NJCAT TECHNOLOGY VERIFICATION

HydroStorm Hydrodynamic Separator

Hydroworks, LLC

February 2018

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Description of Technology

The Hydroworks HydroStorm (HS) separator is a unique hydrodynamic by-pass separator. It incorporates a protected submerged pretreatment zone to collect larger solids, a treatment tank to remove finer solids, and a dual set of weirs to create a high flow bypass. High flows are conveyed directly to the outlet and do not enter the treatment area; however, the submerged pretreatment area still allows removal of coarse solids during high flows.

Under normal or low flows, water enters an inlet area with a horizontal grate. The area underneath the grate is submerged with openings to the main treatment area of the separator. Coarse solids fall through the grate and are either trapped in the pretreatment area or conveyed into the main treatment area depending on the flow rate (**Figure 1**). Fines are transported into the main treatment area. Openings and weirs in the pretreatment area allow entry of water and solids into the main treatment area and cause water to rotate in the main treatment area creating a vortex motion. Water in the main treatment area is forced to rise along the walls of the separator to discharge from the treatment area to the downstream pipe.

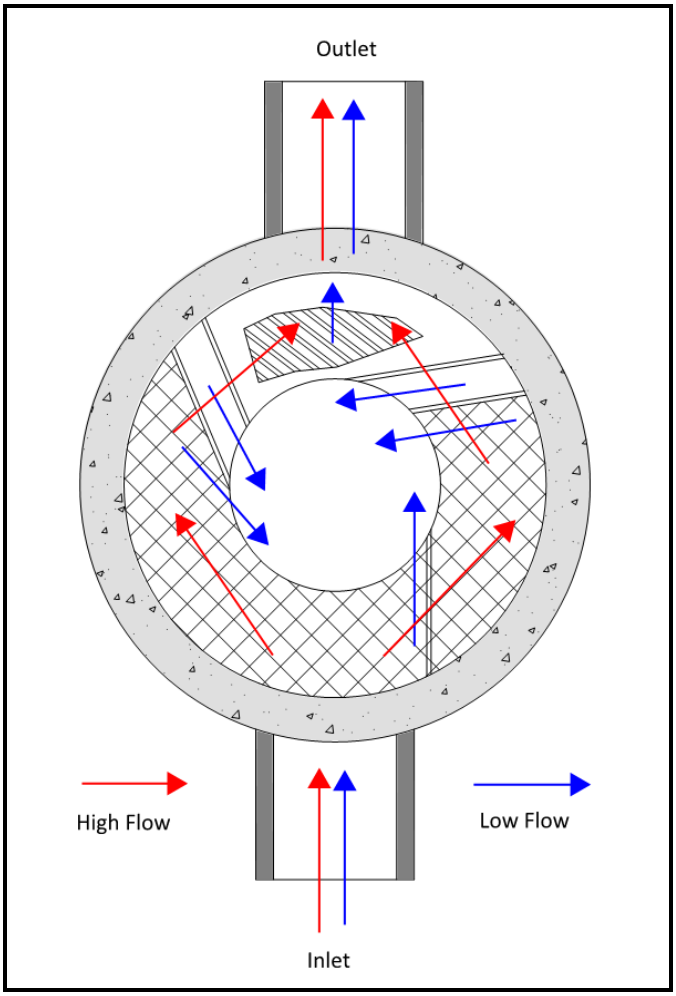

Figure 1 Hydroworks HydroStorm Operation – Plan View

The vortex motion forces solids and floatables to the middle of the inner chamber. Floatables are trapped since the inlet to the treatment area is submerged. The design maximizes the retention of settled solids since solids are forced to the center of the inner chamber by the vortex motion of water while water must flow up the walls of the separator to discharge into the downstream pipe.

A set of high flow weirs near the outlet pipe create a high flow bypass over both the pretreatment area and main treatment chamber. The rate of flow into the treatment area is regulated by the number and size of openings into the treatment chamber and the height of by-pass weirs. High flows flow over the weirs directly to the outlet pipe preventing the scour and resuspension of any fines collected in the treatment chamber.

A central tube is located in the structure to provide access for cleaning. The arrangement of the inlet area and bypass weirs near the outlet pipe facilitate the use of multiple inlet pipes. **Figure 2** is a profile view of the HydroStorm separator showing the flow patterns for low and high flows.

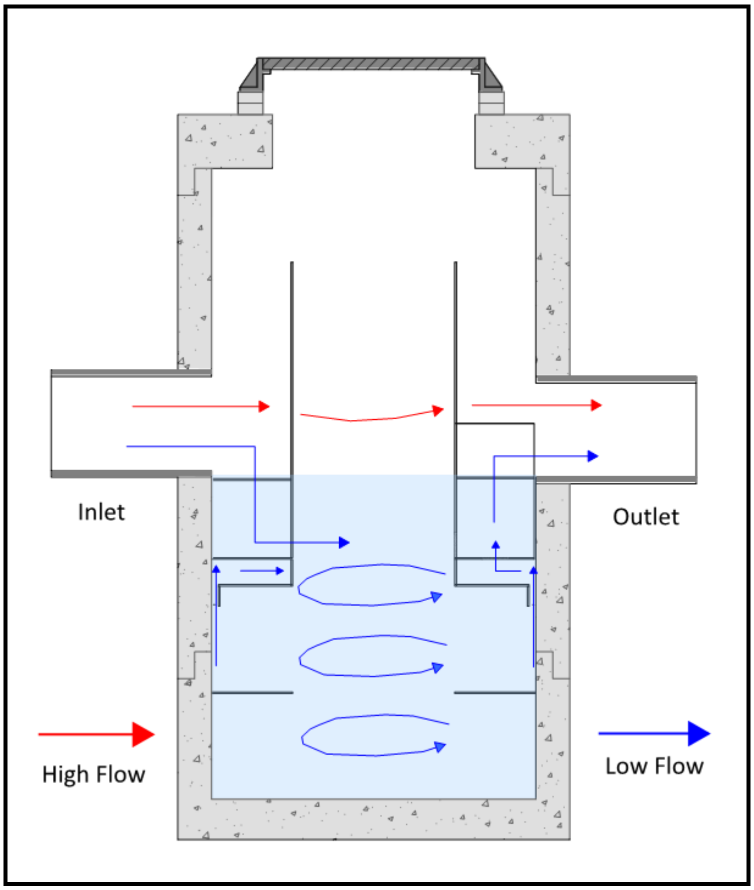

Figure 2 Hydroworks HydroStorm Operation – Profile View

2. Laboratory Testing

The test program was conducted at the Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts, under the direct supervision of Alden's senior stormwater engineer, James Mailloux. Alden has performed verification testing on approximately twenty Hydrodynamic Separator and Filtration Manufactured Treatment Devices (MTDs) for multiple manufacturers under various state and federal testing protocols. Particle size distribution (PSD) analysis was conducted by GeoTesting Express, Inc., Acton, Massachusetts. GeoTesting is an AALA ISO/IEC 17025 accredited independent laboratory. Water quality samples collected during this testing process were analyzed in Alden's Calibration Laboratory, which is ISO 17025 accredited.

Laboratory testing was done in accordance with the New Jersey Department of Environmental Protection "Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device" (January 2013a) (NJDEP Hydrodynamic Protocol). Prior to starting the performance testing program, a quality assurance project plan (QAPP) was submitted to, and approved by, the New Jersey Corporation for Advanced Technology (NJCAT).

2.1 Test Setup

The laboratory test used a full-scale Hydroworks HydroStorm separator (model HS 4) installed in a four (4) foot diameter concrete cylindrical test device. The HS 4 had a sump depth of 4 ft and a sump area of 12.57 ft^2. Aluminum inlet and outlet pipes, 14-inch in diameter, were oriented along the centerline of the unit, with the inverts located 49 and 47 inches above the sump floor, respectively. The pipes were set with 0.25% slopes. A photograph of the installed unit is shown on **Figure 3.**

Figure 3 Photograph of HS 4 Test Unit Installed in Alden Test Loop

The HS 4 test unit was installed in the Alden test loop, shown on **Figure 4,** which is set up as a recirculation system. The loop is designed to provide metered flow up to approximately 17 cfs, using a calibrated orifice plate and venturi differential-pressure meters. Flow was supplied to the unit using either a 20HP or 50HP laboratory pump (flow dependent), drawing water from a 50,000-gallon supply sump. The test flow was set and measured using a differential-pressure meter and control valve. A Differential Pressure (DP) cell and computer Data Acquisition (DA) program was used to record the test flow. Thirty (30) feet of straight 14-inch influent pipe conveyed the metered flow to the unit. Eight (8) feet of 14-inch piping returned the test flow back to the supply sump. The influent and effluent pipes were set at 0.25% slopes. A 14-inch tee was located 4 pipe-diameters upstream of the test unit for injecting sediment into the crown of the influent pipe, using a variable-speed auger feeder. Filtration of the supply sump, to reduce background concentration, was performed with an in-line filter wall containing 1-micron bag filters.

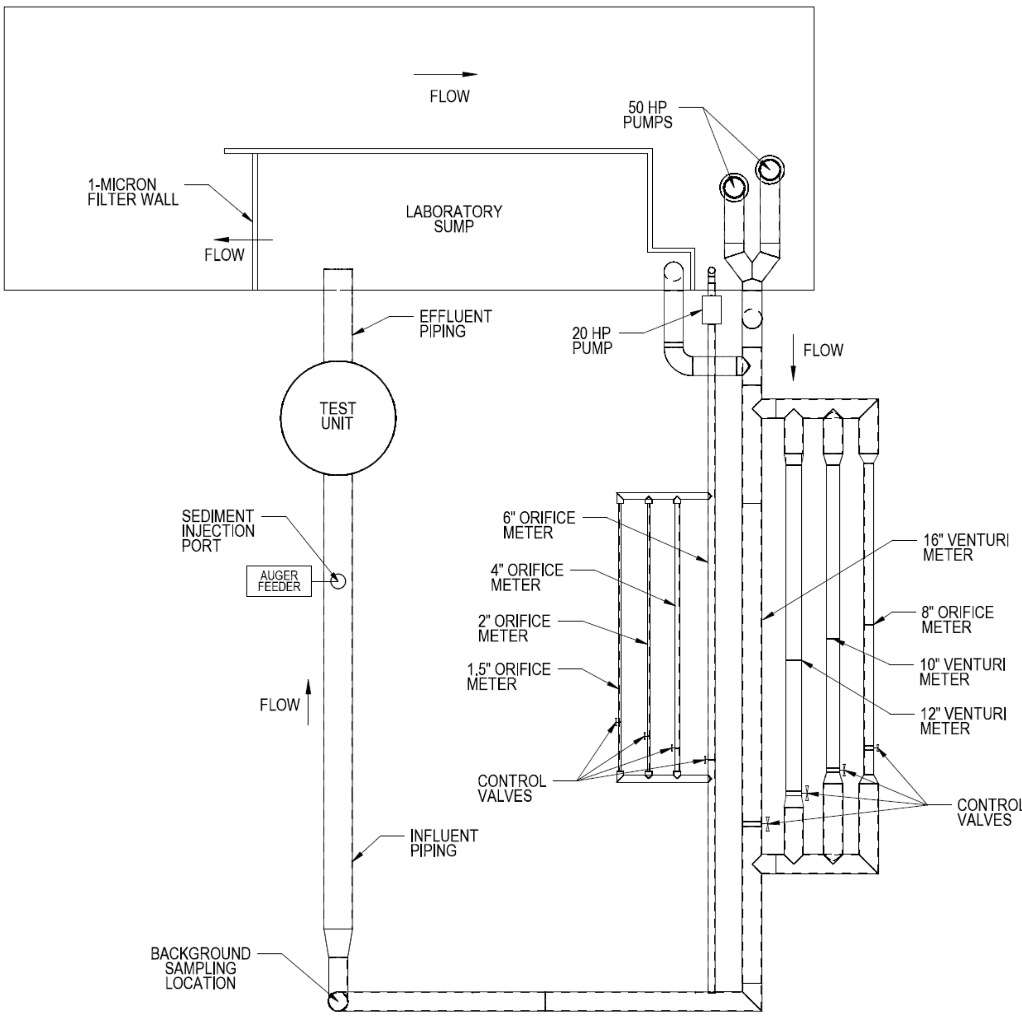

Figure 4 Plan View of Alden Flow Loop

2.2 Hydraulic Testing

The HS 4 was tested with clean water to determine its hydraulic characteristic curves, including loss coefficients (Cd's) and/or K factors, as well as the maximum flow prior to bypass. Flow and water level measurements were recorded for 15 steady-state flow conditions using the computer DA system, which included a data collection program, a 0-250" Rosemount DP cell, and a Druck 0-2 psi Absolute Pressure (AP) cell. Flows were set and measured using calibrated differential-pressure flow meters and control valves. Each test flow was set and operated at steady state for approximately 10 minutes, after which time a minimum of 60 seconds of flow and pressure data were averaged and recorded for each pressure tap location. Water elevations were measured within the treatment unit in the pretreatment channel, inner chamber, and upstream of the outlet area. Measurements within the influent and effluent pipes were taken one pipe-diameter upstream and downstream of the unit.

2.3 Removal Efficiency Testing

Removal testing was conducted on a clean unit utilizing the end-of-pipe grab sampling methodology. Five sediment removal efficiency tests were conducted at flows corresponding to 25%, 50%, 75%, 100% and 125% of the Maximum Treatment Flow Rate (MTFR). A false floor was installed at the 50% collection sump sediment storage depth of 6", as stated by Hydroworks. All tests were run with clean water containing a sediment solids concentration (SSC) of less than 20 mg/L.

A minimum of 25 lbs of test sediment was introduced into the influent pipe for each test. The moisture content of the test sediment was determined using ASTM D4959-07 for each test conducted. In addition, the criterion of the supply water temperature below 80 degrees F was met for all tests conducted.

The test sediment was prepared by Alden to meet the PSD gradation of 1-1000 microns in accordance with the distribution shown in **Table 1** (NJDEP, 2013a). The sediment is silica based, with a specific gravity of 2.65. Random samples of the test batch were analyzed for PSD compliance by GeoTesting Express, Inc., an independent certified analytical laboratory, using the ASTM D422-63 (2007) analytical method. The average of all the samples was used for compliance with the protocol specification.

The target influent sediment concentration was 200 mg/L (+/-20 mg/L) for all tests. The concentration was verified by collecting a minimum of six timed dry samples at the injector and correlating the data with the measured flow rate. Each sample volume was a minimum of 0.1 liters, with the collection time not exceeding one minute. The allowed Coefficient of Variance (COV) for the measured samples is 0.10. The reported concentration was calculated based on the total mass injected during the test and total volume of water introduced during sediment dosing.

Table 1 NJDEP Target Test Sediment Particle Size Distribution

	TSS Removal Test PSD	Scour Test Pre-load PSD
Particle Size (Microns)	**Target Minimum % Less Than[2]**	**Target Minimum % Less Than[3]**
1,000	100	100
500	95	90
250	90	55
150	75	40
100	60	25
75	50	10
50	45	0
20	35	0
8	20	0
5	10	0
2	5	0

1. The material shall be hard, firm, and inorganic with a specific gravity of 2.65. The various particle sizes shall be uniformly distributed throughout the material prior to use.

2. A measured value may be lower than a target minimum % less than value by up to two percentage points, provided the measured d_{50} value does not exceed 75 microns.

3. This distribution is to be used to pre-load the MTD's sedimentation chamber for off-line and on-line scour testing.

Eight (8) background samples of the supply water were collected using an isokinetic sampler at evenly-spaced intervals throughout each test. Collected samples were analyzed for Suspended Solids Concentration (SSC) using ASTM D3977-97 (2013). A 3rd-order curve and corresponding equation was developed for calculating the adjusted effluent concentrations. A correction was made to each timestamp to account for the detention time between the background and effluent sampling locations. The sampler was allowed to flow for the duration of all tests except 25% MTFR, for which the sampler valve was closed after the collection of each sample. The average recorded inflow was adjusted to account for the sampler flow.

Fifteen (15) effluent samples were collected from the end of the effluent pipe at evenly-spaced intervals, using 1-L wide-mouth bottles. Sampling was started after a minimum of three (3) detention times following the initiation of sediment injection, as well as after the interruption of sediment feed for injection verification.

2.4 Scour Testing

A sediment scour test was conducted to evaluate the ability of the HydroStorm to retain captured material during high flows. The 50% capacity (6 inches) false floor was left installed in the collection sump and 4-inches of 50-1000-micron sediment were pre-loaded on the floor. This resulted in preloading to the 83% (10 inches) storage capacity level. All test sediment was evenly distributed and levelled prior to testing.

The unit was filled with clean water (< 20 mg/L background) to the invert of the outlet pipe prior to testing. Testing was conducted at a temperature not exceeding 80 degrees F. The test was initiated within 96 hours of filling the unit.

The test was conducted at 200% MTFR for on-line certification. Testing consisted of conveying the selected target flow through the unit and collecting 15 time-stamped effluent samples (every 2 minutes) for SSC analysis, and a minimum of eight (8) time-stamped background samples evenly spaced throughout the test. The target flow was reached within 5 minutes of commencement of the test. Flow data was continuously recorded every 5 seconds throughout the test and correlated with the samples.

Effluent samples for sediment concentration were collected from the end of the outlet pipe with the use of 1-L bottles.

2.5 Instrumentation and Measuring Techniques

Flow

The inflow to the test unit was measured using one of five (5) calibrated differential-pressure flow meters (2”, 4”, 6”, 8” or 12”). Each meter is 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 the Rosemount® 0 to 250-inch DP cell, also calibrated at Alden prior to testing. The test flow was averaged and recorded every 5-30 seconds (flow dependent) throughout the duration of the test using the in-house computerized DA program. The accuracy of the flow measurement is ±2%. A photograph of the flow meters is shown on **Figure 5.**

Temperature

Water temperature measurements within the supply sump were obtained using a calibrated Omega® DP25 temperature probe and readout device. The calibration was performed at the Alden laboratory prior to testing. The temperature reading was documented at the start and end of each test, to ensure an acceptable testing temperature of less than 80 degrees F.

Figure 5 Photograph Showing Laboratory Flow Meters

Pressure Head

Pressure head measurements were recorded at multiple locations using piezometer taps and a Druck®, Model PTX510, 0 - 2.0 psi cell. The pressure cell was calibrated at Alden prior to testing. Accuracy of the readings is ± 0.001 ft. The cell was installed at a known datum in relation to the tank floor, allowing for elevation readings through the full range of flows. A minimum of 60 seconds of pressure data was averaged and recorded for each pressure tap during steady-state hydraulic testing, using the computerized DA program. A photograph of the pressure measurement instrumentation is shown on **Figure 6**
.

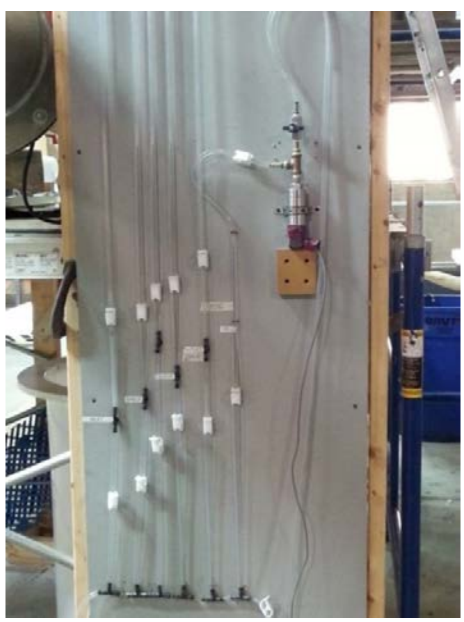

Figure 6 Pressure Measurement Instrumentation

Sediment Injection

The test sediment was injected into the crown of the influent pipe using an Auger® volumetric screw feeder, model VF-1, shown on **Figure 7.** The feed screws used in testing ranged in size from 0.5-inch to 1.0 inch, depending on the test flow. Each auger screw, driven with a variable-speed drive, was calibrated with the test sediment prior to testing, to establish a relationship between the auger speed (0-100%) and feed rate in mg/minute. The calibration, as well as test verification of the sediment feed was accomplished by collecting 1-minute timed dry samples and weighing them on an Ohaus® 4000g x 0.1g, model SCD-010 digital scale. The feeder has a hopper at the upper end of the auger to provide a constant supply of dry test sand.

Figure 7 Photograph Showing Variable-Speed Auger Feeder

Sample Collection

Effluent samples were collected in 1-L bottles from the end of the pipe for sediment concentration analyses. Background concentration samples were collected from the center of the vertical pipe upstream of the test unit with the use of a 0.75-inch isokinetic sampler, shown on **Figure 8**.

Figure 8 Photograph Showing the Background Isokinetic Sampler

Sample Concentration Analysis

Effluent and background concentration samples were analyzed by Alden in accordance with Method B, as described in ASTM Designation: D 3977-97 (Re-approved 2013), "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.

2.6 Data Management and Acquisition

A designated Laboratory Records Book was used to document the conditions and pertinent data entries for each test conducted. All entries are initialed and dated.

A personal computer running an Alden in-house Labview® Data Acquisition program was used to record all data related to instrument calibration and testing. A 16-bit National Instruments® NI6212 Analog to Digital (A/D) board was used to convert the signal from the pressure cells to a voltage. Alden's in-house data collection software, by default, collects one-second averages of data collected at a raw rate of 250 Hz. The system allows very long contiguous data collection by continuously writing the collected 1-second averages and their RMS values to disk. The data output from the program is in tab delimited text format with a user-defined number of significant figures.

Test flow and pressure data were continuously collected at a frequency of 250 Hz. The flow data was averaged and recorded to file every 5 to 30 seconds, depending on the duration of the test. Steady-state pressure data was averaged and recorded over a duration of 60 seconds for each point. The recorded data files were imported into Excel for further analysis and plotting.

Excel based data sheets were used to record all sediment related data used for quantifying injection rate, effluent and background sample concentrations, captured mass and PSD data. The data was input to the designated spreadsheet for final processing.

2.7 Quality Assurance and Control

All instruments were calibrated prior to testing and periodically checked throughout the test program. Instrumentation calibrations were provided.

Flow

The flow meters and pressure cells were calibrated in Alden's Calibration Laboratory. All pressure lines were purged of air prior to initiating each test. A standard water manometer board and Engineers Rule were used to measure the differential pressure and verify the computer measurement of the selected flow meter.

Sediment Injection

The sediment feed (g/min) was verified with the use of a digital stop watch and 4000g calibrated digital scale. The tare weight of the sample container was recorded prior to collection of each sample. The samples were a minimum of 0.1 liters in size, with a maximum collection time of 1-minute. The final sediment concentrations were adjusted for moisture.

Sediment Concentration Analysis

All sediment concentration samples were processed in accordance with the ASTM D3977-97 (2013) analytical method. Gross sample weights were measured using a 4000g x 0.1g calibrated digital scale. The dried sample weights were measured with a calibrated 0.0001g analytical balance. The change in filter weight due to processing was accounted for by including three control filters with each test set. The average of the three values, which was typically (+/- 0.1mg), was used in the final concentration calculations.

Analytical accuracy was verified by preparing two blind control samples and processing using the ASTM method. The final calculated values were within 0.26% and 0.87% of the theoretical sample concentrations, with an average of 0.57% accuracy.

3. Performance Claims

Per the NJDEP verification procedure, the following are the performance claims for the Hydroworks HS 4 based on the results of the laboratory testing conducted.

Total Suspended Solids (TSS) Removal Efficiency

The TSS removal rate of the Hydroworks HS 4 was calculated using the weighted method required by the NJDEP HDS MTD protocol. Based on a MTFR of 0.88 cfs, the HS 4 achieved a weighted TSS removal rate of 50%.

Maximum Treatment Flow Rate (MTFR).

The Hydroworks HS 4 had a total sedimentation area of 12.57 ft^2 and demonstrated a maximum treatment flow rate (MTFR) of 0.88 cfs (395 gpm). This corresponds to a surface loading rate of 31.4 gpm/ft^2 of sedimentation area.

Maximum Sediment Storage Depth and Volume

The maximum sediment storage depth is 12" which equates to 12.6 ft^3 of sediment storage volume. A sediment storage depth of 6 inches corresponds to 50% full sediment storage capacity (6.3 ft^3).

Effective Treatment/Sedimentation Area

The effective treatment area is 12.57 ft^2.

Detention Time and Wet Volume

The wet volume for the HS 4 is 375 gallons. The detention time of the HS 4 is dependent upon flow rate. At the MTFR, the detention time in the HS 4 is 57 seconds.

Online/Offline Installation

Based on the scour testing results the Hydroworks HS 4 qualifies for online installation.

4. Supporting Documentation

The NJDEP Procedure (NJDEP, 2013b) 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. This information was provided to NJCAT and is available upon request.

4.1 Test Sediment PSD Analysis

A commercially-available blend (AGSCO NJDEP 1-1000) was provided by AGSCO Corp., a QAS International ISO-9001 certified company, and adjusted by Alden to meet the NJDEP %-finer acceptance criteria. Test batches of approximately 30 lbs each were prepared in individual 5-gallon buckets, which were arbitrarily selected for each removal test. A well-mixed sample was collected from four (4) random test batches and analyzed for PSD by GeoTesting Express. The average of the samples was used for compliance to the protocol specifications. The D_{50} of the samples ranged from 63 to 71 microns, with an average of 67 microns. The PSD data of the samples are shown in **Table 2** and the corresponding curves are shown on **Figure 9**. The specific gravity of the sediment mix was 2.65.

Table 2 PSD Analysis of Alden NJDEP 1-1000 Micron Test Sediment

Particle size (µm)	NJDEP Target (percent-finer)	Test Sediment Particle Size Distribution (percent-finer)					QA / QC Compliant
		Bucket 1	Bucket 6	Bucket 10	Bucket 14	Average	
1000	**100**	100	100	100	100	**100**	Yes
500	**95**	96	95	95	96	**96**	Yes
250	**90**	91	90	90	92	**91**	Yes
150	**75**	75	74	76	77	**76**	Yes
100	**60**	61	60	60	61	**61**	Yes
75	**50**	52	51	51	52	**52**	Yes
50	**45**	46	45	46	47	**46**	Yes
20	**35**	35	35	36	36	**35**	Yes
8	**20**	21	20	22	22	**21**	Yes
5	**10**	14	14	16	16	**15**	Yes
2	**5**	6	7	7	7	**7**	Yes
D_{50}	**75**	65	71	68	63	**67**	Yes

The sediment particle size distribution (PSD) used for removal efficiency testing exceeded the NJDEP PSD sediment specifications (**Table 1**) across the entire distribution. The D50 of 67 microns was less than the required 75 microns.

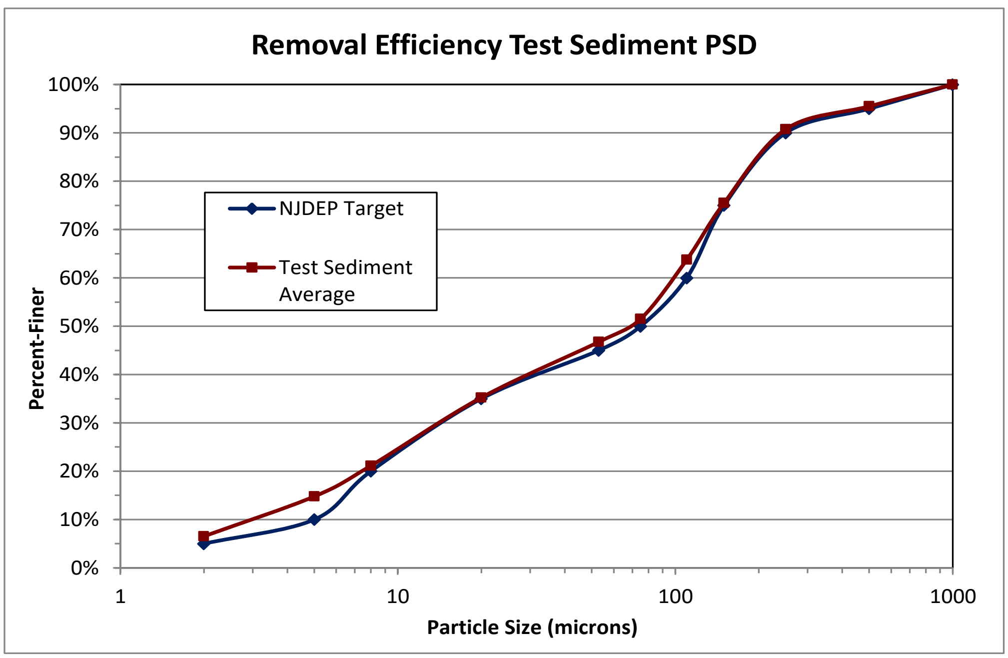

Figure 9 Comparison of PSD Curves of NJDEP and Alden Test Sediments

4.2 Removal Efficiency Testing

Summary

Removal efficiency tests were conducted at the five (5) required flows of 25%, 50%, 75%, 100% and 125% MTFR. The 100% MTFR was 0.88 cfs, resulting in target flows of 0.22, 0.44, 0.66, 0.88 and 1.10 cfs. The 25% MTFR test flow was slightly greater than the +10% target allowance (+13.7%). However, since the higher flow will result in a slightly lower removal efficiency, the measured removal efficiency is deemed conservative and, therefore, the data from this run was accepted. The target influent sediment concentration was 200 mg/l.

The target and measured flow and temperature parameters are shown in **Table 3** and the injected sediment and background data summary is shown in **Table 4**.

Table 3 Test Flow and Temperature Summary

MTFR	Target Flow		Measured Flow		Deviation from Target	Flow Measurement COV	Maximum Temperature	QA / QC Compliant
	cfs	gpm	cfs	gpm			Deg. F	
25%	0.22	98.7	0.25	112.2	13.7%	0.001	62.5	No
50%	0.44	197.5	0.44	195.4	-1.1%	0.002	67.8	Yes
75%	0.66	296.2	0.67	298.7	0.8%	0.004	72.4	Yes
100%	0.88	395.0	0.84	378.4	-4.2%	0.003	76.1	Yes
125%	1.10	493.7	0.99	446.6	-9.5%	0.002	75.7	Yes

Table 4 Injected Sediment Summary

Flow	Target Concentration	Average Injected Concentration	Injector Measurements COV	Mass/Volume Concentration	Injected Mass	Maximum Background Concentration	QA / QC Compliant
gpm	mg/L	mg/L		mg/L	lbs	mg/L	
112.2	200	202	0.01	188	27.28	4.42	Yes
195.4	200	199	0.00	188	26.81	3.54	Yes
298.7	200	209	0.00	209	28.10	8.09	Yes
378.4	200	206	0.00	191	25.92	6.82	Yes
446.6	200	199	0.00	198	26.99	8.91	Yes

Average Influent TSS (mass/volume concentration)

$$Average\ Influent\ TSS\ \left(\frac{mg}{L}\right) = \frac{Average\ Feed\ Rate\ \left(\frac{g}{min}\right) \times \frac{1000\ mg}{g}}{Average\ Water\ Flow\ Rate\ \left(\frac{gal}{min}\right) \times \frac{3.785\ L}{gal}}$$

At the end of each test run, the collected effluent and background samples were processed and quantified. The calculated removal efficiencies ranged from 42.8% to 58.5%, with a weighted removal of 50.1% for the five (5) flows tested. The removal efficiency summary is shown **Table 5** with the corresponding removal curve shown on **Figure 10**. Data for individual flow rate tests is presented in each testing sub-section.

Repeat Tests

It was required to repeat the 50% and 100% MTFR tests due to the background concentrations exceeding the 20 mg/L acceptance limit.

Table 5 Removal Efficiency Summary

Flow	Influent Concentration	Average Adjusted Effluent Concentration	Removal Efficiency	Weight Factor	Weighted Removal
gpm	mg/L	mg/L			
112.2	188.2	78.1	**58.5%**	0.25	**14.6%**
195.4	188.3	89.9	**52.3%**	0.30	**15.7%**
298.7	208.7	115.7	**44.6%**	0.20	**8.9%**
378.4	191.0	107.6	**43.7%**	0.15	**6.6%**
446.6	197.7	113.0	**42.8%**	0.10	**4.3%**
				1.00	**50.1%**

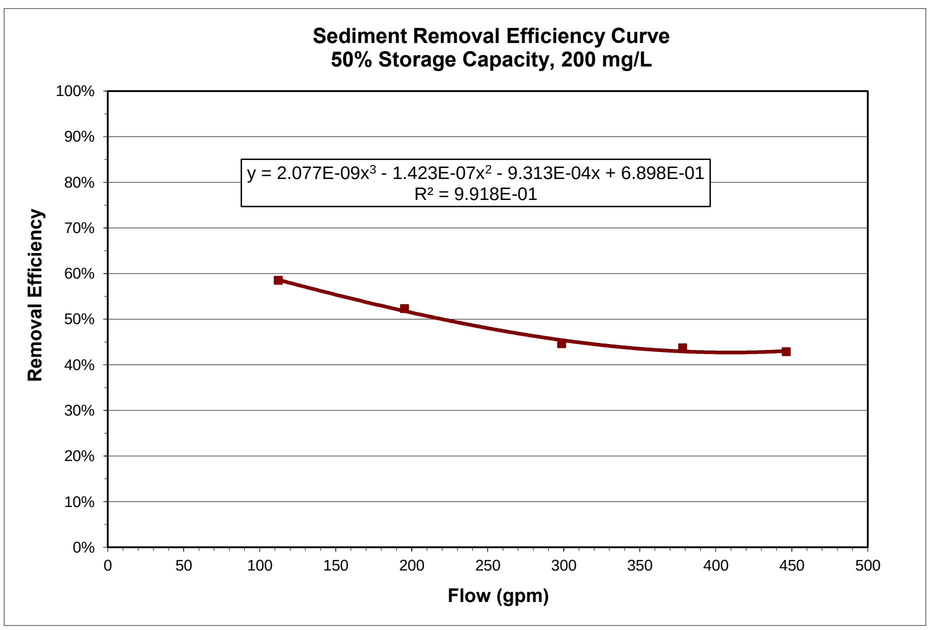

Figure 10 Hydroworks HS 4 Removal Efficiency Curve

25% MTFR (99 gpm)

The test was conducted over a period of 160 minutes. The flow exceeded the +10% tolerance, hence the removal efficiency is considered conservative. The resulting removal efficiency was 58.5%. The test flow was averaged and recorded every 10 seconds throughout the test. The average recorded test flow was 112 gpm, with a COV of 0.001. The recorded temperature for the full test ranged from 61.6 to 62.5 degrees F. The resulting data is shown in **Table 6**.

The injection feed rate of 84.8 g/min was verified by collecting 1-minute weight samples from the injector. The measured influent injection concentrations for the full test ranged from 200 to 206 mg/L, with a mean of 202 mg/L and COV of 0.01. The total mass injected into the unit was 27.3 lbs. The calculated mass-volume concentration for the test was 188 mg/L.

The measured influent concentration and flow data for the complete test is shown on **Figure 11**.

Eight (8) background concentrations samples were collected throughout the test and ranged from 0.3 to 4.4 mg/L. The background curve and equation are shown on **Figure 12**.

Table 6 25% MTFR Background and Effluent Concentration Data

Injection Sample	Sample Time minutes	Sample ID	Sample Time minutes	Effluent Concentration mg/L	Background Concentration mg/L	Adjusted Effluent mg/L
Inj 1	2	**Eff 1, BG 1**	12	77.7	0.6	77.1
Inj 2	30	**Eff 2**	18	71.1	0.6	70.6
Inj 3	59	**Eff 3, BG 2**	24	81.7	0.6	81.1
Inj 4	87	**Eff 4**	41	71.3	1.0	70.3
Inj 5	115	**Eff 5, BG 3**	47	67.7	1.3	66.5
Inj 6	144	**Eff 6**	53	60.1	1.6	58.5
Injection Sampling Duration 60 seconds		**Eff 7, BG 4**	69	78.0	2.4	75.5
		Eff 8	75	73.2	2.8	70.4
		Eff 9, BG 5	81	87.8	3.1	84.7
		Eff 10	98	93.5	3.9	89.6
		Eff 11, BG 6	104	87.4	4.1	83.3
		Eff 12	110	79.2	4.2	75.0
		Eff 13, BG 7	126	85.9	4.2	81.7
		Eff 14	132	81.8	4.0	77.8
		Eff 15, BG 8	138	113.0	3.8	109.3
					Average	**78.1**
		Detention Time (seconds) = 186				
		Detention Volume Based on Hydraulic Head (cu.ft.) = 46.5				
		Mass/Volume Influent Concentration (mg/L) = 188				

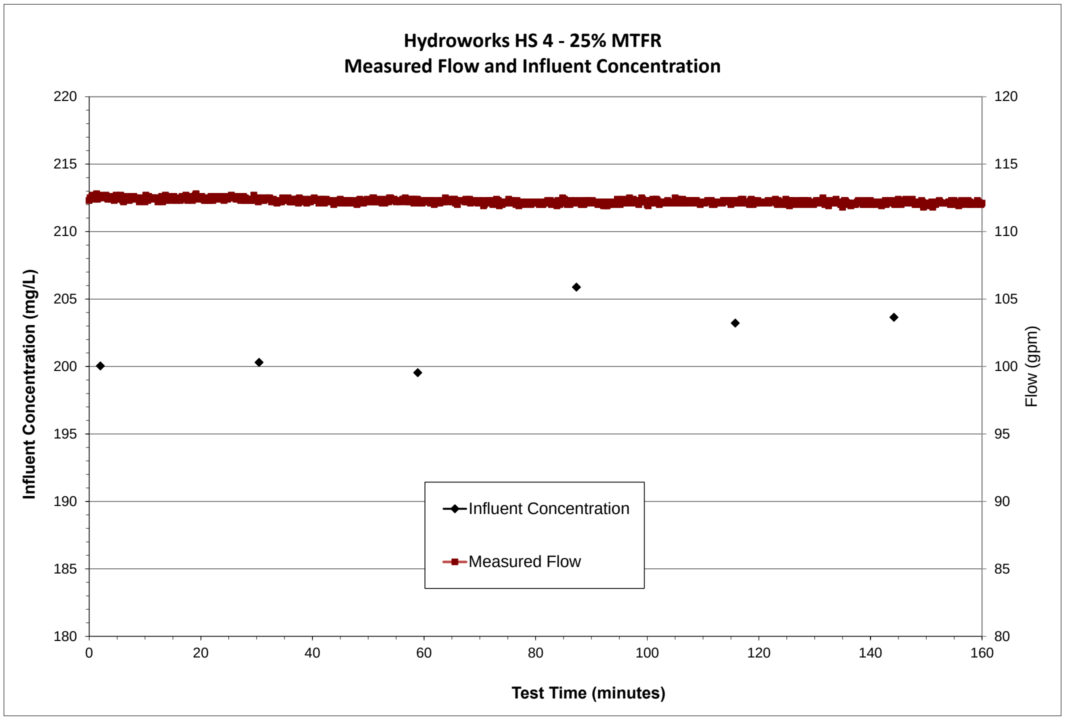

Figure 11 25% MTFR Measured Flow and Influent Concentrations

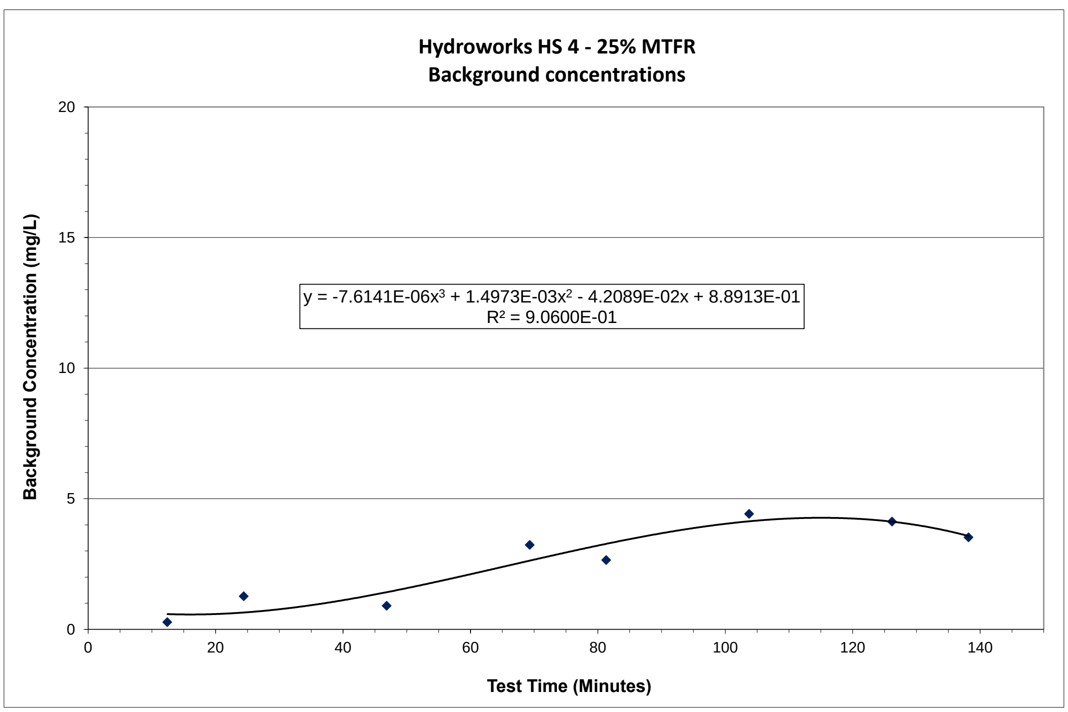

Figure 12 25% MTFR Measured Background Concentrations

50% MTFR (197 gpm)

The test was conducted over a period of 94 minutes. The resulting removal efficiency was 52.3%. The test flow was averaged and recorded every 10 seconds throughout the test. The adjusted average recorded test flow was 195 gpm, with a COV of 0.002. The recorded temperature for the full test ranged from 67.7 to 67.8 degrees F. The resulting data is shown in **Table 7**.

The injection feed rate of 147.6 g/min was verified by collecting 1-minute weight samples from the injector. The measured influent injection concentrations for the full test ranged from 199 to 200 mg/L, with a mean of 199 mg/L and COV of 0.00. The total mass injected into the unit was 26.8 lbs. The calculated mass-volume concentration for the test was 188 mg/L.

The measured influent concentration and flow data for the complete test is shown on **Figure 13**.

Eight (8) background concentrations samples were collected throughout the test and ranged from 0.0 to 3.5 mg/L. The background curve and equation are shown on **Figure 14**.

Table 7 50% MTFR Background and Effluent Concentration Data

Injection Sample	Sample Time (minutes)	Sample ID	Sample Time (minutes)	Effluent Concentration (mg/L)	Background Concentration (mg/L)	Adjusted Effluent (mg/L)
Inj 1	2	**Eff 1, BG 1**	9	51.2	0.0	51.2
Inj 2	18	**Eff 2**	12	85.1	0.1	85.0
Inj 3	34	**Eff 3, BG 2**	15	94.3	0.2	94.1
Inj 4	50	**Eff 4**	25	93.0	0.5	92.5
Inj 5	66	**Eff 5, BG 3**	28	91.5	0.6	90.8
Inj 6	82	**Eff 6**	31	91.8	0.7	91.1
Injection Sampling Duration 60 seconds		**Eff 7, BG 4**	41	89.1	1.1	87.9
		Eff 8	44	99.6	1.2	98.3
		Eff 9, BG 5	47	96.5	1.4	95.1
		Eff 10	57	96.9	1.9	95.0
		Eff 11, BG 6	60	90.1	2.1	88.1
		Eff 12	63	100.0	2.3	97.8
		Eff 13, BG 7	73	97.0	3.0	94.0
		Eff 14	76	125.9	3.2	122.7
		Eff 15, BG 8	79	67.6	3.5	64.1
					Average	**89.8**
		Detention Time (seconds) = 112				
		Detention Volume Based on Hydraulic Head (cu.ft.) = 48.8				
		Mass/Volume Influent Concentration (mg/L) = 188				

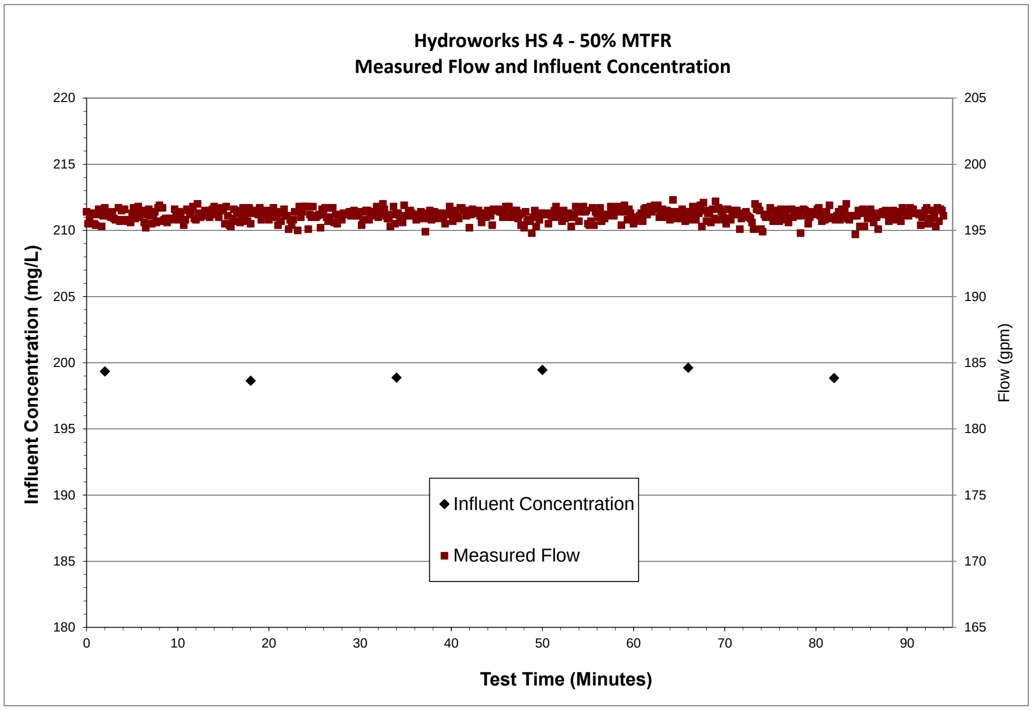

Figure 13 50% MTFR Measured Flow and Influent Concentrations

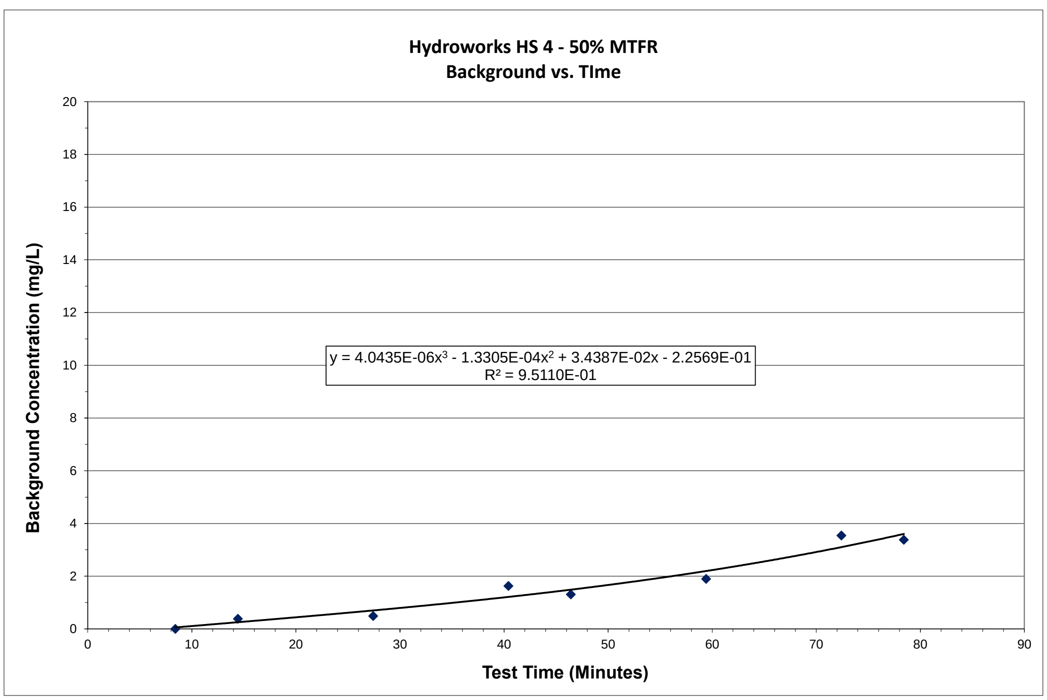

Figure 14 50% MTFR Measured Background Concentrations

75% MTFR (296 gpm)

The test was conducted over a period of 60 minutes. The resulting removal efficiency was 44.6%. The test flow was averaged and recorded every 10 seconds throughout the test. The adjusted average recorded test flow was 299 gpm, with a COV of 0.004. The recorded temperature for the full test ranged from 72.1 to 72.4 degrees F. The resulting data is shown in **Table 8.**

The injection feed rate of 227.1 g/min was verified by collecting 1-minute weight samples from the injector. The measured influent injection concentrations for the full test ranged from 209 to 210 mg/L, with a mean of 209 mg/L and COV of 0.00. The total mass injected into the unit was 28.1 lbs. The calculated mass-volume concentration for the test was 209 mg/L.

The measured influent concentration and flow data for the complete test is shown on **Figure 15**.

Eight (8) background concentrations samples were collected throughout the test and ranged from 0.9 to 8.1 mg/L. The background curve and equation are shown on **Figure 16**.

Table 8 75% MTFR Background and Effluent Concentration Data

Injection Sample	Sample Time	Sample ID	Sample Time	Effluent Concentration	Background Concentration	Adjusted Effluent
	minutes		minutes	mg/L	mg/L	mg/L
Inj 1	2	**Eff 1, BG 1**	6	107.1	1.2	105.8
Inj 2	13	**Eff 2**	8	109.7	1.0	108.7
Inj 3	24	**Eff 3, BG 2**	10	110.3	0.9	109.4
Inj 4	35	**Eff 4**	17	125.1	0.8	124.3
Inj 5	46	**Eff 5, BG 3**	19	120.7	0.9	119.9
Inj 6	57	**Eff 6**	21	139.0	1.0	138.1
		Eff 7, BG 4	28	108.9	1.7	107.2
Injection Sampling Duration		**Eff 8**	30	114.8	2.0	112.8
60 seconds		**Eff 9, BG 5**	32	117.0	2.3	114.7
		Eff 10	39	120.3	3.5	116.7
		Eff 11, BG 6	41	128.7	4.0	124.8
		Eff 12	43	128.9	4.4	124.5
		Eff 13, BG 7	50	85.4	6.0	79.4
		Eff 14	52	137.1	6.5	130.7
		Eff 15, BG 8	54	124.8	7.0	117.8
					Average	**115.7**
		Detention Time (seconds) = 75				
		Detention Volume Based on Hydraulic Head (cu.ft.) = 50.0				
		Mass/Volume Influent Concentration (mg/L) = 209				

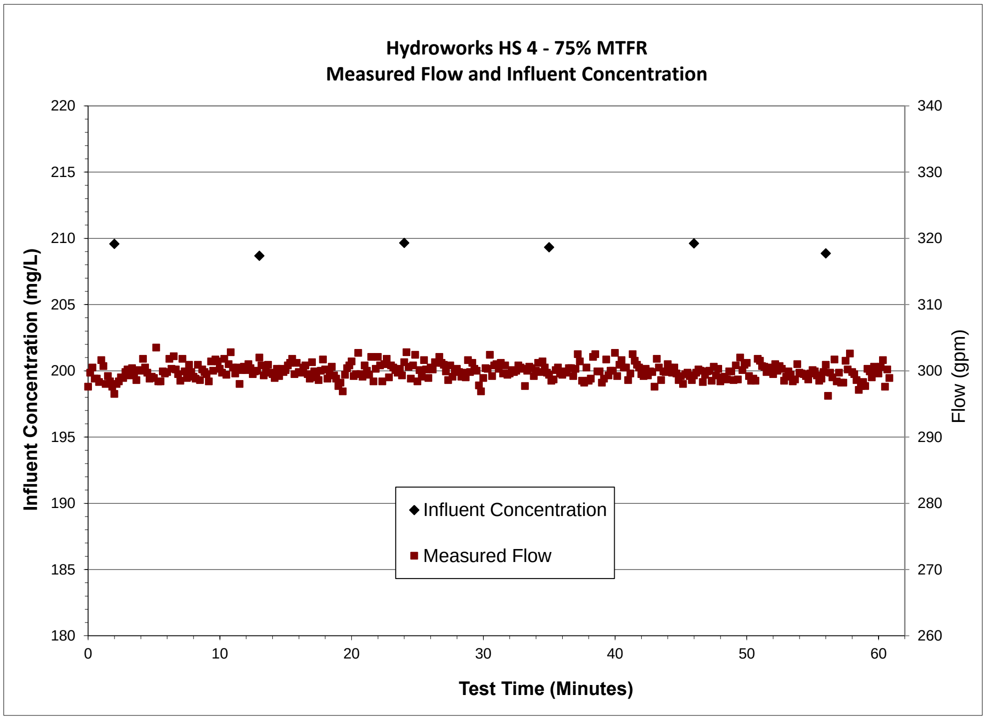

Figure 15 75% MTFR Measured Flow and Influent Concentrations

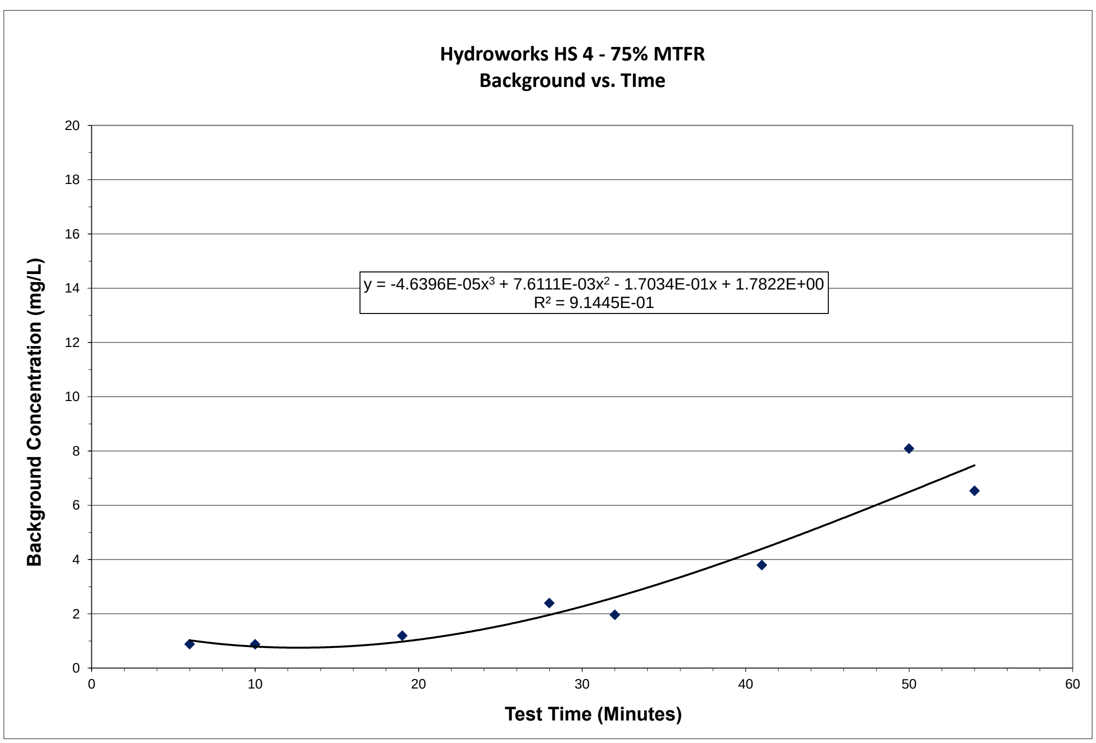

Figure 16 75% MTFR Measured Background Concentrations

100% MTFR (395 gpm)

The test was conducted over a period of 48 minutes. The resulting removal efficiency was 43.7%. The test flow was averaged and recorded every 10 seconds throughout the test. The adjusted average recorded test flow was 378 gpm, with a COV of 0.003. The recorded temperature for the full test ranged from 76.0 to 76.1 degrees F. The resulting data is shown in **Table 9**.

The injection feed rate of 288.8 g/min was verified by collecting 45-second weight samples from the injector. The measured influent injection concentrations for the full test ranged from 206 to 207 mg/L, with a mean of 206 mg/L and COV of 0.00. The total mass injected into the unit was 25.9 lbs. The calculated mass-volume concentration for the test was 191 mg/L.

The measured influent concentration and flow data for the complete test is shown on **Figure 17**.

Eight (8) background concentrations samples were collected throughout the test and ranged from 0.0 to 6.8 mg/L. The background curve and equation are shown on **Figure 18**.

Table 9 100% MTFR Background and Effluent Concentration Data

Injection Sample	Sample Time minutes	Sample ID	Sample Time minutes	Effluent Concentration mg/L	Background Concentration mg/L	Adjusted Effluent mg/L
Inj 1	2	**Eff 1, BG 1**	5	89.2	0.2	89.0
Inj 2	11	**Eff 2**	7	104.4	0.1	104.2
Inj 3	20	**Eff 3, BG 2**	9	107.5	0.1	107.4
Inj 4	29	**Eff 4**	14	99.9	0.2	99.7
Inj 5	38	**Eff 5, BG 3**	16	97.1	0.3	96.8
Inj 6	47	**Eff 6**	18	107.7	0.4	107.3
Injection Sampling Duration 45 seconds		**Eff 7, BG 4**	23	104.9	0.9	104.0
		Eff 8	25	128.2	1.1	127.1
		Eff 9, BG 5	27	113.3	1.4	111.9
		Eff 10	32	137.8	2.3	135.5
		Eff 11, BG 6	34	121.6	2.7	118.9
		Eff 12	36	126.9	3.2	123.7
		Eff 13, BG 7	41	109.0	4.5	104.5
		Eff 14	43	124.6	5.1	119.5
		Eff 15, BG 8	45	69.8	5.7	64.1
					Average	**107.6**
		Detention Time (seconds) = 60				
		Detention Volume Based on Hydraulic Head (cu.ft.) = 51.0				
		Mass/Volume Influent Concentration (mg/L) = 191				

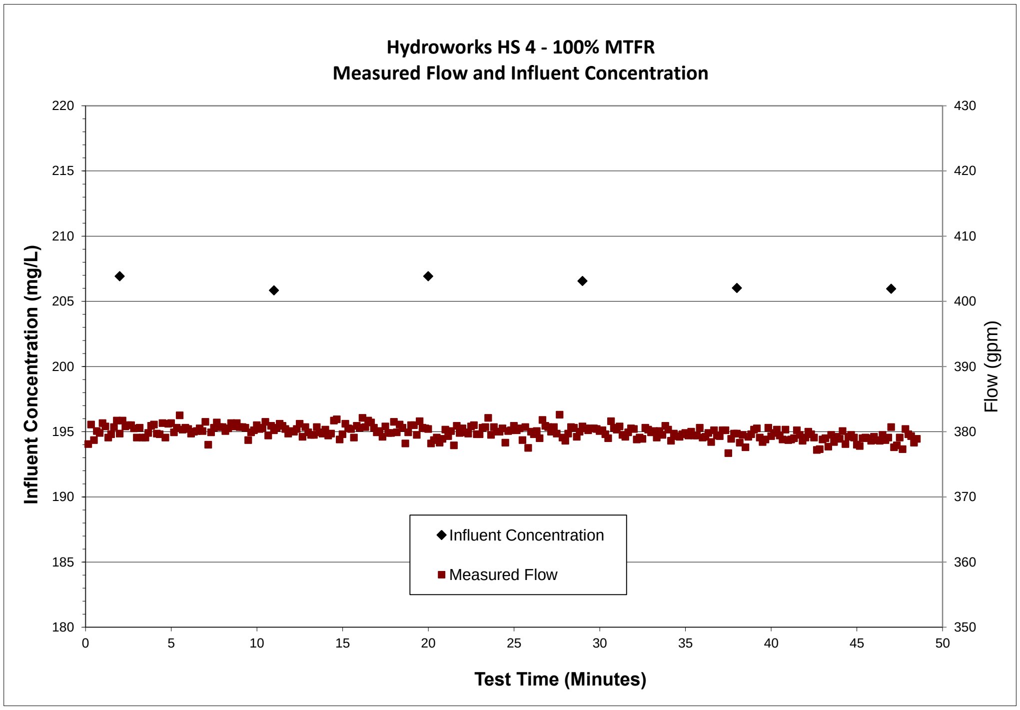

Figure 17 100% MTFR Measured Flow and Influent Concentrations

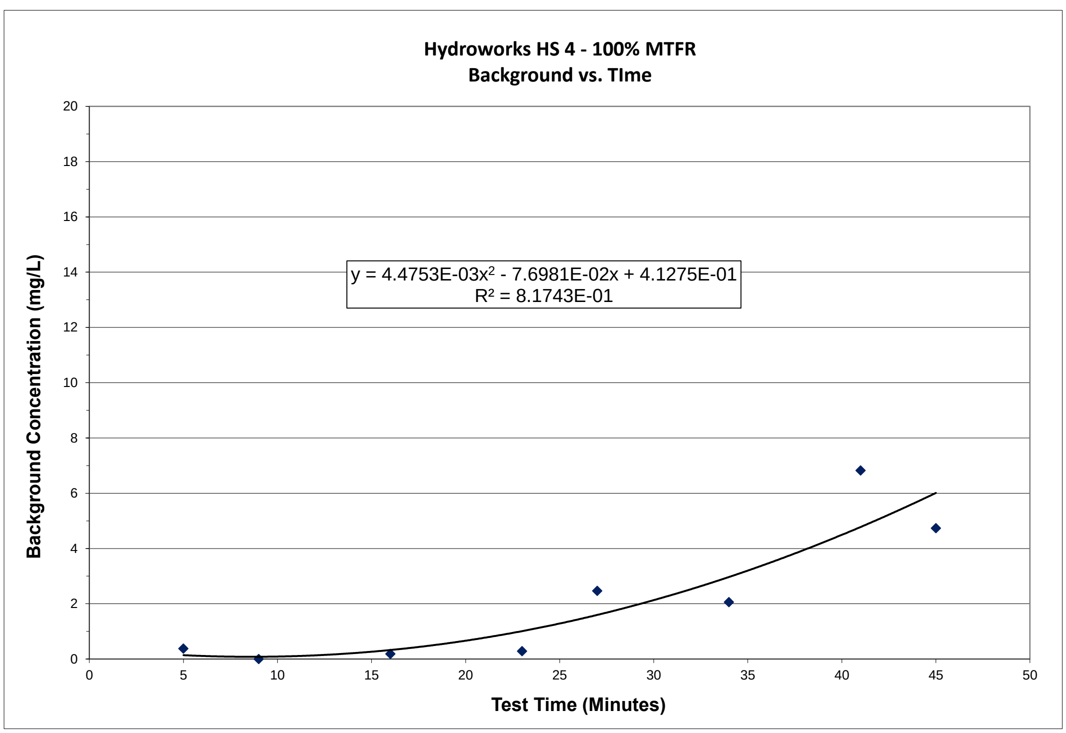

Figure 18 100% MTFR Measured Background Concentrations

125% MTFR (494 gpm)

The test was conducted over a period of 41 minutes. The resulting removal efficiency was 42.8%. The test flow was averaged and recorded every 10 seconds throughout the test. The adjusted average recorded test flow was 447 gpm, with a COV of 0.002. The recorded temperature for the full test was 75.7 degrees F. The resulting data is shown in **Table 10.**

The injection feed rate of 339.8 g/min was verified by collecting 30-second weight samples from the injector. The measured influent injection concentrations for the full test ranged from 198 to 199 mg/L, with a mean of 199 mg/L and COV of 0.00. The total mass injected into the unit was 27.0 lbs. The calculated mass-volume concentration for the test was 198 mg/L.

The measured influent concentration and flow data for the complete test is shown on **Figure 19.**

Eight (8) background concentrations samples were collected throughout the test and ranged from 1.5 to 8.9 mg/L. The background curve and equation are shown on **Figure 20.**

Table 10 125% MTFR Background and Effluent Concentration Data

Injection Sample	Sample Time (minutes)	Sample ID	Sample Time (minutes)	Effluent Concentration (mg/L)	Background Concentration (mg/L)	Adjusted Effluent (mg/L)
Inj 1	2	**Eff 1, BG 1**	5	126.9	1.7	125.2
Inj 2	10	**Eff 2**	7	118.0	1.6	116.5
Inj 3	17	**Eff 3, BG 2**	8	107.6	1.5	106.1
Inj 4	25	**Eff 4**	13	109.0	1.5	107.5
Inj 5	32	**Eff 5, BG 3**	14	106.2	1.6	104.7
Inj 6	40	**Eff 6**	16	118.5	1.7	116.8
Injection Sampling Duration 30 seconds		**Eff 7, BG 4**	20	113.1	2.4	110.7
		Eff 8	22	121.7	2.7	119.0
		Eff 9, BG 5	23	125.3	3.1	122.2
		Eff 10	28	121.5	4.3	117.2
		Eff 11, BG 6	29	125.9	4.8	121.0
		Eff 12	31	116.6	5.3	111.3
		Eff 13, BG 7	35	113.8	7.0	106.8
		Eff 14	37	108.7	7.6	101.1
		Eff 15, BG 8	38	117.2	8.2	108.9
					Average	**113.0**
		Detention Time (seconds) = 52				
		Detention Volume Based on Hydraulic Head (cu.ft.) = 51.9				
		Mass/Volume Influent Concentration (mg/L) = 198				

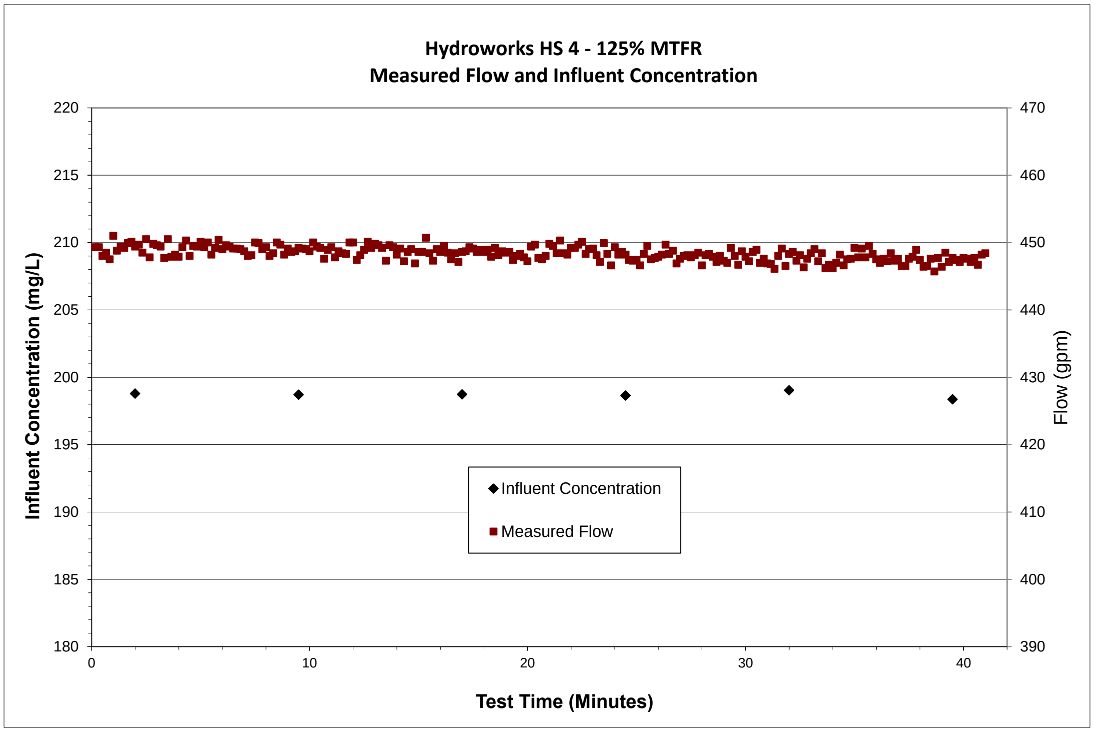

Figure 19 125% MTFR Measured Flow and Influent Concentrations

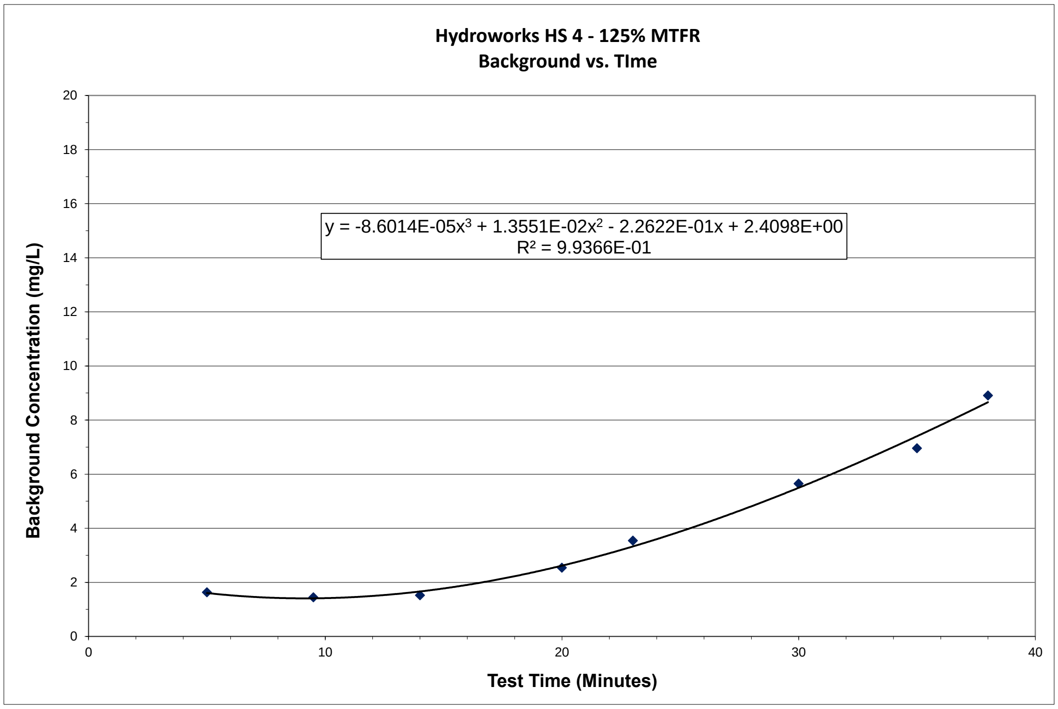

Figure 20 125% MTFR Measured Background Concentrations

4.3 Scour Test

The commercially-available AGSCO NJDEP 50-1000 certified sediment mix was utilized for the scour test. Three random samples of the batch mix were analyzed in accordance with ASTM D422-63 (2007), by CTLGroup prior to testing. The specified less-than (%-finer) values of the sample average were within the specifications listed in Column 3 of **Table 1**, as defined by the protocol. The D_{50} of the 3-sample average was 202 microns. The PSD data of the samples are shown in **Table 11** and the corresponding curves, including the initial AGSCO in-house analysis, are shown on **Figure 21**.

The scour test was conducted with the 50% capacity (6") false floor installed. An additional 4" of the 50-1000-micron test sediment was preloaded on top of the false floor, resulting in the unit being preloaded to the 83% storage capacity of 10".

The test was conducted at a target flow of 900 gpm, which is equal to 228% MTFR. The flow data was recorded every 5 seconds throughout the test and is shown on **Figure 22.** The target flow was reached within 5 minutes of initiating the test. The average recorded steady-state flow was 903 gpm, with a COV of 0.002. The recorded water temperature was 66.2 degrees F.

Eight background samples were collected throughout the duration of the test. The measured concentrations ranged from 1.2 to 3.1 mg/L, with an average concentration of 2.2 mg/L.

A total of 15 effluent samples were collected throughout the test. The measured concentrations ranged from 10.9 to 30.3 mg/L, with an average concentration of 16.8 mg/L. The average adjusted effluent concentration for the test was 14.6 mg/L. The effluent and background concentration data are shown in **Table 12** and on **Figure 23**.

Table 11 PSD Analyses of AGSCO NJDEP 50-1000 Batch Mix

Particle size (µm)	NJDEP %-Finer Specifications	Test Sediment Particle Size (%-Finer)			
		Sample 1	Sample 2	Sample 3	Average
1000	100	100	100	100	**100**
500	90	95	95	95	**95**
250	55	58	58	59	**58**
150	40	41	41	42	**41**
100	25	23	23	23	**23**
75	10	10	10	11	**10**
50	0	1	1	1	**1**

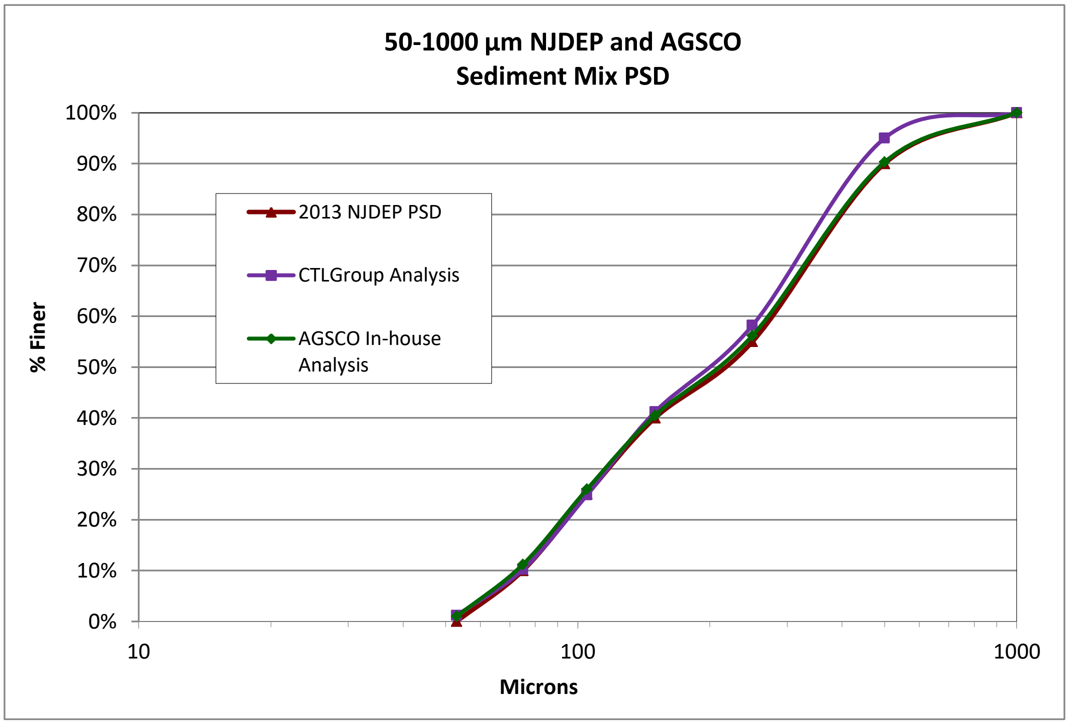

Figure 21 PSD Curves of AGSCO Batch Analysis and NJDEP Specifications

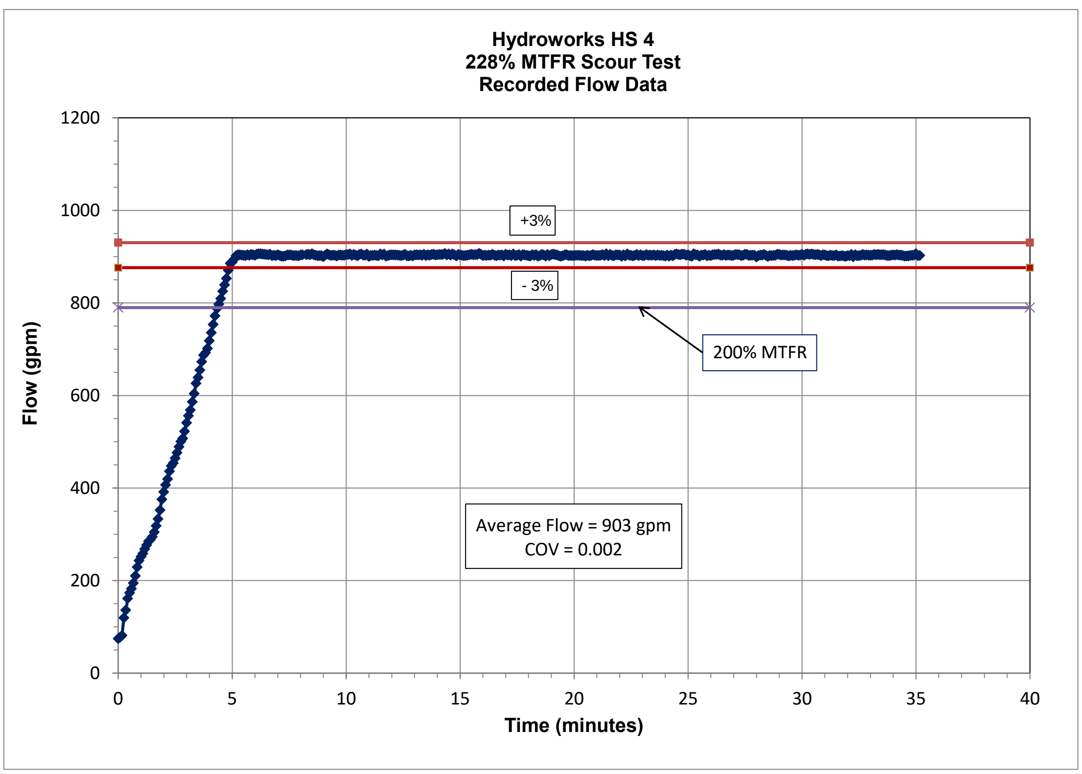

Figure 22 Scour Test Recorded Flow Data

Table 12 Scour Test Background and Effluent Concentration Data

Sample ID	Timestamp (minutes)	Effluent Concentration (mg/L)	Background Concentration (mg/L)	Adjusted Effluent Concentration (mg/L)
EFF 1	6	30.3	1.2	29.1
EFF 2	8	18.4	1.3	17.1
EFF 3	10	24.9	1.4	23.5
EFF 4	12	16.9	2.2	14.7
EFF 5	14	10.9	3.1	7.8
EFF 6	16	19.5	2.6	16.9
EFF 7	18	15.9	2.0	13.9
EFF 8	20	18.0	2.3	15.7
EFF 9	22	12.1	2.5	9.6
EFF 10	24	14.5	2.5	12.0
EFF 11	26	10.9	2.5	8.4
EFF 12	28	15.8	2.4	13.4
EFF 13	30	16.0	2.2	13.8
EFF 14	32	16.5	2.3	14.2
EFF 15	34	11.3	2.4	8.9
	Average	**16.8**	**2.2**	**14.6**

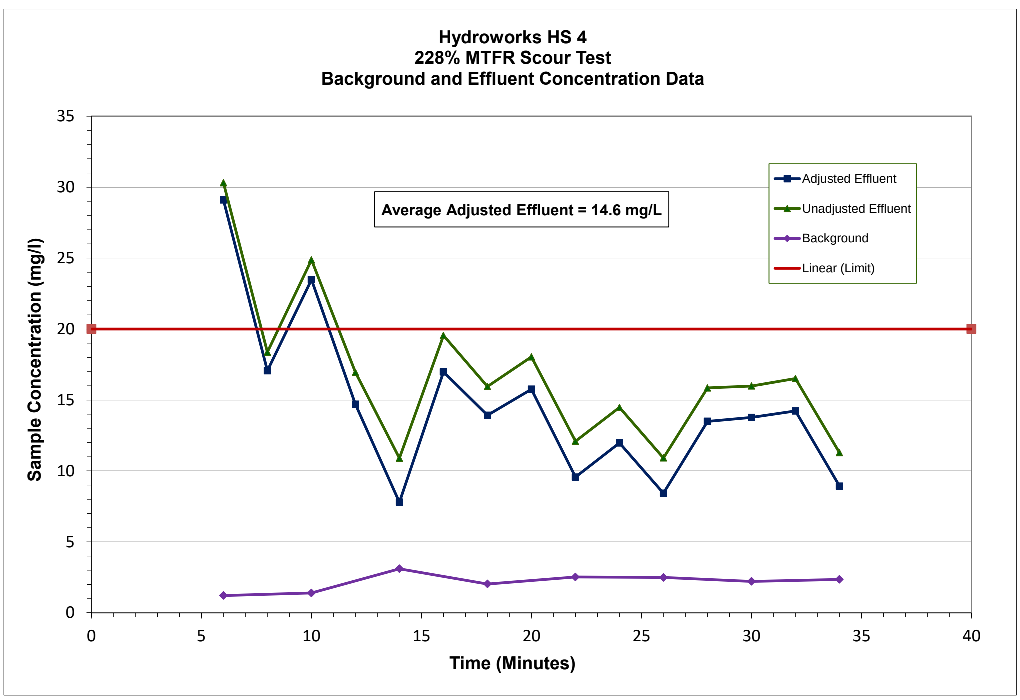

Figure 23 Scour Test Measured Background and Effluent Concentrations

4.4 Hydraulics

Flow (gpm) and water level (ft) within the unit were measured for 15 flows ranging from 0 to 1745 gpm (3.9 cfs). The influent pipe was flowing full at approximately 1500 gpm. The entrance to the effluent pipe was submerged at approximately 1745 gpm. The flow reached bypass at approximately 430 gpm. The recorded data and calculated losses are shown in **Table 13.** The Elevation Curves for five (5) locations are shown on **Figure 24**.

Table 13 Recorded Flow and Elevation Data

Measured Flow		Water Elevations (adjusted to outlet invert)						Losses			
		Inlet Pipe A	Inlet Area	Pretreatment Channel B	Inner Chamber C	Outlet Shelf D	Outlet Pipe E	Inlet El. (A') Corrected for Energy	Outlet El. (E') Corrected for Energy	System Energy Loss A'-E'	Loss Coeff. Outlet Area
gpm	cfs	ft	sq-ft	ft	ft	ft	ft	ft	ft	ft	Cd
0	0	0.170	0.000	0.000	0.000	0.000	-0.009	0.170	0.000	0.000	0.000
25.0	0.06	0.249	0.032	0.153	0.129	0.128	0.064	0.297	0.155	0.142	0.025
50.2	0.11	0.284	0.054	0.201	0.187	0.186	0.095	0.350	0.211	0.139	0.050
100.4	0.22	0.326	0.086	0.284	0.267	0.262	0.144	0.432	0.279	0.153	0.095
150.9	0.34	0.357	0.111	0.360	0.330	0.321	0.185	0.499	0.332	0.166	0.137
202.1	0.45	0.389	0.140	0.433	0.389	0.372	0.219	0.551	0.382	0.169	0.182
278.1	0.62	0.520	0.270	0.545	0.468	0.433	0.265	0.602	0.444	0.157	0.260
350.1	0.78	0.647	0.412	0.653	0.539	0.484	0.300	0.703	0.500	0.203	0.288
431.2	0.96	0.802	0.592	0.803	0.616	0.541	0.342	0.843	0.552	0.291	0.296
502.4	1.12	0.858	0.657	0.871	0.672	0.596	0.371	0.903	0.598	0.305	0.337
602.1	1.34	0.916	0.722	0.927	0.728	0.639	0.418	0.970	0.654	0.316	0.397
702.1	1.56	0.960	0.771	0.973	0.779	0.702	0.461	1.024	0.707	0.317	0.462
999.6	2.23	1.094	0.909	1.091	0.906	0.797	0.571	1.187	0.856	0.332	0.643
1514.0	3.37	1.289	1.054	1.295	1.141	1.024	0.724	1.448	1.088	0.360	0.934
1745.4	3.89	1.404	1.069	1.409	1.271	1.199	0.728	1.610	1.205	0.405	1.016

As seen on **Figure 25**, the calculated system energy loss (influent to effluent) ranged from 0 to 0.291 ft at the point of bypass (431 gpm). The loss decreased as expected due to bypass flow and started increasing once the water elevation reached the top of the outlet pipe. The maximum calculated system loss at 1745 gpm was 0.405 ft. The loss coefficient (Cd) for the insert was based on the area of the insert outlet (0.75 ft^2). The Cd values prior to bypass ranged from 0.03 to 0.30.

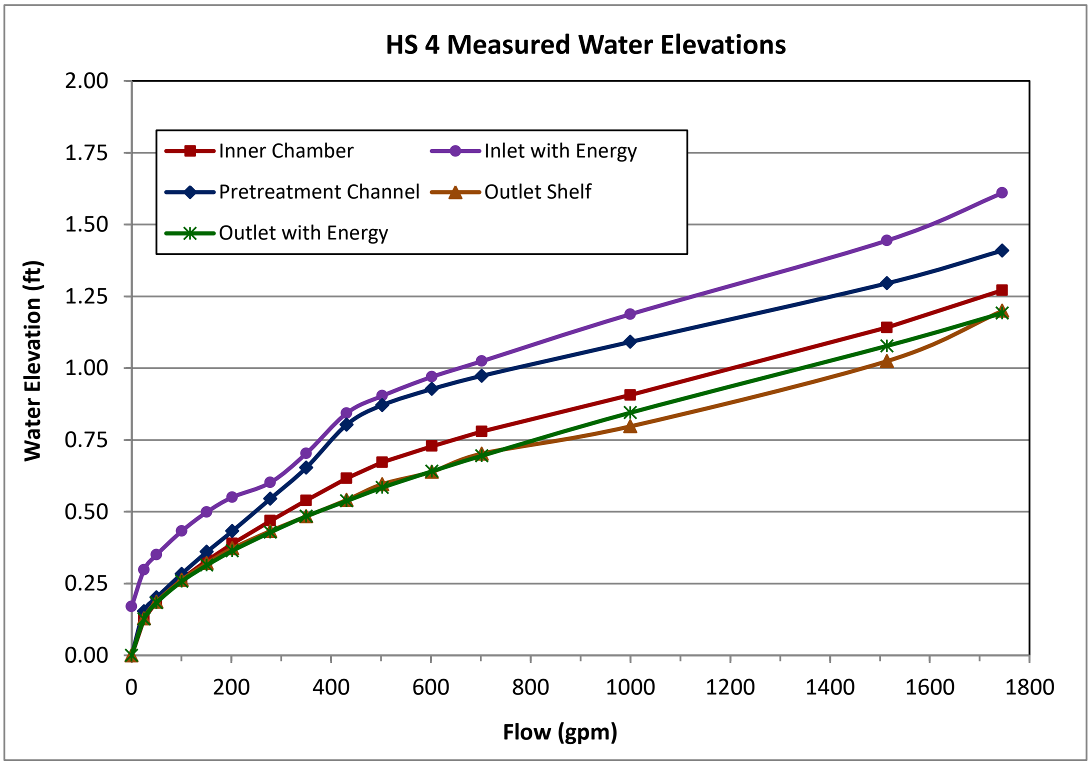

Figure 24 Measured Flow vs Water Elevations

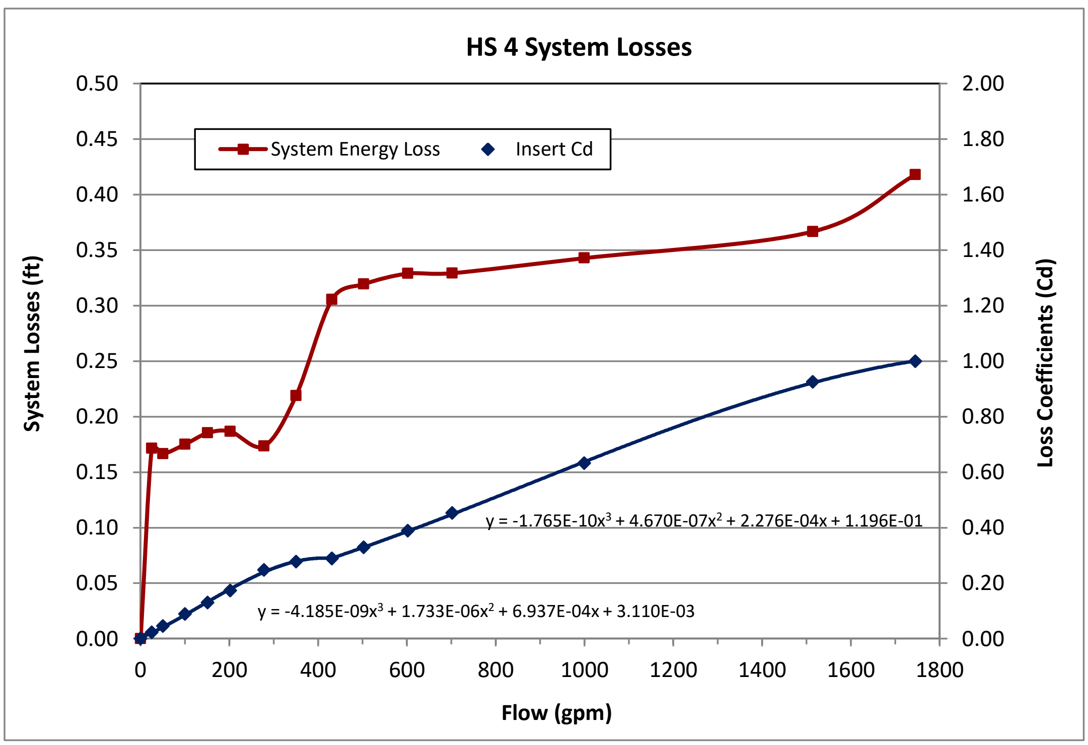

Figure 25 Calculated Losses and Insert Outlet Cd

5. Design Limitations

Hydroworks has been designing separators for site specific applications for over 15 years. Site constraints and design requirements are addressed on a project specific basis. Sizing calculations are performed based on site specific criteria and submittals are provided upon request. Hydraulic assessments including hydraulic gradeline calculations, and buoyancy calculations are provided as part of the design as required.

Required Soil Characteristics

The Hydroworks HS is delivered to the job site as a complete pre-assembled unit housed in a concrete structure. The hydrodynamic separator can be modified to account for most soil conditions (bearing capacity, chemistry, contamination) through changes in footprint, materials and coatings.

Pipe Slope

The Hydroworks HS can be designed as an inlet structure and as a drainage structure with horizontal inlet pipes. Typical pipe slopes range from 0.2% (scour velocity) to 5 % and the use of the HS is acceptable without alteration for these slopes. Higher pipe slopes should be reviewed for hydraulics since the higher velocities will trigger greater headloss and the flow rate for bypass needs to be reviewed to determine if the height of the weirs needs to be modified for site specific conditions.

Invert to Grade

The depth of pipe burial (invert to grade) needs to be reviewed to ensure proper pipe cover for traffic loading and frost requirements as well as constructability/conflicts with minimum product dimensions (thickness of top cap/height of frame and cover). Most design conditions can be accommodated through site specific design changes (ex. Embedding frame and cover in the top cap).

Maximum Flow Rate

Maximum treatment flow rate is dependent on model size. The Hydroworks HS will be sized in New Jersey based upon the NJCAT tested hydraulic loading rate of 31.4 gallons per minute per square foot of settling surface area. Section 6 includes details pertaining to inspection and maintenance of the Hydroworks HS.

Maintenance Requirements

Requirements pertaining to maintenance of the Hydroworks HS will vary depending on pollutant loading and individual site conditions. It is recommended that the system be inspected at least twice during the first year to determine loading conditions for each site. These first-year inspections can be used to establish inspection and maintenance frequency for subsequent years. A maintenance manual is available for download from the Hydroworks website.

Ensuring Proper Installation

All components are pre-installed at the manufacturing plant prior to delivery so installing the separator is the same as installing a standard drainage structure. The inlet and outlet are clearly marked on the precast, so the contractor can properly orient the structure. The contractor is provided with drawings that show the orientation of the cap, inlet and outlet pipes orientation and size, rim and invert elevations, the number of concrete pieces, and heaviest picks. Match lines are provided on the precast pieces to ensure the top cap is properly oriented for maintenance access. The cast iron cap is provided with the structure and is embossed with "Hydroworks" to ensure the structure is easily located for maintenance.

Configurations

The Hydroworks HS separator is available in various configurations. The units can be installed online or offline. The HydroStorm separator has an internal bypass which allows for it to be installed online without the need for any external high flow diversion structure. The Hydroworks HS separator can accept multiple inlet pipes without any modification to the system.

Structural Load Limitations

The Hydroworks HS is housed in a pre-cast concrete structure. All structures are designed for traffic loading based on the standard AASHTO H20 design standard. Installations requiring heavier loading (airports) or non-traffic bearing locations can be accommodated based on a site-specific design by including more or less structural steel and/or greater or less concrete thickness.

Pre-treatment Requirements

The Hydroworks HS has no pre-treatment requirements.

Tailwater Considerations

Site specific tailwater conditions must be assessed on each individual project. Tailwater conditions increase the amount of driving head required for system operation reducing the treatment flow rate prior to bypass if not considered during the design stage. Tailwater conditions need only be considered if they occur frequently enough to affect the long-term performance of the separator (i.e. daily (tidal) or weekly). Hydroworks relies on the engineer of record to provide tailwater information during the design process to determine whether any modifications to the design of the separator are required. Modifications would include changing the weir heights to counteract the reduction in driving head created by the tailwater elevation. Modifications to the weir heights for tailwater conditions must be considered in the context of allowable headloss in the drainage system.

Allowable Headloss

Headloss for the HydroStorm separator is a function of flow velocity in the piping system and the geometry of the internal separator components. The sensitivity of a drainage system to headloss and upstream flooding is site-specific based on downstream tailwater elevations, and the design of the drainage system itself. The introduction of any structure to a drainage system will increase the headloss and hydraulic gradeline. Hydroworks can provide calculations to determine the headloss through the HydroStorm separator based on the hydraulic tests performed at Alden Labs. The engineer of record can determine if the calculated headloss is acceptable for the drainage system in question.

Depth to Seasonal High-Water Table

High groundwater conditions will not affect the operation of the Hydroworks HS. Although the drainage system is intended to be a sealed system and the water table is typically reduced to the level of drainage pipes since water infiltrates the storm network and/or flows through pipe bedding. However, some agencies require buoyancy calculations based on an empty vessel with the water table at the surface. The base of the concrete structure is made with an extension in these cases to satisfy this condition.

6. Maintenance

Routine inspection and maintenance of the Hydroworks HS ensures optimal performance. Stormwater regulations require that all BMPs be inspected and maintained to ensure they are operating as designed to allow for effective pollutant removal and provide protection to receiving water bodies. The frequency of inspection and maintenance depends on numerus factors including land use, average daily traffic, nearby construction activities, on-site material storage, site spill potential, winter sanding activities, and how the separator was sized with respect to annual TSS removal, size of TSS and required sediment storage.

Typically, drainage structures are installed during the early stages of construction. Even if they are not installed to provide sediment and erosion control they will provide this function if installed prior to stabilization of the site. Therefore, it is recommended that the separator be cleaned at the end of the construction period. The Hydroworks HS should be inspected once during the first year of operation for stabilized sites and twice for hot spot installations. Hot spots include:

- High spill potential
- On-site material storage
- Nearby construction or unstabilized site conditions
- High average daily traffic (> 500 vehicles/day)

The inspection and maintenance period can be lengthened or shortened based on the results from the first, and subsequent inspections.

Procedures for inspection, as well as a checklist, are provided in the HydroStorm O&M Manual at: www.hydroworks.com\hydrostormo&m.pdf. Hydroworks recommends the use of a coring tube (Core Pro; Sludge Judge) to determine depths of oil and sediment in the unit. Sediment collected in the separator has a high-water content and can be fine. It is difficult to measure sediment depths in these circumstances with rods or measuring sticks. A coring tube provides the best way to measure sediment depth in a separator.

Depths are provided in the maintenance manual as well as the verification appendix for sediment depths prior to maintenance. Increasing the depth of the structure will also increase the depth for sediment accumulation prior to maintenance, and therefore, needs to be considered for any site-specific application.

The Hydroworks HydroStorm separator should be cleaned using a vacuum truck.

7. Statements

The following signed statements from the manufacturer (Hydroworks, LLC), independent testing laboratory (Alden Research Laboratory) and NJCAT are required to complete the NJCAT 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.

Hydroworks

January 26, 2018

New Jersey Corporation for Advanced Technology
Stevens Institute of Technology
Castle Point on Hudson
Hoboken, NJ 07030

Attention: **Mr. Richard Magee, Sc.D., P.E., BCEE**

Subject: **HydroStorm Verification Report**

Dear Mr. Magee,

We certify that the Hydroworks HydroStorm hydrodynamic separator was tested in strict adherence to the New Jersey Department of Environmental Protection Laboratory Protocol to Assess The Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device (NJDEP HDS Protocol, January 2013).

We certify that all requirements and criteria were met or exceeded during testing of the HydroStorm hydrodynamic separator.

Please do not hesitate to contact us if you have any questions regarding this letter.

Sincerely,

HYDROWORKS LLC,

Graham Bryant, M.Sc., P.Eng.
President

Hydroworks, LLC
136 Central Ave.
Clark NJ 07066

February 12, 2018

Dr. Richard Magee, P.E., BCEE
Executive Director
New Jersey Corporation for Advanced Technology
Center for Environmental Systems
Stevens Institute of Technology
One Castle Point
Hoboken, NJ 07030

Conflict of Interest Statement

Alden Research Laboratory (ALDEN) is a non-biased independent testing entity which receives compensation for testing services rendered. ALDEN does not have any vested interest in the products it tests or their affiliated companies. There is no financial, personal or professional conflict of interest between ALDEN and Hydroworks, LLC.

Protocol Compliance Statement

Alden performed design research testing, as well as verification testing on the Hydroworks HydroStorm 4 (HS 4) separator. All data collected on the selected final design was submitted, including two test runs (50% and 100% MTFR) where the background concentration exceeded the allowable concentration, as discussed in the report. The Technical Report and all required supporting documentation has been submitted as required by the protocol.

Testing performed by ALDEN on the Hydroworks HydroStorm HS 4 unit met or exceeded the requirements as stated in the "New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device", (January 25, 2013), with the following exception:

The reported 25% MTFR test flow was higher than the +10% allowance as per the protocol. However, the higher test flow also results in a higher treatment velocity, which is conservative for removal of sediment particles.

James T. Mailloux

James T. Mailloux

Senior Engineer
Alden Research Laboratory
jmailloux@aldenlab.com

(508) 829-6000 x6446

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

January 25, 2018

Jim Murphy, Chief
NJDEP
Bureau of Non-Point Pollution Control
Division of Water Quality
Mail Code 401-02B, PO Box 420
Trenton, NJ 08625-0420

Dear Mr. Murphy,

Based on my review, evaluation and assessment of the testing conducted on the Hydroworks HydroStorm (Model HS 4) hydrodynamic separator at the Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts, under the direct supervision of Alden's senior stormwater engineer, James Mailloux, 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 (January 25, 2013)"* (NJDEP HDS Protocol) were met or exceeded. Specifically

Test Sediment Feed

The mean PSD of the test sediments comply with the PSD criteria established by the NJDEP HDS protocol. The removal efficiency test sediment PSD analysis was plotted against the NJDEP removal efficiency test PSD specification. The test sediment was shown to be slightly finer than the sediment blend specified by the protocol (<75µ); the test sediment d_{50} was 67 microns. The scour test sediment PSD analysis was plotted against the NJDEP scour test PSD specification and shown to meet the protocol specifications.

Removal Efficiency Testing

In accordance with the NJDEP HDS Protocol, removal efficiency testing was executed on the HydroStorm (HS 4), a 4-ft. diameter commercially available unit, to establish the ability of the HydroStorm to remove the specified test sediment at 25%, 50%, 75%, 100% and 125% of the target MTFR. The HS 4 demonstrated 50.1% annualized weighted solids removal as defined in the NJDEP HDS Protocol. The flow rates, feed rates and influent concentration 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 (maximum of 8.9 mg/L).

Scour Testing

To demonstrate the ability of the HydroStorm to be used as an online treatment device, scour testing was conducted at 228% of the MTFR which exceeds the 200% MTFR required by the NJDEP HDS Protocol. The scour test was conducted with the 50% capacity (6") false floor installed. An additional 4" of the 50-1000-micron test sediment was preloaded on top of the false floor, resulting in the unit being preloaded to the 83% storage capacity of 10".

The average flow rate during the online scour test was 2.01 cfs (903 gpm), which represents 228% of the MTFR (MTFR = 0.88 cfs). Background concentrations were <3.1 mg/L throughout the scour testing, which complies with the 20 mg/L maximum background concentration specified by the test protocol. Unadjusted effluent concentrations ranged from 10.9 mg/L to 30.3 mg/L, with an average concentration of 16.8 mg/L. When adjusted for background concentrations, the average effluent concentration was 14.6 mg/L. These results confirm that the HS 4 did not scour at 200% MTFR and meets the criteria for online use.

Maintenance Frequency

The predicted maintenance frequency for all HydroStorm models is 50 months.

Sincerely,

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

8. References

ASME (1971), *"Fluid Meters Their Theory and Application- Sixth Edition".*

ASTM (2007), *"Standard Test Method for Particle Size Analysis of Soils"*, Annual Book of ASTM Standards, D422-63, Vol. 04.08.

ASTM (2007), *"Standard Test Methods for Determination of Water (Moisture) Content of Soil by Direct Heating"*, Annual Book of ASTM Standards, D4959-07, Vol. 04.08.

ASTM (2013), *"Standard Test Methods for Determining Sediment Concentration in Water Samples",* Annual Book of ASTM Standards, D3977-97, Vol. 11.02.

NJDEP 2013a. *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, 2013.

NJDEP 2013b. *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, 2013.

VERIFICATION APPENDIX

Introduction

- Manufacturer – Hydroworks, LLC. National Headquarters 136 Central Ave, 2nd FL, Clark, NJ 07066. www.hydroworks.com (888)-290-7900
- Hydroworks HydroStorm verified models are shown in **Table A-1** and **Table A-2**.
- TSS Removal Rate – 50%
- Online installation

Detailed Specification

- NJDEP sizing tables and physical dimensions of the Hydroworks HydroStorm verified models are attached (**Table A-1** and **Table A-2**).
- New Jersey requires that the peak flow rate of the NJWQ Design Storm event of 1.25 inch in 2 hours shall be used to determine the appropriate size for the MTD. The HS 4 model has a maximum treatment flow rate (MTFR) of 0.88 cfs (395 gpm), which corresponds to a surface loading rate of 31.4 gpm/ft^2 of sedimentation area.
- Maximum recommended sediment depth prior to cleanout is 6 inches for all model sizes based on the depths provided in **Table A-2**. Hydroworks can increase the overall depth of any model to increase the sediment storage depth for any site-specific storage/maintenance criteria.
- Operations and Maintenance Guide is at: www.hydroworks.com\hydrostormo&m.pdf
- The maintenance frequency for all the HydroStorm models is 4.2 years (50 months).
- Under N.J.A.C. 7:8-5.5, NJDEP stormwater design requirements do not allow a hydrodynamic separator such as the HydroStorm to be used in series with another hydrodynamic separator to achieve an enhanced TSS removal rate.

Table A-1 MTFRs and Sediment Removal Intervals for HydroStorm Models

Model	Diameter (ft)	Maximum Treatment Flow Rate[1] (cfs)	Treatment Area (ft^2)	Hydraulic Loading Rate (gpm/ft^2)	50% Maximum Sediment Storage[3] (ft^3)	Sediment Removal Interval[2] (years)
HS 3	3	0.50	7.1	31.4	3.6	4.2
HS 4	4	0.88	12.6	31.4	6.3	4.2
HS 5	5	1.37	19.6	31.4	9.8	4.2
HS 6	6	1.98	28.3	31.4	14.2	4.2
HS 7	7	2.69	38.5	31.4	19.3	4.2
HS 8	8	3.52	50.3	31.4	25.2	4.2
HS 9	9	4.45	63.6	31.4	31.8	4.2
HS 10	10	5.49	78.5	31.4	39.3	4.2
HS 11	11	6.65	95.0	31.4	47.5	4.2
HS 12	12	7.91	113.0	31.4	56.5	4.2

1. Based on a verified loading rate of 31.4 gpm/ft^2 for test sediment with a mean particle size of 67 µm and an annualized weighted TSS removal of at least 50% using the methodology in the current NJDEP HDS protocol.
2. Sediment Removal Interval (years) = (50% HDS MTD Max Sediment Storage Volume) / (3.366 * MTFR * TSS Removal Efficiency) calculated using equation in Appendix B, Part B of the NJDEP HDS Protocol.
3. 50% Sediment Storage Capacity is equal to manhole area x 6 inches of sediment depth. Each HydroStorm separator has a 12-inch-deep sediment sump.

Table A-2 Standard Dimensions for HydroStorm Models

Model	Diameter (ft)	Maximum Treatment Flow Rate (cfs)	Total Chamber Depth (ft)	Treatment Chamber Depth[1] (ft)	Aspect Ratio[2] (Depth/Diameter)	Sediment Sump Depth (ft)
HS 3	3	0.50	3	2.5	0.83	0.5
HS 4	4	0.88	4	3.5	0.88	0.5
HS 5	5	1.37	4	3.5	0.70	0.5
HS 6	6	1.98	4	3.5	0.58	0.5
HS 7	7	2.69	6	5.5	0.79	0.5
HS 8	8	3.52	7	6.5	0.81	0.5
HS 9	9	4.45	7.5	7	0.78	0.5
HS 10	10	5.49	8	7.5	0.75	0.5
HS 11	11	6.65	9	8.5	0.77	0.5
HS 12	12	7.91	9.5	9	0.75	0.5

1. Treatment chamber depth is defined as the total chamber depth minus ½ the sediment storage depth.
   The aspect ratio is the unit's treatment chamber depth/diameter. The aspect ratio for the tested unit (HS 4) is 0.875. Larger models (>250% MTFR of the unit tested, >2.2 cfs) must be geometrically proportionate to the test unit. A variance of 15% is allowable (0.74 to 1.00).
2. For units <250% MTFR (5 and 6 ft models), the depth must be equal or greater than the depth of the unit treated.