low</b>	<b>1.87</b>
	<b>High</b>	<b>5.35</b>
	<b>Mean</b>	<b>3.59</b>

**Table 5 – Summary of DVS-48 25% MTFR Removal Efficiency**

<b>DVS-48 / 25% MTFR Removal Efficiency</b>		
<b>Total Mass Input (lb)</b>	<b>Total Mass Collected (lb)</b>	<b>Calculated Removal Efficiency</b>
26.4	15.36	58.2%
<b>Dry Weight of Total Mass Collected</b>		
<b>Beginning Weight (second to last weight) (g)</b>	<b>Final Weight (greater than 2 hours in oven) (g)</b>	<b>Change in Weight</b>
6968.26	6965.17	0.04%

**Table 6 – Summary of DVS-48 25% MTFR QA/QC Parameters**

<b>DVS-48 / 25% MTFR QA/QC Parameters</b>			
<b>Flow Rate</b>			
<b>Target (gpm)</b>	<b>Mean (gpm)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
0.25	0.2504	0.002	<0.03
<b>Feed Rate</b>			
<b>Target (mg/min)</b>	<b>Mean (mg/min)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
84,950	82,113	0.01	<0.1
<b>Influent Concentration</b>			
<b>Target (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
200	193	0.01	<0.1
<b>Background Concentration</b>			
<b>Low (mg/l)</b>	<b>High (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Acceptable Threshold (mg/l)</b>
1.87	5.35	3.59	<20

#### *50% MTFR Results*

To establish the performance of the DVS-48 at 50% MTFR a test was conducted in accordance with the criteria in the NJDEP HDS Protocol at a target flow rate of 0.50 cfs. **Table 7** provides an overview of the test conditions and a summary of the results for the 50% MTFR test. The feed rate calibration sample results are provided in **Table 8**. Background and effluent sampling results are presented in **Table 9**. A summary of the mass balance TSS removal efficiency is shown in **Table 10**. The DVS-48 removed 51.9% of the test sediment at an operating rate of 0.499 cfs. Each of the QA/QC parameters that pertain to sampling and flow measurement are presented in **Table 11** and are in compliance with the thresholds defined in the NJDEP HDS Protocol.

**Table 7 – Summary of DVS-48 50% MTFR Laboratory Test**

<b>DVS-48 / 50% MTFR Trial Summary</b>					
<b>Trial Date</b>	<b>Target Flow (cfs)</b>	<b>Detention Time (sec)</b>	<b>Target Sediment Concentration (mg/l)</b>	<b>Target Feed Rate (mg/min)</b>	<b>Test Duration (min)</b>
12/17/2014	0.50	88	200	169,901	75.5
<b>Measured Values</b>					
<b>Mean Flow Rate (cfs)</b>	<b>Mean Influent Concentration (mg/l)</b>	<b>Maximum Water Temperature (°F)</b>	<b>Mean Adjusted Effluent Conc.* (mg/l)</b>	<b>Average Removal Efficiency</b>	<b>QA/AC Compliance</b>
0.499	203	35	98	51.9%	Yes

\* Mean adjusted effluent concentration calculated from mass balance removal efficiency

**Table 8 – Summary of DVS-48 50% MTFR Feed Rate Calibration Sample Results**

<b>DVS-48 / 50% MTFR Feed Rate Calibration Sample Results</b>					
<b>Target Concentration</b>		<b>200 mg/l</b>	<b>Target Feed Rate, (mg/min)</b>		<b>169,901</b>
<b>Sample ID</b>	<b>Sample Time (min)</b>	<b>Sample Weight (mg)</b>	<b>Sample Duration (sec)</b>	<b>Feed Rate (mg/min)</b>	<b>Calc'd Influent Concentration (mg/l)</b>
Feed Rate 1	15:05	88,147	30	176,294	208
Feed Rate 2	15:20	84,904	30	169,808	200
Feed Rate 3	15:35	84,974	30	169,948	200
Feed Rate 4	15:50	85,695	30	171,390	202
Feed Rate 5	16:05	86,265	30	172,530	203
Feed Rate 6	16:20	86,265	30	172,530	203
			<b>Mean</b>	<b>172,083</b>	<b>203</b>

**Table 9 – Summary of DVS-48 50% MTFR Background Results**

<b>DVS-48 / 50% MTFR Background Sample Results</b>		
<b>Sample ID</b>	<b>Time (min)</b>	<b>Concentration (mg/l)</b>
Background 1	15:05	3.39
Background 2	15:16	3.22
Background 3	15:26	2.94
Background 4	15:38	3.01
Background 5	15:48	4.00
Background 6	16:01	4.49
Background 7	16:09	5.78
Background 8	16:20	5.41
	<b>Low</b>	<b>2.94</b>
	<b>High</b>	<b>5.78</b>
	<b>Mean</b>	<b>4.03</b>

**Table 10 – Summary of DVS-48 50% MTFR Removal Efficiency**

<b>DVS-48 / 50% MTFR Removal Efficiency</b>		
<b>Total Mass Input (lb)</b>	<b>Total Mass Collected (lb)</b>	<b>Calculated Removal Efficiency</b>
27.2	14.11	51.9%
<b>Dry Weight of Total Mass Collected</b>		
<b>Beginning Weight (second to last weight) (g)</b>	<b>Final Weight (greater than 2 hours in oven) (g)</b>	<b>Change in Weight *</b>
6393.52	6401.51	-0.12%

\* The lightest weight was used for analysis



**Table 11 – Summary of DVS-48 50% MTFR QA/QC Parameters**

<b>DVS-48 / 50% MTFR QA/QC Parameters</b>			
<b>Flow Rate</b>			
<b>Target (gpm)</b>	<b>Mean (gpm)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
0.50	0.499	0.01	<0.03
<b>Feed Rate</b>			
<b>Target (mg/min)</b>	<b>Mean (mg/min)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
169,901	172,083	0.01	<0.1
<b>Influent Concentration</b>			
<b>Target (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
200	203	0.01	<0.1
<b>Background Concentration</b>			
<b>Low (mg/l)</b>	<b>High (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Acceptable Threshold (mg/l)</b>
2.94	5.78	4.03	<20

#### *75% MTFR Results*

To establish the performance of the DVS-48 at 75% MTFR a test was conducted in accordance with the criteria in the NJDEP HDS Protocol at a target flow rate of 0.75 cfs. **Table 12** provides an overview of the test conditions and a summary of the results for the 75% MTFR test. The feed rate calibration sample results are provided in **Table 13**. Background and effluent sampling results are presented in **Table 14**. A summary of the mass balance TSS removal efficiency is shown in **Table 15**. The DVS-48 removed 52.7% of the test sediment at an operating rate of 0.752 cfs. Each of the QA/QC parameters that pertain to sampling and flow measurement are presented in **Table 16** and are in compliance with the thresholds defined in the NJDEP HDS Protocol

**Table 12 – Summary of DVS-48 75% MTFR Laboratory Test**

<b>DVS-48 / 75% MTFR Trial Summary</b>					
<b>Trial Date</b>	<b>Target Flow (cfs)</b>	<b>Detention Time (sec)</b>	<b>Target Sediment Concentration (mg/l)</b>	<b>Target Feed Rate (mg/min)</b>	<b>Test Duration (min)</b>
12/22/2014	0.75	66	200	254,851	50.5
<b>Measured Values</b>					
<b>Mean Flow Rate (cfs)</b>	<b>Mean Influent Concentration (mg/l)</b>	<b>Maximum Water Temperature (°F)</b>	<b>Mean Adjusted Effluent Conc.* (mg/l)</b>	<b>Average Removal Efficiency</b>	<b>QA/AC Compliance</b>
0.752	202	37	96	52.7%	Yes

\* Mean adjusted effluent concentration calculated from mass balance removal efficiency

**Table 13 – Summary of DVS-48 75% MTFR Feed Rate Calibration Sample Results**

<b>DVS-48 / 75% MTFR Feed Rate Calibration Sample Results</b>					
<b>Target Concentration</b>		<b>200 mg/l</b>	<b>Target Feed Rate, (mg/min)</b>		<b>254,851</b>
<b>Sample ID</b>	<b>Sample Time (min)</b>	<b>Sample Weight (mg)</b>	<b>Sample Duration (sec)</b>	<b>Feed Rate (mg/min)</b>	<b>Calc'd Influent Concentration (mg/l)</b>
Feed Rate 1	15:55	121,120	30	242,240	190
Feed Rate 2	16:05	133,047	30	266,094	208
Feed Rate 3	16:15	130,674	30	261,348	205
Feed Rate 4	16:25	135,940	30	271,880	213
Feed Rate 5	16:35	128,752	30	257,504	201
Feed Rate 6	16:45	125,058	30	250,116	196
			<b>Mean</b>	<b>258,197</b>	<b>202</b>

**Table 14 – Summary of DVS-48 75% MTFR Background Results**

<b>DVS-48 / 75% MTFR Background Sample Results</b>		
<b>Sample ID</b>	<b>Time (min)</b>	<b>Concentration (mg/l)</b>
Background 1	15:55	3.96
Background 2	16:02	3.01
Background 3	16:10	4.40
Background 4	16:16	4.08
Background 5	16:24	4.74
Background 6	16:31	4.06
Background 7	16:38	3.19
Background 8	16:45	3.13
	<b>Low</b>	<b>3.01</b>
	<b>High</b>	<b>4.74</b>
	<b>Mean</b>	<b>3.82</b>

**Table 15 – Summary of DVS-48 75% MTFR Removal Efficiency**

<b>DVS-48 / 75% MTFR Removal Efficiency</b>		
<b>Total Mass Input (lb)</b>	<b>Total Mass Collected (lb)</b>	<b>Calculated Removal Efficiency</b>
26.8	14.14	52.7%
<b>Dry Weight of Total Mass Collected</b>		
<b>Beginning Weight (second to last weight) (g)</b>	<b>Final Weight (greater than 2 hours in oven) (g)</b>	<b>Change in Weight*</b>
6411.63	6417.29	-0.09%

\* The lightest weight was used for analysis

**Table 16 – Summary of DVS-48 75% MTFR QA/QC Parameters**

<b>DVS-48 / 75% MTFR QA/QC Parameters</b>			
<b>Flow Rate</b>			
<b>Target (gpm)</b>	<b>Mean (gpm)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
0.75	0.752	0.001	<0.03
<b>Feed Rate</b>			
<b>Target (mg/min)</b>	<b>Mean (mg/min)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
254,851	258,197	0.04	<0.1
<b>Influent Concentration</b>			
<b>Target (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
200	202	0.04	<0.1
<b>Background Concentration</b>			
<b>Low (mg/l)</b>	<b>High (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Acceptable Threshold (mg/l)</b>
3.01	4.74	3.82	<20

*100% MTFR Results*

To establish the performance of the DVS-48 at 100% MTFR a test was conducted in accordance with the criteria in the NJDEP HDS Protocol at a target flow rate of 1.00 cfs. **Table 17** provides an overview of the test conditions and a summary of the results for the 100% MTFR test. The feed rate calibration sample results are provided in **Table 18**. Background and effluent sampling results are presented in **Table 19**. A summary of the mass balance TSS removal efficiency is shown in **Table 20**. The DVS-48 removed 47.9% of the test sediment at an operating rate of 1.000 cfs. Each of the QA/QC parameters that pertain to sampling and flow measurement are presented in **Table 21** and are in compliance with the thresholds defined in the NJDEP HDS Protocol.

**Table 17 – Summary of DVS-48 100% MTFR Laboratory Test**

<b>DVS-48 / 100% MTFR Trial Summary</b>					
<b>Trial Date</b>	<b>Target Flow (cfs)</b>	<b>Detention Time (sec)</b>	<b>Target Sediment Concentration (mg/l)</b>	<b>Target Feed Rate (mg/min)</b>	<b>Test Duration (min)</b>
12/29/2014	1.00	44	200	339,802	40
<b>Measured Values</b>					
<b>Mean Flow Rate (cfs)</b>	<b>Mean Influent Concentration (mg/l)</b>	<b>Maximum Water Temperature (°F)</b>	<b>Mean Adjusted Effluent Conc.* (mg/l)</b>	<b>Average Removal Efficiency</b>	<b>QA/AC Compliance</b>
1.000	202	35	105	47.9%	Yes

\* Mean adjusted effluent concentration calculated from mass balance removal efficiency

**Table 18 – Summary of DVS-48 100% MTFR Feed Rate Calibration Sample Results**

<b>DVS-48 / 100% MTFR Feed Rate Calibration Sample Results</b>					
<b>Target Concentration 200 mg/l</b>			<b>Target Feed Rate, (mg/min) 339,802</b>		
<b>Sample ID</b>	<b>Sample Time (min)</b>	<b>Sample Weight (mg)</b>	<b>Sample Duration (sec)</b>	<b>Feed Rate (mg/min)</b>	<b>Calc'd Influent Concentration (mg/l)</b>
Feed Rate 1	14:50	104,595	20	313,785	185
Feed Rate 2	14:58	116,228	20	348,684	205
Feed Rate 3	15:06	117,269	20	351,807	207
Feed Rate 4	15:14	115,668	20	347,004	204
Feed Rate 5	15:22	117,269	20	351,807	207
Feed Rate 6	15:30	116,120	20	348,360	205
			<b>Mean</b>	<b>343,575</b>	<b>202</b>

**Table 19 – Summary of DVS-48 100% MTFR Background Results**

<b>DVS-48 / 100% MTFR Background Sample Results</b>		
<b>Sample ID</b>	<b>Time (min)</b>	<b>Concentration (mg/l)</b>
Background 1	14:50	2.83
Background 2	14:56	2.63
Background 3	15:01	2.49
Background 4	15:07	2.77
Background 5	15:13	2.83
Background 6	15:19	3.08
Background 7	15:24	3.01
Background 8	15:30	2.74
	<b>Low</b>	<b>2.49</b>
	<b>High</b>	<b>3.08</b>
	<b>Mean</b>	<b>2.80</b>

**Table 20 – Summary of DVS-48 100% MTFR Removal Efficiency**

<b>DVS-48 / 100% MTFR Removal Efficiency</b>		
<b>Total Mass Input (lb)</b>	<b>Total Mass Collected (lb)</b>	<b>Calculated Removal Efficiency</b>
29.3	14.03	47.9%
<b>Dry Weight of Total Mass Collected</b>		
<b>Beginning Weight (second to last weight) (g)</b>	<b>Final Weight (greater than 2 hours in oven) (g)</b>	<b>Change in Weight</b>
6372.39	6365.92	0.10%

**Table 21 – Summary of DVS-48 100% MTFR QA/QC Parameters**

<b>DVS-48 / 100% MTFR QA/QC Parameters</b>			
<b>Flow Rate</b>			
<b>Target (gpm)</b>	<b>Mean (gpm)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
1.00	1.000	0.002	<0.03
<b>Feed Rate</b>			
<b>Target (mg/min)</b>	<b>Mean (mg/min)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
339,802	343,575	0.04	<0.1
<b>Influent Concentration</b>			
<b>Target (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
200	202	0.04	<0.1
<b>Background Concentration</b>			
<b>Low (mg/l)</b>	<b>High (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Acceptable Threshold (mg/l)</b>
2.49	3.08	2.80	<20

#### *125% MTFR Results*

To establish the performance of the DVS-48 at 125% MTFR a test was conducted in accordance with the criteria in the NJDEP HDS Protocol at a target flow rate of 1.25 cfs. **Table 22** provides an overview of the test conditions and a summary of the results for the 125% MTFR test. The feed rate calibration sample results are provided in **Table 23**. Background and effluent sampling results are presented in **Table 24**. A summary of the mass balance TSS removal efficiency is shown in **Table 25**. The DVS-48 removed 41.7% of the test sediment at an operating rate of 1.251 cfs. Each of the QA/QC parameters that pertain to sampling and flow measurement are presented in **Table 26** and are in compliance with the thresholds defined in the NJDEP HDS Protocol.

**Table 22 – Summary of DVS-48 125% MTFR Laboratory Test**

<b>DVS-48 / 125% MTFR Trial Summary</b>					
<b>Trial Date</b>	<b>Target Flow (cfs)</b>	<b>Detention Time (sec)</b>	<b>Target Sediment Concentration (mg/l)</b>	<b>Target Feed Rate (mg/min)</b>	<b>Test Duration (min)</b>
11/14/2014	1.25	35	200	424,752	30.5
<b>Measured Values</b>					
<b>Mean Flow Rate (cfs)</b>	<b>Mean Influent Concentration (mg/l)</b>	<b>Maximum Water Temperature (°F)</b>	<b>Mean Adjusted Effluent Conc.* (mg/l)</b>	<b>Average Removal Efficiency</b>	<b>QA/AC Compliance</b>
1.251	197	36	115	41.7%	Yes

\* Mean adjusted effluent concentration calculated from mass balance removal efficiency

**Table 23 – Summary of DVS-48 125% MTFR Feed Rate Calibration Sample Results**

<b>DVS-48 / 125% MTFR Feed Rate Calibration Sample Results</b>					
<b>Target Concentration 200 mg/l</b>			<b>Target Feed Rate, (mg/min) 424,752</b>		
<b>Sample ID</b>	<b>Sample Time (min)</b>	<b>Sample Weight (mg)</b>	<b>Sample Duration (sec)</b>	<b>Feed Rate (mg/min)</b>	<b>Calc'd Influent Concentration (mg/l)</b>
Feed Rate 1	15:02	102,412	15	409,648	193
Feed Rate 2	15:06	105,475	15	421,900	198
Feed Rate 3	15:12	102,723	15	410,892	193
Feed Rate 4	15:18	105,656	15	422,624	199
Feed Rate 5	15:24	106,587	15	426,348	201
Feed Rate 6	15:30	105,666	15	422,664	199
			<b>Mean</b>	<b>419,013</b>	<b>197</b>



**Table 24 – Summary of DVS-48 125% MTFR Background Results**

<b>DVS-48 / 125% MTFR Background Sample Results</b>		
<b>Sample ID</b>	<b>Time (min)</b>	<b>Concentration (mg/l)</b>
Background 1	15:00	4.20
Background 2	15:04	3.99
Background 3	15:08	4.17
Background 4	15:13	2.41
Background 5	15:17	2.95
Background 6	15:21	2.25
Background 7	15:25	1.87
Background 8	15:30	3.56
	<b>Low</b>	<b>1.87</b>
	<b>High</b>	<b>4.20</b>
	<b>Mean</b>	<b>3.18</b>

**Table 25 – Summary of DVS-48 125% MTFR Removal Efficiency**

<b>DVS-48 / 125% MTFR Removal Efficiency</b>		
<b>Total Mass Input (lb)</b>	<b>Total Mass Collected (lb)</b>	<b>Calculated Removal Efficiency</b>
27.0	11.26	41.7%
<b>Dry Weight of Total Mass Collected</b>		
<b>Beginning Weight (first weight) (g)</b>	<b>Final Weight (greater than 2 hours in oven) (g)</b>	<b>Change in Weight*</b>
5105.60	5110.81	-0.10%

\* The lightest weight was used for analysis

**Table 26 – Summary of DVS-48 125% MTFR QA/QC Parameters**

<b>DVS-48 / 125% MTFR QA/QC Parameters</b>			
<b>Flow Rate</b>			
<b>Target (gpm)</b>	<b>Mean (gpm)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
1.25	1.251	0.001	<0.03
<b>Feed Rate</b>			
<b>Target (mg/min)</b>	<b>Mean (mg/min)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
424,752	419,013	0.02	<0.1
<b>Influent Concentration</b>			
<b>Target (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Coefficient of Variance</b>	<b>Acceptable Parameters Coefficient of Variance</b>
200	197	0.02	<0.1
<b>Background Concentration</b>			
<b>Low (mg/l)</b>	<b>High (mg/l)</b>	<b>Mean (mg/l)</b>	<b>Acceptable Threshold (mg/l)</b>
1.87	4.2	3.18	<20

*Annualized Weighted TSS Removal Efficiency*

The NJDEP-specified annual weighted TSS removal efficiency calculation is shown in **Table 27** using the results from the removal efficiency testing.

*Testing in accordance with the provisions detailed in the NJDEP HDS Protocol demonstrate that the DVS-48 achieved a 52.0% annualized weighted TSS removal at an MTFR of 1.00 cfs (35.7 gpm/sf). This testing demonstrates that the DVS-48 exceeds the NJDEP requirement that HDS devices demonstrate at least 50% weighted annualized TSS removal efficiency at the MTFR.*

**Table 27 – Annualized Weighted TSS Removal of the DVS-48  
Tested in Accordance with the NJDEP HDS Protocol at an MTFR of 1.00 cfs**

<b>DVS-48 Annualized Weighted TSS Removal at 1.00 cfs MTFR</b>					
<b>Tested Flow Rate as Percentage of MTFR</b>	<b>Actual Tested Flow Rate (cfs)</b>	<b>Actual Percent MTFR</b>	<b>Measured Removal Efficiency</b>	<b>Annual Weighting Factor</b>	<b>Weighted Removal Efficiency</b>
25%	0.250	25%	58.2%	0.25	14.6%
50%	0.499	50%	51.9%	0.30	15.6%
75%	0.752	75%	52.7%	0.20	10.5%
100%	1.000	100%	47.9%	0.15	7.2%
125%	1.251	125%	41.7%	0.10	4.2%
<b>Weighted Annualized TSS Removal Efficiency</b>					<b>52.0%</b>

#### **4.3 Test Sediment PSD Analysis – Scour Testing**

The sediment used for scour testing was analyzed to confirm that it met the particle size distribution (PSD) requirements of the NJDEP protocol. The analysis followed procedures outlined in ASTM 422-63 for particle analysis for soils and employed both hydrometer and sieve analyses. The mixture satisfied the tolerance prescribed in the protocol in that it did not deviate more than 2% below the target minimum percent-less-than value at the given sizes. The specific gravity of the scour mixture was 2.65. **Table 28** is a tabular summary of protocol PSD versus measured PSD of the scour mixture. **Figure 5** shows the distribution of particles from the average of three samples of the scour mixture.

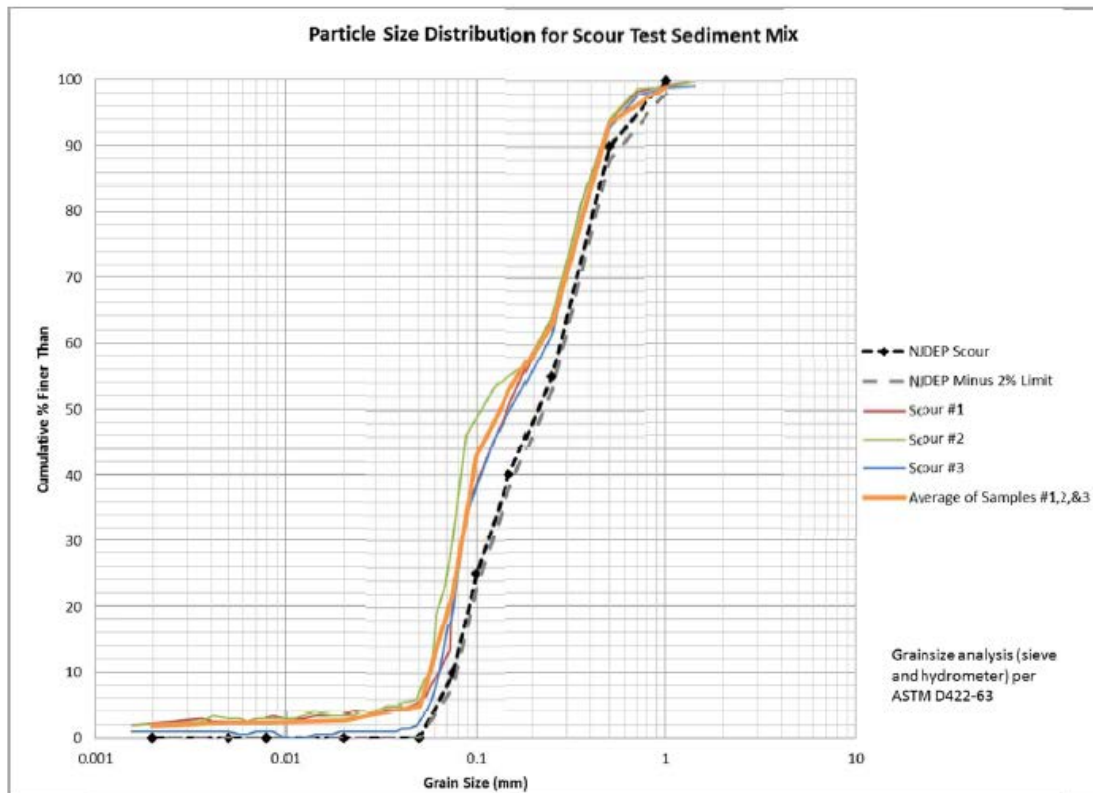
**Table 28 – Particle Size Distribution – Scour Test**

Particle Size ( $\mu\text{m}$ )	Target Minimum % Less Than	Average of 3 Samples % Less Than	Acceptable?
1000	100	99	Yes*
500	95	94	Yes*
250	90	88	Yes*
150	75	84	Yes
100	60	77	Yes
75	50	63	Yes
50	45	53	Yes
20	35	38	Yes
8	20	35	Yes
5	10	34	Yes
2	5	28	Yes

Target Minimum From: "TSS Removal Test PSD", Table 1, Test Sediment Particle Size Distribution in NJDEP Laboratory Protocol for HDS MTDs, 2013 [1]

\* Per footnote 2 of the referenced table, a measured value may be lower than a target minimum %less than value by up to two percentage points, provided the measured d50 value does not exceed 75  $\mu\text{m}$ . The measured (average) d50 is 43  $\mu\text{m}$ .

**Figure 5 - Scour Test Pre-Load Sediment Mix Particle Size Distribution**



#### 4.4 Scour Testing for Online Installation

The scour test was conducted at a flow rate of 2.0 cfs which is 200% of the MTFR for the DVS-48. Influent samples were taken every four minutes and effluent samples were taken every two minutes. The test results showing total suspended solids (TSS) for both influent (background) and effluent samples are summarized in **Table 29** below. The average background TSS concentration was 2.61 mg/L and the average effluent TSS concentration was 1.99 mg/L. The flow rate COV was 0.0009. No attempt to adjust the effluent concentration for the background levels was made since it is clear that the effluent TSS concentration is well below 20 mg/L at the 200% MTFR. The mean temperature during the test was 35 °F.

Testing at 200% of the proposed MTFR for the DVS-48 with sediment preloaded in the sedimentation sump has confirmed that previously captured sediment does not wash out and that the DVS meets the criteria for online use.

**Table 29 – Scour Test Influent (Background) and Effluent Concentrations**

<b>DVS-48 Concentration of Background Samples during Scour Testing</b>			
<b>Sample Number</b>	<b>Sample Time (min)</b>	<b>Influent Concentration (mg/l)</b>	<b>Effluent Concentration (mg/l)</b>
1	2	2.52	2.63
	4		2.59
2	6	3.03	2.76
	8		2.96
3	10	2.92	2.05
	12		2.15
4	14	2.56	2.04
	16		1.66
5	18	2.21	2.44
	20		1.99
6	22	2.74	1.99
	24		1.60
7	26	2.27	0.91
	28		1.15
8	30	2.63	0.86
Mean		2.61	1.99

## **5. Design Limitations**

Oldcastle Stormwater Solutions has an engineering team that typically works with the project site design engineer to ensure correct product application. Design constraints are addressed during this process.

### *Required Soil Characteristics*

The DVS stormwater treatment system is provided as a complete unit installed in a concrete manhole. Like a standard manhole, the system may be installed in all soil types. The project site design engineer typically specifies a crushed gravel foundation appropriate for the bearing strength of the soil at the project site.

### *Slope*

Slopes exceeding 10% may affect the performance of the DVS stormwater treatment system because of increased inlet velocities. The Oldcastle Stormwater Solutions engineering team will work with the project site design engineer to evaluate design options for applications on sites with steep slopes.

### *Maximum Flow Rate*

The maximum treatment flow rate varies depending on model size but is based on a consistent hydraulic loading rate of 35.7 gallons per minute per square foot.

### *Maintenance Requirements*

Maintenance requirements for the DVS stormwater treatment system depend on site conditions and pollutant characteristics. The system must be inspected at regular intervals and maintained when necessary to ensure optimal performance. Section 6 of this report includes a detailed description of inspection and maintenance requirements for the DVS.

### *Driving Head*

The driving head required for a given DVS model at the maximum treatment flow rate or during bypass for online units, depends on the model size and storm sewer characteristics. The engineering team at Oldcastle Stormwater Solutions will work with the project site design engineer to ensure that the hydraulic gradeline upstream of a DVS application will not cause adverse impact on storm sewer operation.

### *Installation Limitations*

Oldcastle Stormwater Solutions provides contractors with detailed assembly and installation instructions prior to delivery. A contractor may also request onsite assistance from a qualified member of the Oldcastle Stormwater Solutions team. Pick weights are also provided prior to delivery so that the contractor can have the appropriate equipment onsite to set the DVS unit.

### *Configurations*

DVS units are equipped with an internal bypass so that they may be installed online or offline. Bypass flow is routed past the treatment chamber and directly to the outlet pipe to prevent re-suspension of previously captured sediment and other pollutants.

### *Structural Load Limitations*

DVS units are typically designed to meet H-20 loading (32,000 pound axel load). If heavier loads are anticipated, the DVS structure can be designed and fabricated to meet the increased loading.

### *Pretreatment Requirements*

There are no pretreatment requirements for the DVS stormwater treatment system.

### *Limitations in Tailwater*

Significant tailwater conditions will increase the corresponding driving head required to operate the system. The engineering team at Oldcastle Stormwater Solutions will work with the project site design engineer to ensure that the maximum treatment flow rate is reached prior to internal bypass when tailwater conditions are present.

### *Depth to Seasonal High Water Table*

The treatment performance of the DVS unit will not be affected by high groundwater. If high groundwater is anticipated, the engineering team at Oldcastle Stormwater Solutions will work with the project site design engineer to evaluate the need for anti-buoyancy measures and provide guidance for appropriate counter measures.

## **6. Maintenance Plans**

State and Local regulations require all stormwater management systems to be inspected on a regular basis and maintained as necessary to ensure performance and protect downstream receiving waters. Without maintenance, excessive pollutant buildup can limit system performance by reducing the operating capacity and increase the potential for scouring of pollutants during periods of high flow. An “Inspection and Maintenance Guide” is available at [http://www.kristar.com/images/downloads/manuals/Dual\\_Vortex\\_Separator\\_Inspection\\_and\\_Maintenance\\_Guide\\_4\\_20\\_15.pdf](http://www.kristar.com/images/downloads/manuals/Dual_Vortex_Separator_Inspection_and_Maintenance_Guide_4_20_15.pdf) for the DVS and includes recommendations for inspection and maintenance equipment and procedures and as well as a form that may be used to log findings. Important information describing inspection and maintenance equipment and procedures have been extracted from this document and provided below.

### *Inspection Equipment*

The following equipment is helpful when conducting DVS inspection:

- Recording device (pen and paper form, voice recorder, iPad, etc.)
- Suitable clothing (appropriate footwear, gloves, hardhat, safety glasses, etc.)
- Traffic control equipment (cones, barricades, signage, flagging, etc.)
- Manhole hook or pry bar
- Flashlight
- Tape measure
- Measuring stick or sludge sampler
- Long-handled net (optional)
- Replacement sorbent pads (optional)

### *Inspection Procedures*

Inspection is essential to consistent system performance and is easily completed. Inspection is typically conducted a minimum of twice per year but since pollutant transport and deposition varies from site to site, a site-specific maintenance frequency should be established during the first two or three years of operation.

DVS inspections are visual and are conducted without entering the unit. To complete an inspection, safety measures including traffic control should be deployed before the access covers are removed. Once the covers have been removed, the following items should be checked and recorded to determine whether maintenance is required:

- Inspect the internal components and note whether there are any broken or missing parts. In the unlikely event that internal parts are broken or missing, contact Oldcastle Stormwater Solutions at (800) 579-8819 to determine appropriate corrective action.
- Note whether the inlet or outlet pipe is blocked or obstructed.
- Observe, quantify, and record the accumulation of floating trash and debris in the baffled chambers around the vortex tubes. The significance of accumulated floating trash and debris is a matter of judgment. A long-handled net may be used to retrieve the bulk of trash and debris at the time of inspection if full maintenance due to accumulation of oils or sediment is not yet warranted.
- Observe, quantify, and record the accumulation of oils in the baffled chambers around the vortex tubes. If sorbent pads have been used to absorb free oil and grease, observe and record their condition. Unless the sorbent pads are tethered to the internal baffles, spent pads may be netted and replaced at the time of inspection. The significance of accumulated floating oil is a matter of judgment. However, if there is evidence of an oil or fuel spill, immediate maintenance is warranted.
- Finally, observe, quantify, and record the accumulation of sediment in the sediment storage sump. A calibrated dipstick, tape measure, or sludge sampler may be used to determine the amount of accumulated sediment. The depth of sediment may be determined by calculating the difference between the measurement from the rim of the DVS to the top of the accumulated sediment and the measurement from the rim of the DVS to the bottom of the DVS structure. Finding the top of the accumulated sediment takes some practice and a light touch, but increasing resistance as the measuring device is lowered toward the bottom of the unit indicates the top of the accumulated sediment.



### *Maintenance Triggers*

Maintenance should be scheduled if any of the following conditions are identified during the inspection:

- Internal components are broken or missing.
- Inlet or outlet piping is obstructed.
- The accumulation of floating trash and debris that cannot be retrieved with a net and/or oil in the baffled chambers around the vortex tubes is significant.
- Tethered sorbent pads, if used, are dirty or saturated.
- The sediment level in the sediment storage sump is greater than 12 inches. The capacity of the sediment sump is 18 inches of sediment depth for all DVS models. Sediment depths greater than 18 inches will begin to affect the performance of the system.

### *Maintenance Equipment*

The following equipment is helpful when conducting DVS maintenance:

- Suitable clothing (appropriate footwear, gloves, hardhat, safety glasses, etc.)
- Traffic control equipment (cones, barricades, signage, flagging, etc.)
- Manhole hook or pry bar
- Confined space entry equipment, if needed
- Flashlight
- Tape measure
- Sorbent pads
- Vacuum truck

### *Maintenance Procedures*

Maintenance should be conducted during dry weather when no flow is entering the system. All maintenance, except possibly the attachment of sorbent pads (if required), may be conducted without entering the DVS structure. Once safety measures such as traffic control are deployed, the access covers may be removed and the following activities may be conducted to complete maintenance:

- Remove floating trash, debris, and oils from the water surface using an extension on the end of the boom hose of the vacuum truck. Continue using the vacuum truck to completely dewater the structure through the vortex tubes and evacuate all accumulated sediment from the sediment sump. Some jetting may be required to fully evacuate sediment from the sump. This is easily achieved by inserting a jet hose through the vortex tube opposite the tube used for vacuum hose access.
- If sorbent pads are required and are tethered to the structure, only personnel that are OSHA Confined Space Entry trained and certified may enter the structure to remove and replace the spent pads.

- The structure does not need to be refilled with water after maintenance is complete. The system will fill with water when the next storm event occurs.
- All material removed from the DVS during maintenance must be disposed of in accordance with local regulations. In most cases, the material may be handled in the same manner as disposal of material removed from sump catch basins or manholes.

## **7. Statements**

The following pages comprise the signed statements from Oldcastle (the manufacturer), St. Anthony Falls Laboratory (the independent test facility), and NJCAT required to complete the verification process.

In addition, it should be noted that this report has been subjected to public review (e.g. stormwater industry) and all comments and concerns have been satisfactorily addressed.



7921 Southpark Plaza, Suite 200, Littleton, CO 80120

(800) 579-8819

May 21, 2015

Dr. Richard Magee, Sc.D, P.E., BCEE  
Technical Director  
New Jersey Corporation for Advanced Technology  
c/o Center for Environmental Systems  
Stevens Institute of Technology  
One Castle Point on Hudson  
Hoboken, NJ 07030

Re: Verification of DVS according to NJDEP HDS Laboratory Testing Protocol

Dear Dr. Magee,

Performance of the Dual Vortex Separator (DVS) by Oldcastle Stormwater Solutions was recently verified according to the NJDEP HDS laboratory testing protocol by the research staff at St. Anthony Falls Laboratory (SAFL) at the University of Minnesota. Based on work with SAFL staff, observations during testing, and review of the SAFL test report and appendices, Oldcastle Stormwater Solutions believes that all applicable testing protocol requirements were met or exceeded. Additionally, we believe that all of the required documentation has been provided to support verification of the DVS.

Please contact me if you have any questions or concerns. Thank you.

A handwritten signature in blue ink, appearing to read "Jay Holtz", with a stylized flourish at the end.

Jay Holtz, PE  
Director of Engineering  
Oldcastle Stormwater Solutions  
971-271-0796  
[jay.holtz@oldcastlestormwater.com](mailto:jay.holtz@oldcastlestormwater.com)

# UNIVERSITY OF MINNESOTA

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*Twin Cities Campus*

*Saint Anthony Falls Laboratory  
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Minneapolis, MN 55414*

*Dept. Main Office: 612-624-4363  
Fax: 612-624-4398*

The University of Minnesota St. Anthony Falls Laboratory hereby certifies that:

- I. The performance tests performed at the University of Minnesota St. Anthony Falls Laboratory, an independent test facility, for the DVS-48 Dual Vortex Separator, a Hydrodynamic Sedimentation Manufactured Treatment Device manufactured by Oldcastle Precast, Inc., met or exceeded the applicable testing protocol requirements of "New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device," dated January 25, 2013.
- II. To the best of our knowledge, the personnel of the St. Anthony Falls Laboratory, University of Minnesota, involved in this project, and the institution, have no financial conflict of interest regarding test results.

By: \_\_\_\_\_

Jeffery Marr  
Principal Investigator  
St. Anthony Falls Laboratory  
University of Minnesota

Date: \_\_\_\_\_

5-21-15



**Center for Environmental Systems  
Stevens Institute of Technology  
One Castle Point  
Hoboken, NJ 07030-0000**

May 22, 2015

Titus Magnanao  
NJDEP  
Division of Water Quality  
Bureau of Non-Point Pollution Control  
401-02B  
PO Box 420  
Trenton, NJ 08625-0420

Dear Mr. Magnanao,

Based on my review, evaluation and assessment of the testing conducted on the Dual Vortex Separator (DVS) Stormwater Treatment Device (Oldcastle Stormwater Solutions) at the University of Minnesota St. Anthony Falls Laboratory (SAFL), the test protocol requirements contained in the "New Jersey Laboratory Testing Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device" (NJDEP HDS Protocol) were met or exceeded. Specifically:

*Test Sediment Feed*

The mean PSD of the SAFL sediment for removal efficiency testing complied with the PSD criteria established by the NJDEP HDS protocol. The SAFL removal efficiency test sediment PSD analysis was plotted against the NJDEP removal efficiency test PSD specification. The test sediment was shown to be significantly finer ( $d_{50}$  of 43  $\mu\text{m}$  vs. 75  $\mu\text{m}$ ) than the sediment blend specified by the protocol. The SAFL scour test sediment PSD analysis was plotted against the NJDEP scour test sediment PSD specification and shown to be appreciably finer than specified by the protocol.

*Removal Efficiency Testing*

In accordance with the NJDEP HDS Protocol, removal efficiency testing was executed on a Model DVS-48 in order to establish the ability of the Dual Vortex Separator to remove the specified test sediment at 25%, 50%, 75%, 100% and 125% of the target MTFR. Prior to the start of testing Oldcastle Stormwater Solutions (Oldcastle Precast) reviewed existing data and decided to utilize a target MTFR of 1.00 cfs. This target was chosen based on the ultimate goal of demonstrating greater than 50% annualized weighted solids removal as defined in the NJDEP HDS Protocol. The flow rates, sediment feed rates and TSS influent concentrations all met the

NJDEP HDS test protocol's coefficient of variance requirements and the background concentration for all five test runs never exceeded 20 mg/L. Background TSS concentration averaged 3.48 mg/L over all samples and all test runs. The highest background TSS concentration was 5.87 mg/L. The maximum water temperature during the five removal efficiency tests ranged from 34 F to 37 F.

### *Scour Testing*

In order to demonstrate the ability of the Dual Vortex Separator to be used as an online treatment device scour testing was conducted at 200% of the MTFR in accordance with the NJDEP HDS Protocol. The average flow rate during the online scour test was 1.993 cfs. Background concentrations ranged from 2.21 mg/L to 3.03 mg/L with a mean of 2.61 mg/L, which complies with the 20 mg/L maximum background concentration specified by the test protocol. Unadjusted effluent concentrations ranged from 0.86 mg/L to 2.96 mg/L with a mean of 1.99 mg/L. No attempt to adjust the effluent concentration for the background concentrations was made since it is clear that the effluent TSS concentration is well below 20 mg/L at the 200% MTFR. The mean temperature during the scour test was 35 F. These results confirm that the DVS-48 met the criteria for online use.

### *Maintenance Frequency*

The predicted maintenance frequency for all models exceeds 5.5 years.

Sincerely,



Richard S. Magee, Sc.D., P.E., BCEE

## **8. References**

St. Anthony Falls Lab, 2015. *Laboratory Test Report Dual Vortex Separator, Model DVS-48*. Prepared by St. Anthony Falls Laboratory, University of Minnesota. March.

St. Anthony Falls Lab, 2015. *Appendix to Laboratory Test Report Dual Vortex Separator, Model DVS-48*. Prepared by St. Anthony Falls Laboratory, University of Minnesota. March.

Oldcastle Stormwater Solutions, 2015. *Dual Vortex Separator, Inspection and Maintenance Guide*. Prepared by Oldcastle Stormwater Solutions. March.

NJDEP 2013a. *New Jersey Department of Environmental Protection Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology*. Trenton, NJ. January 25.

NJDEP 2013b. *New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device*. Trenton, NJ. January 25.

## **VERIFICATION APPENDIX**



### ***Introduction***

- Manufacturer – Oldcastle Stormwater Solutions, 7921 Southpark Plaza, Suite 200, Littleton, CO 80120. *Phone:* 800-579-8819. *Website:* [www.oldcastlestormwater.com](http://www.oldcastlestormwater.com).
- MTD – Dual Vortex Separator (DVS). Verified DVS models are shown in Table A-1.
- TSS Removal Rate – 50%
- On-line installation

### ***Detailed Specification***

- NJDEP sizing tables attached as Table A-1 and A-2.
- Pick weights and installation procedures vary with model size. Oldcastle Stormwater Solutions provides contractors with project-specific unit pick weights and installation instructions prior to delivery.
- Maximum recommended sediment depth prior to cleanout is 9 inches.
- For a reference inspection and maintenance plan download the Oldcastle Stormwater Solutions Dual Vortex Separator Inspection and Maintenance Guide at: [http://www.kristar.com/images/downloads/manuals/Dual\\_Vortex\\_Separator\\_Inspection\\_and\\_Maintenance\\_Guide\\_4\\_20\\_15.pdf](http://www.kristar.com/images/downloads/manuals/Dual_Vortex_Separator_Inspection_and_Maintenance_Guide_4_20_15.pdf)
- Under N.J.A.C. 7:8-5.5, NJDEP stormwater design requirements do not allow a hydrodynamic separator such as the DVS to be used in series with another hydrodynamic separator to achieve an enhanced total suspended solids (TSS) removal rate.

<b>Table A-1</b> <b>MTFRs and Required Sediment Removal Intervals for DVS Models</b>						
<b>DVS Model</b>	<b>Manhole Diameter (ft)</b>	<b>Maximum Treatment Flow Rate (cfs)</b>	<b>Effective Treatment Area (sf)</b>	<b>Hydraulic Loading Rate (gpm/sf)</b>	<b>50% Max. Sediment Volume (cf)</b>	<b>Sediment Removal Interval (months)</b>
DVS-36	3	0.56	7.07	35.7	5.30	67
DVS-48	4	1.00	12.57	35.7	9.42	67
DVS-60	5	1.56	19.63	35.7	14.73	67
DVS-72	6	2.25	28.27	35.7	21.21	67
DVS-84	7	3.06	38.48	35.7	28.86	67
DVS-96	8	4.00	50.27	35.7	37.70	67
DVS-120	10	6.25	78.54	35.7	58.90	67
DVS-144	12	9.00	113.10	35.7	84.82	67
<b>Notes:</b> <ul style="list-style-type: none"> <li>Sediment removal interval calculated using the “monthly” calculation in Section B, Appendix A of the NJDEP HDS protocol.</li> <li>In certain areas, DVS units are available in other diameters. Units not listed here are sized not to exceed a hydraulic loading rate of 35.7 gpm/sf and maintain an acceptable aspect ratio.</li> <li>50% sediment storage volume is equal to the effective treatment area x 9” of sediment. The maximum sediment storage volume occurs at 18” of sediment depth.</li> </ul>						

<b>Table A-2</b> <b>Dimensional Overview for DVS Models</b>								
<b>DVS Model</b>	<b>Manhole Diameter (ft)</b>	<b>Maximum Treatment Flow Rate (cfs)</b>	<b>Treatment Chamber Depth (ft)</b>	<b>Sediment Sump Depth (ft)</b>	<b>Total Depth Below Inverts (ft)</b>	<b>Aspect Ratio (Dia/Depth)</b>	<b>50% Max. Sediment Volume (cf)</b>	<b>Oil Storage Capacity (cf)</b>
DVS-36	3	0.56	3.00	1.50	4.50	1.00	5.30	6.07
DVS-48	4	1.00	3.50	1.50	5.00	0.88	9.42	15.08
DVS-60	5	1.56	4.50	1.50	6.00	0.90	14.73	28.63
DVS-72	6	2.25	5.50	1.50	7.00	0.92	21.21	48.54
DVS-84	7	3.06	6.50	1.50	8.00	0.93	28.86	79.21
DVS-96	8	4.00	7.50	1.50	9.00	0.94	37.70	116.45
DVS-120	10	6.25	9.00	1.50	10.50	0.90	58.90	225.80
DVS-144	12	9.00	10.50	1.50	12.00	0.88	84.82	388.30
<b>Notes:</b> <ul style="list-style-type: none"> <li>Treatment chamber depth is defined as the depth below the invert to the top of the sediment storage area (18” above the bottom of the unit).</li> <li>The aspect ratio is the unit’s diameter/treatment chamber depth. The aspect ratio for the tested unit is 0.88. An aspect ratio of 0.88 or greater indicates that the treatment depth of the unit is proportional to or deeper than required based on the diameter to depth relationship in the tested model. An aspect ratio less than 0.88 would indicate insufficient treatment chamber depth.</li> <li>The detention time is the treatment chamber wet volume/MTFR.</li> <li>The total wet volume includes the volume of the sediment sump.</li> </ul>								