NJCAT TECHNOLOGY VERIFICATION

Removal Efficiency of Suspended Sediment with a Median Particle Size of 110 microns

Cascade Separator™
Contech Engineered Solutions, LLC

November 2019

(Amended Table A-1 August 2020)

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In September 2019, the Cascade Separator™ received New Jersey Corporation for Advanced Technology (NJCAT) verification for testing completed under the New Jersey Department of Environmental Protection (NJDEP) Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device (NJDEP Protocol) dated January 25, 2013. The Cascade Separator met the NJDEP Protocol requirements by demonstrating 50% weighted TSS removal with a target median particle size (D_{50}) of 75 µm at a target inlet sediment concentration of 200 mg/L.

Many jurisdictions in the United States are interested in data demonstrating solids removal for coarser particle sizes than that tested for NJDEP certification. A common standard used to evaluate and size hydrodynamic separators in other parts of North America is to utilize a sediment gradation with a D_{50} of 110 µm. The objective of this additional laboratory evaluation was to determine the total suspended solids (TSS) removal by the Cascade over a range of operating rates using a sediment gradation with a median particle size (D_{50}) of 110 µm at a target inlet sediment concentration of 280 mg/L. **The results of the study were submitted to NJCAT for verification, but the testing procedure falls outside of the NJDEP Protocol and process and therefore was not submitted to NJDEP for certification.**

2. DESCRIPTION OF TECHNOLOGY

The Cascade Separator is a manufactured treatment device (MTD) designed to protect waterways from stormwater runoff. The hydrodynamic separator device separates and traps trash, debris and sediment, even at high flow rates, and provides easy access for maintenance. The Cascade Separator is commonly used as a standalone stormwater quality control practice and as pretreatment for filtration, detention/infiltration, bioretention, rainwater harvesting systems and Low Impact Development designs.

The Cascade Separator (**Figure 1**) accepts flow through an inlet. Water enters the inlet chamber where a specially designed insert splits the flow into two flumes, creating vortices that rotate in opposite directions in the center chamber. This creates high and low velocity regions in the center chamber that facilitates the settling of particles. As water travels downward through the center chamber, sediment settles into the sump area where it is retained until maintenance is performed. The slanted skirt provides scour protection during peak events and its incline facilitates sediment transport into the sump. Treated stormwater moves upwards, leaves the center cylinder through the outlet window and travels through the outlet channel before exiting the system. Refer to the black flow arrows in **Figure 2** for the treatment flow path. The outlet deck incorporates two pipes that extend downward and allow the system to drain to the outlet pipe invert elevation after the storm event has subsided, while also preventing captured floating materials from leaving the system. The green arrows in **Figure 2** show the flow path through these components.

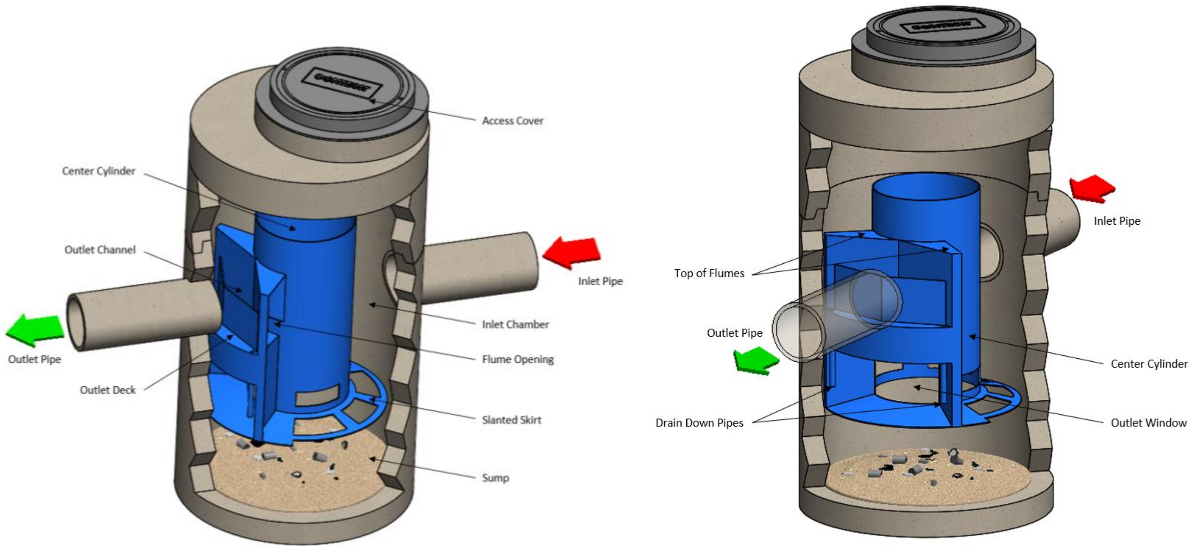


Figure 1: Model of the Cascade Separator

The Cascade Separator is designed to handle high flow rates without scouring previously captured pollutants. Each model is designed to allow a maximum flow rate through the treatment chambers and has an internal flow bypass for storm events that exceed the specific flow rate. While in internal bypass, the unit continues to treat the stormwater that enters the flumes while the excess flow passes over the flumes and exits the system untreated. This internal bypass feature allows the Cascade Separator to be installed online, therefore eliminating the need for additional bypass structures. The red arrows in **Figure 2** show how excess flow is bypassed over the flumes.

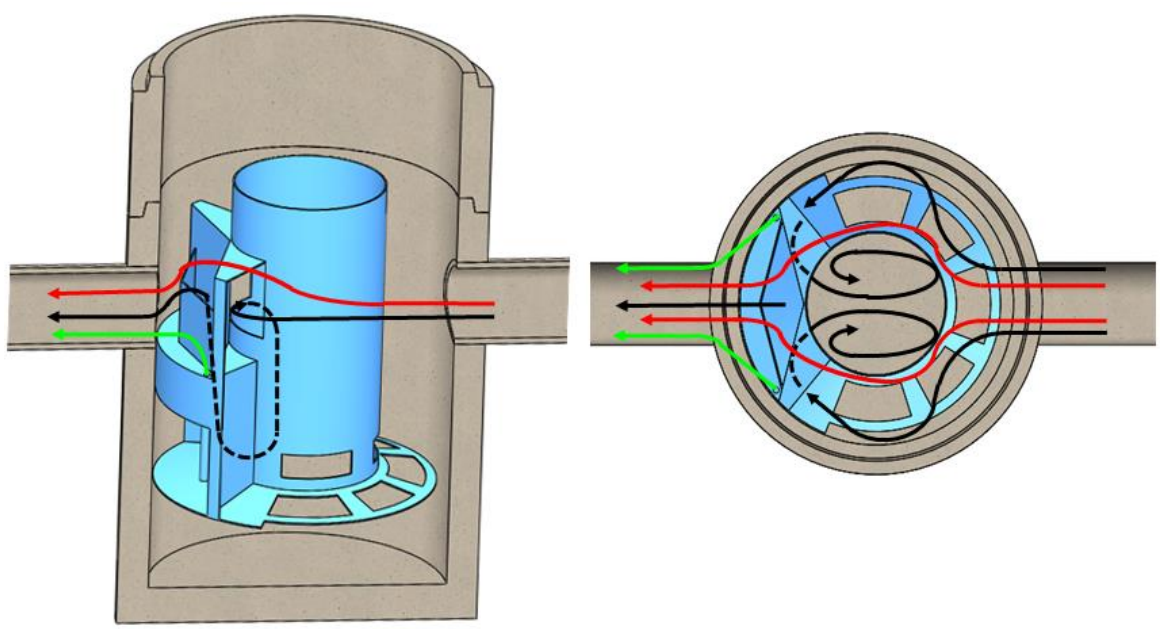


Figure 2: Cascade Separator Flow Paths

3. Laboratory Testing

All removal efficiency testing for this project was carried out at Contech's Portland, Oregon laboratory in April and May 2019. Independent third-party oversight was provided by Scott Wells, Ph.D. and his associate Chris Berger, Ph.D. Dr. Scott Wells and Dr. Chris Berger, from Portland State University, have extensive backgrounds in water quality including direct experience with the laboratory evaluation of stormwater MTDs. Dr. Scott Wells and Dr. Chris Berger have no conflict of interest that would disqualify them from serving as independent third-party observers during this testing process.

Test sediment samples for particle size distribution (PSD) analysis were processed in-house, under third-party observation according to ASTM D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. Test sediment samples for moisture content were processed in-house, under third-party observation according to ASTM D2216-2019 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. TSS samples were processed in-house, under third-party observation according to ASTM D3977-97(2013) Standard Test Methods for Determining Sediment Concentration in Water Samples.

3.1. Test Unit

Laboratory testing was completed on a full-scale, dimensionally accurate 4 ft diameter Cascade Separator (CS-4) lab model, whose components and material are comparable to the commercially available product (**Figure 3**). The Cascade Separator was housed in a 4 ft diameter aluminum manhole with aluminum influent and effluent pipes, with the same inside diameter (ID) as a 24 in. PVC pipe (22.5 in. ID). The CS-4 has a depth of 48 in. from housing floor to effluent pipe invert. The CS-4 outlet channel height is 10.5 in. above the outlet pipe invert. The effective treatment area is 12.6 ft^2 and the maximum sediment storage capacity is 18.8 ft^3, or a depth of 18 in. above the floor. Removal efficiency was conducted at 50% of the maximum sediment storage depth. To accomplish this, an aluminum false floor was installed at 50% of the sediment storage depth, or 39 in. below the outlet pipe invert. The CS-4 permanent pool volume is 40.8 ft^3 from 50% sediment storage depth to outlet pipe invert. For this testing, the approximate full operation volume of 58.6 ft^3 (50% sediment storage depth to internal bypass elevation, 56 in. height) will be used to calculate the detention time as it is more conservative.

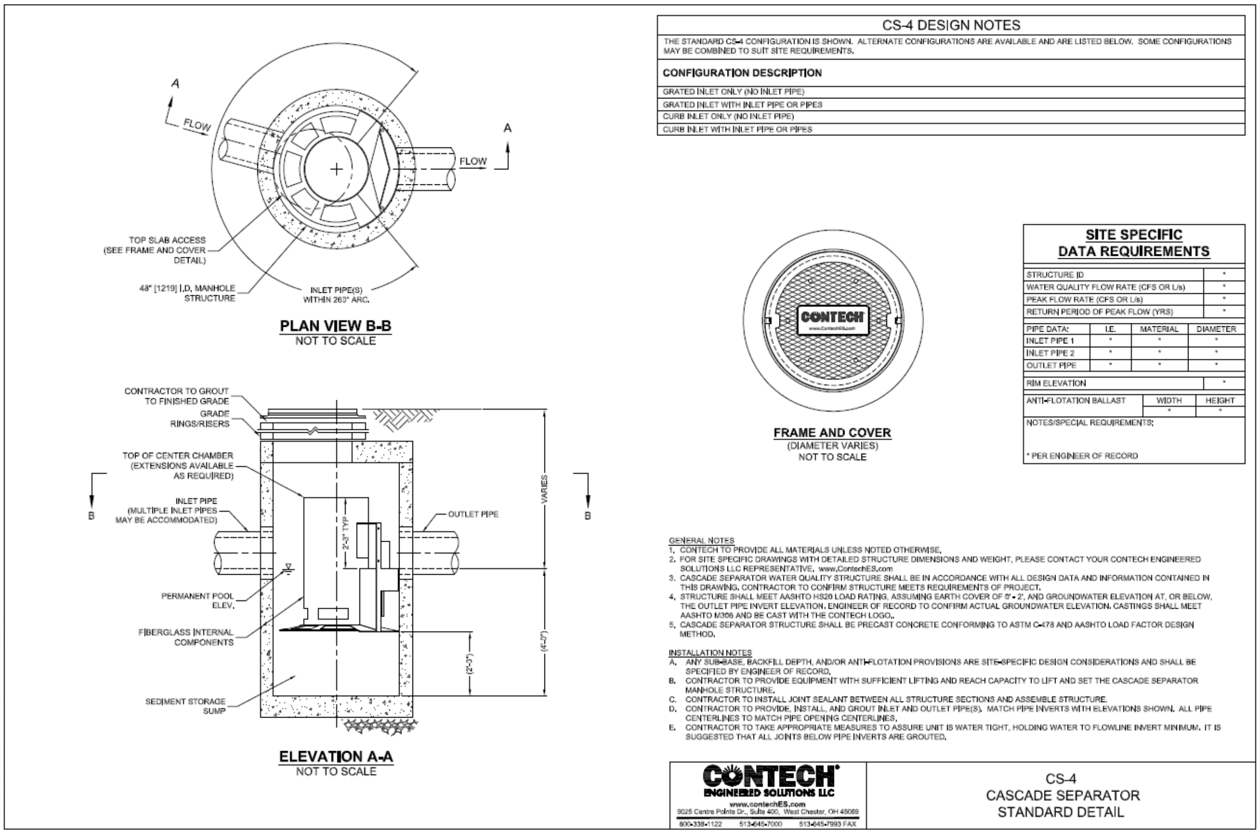


Figure 3: Cascade Separator Standard Detail

3.2. TEST SYSTEM

The Cascade Separator was tested on a recirculating laboratory system capable of delivering flow rates up to 5 cfs (**Figure 4**). During removal efficiency tests, clean water was drawn from a 3,500-gal influent tank using a 15 HP, Berkeley B6ZPLS centrifugal pump (Pump 1). Closed loop flow-control was maintained with a proportional-integral-derivative controlled variable frequency drive (VFD). The feedback signal to the VFD was provided from a Seametrics IMAG 4700 8 in. flowmeter. All flow from Pump 1 to the test unit was measured by the flowmeter (+/- 1.0% of reading) and logged at 5 sec intervals. Influent flow traveled through an inlet junction and into the influent pipe where background TSS samples were taken from a ¾ in. PVC pipe sampling port at the bottom of the influent pipe, upstream of the sediment injection point (**Figure 5**). Influent water was then dosed with sediment at the crown of the pipe from an Auger Feeders VF2 volumetric sediment feeder, located 112.5 in. upstream of the test unit (**Figure 6**). Influent water entered the manhole housing, was treated by the Cascade Separator, and exited the unit via the effluent pipe. Water exited the effluent pipe in a free-fall stream, where effluent TSS grab samples were taken by making a single sweeping pass through the cross section of the effluent stream before it entered the 2,350 gal effluent tank (**Figure 7**).

Effluent water traveled through an array of bag filters located inside the effluent tank and was then pumped through cartridge filter housings using a 25 HP Berkeley B5ZPBHS centrifugal pump (Pump 2). To maintain water balance between the isolated influent and effluent tanks, a closed-looped flow-control on Pump 2 was maintained using feedback from a Seametrics IMAG 4700 8 in. flowmeter. The filtered water was discharged into the influent tank for re-use. Flocculants were not used to reduce background TSS at any time.

The test water temperature was maintained using a Coates 32024CPH 24 kW heater, which recirculated influent water. Water temperature was measured in the inlet junction with an Omega HSRTD-3-100-B-80-E resistance temperature detector and logged at 5 sec intervals.

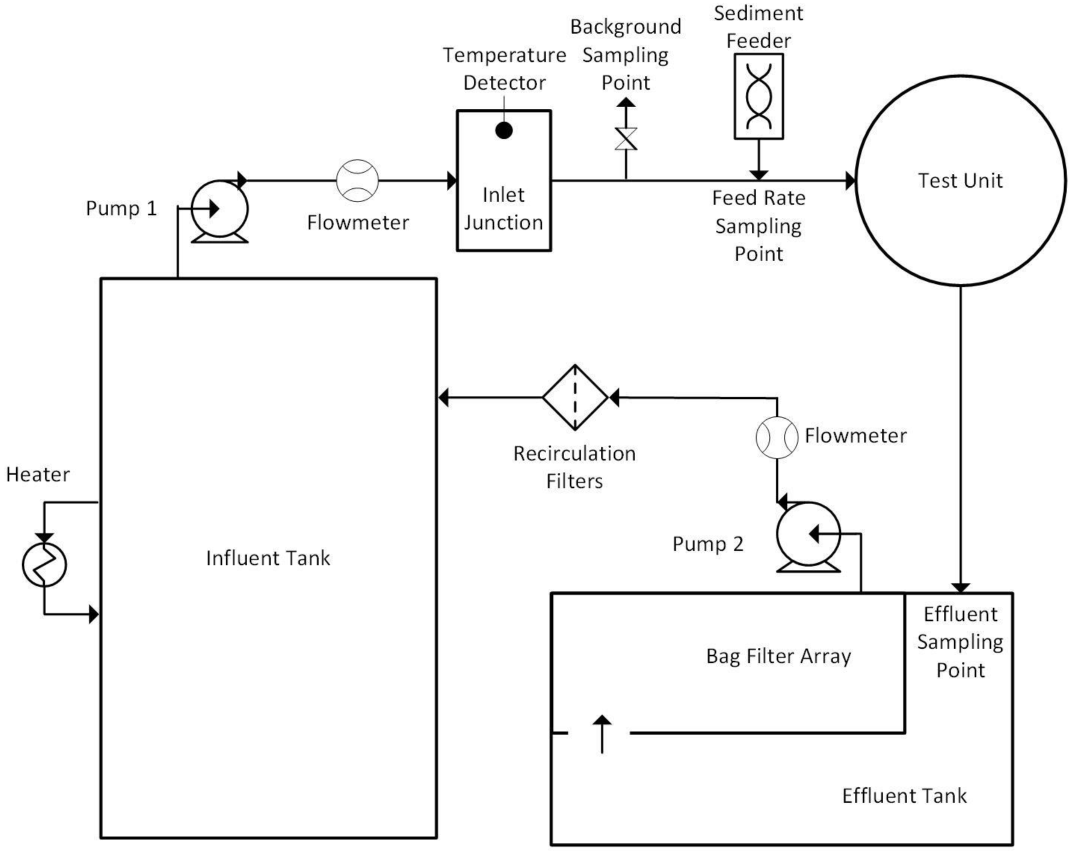


Figure 4: Lab Setup for Removal Efficiency Tests

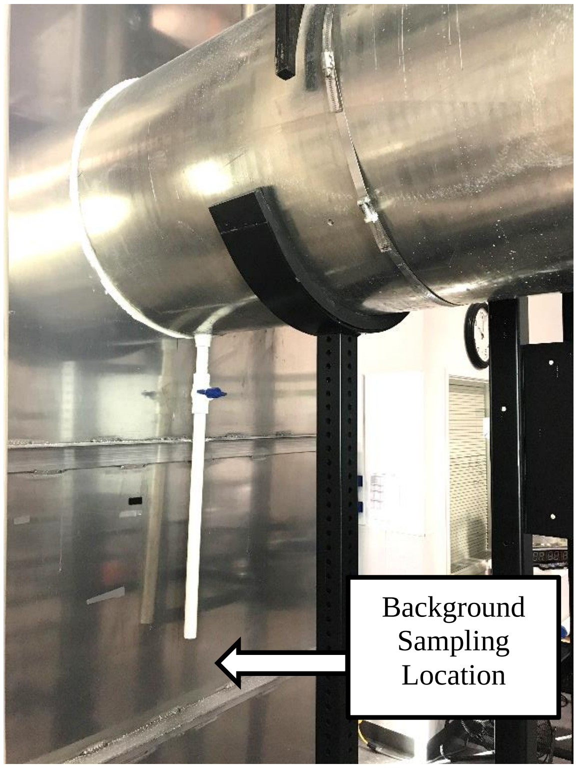


Figure 5: Background Sampling Location

Figure 6: Sediment Injection Location and Feed Rate Sampling Location

Figure 7: Manhole and Effluent Grab Sampling Location

3.3. TEST SEDIMENT

The sediment used for removal efficiency tests was a custom silica blend with a specific gravity of 2.65. The test sediment was blended in-house and used as an alternative to US Silica OK-110 sediment (**Figure 8**), which is no longer produced commercially. The custom sediment had a target D_{50} of 110 µm, with a range of particle sizes from 53 µm to 250 µm. After blending, the test sediment was batched, labeled and stored in covered bins for the duration of this project. Sediment sampling and analysis were conducted in-house, under third party observation. Twelve subsamples, taken from various locations within the test sediment bins were composited. From the composite, three samples were taken for PSD analysis and three samples for moisture content analysis. The average PSD (**Table 2**) derived from the three samples was used to determine compliance with the target PSD (**Figure 8**). The average sediment moisture content was used in feed rate calculations (**Equation 1**) and carried through in influent mass calculations (**Equation 2**).

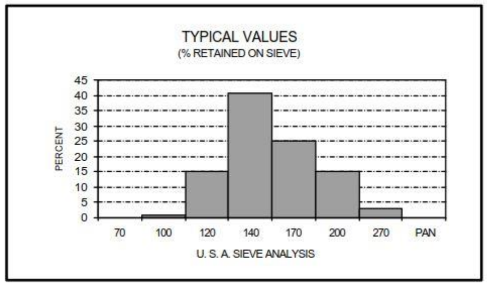
U.S. SILICA
Sands of Time

PRODUCT DATA

OK-110

UNGROUND SILICA

PLANT: MILL CREEK, OKLAHOMA



		TYPICAL VALUES		
USA STD SIEVE SIZE		% RETAINED		% PASSING
MESH	MILLIMETERS	INDIVIDUAL	CUMULATIVE	CUMULATIVE
70	0.212	0.2	0.2	99.8
100	0.150	1.0	1.2	98.8
120	0.125	15.0	16.2	83.8
140	0.106	40.8	57.0	43.0
170	0.088	25.0	82.0	18.0
200	0.075	15.0	97.0	3.0
270	0.053	3.0	100.0	0.0
PAN		0.0	100.0	

Figure 8: US Silica OK-110 Product Data Sheet

3.4. Removal Efficiency Testing Procedure

Three separate, continuous removal efficiency tests were performed over a range of hydraulic loading rates. The three resulting removal efficiency values at each hydraulic loading rate were plotted with a curve fit applied.

Each continuous test started with the highest target flow rate and continued with flow rates decreasing incrementally through the target values: 1.50 cfs, 1.20 cfs, 0.90 cfs, 0.60 cfs and 0.30 cfs. During each continuous test, each flow rate trial commenced once the feed rate was set and the flow rate was stabilized at the target rate for a minimum of three detention times. A sediment feed rate sample was taken at the beginning of each flow rate trial and a minimum of three detention times passed before the six effluent samples and six paired background samples were taken. After all effluent and background samples were collected, the second feed rate sample was taken. Each flow rate trial ended following the second feed rate sample. The flow rate and corresponding feed rate were then re-adjusted and allowed to stabilize before starting the next flow rate trial. Testing continued in this manner until the full set of flow rates were evaluated. The sampling procedure was the same for all flow rate trials, but the sample spacing and trial duration varied to accommodate differences in detention time (**Table 1**). The system was cleaned prior to each continuous test, but not between the flow rate trials within a test.

Table 1: Continuous Test Sampling Plan

Time (mm:ss)	Sample		
START OF CONTINUOUS TEST			
Stabilize flow for minimum duration of 01:57			
00:00	START 1.5 CFS TRIAL		
00:00	FEED 1		
03:00		EFF 1	BACK 1
03:30		EFF 2	BACK 2
04:00		EFF 3	BACK 3
04:30		EFF 4	BACK 4
05:00		EFF 5	BACK 5
05:30		EFF 6	BACK 6
05:30	FEED 2		
06:30	STOP 1.5 CFS TRIAL		
Stabilize flow for minimum duration of 02:27			
00:00	START 1.2 CFS TRIAL		
00:00	FEED 1		
03:30		EFF 1	BACK 1
04:00		EFF 2	BACK 2
04:30		EFF 3	BACK 3
05:00		EFF 4	BACK 4
05:30		EFF 5	BACK 5
06:00		EFF 6	BACK 6
06:00	FEED 2		
07:00	STOP 1.2 CFS TRIAL		
Stabilize flow for minimum duration of 03:15			
00:00	START 0.9 CFS TRIAL		
00:00	FEED 1		
04:30		EFF 1	BACK 1
05:00		EFF 2	BACK 2
05:30		EFF 3	BACK 3
06:00		EFF 4	BACK 4
06:30		EFF 5	BACK 5
07:00		EFF 6	BACK 6
07:00	FEED 2		
08:00	STOP 0.9 CFS TRIAL		

Time (mm:ss) *Continued*	Sample *Continued*		
Stabilize flow for minimum duration of 04:53			
00:00	START 0.6 CFS TRIAL		
00:00	FEED 1		
06:00		EFF 1	BACK 1
06:30		EFF 2	BACK 2
07:00		EFF 3	BACK 3
07:30		EFF 4	BACK 4
08:00		EFF 5	BACK 5
08:30		EFF 6	BACK 6
08:30	FEED 2		
09:30	STOP 0.6 CFS TRIAL		
Stabilize flow for minimum duration of 09:46			
00:00	START 0.3 CFS TRIAL		
00:00	FEED 1		
11:00		EFF 1	BACK 1
11:30		EFF 2	BACK 2
12:00		EFF 3	BACK 3
12:30		EFF 4	BACK 4
13:00		EFF 5	BACK 5
13:30		EFF 6	BACK 6
13:30	FEED 2		
14:30	STOP 0.3 CFS TRIAL		
END OF CONTINUOUS TEST			

During all testing the flow rate was held steady at ±10% of the target value with a target coefficient of variation (COV) of less than 0.03. Water temperature remained below 80 °F during all testing.

For each flow trial, sediment was injected at a known rate to produce a target average influent concentration of 280 mg/L (± 10%) with a COV of less than 0.10. Feed rates were determined by sampling the injection stream once at the beginning and once at the end of each flow trial. Samples were collected in clean, 1 L bottles at the injection point (**Figure 6**) for a target duration of 60 s. Sediment sample collection time was measured using a Thomas Scientific 1235026 traceable stopwatch. The samples were weighed to the mg (in-house) using an Ohaus AR3130 calibrated balance and feed rate for each run was calculated using **Equation 1**. Average influent TSS concentration was calculated from the average test feed rate and average flow rate for the flow trial using **Equation 2**.

$$\text{Feed Rate}\left({}^{\text{g}}/_{\text{min}}\right) = \frac{\text{Mass}_{\text{sample+bottle}}(\text{g}) - \text{Mass}_{\text{bottle}}(\text{g})}{\text{Time}_{\text{collection}}(\text{s}) \times \frac{\text{min}}{60\text{ s}}} \times [1 - \text{Sediment Moisure Content}]$$

Equation 1

$$Average\ Influent\ TSS\left({}^{mg}/_{L}\right) = \frac{Average\ Feed\ Rate\left({}^{g}/_{min}\right) \times \frac{1000\ mg}{g}}{Average\ Flow\ Rate\left({}^{gal}/_{min}\right) \times \frac{3.78541\ L}{gal}}$$

Equation 2

Six effluent grab samples were collected at evenly-spaced intervals during each flow rate trial. After the first feed rate sample was collected, effluent sampling began after a minimum of three detention times passed. Each sample volume was a minimum of 0.5 L. Samples were collected in clean, 1 L bottles by sweeping the bottle through the cross-section of the free-discharge effluent stream in a single pass. In the cases where the effluent TSS concentration was non-detect (ND), a value of half the detection limit was substituted. The detection limit is 1.55 mg/L.

Background samples were taken simultaneously with every effluent sample. Each sample was a minimum of 0.5 L in volume and was collected in a clean, 1 L bottle from the background sampling port. Background samples were collected after the sampling port was opened and the line was flushed for 3 sec. In the cases where the background TSS concentration was non-detect (ND), a value of half the detection limit was substituted. Average background concentration did not exceed 20 mg/L during any test. Paired effluent and background TSS concentration measurements were used to calculate an average adjusted effluent TSS value (**Equation 3**).

$$\text{Average Adjusted Effluent TSS}\left({}^{\text{mg}}/_{\text{L}}\right) = \frac{1}{6}\sum_{\text{i}=1}^{6}\left[\text{Effluent TSS}\left({}^{\text{mg}}/_{\text{L}}\right) - \text{Background TSS}\left({}^{\text{mg}}/_{\text{L}}\right)\right]_{\text{i}}$$

Equation 3

Removal efficiency at each flow rate was calculated using **Equation 4**. All removal efficiency values were plotted against the applicable hydraulic loading rate with a linear curve fit applied. The curve fit equation was used to determine the hydraulic loading rate at which 80% removal efficiency and 80% annualized weighted removal efficiency would occur. The New Jersey rainfall weighting factors used for the annualized removal efficiency determination are outlined in Table 1 of Appendix A, Section A in the NJDEP Protocol.

$$Removal\ Efficiency\ (\%) = \frac{Average\ Influent\ TSS\ \left({}^{mg}/_{L}\right) - Average\ Adjusted\ Effluent\ \left({}^{mg}/_{L}\right)}{Average\ Influent\ TSS\ \left({}^{mg}/_{L}\right)} \times 100$$

Equation 4

4. PERFORMANCE CLAIMS

Some of the following performance claims are specific to the 4 ft Cascade Separator, the model size tested in this study. Additional information for all models is provided in **Table A-1.**

VERIFIED TOTAL SUSPENDED SOLIDS REMOVAL RATE

In general, the 'point on a curve' method to size an MTD for a target removal efficiency of a target particle size is a straightforward approach. The hydraulic loading rate which achieves the target removal efficiency is determined by interpolating or using a curve fit equation from the hydraulic loading rate v removal efficiency data set, which typically spans a large range of tested flow rates.

The testing performed on the Cascade Separator resulted in a hydraulic loading rate v removal efficiency curve fit equation on a data set spanning from 0.31 to 1.51 cfs. Removal efficiencies ranged from 60.3% to 100% respectively. The curve fit equation was used to determine that the hydraulic loading rate of 33.78 gpm/ft^2 of effective treatment area achieved 80% removal efficiency of the target particle size with a D_{50} of 110 µm at the target sediment inlet concentration of 280 mg/L.

VERIFIED ANNUALIZED TOTAL SUSPENDED SOLIDS REMOVAL RATE

Net annual sizing is another method for sizing MTDs for a target removal efficiency of a target particle size. This sizing method predicts MTD performance over a typical rain year by using annual rainfall intensity distributions from long-term records to develop a model. The net annual model will vary based on regional rainfall differences, allowing sizing for specific site needs. The model ties the annual occurrence of rainfall intensities to expected performance by applying weighting factors to the MTD removal efficiencies over a range of hydraulic loading rates. The fractional removal efficiencies are then summed to represent the net annualized removal efficiency of the MTD at the treatment flow rate.

In this laboratory testing, the New Jersey rainfall weighting factors in the NJDEP protocol were applied to the Cascade curve fit equation to determine the hydraulic loading rate at which an annualized weighted removal efficiency of 80% would occur. The Cascade Separator achieved 80% annualized TSS removal of the 110 µm test particle size at a hydraulic loading rate of 52.99 gpm/ft^2.

MAXIMUM SEDIMENT STORAGE DEPTH AND VOLUME

The maximum sediment storage depth is 18 in. on all Cascade Separator models. The CS-4 has a maximum sediment storage volume of 18.8 ft^3.

EFFECTIVE TREATMENT AREA

The effective treatment area, or sedimentation area is 12.6 ft^2 on the CS-4.

DETENTION TIME AND VOLUME

The operational volume of the CS-4 is 58.6 ft^3 from the 50% maximum sediment storage depth to inlet water surface elevation at full treatment capacity. Detention time will vary by flow rate, the detention time for the annualized maximum treatment flow rate (MTFR) of 1.48 cfs (666 gpm) is 39 s.

ONLINE OR OFFLINE INSTALLATION

In September 2019, the Cascade Separator received NJDEP certification qualifying it for online installation for the New Jersey water quality design storm.

5. SUPPORTING DOCUMENTATION

Copies of collected and measured data, spreadsheets containing original data from all performance test runs and particle size analysis, as well as all pertinent calculations have been provided to NJCAT for verification.

5.1. TEST SEDIMENT PSD

The average moisture content of the test sediment was determined to be 0.02%. The average PSD of the test sediment and US Silica standard are presented in **Table 2** and **Figure 9**. For a clear comparison, the percent finer values were interpolated to match the particle diameters listed in the US Silica OK-110 product data sheet (**Figure 8**). The test sediment distribution has a D_{50} particle size of 110 µm.

Table 2: Average Removal Efficiency Test Sediment PSD

Particle Diameter (µm)	Percent Finer by Mass (%)	
	US Silica OK-110 (Typical)	Average Test Sediment
500	-	99.9
212	99.8	99.2
150	98.8	98.2
125	83.8	79.0
106	43.0	41.9
88	18.0	18.6
75	3.0	1.4
53	0.0	0.1
D50	109 µm	110 µm

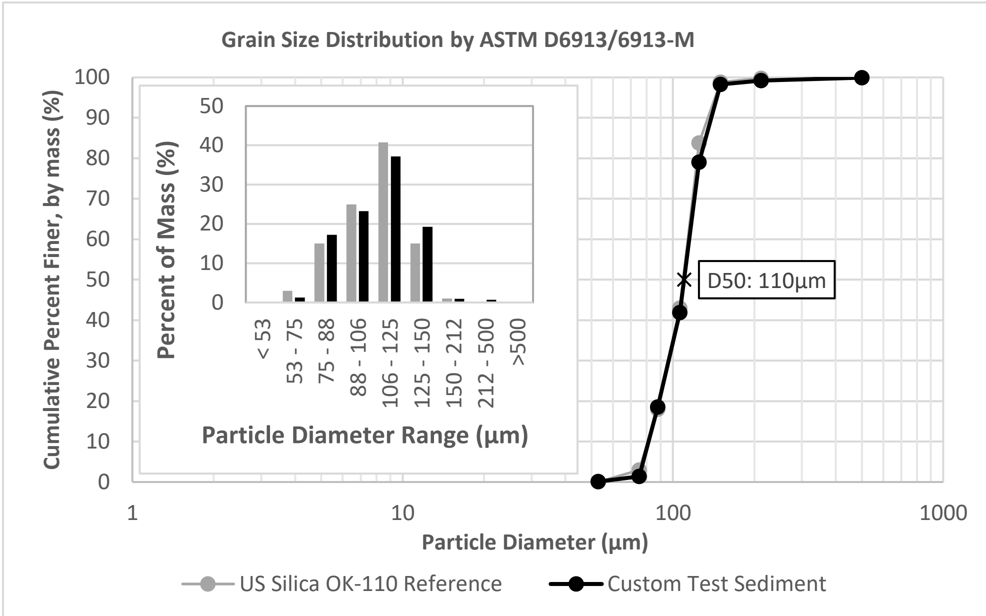


Figure 9: Test Sediment PSD

5.2. Removal Efficiency Test Results

A total of three continuous tests, comprised of five flow rate trials each, were conducted to evaluate TSS removal of a sediment gradation with a D50 of 110 µm. The CS-4 Cascade Separator achieved a TSS removal efficiency of 80% at a flow rate of 0.946 cfs or 424 gpm (33.78 gpm/ft^2) and an annualized weighted removal efficiency of 80% at a flow rate of 1.484 cfs or 666 gpm (52.99 gpm/ft^2). These performance claims were determined from a curve that is based on the verified test data generated in this study. This approach, while not typical of previous NJCAT verifications, is standard engineering practice.

Summary results from all continuous tests are included in **Table 3**, **Table 4** and **Figure 10**. Detailed results including sampling times, sample data and QA/QC results from each test are presented in **Table 5** through **Table 25.**

Table 3: Summary of Removal Efficiency Results

Average Flow Rate (cfs)	Average Hydraulic Loading Rate (gpm/ft^2)	Flow Rate (cfs)	Hydraulic Loading Rate (gpm/ft^2)	Influent TSS (mg/L)	Adjusted Effluent TSS (mg/L)	Removal Efficiency (%)	Average Removal Efficiency (%)
1.51	54.0	1.51	54.0	279	111	60.3	61.2
		1.51	54.0	275	102	62.8	
		1.51	54.0	277	110	60.4	
1.21	43.2	1.21	43.3	275	80.5	70.7	69.9
		1.21	43.2	274	81.1	70.4	
		1.21	43.3	275	86.3	68.7	
0.91	32.5	0.91	32.5	286	53.8	81.2	81.2
		0.91	32.5	281	53.2	81.1	
		0.91	32.5	277	51.5	81.4	
0.61	21.7	0.61	21.7	274	16.6	94.0	94.0
		0.61	21.7	269	14.2	94.7	
		0.61	21.7	268	18.2	93.2	
0.31	11.0	0.31	11.0	262	0.30	99.9	99.9
		0.31	11.0	272	0.28	99.9	
		0.31	11.0	260	0.13	100	

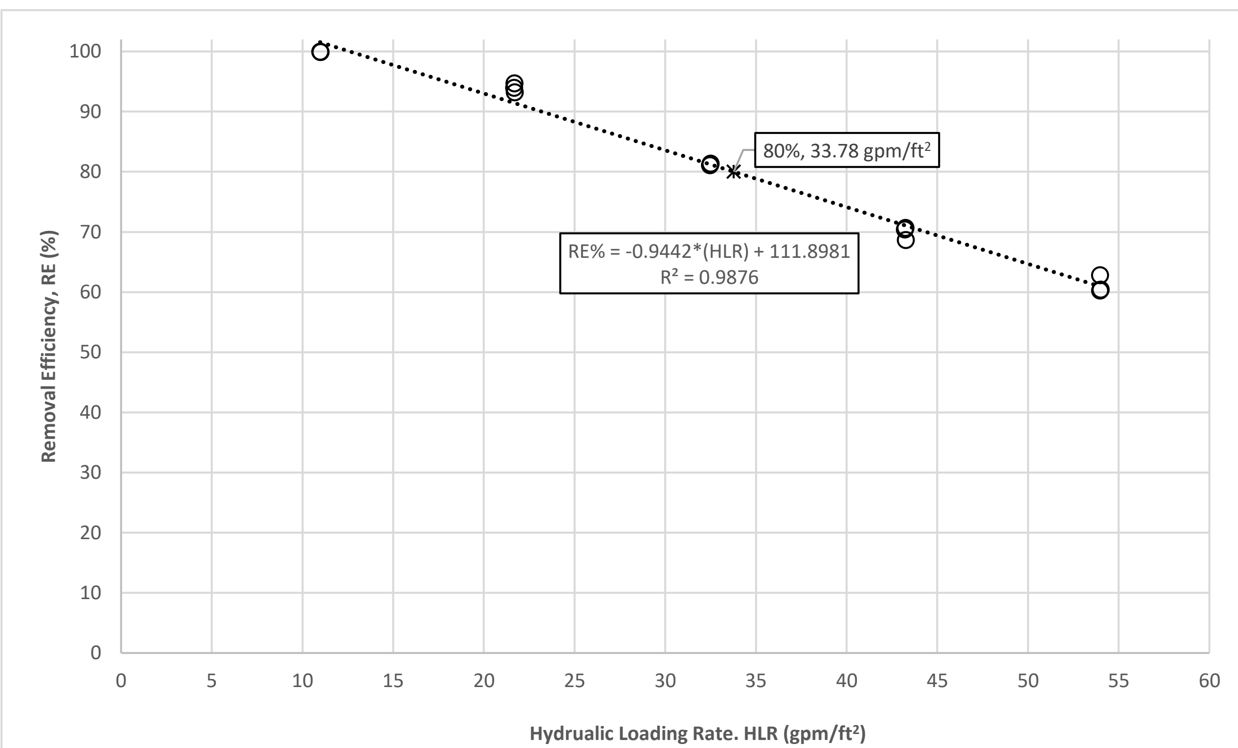


Figure 10: Removal Efficiency Results

Table 4: Annualized Removal Efficiency Results*

Annualized Treatment Hydraulic Loading Rate (gpm/ft^2)	Annualized Treatment Flow Rate for CS-4 (cfs)	Percent of Treatment Flow Rate (%)	Flow Rate (cfs)	Removal Efficiency (%)	Weighting Factor	Weighted Removal Efficiency (%)
52.99	1.48	25	0.37	99.4	0.25	24.8
		50	0.74	86.9	0.30	26.1
		75	1.11	74.4	0.20	14.9
		100	1.48	61.9	0.15	9.3
		125	1.85	49.4	0.10	4.9
Annualized Removal Efficiency at 52.99 gpm/ft^2 (%):						80.0

*Per NJDEP Protocol methodology

TEST 01 RESULTS

The results from Test 01 (T01) are summarized in **Table 5**. Complete sample data for each flow rate trial can be found in **Table 6** through **Table 10**. QA/QC results can be found in **Table 11**. The flow rate COV for trial T01-0.3 (0.05) exceeded the QA/QC limit of 0.03

The slightly higher flow rate variability (**Table 11**) did not appear to impact the removal efficiency result for this flow trial. The removal for T01-0.3 was 99.9%, which is equivalent to the removal efficiencies in the repeat flow rate trials (T02-0.3 at 99.9% and T03-0.3 at 100%). If the data point for this trial was excluded from the linear fit (**Figure 10**), the Cascade CS-4 would still achieve a removal efficiency of 80% at 0.946 cfs. The data point for trial T01-0.3 is considered representative and is included in the data set used for calculations.

Table 5: Test 01 Summary Results

Flow Trial ID	Average Flow Rate (cfs)	Average Hydraulic Loading Rate (gpm/ft^2)	Detention Time (mm:ss)	Sediment Injection Duration (min)	Average Influent TSS (mg/L)	Average Adjusted Effluent TSS Conc. (mg/L)	Removal Efficiency (%)
T01-1.5	1.51	54.0	0:38	4.50	279	111	60.3
T01-1.2	1.21	43.3	0:48	5.00	275	80.5	70.7
T01-0.9	0.91	32.5	1:04	6.00	286	53.8	81.2
T01-0.6	0.61	21.7	1:36	7.50	274	16.6	94.0
T01-0.3	0.31	11.0	3:10	12.50	262	0.30	99.9

Table 6: T01-1.5 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:00	764	ND	0.78
Background 2	3:30	807	ND	0.78
Background 3	4:00	739	ND	0.78
Background 4	4:30	737	ND	0.78
Background 5	5:00	762	ND	0.78
Background 6	5:30	885	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:00	863	97.6	96.8
Effluent 2	3:30	959	108	107
Effluent 3	4:00	987	118	117
Effluent 4	4:30	957	123	122
Effluent 5	5:00	966	108	107
Effluent 6	5:30	997	115	114
			Average	*111*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	717.669	60	717.669	279
Feed Rate 2	5:30	715.508	60	715.508	279
			Average	*716.589*	*279*

Table 7: T01-1.2 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:30	908	ND	0.78
Background 2	4:00	655	ND	0.78
Background 3	4:30	837	ND	0.78
Background 4	5:00	765	ND	0.78
Background 5	5:30	804	ND	0.78
Background 6	6:00	748	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:30	885	84.7	83.9
Effluent 2	4:00	962	83.1	82.3
Effluent 3	4:30	951	77.8	77.1
Effluent 4	5:00	880	81.1	80.3
Effluent 5	5:30	866	89.5	88.7
Effluent 6	6:00	976	71.8	71.0
			Average	*80.5*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	564.704	60	564.704	274
Feed Rate 2	6:00	565.431	60	565.431	275
			Average	*565.068*	*275*

Table 8: T01-0.9 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	4:30	860	ND	0.78
Background 2	5:00	862	ND	0.78
Background 3	5:30	913	ND	0.78
Background 4	6:00	861	ND	0.78
Background 5	6:30	654	ND	0.78
Background 6	7:00	934	ND	0.78
			Average	0.78

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	4:30	929	53.0	52.2
Effluent 2	5:00	922	43.0	42.2
Effluent 3	5:30	973	59.2	58.4
Effluent 4	6:00	932	57.2	56.4
Effluent 5	6:30	955	66.5	65.7
Effluent 6	7:00	860	48.4	47.6
			Average	53.8

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	442.820	60	442.820	287
Feed Rate 2	7:00	440.314	60	440.314	285
			Average	441.567	286

Table 9: T01-0.6 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	6:00	761	ND	0.78
Background 2	6:30	768	ND	0.78
Background 3	7:00	803	ND	0.78
Background 4	7:30	772	ND	0.78
Background 5	8:00	862	ND	0.78
Background 6	8:30	750	ND	0.78
			Average	0.78

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	6:00	788	17.0	16.2
Effluent 2	6:31	882	17.7	16.9
Effluent 3	7:00	954	18.6	17.8
Effluent 4	7:30	932	18.3	17.6
Effluent 5	8:00	890	15.0	14.2
Effluent 6	8:30	966	17.6	16.8
			Average	16.6

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	285.438	60	285.438	277
Feed Rate 2	8:30	280.455	60	280.455	272
			Average	282.947	274

Table 10: T01-0.3 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	11:00	878	ND	0.78
Background 2	11:30	857	ND	0.78
Background 3	12:00	770	ND	0.78
Background 4	12:30	851	ND	0.78
Background 5	13:00	827	ND	0.78
Background 6	13:30	730	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	11:00	895	1.79	1.01
Effluent 2	11:30	969	ND	0.00
Effluent 3	12:00	938	ND	0.00
Effluent 4	12:30	930	ND	0.00
Effluent 5	13:00	836	1.56	0.78
Effluent 6	13:30	902	ND	0.00
			Average	*0.30*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	137.291	60	137.291	262
Feed Rate 2	13:30	136.488	60	136.488	261
			Average	*136.889*	*262*

Table 11: Test 01 QA/QC

FLOW RATE AND WATER TEMPERATURE					
Test ID	QAQC PASS/FAIL	Target Flow Rate (ft^3/s)	Average Flow Rate (ft^3/s) (±10% of Target)	Flow Rate COV (<0.03)	Maximum Water Temperature (°F) (<80 °F)
T01-1.5	PASS	1.50	1.51	0.01	76.5
T01-1.2	PASS	1.20	1.21	0.01	76.4
T01-0.9	PASS	0.90	0.91	0.005	76.3
T01-0.6	PASS	0.60	0.61	0.01	76.2
T01-0.3	PASS*	0.30	0.31	0.05	76.1
INFLUENT AND BACKGROUND CONCENTRATION					
Test ID	QAQC PASS/FAIL	Target Influent TSS (mg/L)	Average Influent TSS (mg/L) (±10% of Target)	Feed Rate COV (<0.1)	Average Background TSS (<20 mg/L)
T01-1.5	PASS	280	279	0.002	0.78
T01-1.2	PASS	280	275	0.001	0.78
T01-0.9	PASS	280	286	0.004	0.78
T01-0.6	PASS	280	274	0.01	0.78
T01-0.3	PASS	280	262	0.004	0.78

*See the paragraphs on page 15 prior to Table 5 for discussion

TEST 02 RESULTS

The results from Test 02 (T02) are summarized in **Table 12**. Complete sample data for each flow rate trial can be found in **Table 13** through **Table 17**. QA/QC results can be found in **Table 18**.

Table 12: Test 02 Summary Results

Flow Trial ID	Average Flow Rate (ft^3/s)	Average Hydraulic Loading Rate (gpm/ft^2)	Detention Time (mm:ss)	Sediment Injection Duration (min)	Average Influent TSS (mg/L)	Average Adjusted Effluent TSS (mg/L)	Removal Efficiency (%)
T02-1.5	1.51	54.0	0:38	4.50	275	102	62.8
T02-1.2	1.21	43.2	0:48	5.00	274	81.1	70.4
T02-0.9	0.91	32.5	1:04	6.00	281	53.2	81.1
T02-0.6	0.61	21.7	1:36	7.50	269	14.2	94.7
T02-0.3	0.31	11.0	3:10	12.50	272	0.28	99.9

Table 13: T02-1.5 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:00	825	ND	0.78
Background 2	3:30	778	ND	0.78
Background 3	4:00	777	ND	0.78
Background 4	4:30	741	ND	0.78
Background 5	5:00	698	ND	0.78
Background 6	5:30	707	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:00	889	102	101
Effluent 2	3:30	966	110	109
Effluent 3	4:00	952	99.0	98.2
Effluent 4	4:30	887	89.8	89.0
Effluent 5	5:00	906	100	99
Effluent 6	5:30	992	118	117
			Average	*102*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	701.788	60	701.788	273
Feed Rate 2	5:30	710.498	60	710.498	277
			Average	*706.143*	*275*

Table 14: T02-1.2 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:30	804	ND	0.78
Background 2	4:00	889	ND	0.78
Background 3	4:30	908	ND	0.78
Background 4	5:00	803	ND	0.78
Background 5	5:30	774	ND	0.78
Background 6	6:00	776	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:30	941	80.5	79.7
Effluent 2	4:00	955	81.2	80.4
Effluent 3	4:30	944	85.4	84.6
Effluent 4	5:00	956	85.0	84.3
Effluent 5	5:30	839	81.0	80.2
Effluent 6	6:00	947	78.2	77.5
			Average	*81.1*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	560.833	60	560.833	273
Feed Rate 2	6:00	566.118	60	566.118	275
			Average	*563.475*	*274*

Table 15: T02-0.9 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	4:30	739	ND	0.78
Background 2	5:00	839	ND	0.78
Background 3	5:30	739	ND	0.78
Background 4	6:00	780	ND	0.78
Background 5	6:30	859	ND	0.78
Background 6	7:00	788	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	4:30	687	63.5	62.7
Effluent 2	5:00	950	55.1	54.3
Effluent 3	5:30	898	54.1	53.3
Effluent 4	6:00	946	55.2	54.4
Effluent 5	6:30	972	50.2	49.5
Effluent 6	7:00	962	45.6	44.8
			Average	*53.2*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	436.119	60	436.119	282
Feed Rate 2	7:00	433.142	60	433.142	280
			Average	*434.630*	*281*

Table 16: T02-0.6 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	6:00	794	ND	0.78
Background 2	6:30	913	ND	0.78
Background 3	7:00	849	ND	0.78
Background 4	7:30	808	ND	0.78
Background 5	8:00	894	ND	0.78
Background 6	8:30	770	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	6:00	895	21.6	20.8
Effluent 2	6:30	851	16.0	15.2
Effluent 3	7:00	954	13.2	12.4
Effluent 4	7:30	962	12.1	11.3
Effluent 5	8:00	953	13.1	12.3
Effluent 6	8:30	966	13.8	13.0
			Average	*14.2*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	276.959	60	276.959	268
Feed Rate 2	8:30	277.038	60	277.038	269
			Average	*276.999*	*269*

Table 17: T02-0.3 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	11:00	906	ND	0.78
Background 2	11:30	871	ND	0.78
Background 3	12:00	836	ND	0.78
Background 4	12:30	823	ND	0.78
Background 5	13:00	772	ND	0.78
Background 6	13:30	833	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	11:00	956	ND	0.00
Effluent 2	11:30	945	1.59	0.81
Effluent 3	12:00	939	ND	0.00
Effluent 4	12:30	932	ND	0.00
Effluent 5	13:00	917	1.64	0.86
Effluent 6	13:30	936	ND	0.00
			Average	*0.28*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	142.224	60	142.224	272.1
Feed Rate 2	13:30	141.984	60	141.984	271.7
			Average	*142.104*	*272*

Table 18: Test 02 QA/QC

FLOW RATE AND WATER TEMPERATURE					
Test ID	QAQC PASS/FAIL	Target Flow Rate (ft^3/s)	Average Flow Rate (ft^3/s) (±10% of Target)	Flow Rate COV (<0.03)	Maximum Water Temperature (°F) (<80 °F)
T02-1.5	PASS	1.50	1.51	0.01	75.9
T02-1.2	PASS	1.20	1.21	0.01	76.0
T02-0.9	PASS	0.90	0.91	0.01	75.9
T02-0.6	PASS	0.60	0.61	0.005	75.9
T02-0.3	PASS	0.30	0.31	0.02	76.0
INFLUENT AND BACKGROUND CONCENTRATION					
Test ID	QAQC PASS/FAIL	Target Influent TSS (mg/L)	Average Influent TSS (mg/L) (±10% of Target)	Feed Rate COV (<0.1)	Average Background TSS (<20 mg/L)
T02-1.5	PASS	280	275	0.01	0.78
T02-1.2	PASS	280	274	0.01	0.78
T02-0.9	PASS	280	281	0.005	0.78
T02-0.6	PASS	280	269	0.0002	0.78
T02-0.3	PASS	280	272	0.001	0.78

Test 03 Results

The results from Test 03 (T03) are summarized in **Table 19**. Complete sample data for each flow rate trial can be found in **Table 20** through **Table 24**. QA/QC results can be found in **Table 25**.

Table 19: Test 03 Summary Results

Flow Trial ID	Average Flow Rate (ft^3/s)	Average Hydraulic Loading Rate (gpm/ft^2)	Detention Time (mm:ss)	Sediment Injection Duration (min)	Average Influent TSS (mg/L)	Average Adjusted Effluent TSS (mg/L)	Removal Efficiency (%)
T03-1.5	1.51	54.0	0:38	4.50	277	110	60.4
T03-1.2	1.21	43.3	0:48	5.00	275	86.3	68.7
T03-0.9	0.91	32.5	1:04	6.00	277	51.5	81.4
T03-0.6	0.61	21.7	1:36	7.50	268	18.2	93.2
T03-0.3	0.31	11.0	3:10	12.50	260	0.13	100

Table 20: T03-1.5 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:00	858	ND	0.78
Background 2	3:30	755	ND	0.78
Background 3	4:00	724	ND	0.78
Background 4	4:30	735	ND	0.78
Background 5	5:00	753	ND	0.78
Background 6	5:30	752	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:00	950	115	114
Effluent 2	3:30	935	108	107
Effluent 3	4:00	938	100	98.9
Effluent 4	4:30	918	107	106
Effluent 5	5:00	914	118	118
Effluent 6	5:30	980	115	115
			Average	*110*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	710.513	60	710.513	277
Feed Rate 2	5:30	713.565	60	713.565	278
			Average	*712.039*	*277*

Table 21: T03-1.2 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	3:30	736	ND	0.78
Background 2	4:00	820	ND	0.78
Background 3	4:30	741	ND	0.78
Background 4	5:00	851	ND	0.78
Background 5	5:30	865	ND	0.78
Background 6	6:00	819	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	3:30	919	86.1	85.3
Effluent 2	4:00	971	92.5	91.7
Effluent 3	4:30	964	90.3	89.5
Effluent 4	5:00	964	82.6	81.8
Effluent 5	5:30	966	89.8	89.0
Effluent 6	6:00	970	81.4	80.6
			Average	*86.3*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	563.549	60	563.549	274
Feed Rate 2	6:00	569.778	60	569.778	277
			Average	*566.664*	*275*

Table 22: T03-0.9 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	4:30	835	ND	0.78
Background 2	5:00	787	ND	0.78
Background 3	5:30	724	ND	0.78
Background 4	6:00	830	ND	0.78
Background 5	6:30	806	ND	0.78
Background 6	7:00	765	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	4:30	924	52.5	51.7
Effluent 2	5:00	960	52.2	51.4
Effluent 3	5:30	931	51.8	51.0
Effluent 4	6:00	982	59.6	58.8
Effluent 5	6:30	955	45.4	44.7
Effluent 6	7:00	943	52.5	51.7
			Average	*51.5*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	429.416	60	429.416	278
Feed Rate 2	7:00	426.248	60	426.248	276
			Average	*427.832*	*277*

Table 23: T03-0.6 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	6:00	795	ND	0.78
Background 2	6:30	831	ND	0.78
Background 3	7:00	769	ND	0.78
Background 4	7:30	845	ND	0.78
Background 5	8:00	812	ND	0.78
Background 6	8:30	862	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	6:00	936	17.0	16.2
Effluent 2	6:30	943	18.0	17.3
Effluent 3	7:00	951	18.9	18.1
Effluent 4	7:30	966	21.5	20.8
Effluent 5	8:00	962	19.5	18.8
Effluent 6	8:30	951	19.0	18.2
			Average	*18.2*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	276.698	60	276.698	268
Feed Rate 2	8:30	276.160	60	276.160	267
			Average	*276.429*	*268*

Table 24: T03-0.3 Background TSS, Effluent TSS and Feed Rate

Background Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Reported Background TSS (mg/L)	Background TSS (mg/L)
Background 1	11:00	765	ND	0.78
Background 2	11:30	737	ND	0.78
Background 3	12:00	771	ND	0.78
Background 4	12:30	820	ND	0.78
Background 5	13:00	775	ND	0.78
Background 6	13:30	799	ND	0.78
			Average	*0.78*

Effluent Sample ID	Test Time (mm:ss)	Sample Volume (mL)	Effluent TSS (mg/L)	Adjusted Effluent TSS (mg/L)
Effluent 1	11:00	902	1.55	0.77
Effluent 2	11:30	921	ND	0.00
Effluent 3	12:00	954	ND	0.00
Effluent 4	12:30	966	ND	0.00
Effluent 5	13:00	851	ND	0.00
Effluent 6	13:30	932	ND	0.00
			Average	*0.13*

Feed Rate Sample ID	Test Time (mm:ss)	Moisture Corrected Sample Mass (g)	Sampling Duration (s)	Feed Rate (g/min)	Calculated Influent TSS (mg/L)
Feed Rate 1	0:00	133.795	60	133.795	256
Feed Rate 2	13:30	137.289	60	137.289	263
			Average	*135.542*	*260*

Table 25: Test 03 QA/QC

FLOW RATE AND WATER TEMPERATURE					
Test ID	QAQC PASS/FAIL	Target Flow Rate (ft^3/s)	Average Flow Rate (ft^3/s) (±10% of Target)	Flow Rate COV (<0.03)	Maximum Water Temperature (°F) (<80 °F)
T03-1.5	PASS	1.50	1.51	0.01	76.0
T03-1.2	PASS	1.20	1.21	0.01	76.0
T03-0.9	PASS	0.90	0.91	0.01	76.0
T03-0.6	PASS	0.60	0.61	0.01	76.0
T03-0.3	PASS	0.30	0.31	0.01	76.0
INFLUENT AND BACKGROUND CONCENTRATION					
Test ID	QAQC PASS/FAIL	Target Influent TSS (mg/L)	Average Influent TSS (mg/L) (±10% of Target)	Feed Rate COV (<0.1)	Average Background TSS (<20 mg/L)
T03-1.5	PASS	280	277	0.003	0.78
T03-1.2	PASS	280	275	0.01	0.78
T03-0.9	PASS	280	277	0.01	0.78
T03-0.6	PASS	280	268	0.001	0.78
T03-0.3	PASS	280	260	0.02	0.78

6. Design Limitations

Contech's engineering staff typically works with the site design engineer to ensure all potential constraints are addressed during the specification process and that the Cascade Separator treatment system will function as intended. Each install will have unique limitations or requirements, the following limitations should be considered general and not all-inclusive.

Required Soil Characteristics

The Cascade Separator is an enclosed system that is typically housed within a concrete manhole. The functionality of the Cascade Separator system is not affected by existing soil conditions at install location and as such the unit can be installed in all soil types.

Slope

It is generally not advisable to install the Cascade Separator unit with steep pipe slopes. When the Cascade Separator is being considered with pipe slopes exceeding 10% Contech recommends contacting their engineering staff to evaluate the design prior to specification.

Flow Rate

The hydraulic loading rate for 80% removal of 110 µm particles is 33.78 gpm/ft^2 of effective treatment area. The hydraulic loading rate for 80% annualized removal efficiency is 52.99 gpm/ft^2.

Maintenance Requirements

The Cascade Separator system must be inspected at regular intervals and maintained when necessary to ensure optimum performance. The rate at which the system collects pollutants depends heavily on specific site activities. See Maintenance Plan below for a more detailed discussion of maintenance and inspection requirements.

Driving Head

The driving head required for a given Cascade Separator model is typically a function of the model size and storm sewer characteristics. Contech's engineering staff consults with the design engineer on each project to ensure there will not be any adverse impacts to the hydraulic grade-line as a result of installing the Cascade Separator unit.

Installation Limitations

Prior to installation, Contech provides contractors detailed installation and assembly instructions and is also available to consult onsite during installation. Pick weights for Cascade Separator components are provided prior to delivery so that the contractor can secure proper equipment for lifting Cascade Separator units into place.

Configurations

Cascade Separator units can be installed online or offline. Online units can convey excess flows around the treatment chambers of the unit without the need for an external bypass structure. Contech's engineering staff can help determine the pipe size based on the site requirements.

Load Limitations

Cascade Separator units are typically designed for HS-20 loading (32,000 pounds per truck axle). If additional loading is expected it is advisable to contact Contech to assess loading options.

Pretreatment Requirements

There are no pre-treatment requirements for the Cascade Separator stormwater treatment system.

Limitations on Tailwater

If tailwater is present it is important to increase the available driving head within the unit to ensure that the full treatment flow rate is still treated prior to any internal bypass.

Depth to Seasonal High-Water Table

Cascade Separator unit performance is not typically impacted by high groundwater. Occasionally, when groundwater is expected to be within several feet of finished grade it may be necessary to add a base extension to the unit to counter buoyant forces. If high groundwater is expected, Contech's engineering staff can evaluate whether anti-buoyancy measures are required during the design process.

Additional Limitations

Each Cascade Separator has a recommended maximum inlet and outlet pipe size. When the size of the main storm drain exceeds the Cascade Separator maximum pipe size, Contech recommends contacting their engineering staff. In some conditions a larger pipe can be accommodated. The maximum pipe diameter for each Cascade Separator model is shown in **Table A-1**.

MAINTENANCE PLAN

The Cascade Separator system should be inspected at regular intervals and maintained when necessary to ensure optimum performance. The rate at which the system collects sediment and debris will depend upon on-site activities and site pollutant characteristics. For example, unstable soils or heavy winter sanding will cause the sediment storage sump to fill more quickly but regular sweeping of paved surfaces will slow accumulation. Additional information on maintenance, including a simple Inspection & Maintenance Log form, can be found in the Cascade Separator Inspection and Maintenance Guide at:

https://www.conteches.com/Portals/0/Documents/Maintenance%20Guides/Cascade-Maintenance%20Guide.pdf?ver=2018-11-05-093254-300

INSPECTION

Inspection is the key to effective maintenance and is easily performed. Pollutant transport and deposition may vary from year to year and regular inspections will help ensure that the system is cleaned out at the appropriate time. At a minimum, inspections should be performed twice per year (i.e. spring and fall). However, more frequent inspections may be necessary in climates where winter sanding operations may lead to rapid accumulations, or in equipment wash-down areas. Installations should also be inspected more frequently where excessive amounts of trash are expected.

A visual inspection should ascertain that the system components are in working order and that there are no blockages or obstructions in the inlet chamber, flumes or outlet channel. The inspection should also quantify the accumulation of hydrocarbons, trash and sediment in the system. Measuring pollutant accumulation can be done with a calibrated dipstick, tape measure or other measuring instrument. If absorbent material is used for enhanced removal of hydrocarbons, the level of discoloration of the sorbent material should also be identified during inspection. It is useful and often required as part of an operating permit to keep a record of each inspection. A simple form for doing so is provided in the Cascade Separator Inspection and Maintenance Guide.

Access to the Cascade Separator unit is typically achieved through one manhole access cover. The opening allows for inspection and cleanout of the center chamber (cylinder) and sediment storage sump, as well as inspection of the inlet chamber and slanted skirt. For large units, multiple manhole covers allow access to the chambers and sump.

The Cascade Separator system should be cleaned when the level of sediment in the sump has reached a depth of 9 in. or more to avoid exceeding the maximum 18 in. sediment depth (from standard sump floor level). The system should also be cleaned when an appreciable level of hydrocarbons and trash has accumulated. If sorbent material is used, it must be replaced when significant discoloration has occurred. Performance may be impacted when maximum sediment storage capacity is exceeded. The level of sediment is easily determined by measuring from finished grade down to the top of the sediment pile. To avoid underestimating the level of sediment in the chamber, the measuring device must be lowered to the top of the sediment pile carefully. Finer, silty particles at the top of the pile typically offer less resistance to the end of the rod than larger particles toward the bottom of the pile. Once this measurement is recorded, it should be compared to the as-built drawing for the unit to determine if the height of the sediment pile off the bottom of the sump floor exceeds 50% (9 in.) of the total height of sediment storage sump.

CLEANING

Cleaning of a Cascade Separator system should be done during dry weather conditions when no flow is entering the system. The use of a vacuum truck is generally the most effective and convenient method of removing pollutants from the system. Simply remove the manhole cover and insert the vacuum hose down through the center chamber and into the sump. The system should be completely drained down and the sump fully evacuated of sediment. The areas outside the center chamber and the slanted skirt should also be washed off if pollutant build-up exists in these areas.

In installations where the risk of petroleum spills is small, liquid contaminants may not accumulate as quickly as sediment. However, the system should be cleaned out immediately in the event of an oil or gasoline spill. Motor oil and other hydrocarbons that accumulate on a more routine basis should be removed when an appreciable layer has been captured. To remove these pollutants, it may be preferable to use absorbent pads since they are usually less expensive to dispose than the oil/water emulsion that may be created by vacuuming the oily layer. Trash and debris can be netted out to separate it from the other pollutants. Then the system should be power washed to ensure it is free of trash and debris.

Manhole covers should be securely seated following cleaning activities to prevent leakage of runoff into the system from above and to ensure proper safety precautions. Confined space entry procedures need to be followed if physical access is required. Disposal of all material removed from the Cascade Separator system must be done in accordance with local regulations. In many locations, disposal of evacuated sediments may be handled in the same manner as disposal of sediments removed from catch basins or deep sump manholes. Check your local regulations for specific requirements on disposal. If any components are damaged, replacement parts can be ordered from the manufacturer.

7. STATEMENTS

The following signed conflict of interest and testing oversight statements from the third-party observer (Scott A. Wells and associates) are provided.

Scott A. Wells and Associates

Environmental Engineering and Modeling

2382 SW Cedar Street

Portland, OR 97205 USA

May 10, 2019

To Whom It May Concern:

Scott A. Wells and Associates provides environmental consulting services focusing on water quality and hydrodynamic models of hydraulic structures, rivers, reservoirs, and estuary systems. We are familiar with stormwater treatment research having conducted many studies in the past on the efficiency of particle and oil and grease removal using a CDS device. We also are familiar with the use of an analytical laboratory to process samples, proper sample technique, and calculations of flow, pollutant concentration, and pollutant loading. Our clients include the federal government (EPA, USBR, Corps of Engineers), state government (such as the Washington Department of Ecology and Departments of Environmental Quality in Idaho and Oregon), private consulting firms and government organizations in both the United States and abroad (China, Israel, Brazil, Canada). Either Scott Wells, Ph.D., P.E., or Chris Berger, Ph.D., P.E., will served as observers for this series of tests.

Scott Wells and Associates has provided the service of third party review of stormwater device testing to Contech Engineered Solutions between 2007 and 2018. Beyond this past review work, Scott Wells and Associates and Contech have no relationships that would constitute a conflict of interest, as outlined in *Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology* (NJDEP 2013). For example, we have no ownership stake, do not receive commissions, do not have licensing agreements, do not receive funds or grants beyond those associated with the testing program.

Let me know if you have further questions on potential conflicts of interest.

Truly,

Scott A. Wells, P.E., Ph.D.

Christopher J. Berger, P. E., Ph.D.

503-935-6379

drswells@outlook.com

Scott A. Wells and Associates

Environmental Engineering and Modeling
2382 SW Cedar Street
Portland, OR 97205 USA

May 10, 2019

To Whom It May Concern:

Re: Cascade Separator Removal Efficiency of Suspended Sediment with Median Particle Size of 110 microns

Performance testing of the Contech Cascade Separator was overseen by Dr. Chris Berger and Dr. Scott Wells between April 22 and May 2, 2019 at the Contech Portland, Oregon laboratory. All phases of the analytical testing were also observed at the Contech laboratory. These tests included the particle size distribution by sieve analysis, moisture content, and sediment concentration in water samples. The flow rates and frequency of sampling reported for the performance tests were observed and are reported accurately. The test used applicable protocol, as outlined in the quality assurance project plan, and their Technical Bulletin (02) accurately reflects the testing observed by Dr. Berger and Dr. Wells.

Let us know if you have further questions on our observations of the testing performed in the laboratory.

Truly,

Scott A. Wells, P.E., Ph.D.   Christopher J. Berger, P. E., Ph.D.

503-935-6379

drswells@outlook.com

VERIFICATION APPENDIX

INTRODUCTION

- Contech Engineered Solutions is the manufacturer of the Cascade Separator hydrodynamic separation MTD

  Contech Engineered Solutions
  9025 Centre Point Drive
  West Chester, OH 45069
  Phone: (513) 645-7000
  Fax: (513) 645-7993
  www.ContechES.com

- MTD: Contech Cascade Separator™. Verified Contech Cascade models are shown in **Table A-1.**

- The Cascade Separator demonstrated a net annual 80% TSS removal rate of 110µm particles at the target influent sediment concentration of 280 mg/L.

- In September 2019, the Cascade Separator received NJDEP certification qualifying it for online installation for the New Jersey water quality design storm.

DETAILED SPECIFICATION

- Sizing table for the Cascade Separator is attached (**Table A-1**)

- Prior to installation, Contech provides contractors detailed installation and assembly instructions and is also available to consult onsite during installation.

- Maximum sediment depth for all units is 18 in. Recommended sediment depth prior to cleaning is 9 inches or more.

- See Contech Cascade Separator Inspection and Maintenance Guide for additional detailed maintenance information at:
  https://www.conteches.com/Portals/0/Documents/Maintenance%20Guides/Cascade-Maintenance%20Guide.pdf?ver=2018-11-05-093254-300

Table A-1: Cascade Separator Treatment Flow Rata, and Standard Dimensions

Model Number	Manhole Diameter (ft)	Annualized Maximum Treatment Flow Rate (cfs)	Hydraulic Loading Rate[1] (gpm/ft^2)	100% Maximum Sediment Storage Depth (in)	100% Maximum Sediment Storage Volume (ft^3)
CS-3	3	0.84	52.99	18	10.6
CS-4	4	1.48	52.99	18	18.8
CS-5	5	2.31	52.99	18	29.5
CS-6	6	3.33	52.99	18	42.4
CS-8	8	5.93	52.99	18	75.4
CS-10	10	9.27	52.99	18	117.8
CS-12	12	13.35	52.99	18	169.6
Model Number	**Effective Treatment Area (ft^2)**	**Effective Treatment Depth[2] (in)**	**Chamber Depth[3] (in)**	**Aspect Ratio[4]**	**Maximum Pipe Diameter (in)**
CS-3	7.1	27	36	0.75	18
CS-4	12.6	39	48	0.81	24
CS-5	19.6	45	54	0.75	30
CS-6	28.3	51	60	0.71	42
CS-8	50.3	66	75	0.69	48
CS-10	78.5	83	92	0.69	60
CS-12	113.1	99	108	0.69	72

[1] Hydraulic loading rate is defined as the ratio of treatment flow rate to effective treatment area
[2] Effective treatment depth is defined as depth from effluent invert to 50% maximum sediment storage depth
[3] Chamber depth is defined as depth from effluent invert to sump floor
[4] Aspect ratio is defined as the ratio of effective treatment depth to manhole diameter. All models are geometrically proportional to the tested CS-4 within the allowable ±15% tolerance (0.69 -0.93)