NJCAT TECHNOLOGY VERIFICATION

StormScape™ Filter

Hydro International

June 2020

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1. Description of Technology

The StormScape™ Filter (StormScape) is a stormwater treatment system that filters polluted stormwater in a downward flow, horizontal media bed. Each StormScape consists of an array of surface pavers that protect a bed of engineered filtration media **(Figure 1)**. The framework supporting the surface pavers are supported by legs mounted to concrete footings **(Figure 2)**. Lightweight materials used in the construction include stainless steel, aluminum, and recycled rubber.

There are two options of installation available. In one arrangement, the "underdrain" option, the system is installed directly in a rough excavation with no enclosing box or liner, but with an underdrain comprised of a perforated discharge pipe embedded in coarse stone, while ensuring that the regulatory requirements for separation from seasonal high water table are met. The discharge pipe is installed with an unperforated riser that acts as both a bypass and as an inspection port. This report details a test of the "underdrain" configuration without testing the internal bypass and should be used in an offline installation.

Alternatively, if the surrounding soil testing confirms that the soil meets all regulatory requirements for infiltration (i.e., soil hydraulic conductivity, seasonal high water table, and groundwater mounding), the open structure of the system allows for installation as a "stand-alone" MTD that encourages stormwater infiltration and runoff volume reduction by maximizing contact with native soils. The "stand-alone" arrangement was not tested.

In both the "underdrain" and "stand-alone" configurations, the StormScape can be constructed with modular components to allow for multiple units to be nested together.

The 4-ft x 6-ft StormScape described in this report is supplied as a complete open-frame system and is installed in a rough excavation that may or may not be exactly 48 inches x 72 inches as shown in the installation guide linked here (click button "Access this resource"): https://hydro-int.com/en/resources/stormscape-installation-maintenance-manual

In some installations where the system is placed in a planted depression, this wider excavation can allow for a small amount of additional filter surface area. In installations where the system is installed as part of a sidewalk, the surface area is limited to a 4-ft x 6-ft frame size. In either installation method, the wider excavation provides more storage volume and expanded contact area with native soils. The single, full-scale test unit described in this plan uses a test vessel measuring 52.5 inches wide by 79 inches long to replicate this over-sized excavation. All performance claims, however, are reported per square foot of filter surface and the performance claims for the 4-ft x 6-ft StormScape only credit 24 sq.ft. of filter surface area.

The flow path is arranged to create an outer pre-treatment zone and an inner filtration zone. As water enters the curb opening, it is distributed by a perforated flow spreading baffle **(Figure 3)**. This baffle slows the water, controlling media scour and encouraging the deposition of trash and coarse sediment. As the stormwater enters the inner treatment zone the full surface of the filtration media, including the inner zone, is made available for filtration. Sediment and particulate pollutants are physically captured in the mulch and top layers of the engineered media. The discharge pipe is embedded in ¾" drain rock or equal.

Figure 1: Rendering of three StormScape™ units installed in a parking area. Perforations on flow spreading baffle enlarged for visibility

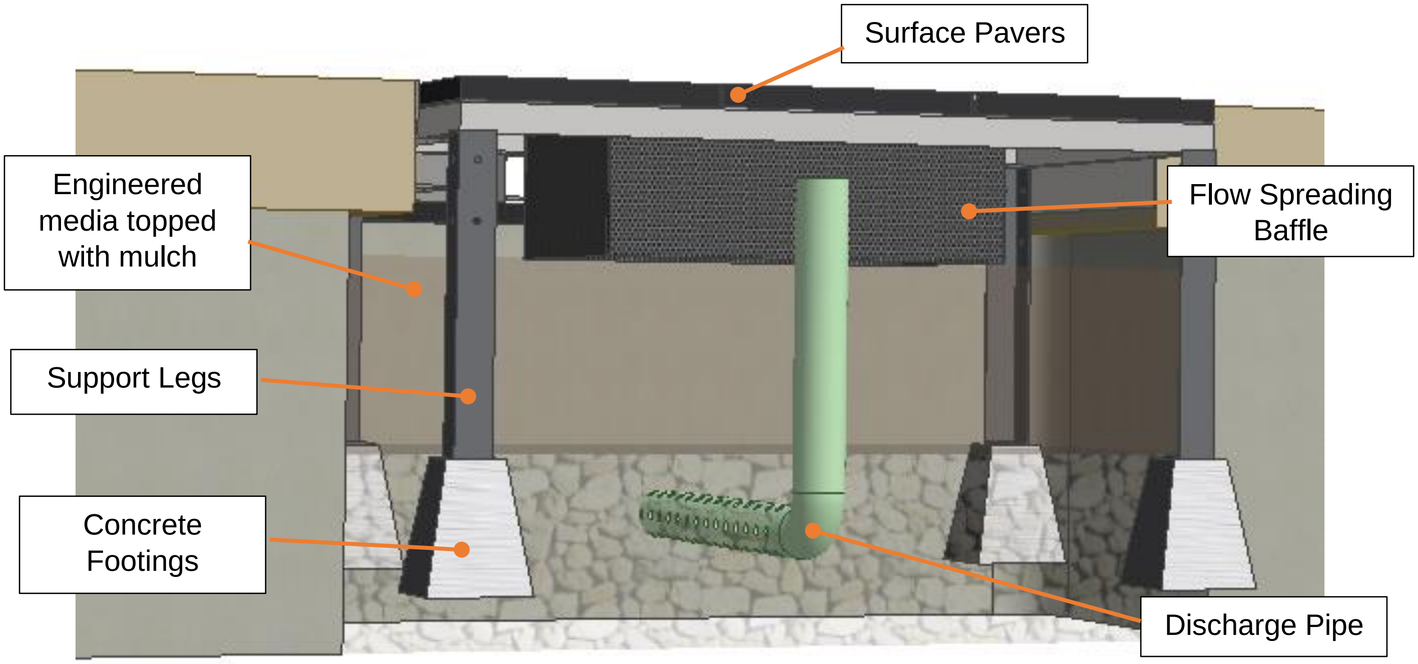

Figure 2 Diagram showing the components of a typical StormScape system

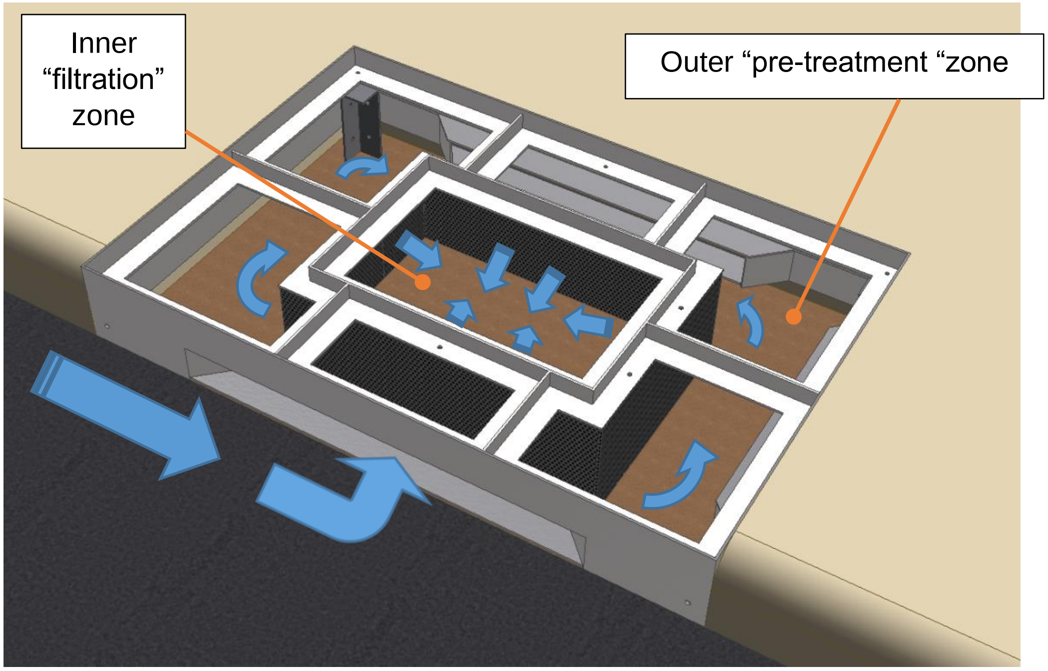

Figure 3 Diagram showing treatment zones and flow path within the StormScape. Surface pavers have been removed for clarity

2. Laboratory Testing

The New Jersey Department of Environmental Protection (NJDEP) maintains a list of certified stormwater manufactured treatment devices (MTDs) that can be installed on newly developed or redeveloped sites to achieve stormwater treatment requirements for Total Suspended Solids (TSS). Manufactured treatment devices are evaluated for certification according to the *New Jersey Department of Environmental Protection Process for Approval of Use for Manufactured Treatment Devices (NJDEP 2013a*) (hereafter referred to as “NJDEP Approval Process”). The NJDEP Approval Process requires that TSS treatment devices operating on filtration principles be tested according to the *New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device (NJDEP 2013b)* (hereafter referred to as “NJDEP Protocol”). In addition, the NJDEP Approval Process requires submittal of a Quality Assurance Project Plan (QAPP) to the New Jersey Corporation for Advanced Technology (NJCAT) for review and approval prior to testing to ensure that all laboratory procedures will be conducted in strict accordance with the NJDEP Protocol *(NJDEP 2013).* The QAPP was submitted and approved by NJCAT in May 2019 prior to commencement of testing.

Testing was conducted in July through November 2019 by Hydro International (“Hydro”) at the company’s full-scale hydraulic testing facility in Portland, Maine. Since testing was carried out in-house, Hydro contracted with FB Environmental Associates of Portland, Maine to provide Protocol required third party oversight. FB Environmental Associates representatives were present during all testing procedures. The test program was conducted in accordance with the NJDEP Protocol in two phases: removal efficiency testing and sediment mass loading capacity testing.

2.1 Test Setup

A schematic drawing of the laboratory setup is shown in **Figure 4** and key dimensions of the filter test vessel are shown in **Figure 5**. Operating as a recirculating closed loop system, water from a 20,000-gallon supply tank is filled with clean water and is pumped to the system through a 2-inch line. Opening a flow control valve allows water to flow through a turbine flow meter and into the test vessel containing the StormScape. After traveling through the filter media, the flow is collected in a 4-inch perforated discharge pipe embedded in stone at the bottom of the tank. This discharge falls freely into a 700-gallon discharge tank. Once the water elevation in the discharge tank reaches a predetermined level, the treated water is returned to the supply tank. A control loop with a heater and heater pump maintains the water temperature in the supply tank.

Background samples were taken with 1-liter wide mouth bottles at the background sample port located 45 inches upstream of the StormScape test vessel inlet chute. The port was operated with a 1-in. ball valve. Before a sample was taken, the line was flushed to ensure influent background samples were representative. The time each background and effluent sample was collected was recorded so that samples could be time stamped.

Water temperature was measured in the supply tank with a thermocouple connected to the data acquisition unit. This is a representative location to measure water temperature because all test water must pass through this tank immediately before passing through the rest of the test setup. Maximum temperature remained below 80°F for the duration of the test. Temperature was recorded every 10 seconds. The original thermocouple calibration was confirmed by the independent observer prior to testing.

A data acquisition unit, the DATAQ DI-245, is connected to a computer system running WINDAQ software. The flow meter, Dwyer pressure transducer and thermocouple are connected to the DATAQ unit. Test data are recorded throughout the test, saved and submitted with the test report.

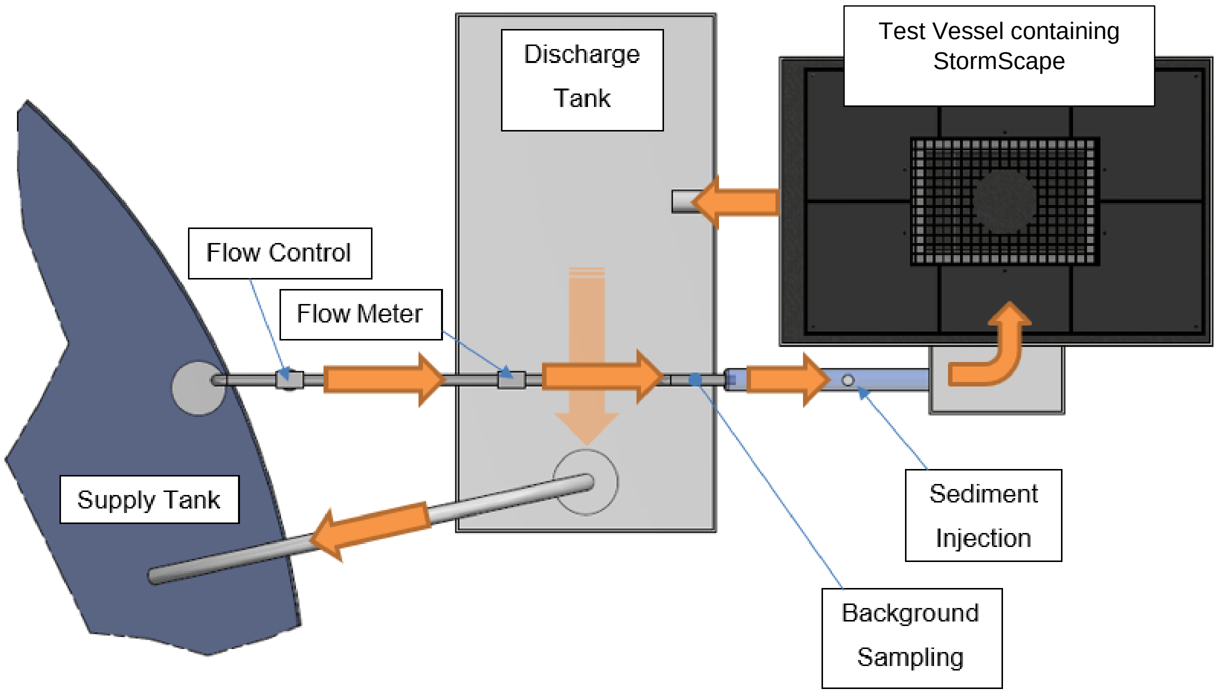

Figure 4 Laboratory Testing Arrangement Diagram

Test Unit Description

The test vessel (**Figure 5**) included one full-scale commercially available 4-ft x 6-ft StormScape. As described in Section 1, the internal dimensions of the test vessel are 79 inches long by 52.5 inches wide to mimic the oversized condition of a rough excavation. A background sample port is located 45 inches from the test vessel inlet and the auger feed port is located 15 inches from the test vessel inlet. Water is pumped from the supply tank through a two-inch control valve and flow meter and enters a 38-inch length of four-inch PVC pipe at 5% slope. During testing this pipe does not run full and allows for observable transport and mixing of the test sediment. The inlet to the system is an open trough intended to mimic the curb inlet of a typical installation. The inlet trough is 24 by 12 inches and 9 inches deep and is positioned 30 inches from the Test Vessel floor. It is sloped towards the Test Vessel to discourage build-up of sediment. The filter discharge port is on the adjacent side and the centerline is 4.25 inches from the test vessel floor. The maximum design driving head is represented by 9 inches of head accumulated above the filtration media, 33 inches above the tank floor. The Test Vessel contains 6 inches of drain rock and 18 inches of filter media. This water level represents the appropriate grading of the curb inlet to ensure external bypass of the filter system during high flow events. Key test vessel dimensions are shown in **Figure 5** below.

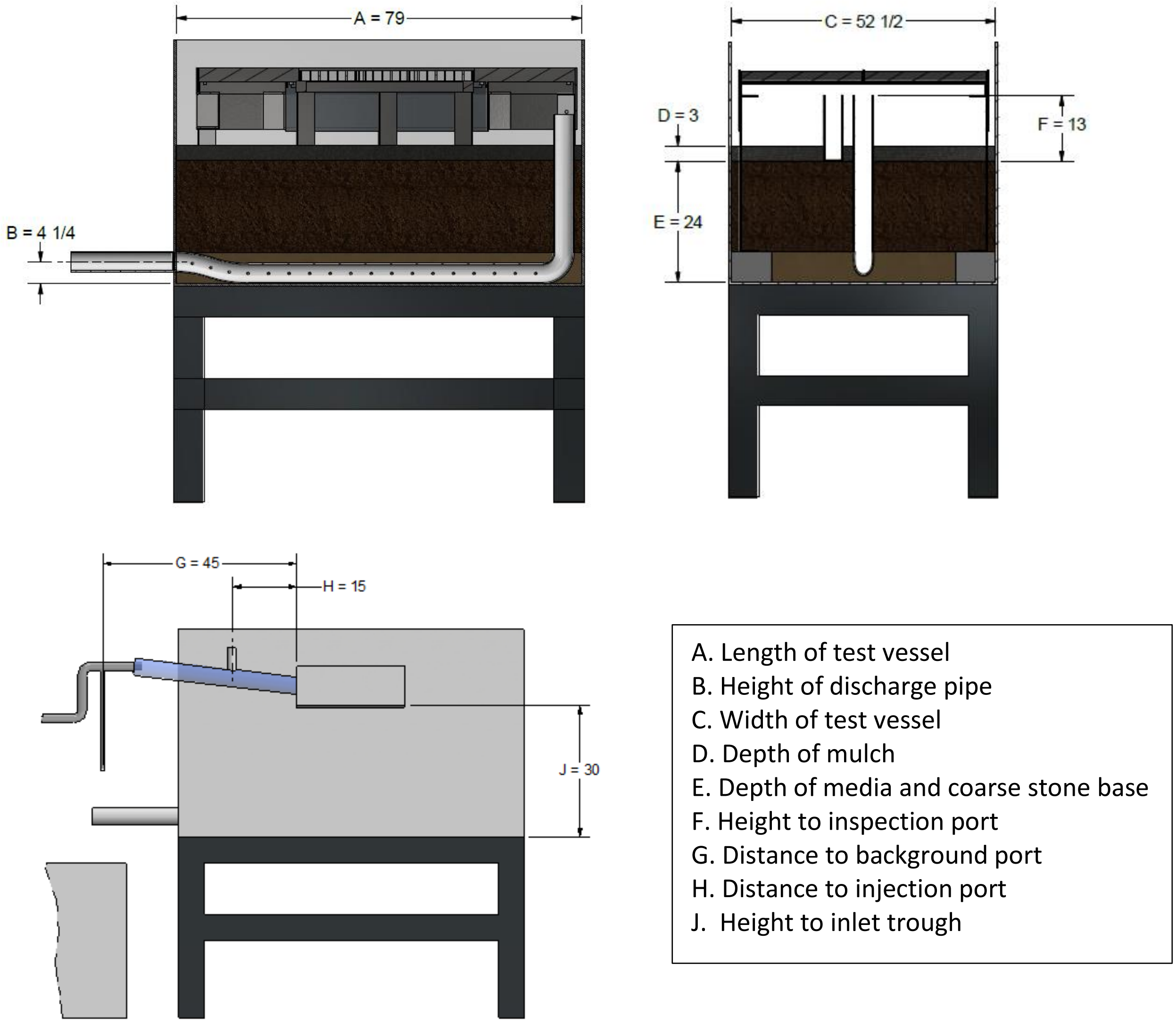

Figure 5 Key Dimensions of Test Vessel

2.2 Test Sediment

The test sediment was a blend of commercially available silica sand grades. The sediment was blended by Hydro and the particle size distribution was independently confirmed by GeoTesting Express in Acton, Massachusetts certifying that the supplied silica meets the specification within tolerance using ASTM D-422 as described in Section 5B of the Protocol. Results of particle size gradation testing are shown in **Table 1a** and **Figure 6a** below. The D_{50} of this blend is 64 microns.

Table 1a Particle Size Distribution Results of Test Sediment Samples (July 2019)

Particle Size (µm)	% Finer				Test Sediment Average	Diff. from Protocol
	Protocol	Sample 1	Sample 2	Sample 3		
1000	100	100	100	100	100	0
500	95	99	99	99	99	-4
250	90	94	94	94	94	-4
150	75	84	84	84	84	-9
100	60	63	63	63	63	-3
75	50	53	53	53	53	-3
50	45	45	46	45	45	-0
20	35	35	36	35	35	-0
8	20	20	20	20	20	-0
5	10	14	14	14	14	-4
2	5	8	8	8	8	-3

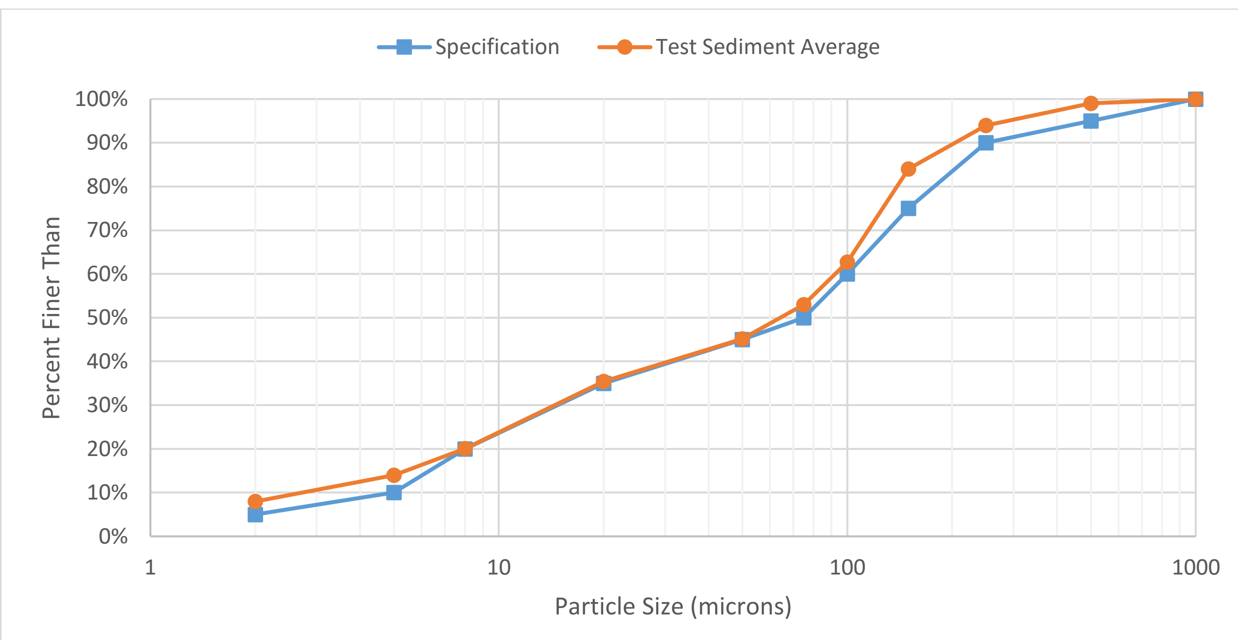

Figure 6a Avg. PSD of Test Sediment Compared to Protocol Specification (July 2019)

Starting with Test 33, a second batch of test sediment was used to fill the feed auger. Again, this sediment was blended by Hydro and the particle size distribution was independently confirmed by GeoTesting Express certifying that the supplied silica meets the specification within tolerance as described in Section 5B of the Protocol. Results of particle size gradation testing are shown in **Table 1b** and **Figure 6b** below. The D_{50} of this sediment blend is 68 microns.

Table 1b Particle Size Distribution Results of Test Sediment Samples (October 2019)

Particle Size (µm)	% Finer				Test Sediment Average	Diff. from Protocol
	Protocol	Sample 1	Sample 2	Sample 3		
1000	100	100	100	100	100	0
500	95	98	98	98	98	-3
250	90	93	93	93	93	-3
150	75	83	83	82	83	-8
100	60	59	61	60	60	0
75	50	50	52	52	51	-1
50	45	42	46	46	45	0
20	35	34	32	33	33	2
8	20	20	18	19	19	1
5	10	15	13	14	14	-4
2	5	9	9	9	9	-4

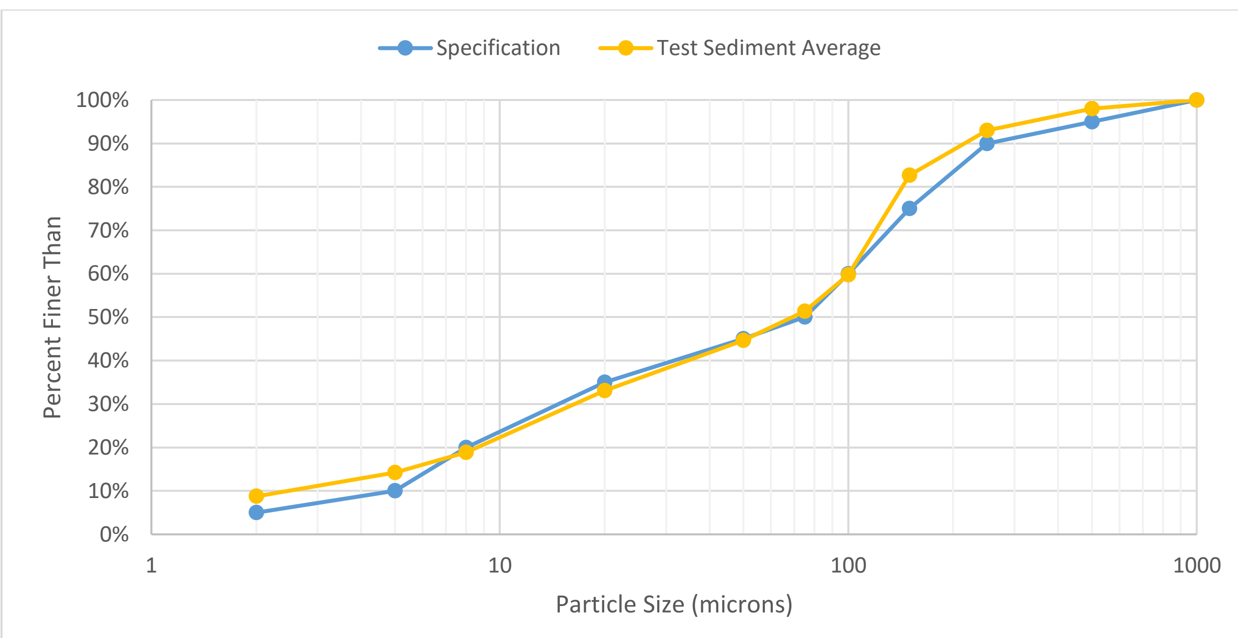

Figure 6b Avg. PSD of Test Sediment Compared to Protocol Specification (October 2019)

2.3 Sediment Removal Efficiency Testing

The StormScape performance was determined by testing its sediment removal efficiency. In accordance with the NJDEP filtration Protocol Section 5, this was tested in the laboratory by seeding the system with a known test sediment gradation and determining what proportion of the material is retained within the filtration device. The removal efficiency testing occurred by repeatedly testing the unit at the maximum treatment flow rate (MTFR) for ten runs as specified in the Protocol.

Background samples were taken at the background sample port located upstream of the StormScape test setup. Influent background samples were taken in correspondence with the odd numbered effluent samples (first, third, and fifth). The collection time was recorded for each background and effluent sample. The background data were used to adjust the effluent samples for background concentration.

The test sediment feed rate and total mass of test sediment introduced during each test run were a known quantity. The target influent concentration was 200 mg/L. Total mass introduced was determined by weighing the mass of sediment placed in the auger hopper at the start of the test and then emptying the hopper at the end of the test to weigh the sediment remaining. All masses were taken with an Ohaus D25WR laboratory balance.

Three sediment feed calibration samples were taken from the injection point at the start, middle and just prior to the conclusion of dosing during each test. Samples were taken by interrupting the dry sediment feed from the auger and weighing a one-minute sample with a Denver Instrument TR203 laboratory balance. The concentration coefficient of variance (COV) of these samples was not to exceed 0.10.

A G2 turbine flow meter was located between the supply tank and the test tank and flow rates were recorded every 10 seconds. The flow meter calibration was confirmed by the independent observer using the "time to fill" method prior to testing.

Water level in the test tank was measured with a VersaLine pressure transducer located on the surface of the filtration media. Another pressure transducer measured water level in the discharge tank. The water levels were recorded every 10 seconds. Pressure transducer calibrations were confirmed by the independent observer prior to testing.

Once a constant feed of test sediment and flow rate was established, the first effluent sample was collected after 17m50s had passed. This duration represents more than three times the required minimum of three MTD detention times using the calculated wet volume. The effluent samples were collected from the test vessel discharge pipe and time stamped in 1-liter bottles using the grab sample method as described in Section 5G of the Protocol.

The time interval between sequential samples was evenly spaced during the test sediment feed period to achieve six effluent samples. However, when the test sediment feed was interrupted for measurement, the next effluent sample collected was after a time of 17m50s. Effluent samples of the drawdown volume were taken corresponding to one-third and two-thirds of the drawdown discharge by volume. An example sampling schedule is given in **Table 2**.

Table 2 Example Sampling Time for TSS Removal Efficiency Testing

Elapsed Time	Dry Feed Sample	Effluent Sample	Background Sample
0:00:00	1		
0:18:50		1	1
0:19:20		2	
0:19:50		3	2
0:20:20	2		
0:39:10		4	
0:39:40		5	3
0:40:10		6	
0:40:40	3		
1/3 Drawdown		7	
2/3 Drawdown		8	

All effluent samples were analyzed for SSC in accordance with ASTM 3977-97 (2013) "Standard Test Methods for Determining Sediment Concentrations in Water Samples." Samples were sealed by the independent observer and delivered to Maine Environmental Laboratory (Accredited by the National Environmental Laboratory Accreditation Conference (NELAC) and certified by the states of Maine and New Hampshire) for processing. Removal efficiency was calculated per **Equation 1**. After the test, drawdown water was captured in the discharge tank and the volume was calculated using the dimensions of the tank and change in head level.

$$\textbf{Removal Eff.}(\%) = \frac{\textbf{Mass of Sediment Added} - \begin{pmatrix}\textbf{Avg. Adj. Eff. TSS Conc.}\times \\ \textbf{Vol. of Water during} \\ \textbf{Sediment Addition}\end{pmatrix} - \begin{pmatrix}\textbf{Avg. Drawdown TSS Conc.}\times \\ \textbf{Total Vol. of Drawdown}\end{pmatrix}}{\textbf{Mass of Sediment Added}} \times \mathbf{100}$$

Equation 1 Equation for Calculating Removal Efficiency

2.4 Sediment Mass Loading Capacity Testing

Upon completing the Removal Efficiency Testing, the Protocol continued with Sediment Mass Loading Capacity Testing used to determine the maximum mass of test sediment that can be captured by the MTD at the MTFR prior to passing the maximum driving head. The influent flow rate was then reduced to 90% of the MTFR and testing continued until the maximum driving head was again exceeded.

2.5 Scour Testing

No scour testing was conducted. The removal efficiency results will be applicable to off-line configurations designed to divert flows in excess of the MTFR away from the filter inlet. In the case of curbside installations like the StormScape, the curb inlet is designed to bypass flow down the curbside when the maximum driving head is reached.

2.6 Quality Objectives and Criteria

Samples sent to the external lab were shipped to the lab for analysis as soon as possible following the test run. Auger sample weights analyzed in-house were observed by the third party witness and were conducted immediately following sample collection.

A Chain of Custody form was used for externally analyzed samples to record sample containers and sampling date and time for each test run. A copy of these forms was also maintained by Hydro. Sample bottles were labeled to identify the test run and sample type (background or effluent), which corresponded to the sample identification on the Chain of Custody form. All sample marking and transportation was conducted by the third party witness.

Data were recorded and maintained in accordance with standard laboratory procedures used at Hydro. Hard copies of all original data sets are maintained on site.

The following quality criteria had to be met in order for the data from a run to be included in the report:

- Background TSS concentrations ≤ 20 mg/L
- Temperature of test water ≤ 80 degrees Fahrenheit
- Variation in calculated influent concentration ≤ 10% of target concentration
- COV of dry calibration samples ≤ 0.10

The 2013 Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device and subsequent guidance documents published by the NJDEP specifies that flow rates used in testing filter systems must not vary more than 10% from the target flow rate and must maintain a COV ≤ 0.03. This guidance and prior filtration testing precedent was used as a guideline for the filter test program.

3. Performance Claims

Per the NJDEP verification procedure and based on the laboratory testing conducted for the StormScape, the following are the performance claims made by Hydro.

Total Suspended Solids (TSS) Removal Efficiency

The 28.8 sq.ft. Hydro StormScape™ when operating under a hydraulic loading rate of 42 gpm and evaluated in accordance with the *New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device* achieves removal efficiencies of the NJDEP specified gradation of silica of 90.4%.

Effective Sedimentation Treatment Area (ESTA)

The Effective Sedimentation Treatment Area is the surface area of the 52.5 inch by 79-inch rectangular vessel. This equates to 28.8 sq. ft.

Effective Filtration Treatment Area

In a horizontal bed filter the Effective Filtration Treatment Area is equal to the Effective Sedimentation Treatment Area.

Maximum Treatment Flow Rate (MTFR)

The MTFR for the 28.8 sq. ft. Hydro StormScape™ tested equates to 42 gpm. For other unit sizes, the loading rate is 1.46 gpm/sq. ft. or 140 inches per hour. The MTFR for a system sized at exactly 4-ft x 6-ft is 35 gpm.

Sediment Mass Load Capacity

Considering the change in operating head relative to the sediment mass captured, the 28.8 sq.ft. StormScape has a mass loading capture capacity of 105.4 lbs (47.8 kg). This is the total amount of sediment captured by the system with test runs 41 and 46 removed. These are the runs where the maximum driving head level was exceeded. For other unit sizes, the loading rate is 3.66 lbs per square foot of filter. The sediment load for a system sized at exactly 4-ft x 6-ft is 88 lbs (40 kg).

Maximum Allowable Inflow Drainage Area

To ensure the drainage area and expected annual sediment load does not cause higher than intended bypass flows, the sediment mass capture capacity of 3.66 pounds per square foot of filter is used to limit the treatable drainage area per unit. Given the Protocol requirements for "Maximum Allowable Inflow Drainage Area" the 28.8 sq.ft. StormScape can effectively treat 0.176 acres per test unit at 600 lbs per acre of drainage area annually. For other unit sizes, the treatment rate is .0061 acres (266 square feet of drainage area) per square foot of filter.

Wet Volume and Detention Time

The wet volume for each test run was determined empirically by measuring the change in water level in the discharge tank after the test time was completed. Volume ranged from a minimum of 93.6 gallons to a maximum of 196.0 gallons, generally increasing throughout the test program. Given a flow rate of 42 gpm, this equates to a detention time ranging from 2.23 minutes to 5.21 minutes. A summary of calculated detention times is presented in **Table 2a**. The time accounted for in the schedule before the resumption of effluent sampling was 17.83 minutes for the 100% MTFR tests and 19.83 minutes for the 90% MTFR tests. A check to verify that 3X the detention time did not exceed the scheduled resumption of sampling time is also included in the table below.

Table 2a Detention Time Check Summary

Run #	Flow Rate (gpm)	Draindown Volume (gal)	Detention Time (m)	Sampling Time	Sample Time > 3X Detention Time?
1	42.19	112	2.644	17.833	YES
2	42.01	106	2.522	17.833	YES
3	42.10	121	2.865	17.833	YES
4	41.88	121	2.880	17.833	YES
5	41.91	95	2.278	17.833	YES
6	41.99	94	2.228	17.833	YES
7	41.99	103	2.444	17.833	YES
8	42.27	101	2.401	17.833	YES
9	42.26	109	2.585	17.833	YES
10	42.31	106	2.495	17.833	YES
11	42.27	106	2.497	17.833	YES
12	42.52	116	2.719	17.833	YES
13	42.49	108	2.548	17.833	YES
14	42.41	97	2.288	17.833	YES
15	42.44	111	2.614	17.833	YES
16	42.51	98	2.306	17.833	YES
17	40.17	114	2.844	17.833	YES
18	43.06	111	2.568	17.833	YES
19	43.16	130	3.023	17.833	YES
20	43.22	112	2.599	17.833	YES
21	43.33	112	2.583	17.833	YES
22	43.38	141	3.262	17.833	YES
23	42.52	141	3.328	17.833	YES
24	42.52	141	3.328	17.833	YES
25	42.61	141	3.321	17.833	YES
26	42.65	141	3.318	17.833	YES
27	42.74	143	3.351	17.833	YES
28	42.65	130	3.059	17.833	YES
29	42.81	144	3.359	17.833	YES
30	42.67	142	3.320	17.833	YES
31	42.38	125	2.956	17.833	YES
32	41.87	155	3.702	17.833	YES
33	42.17	164	3.892	17.833	YES
34	42.19	149	3.523	17.833	YES
35	42.19	156	3.697	17.833	YES

Run #	Flow Rate (gpm)	Draindown Volume (gal)	Detention Time (m)	Sampling Time	Sample Time > 3X Detention Time?
36	42.21	159	3.769	17.833	YES
37	42.34	154	3.648	17.833	YES
38	42.24	153	3.629	17.833	YES
39	41.77	147	3.513	17.833	YES
40	41.89	143	3.406	17.833	YES
41	42.16	169	4.012	17.833	YES
42	37.33	130	3.470	19.833	YES
43	37.49	146	3.893	19.833	YES
44	37.49	140	3.733	19.833	YES
45	37.70	141	3.753	19.833	YES
46	37.62	196	5.210	19.833	YES

4. Supporting Documentation

The NJDEP Procedure (NJDEP, 2013) 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 Removal Efficiency

During initial testing, 10 removal efficiency testing runs were completed in accordance with the NJDEP Filter Protocol. The target flow rate and influent sediment concentration were 42 gpm and 200 mg/L respectively.

The flow meter and data logger took a reading every 10 seconds. The flow data has been summarized in **Table 3** including the compliance to the QA/QC acceptance criteria. The average flow rate for all removal efficiency runs was 42.09 gpm.

The maximum temperature data is summarized in **Table 4**. It should be noted that the temperature gauge exceeded the 80-degree acceptance criteria on run 9. This appears to have been an error in the data collection equipment as the manual thermometer installed was still within range. The witness checked the test water temperature with the manual thermometer at the start and end of each test.

Influent Sediment Concentrations are summarized in **Table 5**, Background Sediment Concentrations are summarized in **Table 6**, and Adjusted Effluent Concentrations are summarized in **Table 7**, along with compliance to NJDEP Protocol QA/QC criteria.

The remaining tables report all other parameters measured that are required to demonstrate compliance to NJDEP Protocol QA/QC criteria. **Table 8** summarizes the cumulative removal efficiencies for the first ten test runs. The cumulative removal efficiency for test runs 1-10 was 90.3 %.

Table 3 Removal Efficiency Flow Rates

Run	Target Flow Rate (gpm)	Average Flow Rate (gpm)	Variance (gpm)	% Variance	QA/QC (Var ≤ 10%)	COV	QA/QC (COV ≤ 0.03)
1	42.00	42.19	0.19	0.45%	YES	0.007	YES
2	42.00	42.01	0.01	0.02%	YES	0.006	YES
3	42.00	42.10	0.10	0.25%	YES	0.003	YES
4	42.00	41.88	0.12	0.29%	YES	0.003	YES
5	42.00	41.91	0.09	0.21%	YES	0.003	YES
6	42.00	41.99	0.01	0.02%	YES	0.003	YES
7	42.00	41.99	0.01	0.02%	YES	0.003	YES
8	42.00	42.27	0.27	0.65%	YES	0.003	YES
9	42.00	42.26	0.26	0.61%	YES	0.003	YES
10	42.00	42.31	0.31	0.73%	YES	0.003	YES
AVG	**42.00**	**42.09**	**0.14**	**0.32%**		**0.004**	

Table 4 Removal Efficiency Maximum Temperatures

Run	DATAQ Maximum Temp (F)	QA/QC (< 80 F)
1	78.05	YES
2	76.24	YES
3	74.43	YES
4	75.75	YES
5	79.37	YES
6	79.54	YES
7	74.76	YES
8	76.57	YES
9	81.52	YES*
10	70.14	YES
AVG	**76.64**	

***** This appears to have been an error in the data collection equipment as temperatures taken with the manual thermometer at the start and end of the test were still within range.

Table 5 Removal Efficiency Influent Sediment Concentrations

Run	Target Conc. (mg/L)	Inf. Conc. (mg/L)	Var. (mg/L)	% Var.	QA/QC (Var≤10%)	Feed Rate Samples (mg/s)			COV	QA/QC (COV≤0.1)
1	200	193.63	6.37	3.19%	YES	507.77	517.43	516.57	0.010	YES
2	200	192.28	7.72	3.86%	YES	513.30	513.82	512.35	0.001	YES
3	200	192.32	7.68	3.84%	YES	500.38	502.02	525.08	0.027	YES
4	200	190.53	9.47	4.73%	YES	528.03	516.35	506.85	0.021	YES
5	200	198.25	1.75	0.87%	YES	518.80	519.78	539.05	0.022	YES
6	200	190.94	9.06	4.53%	YES	505.90	517.00	509.50	0.011	YES
7	200	185.98	14.02	7.01%	YES	502.73	507.80	500.18	0.008	YES
8	200	184.59	15.41	7.70%	YES	511.68	501.68	513.68	0.013	YES
9	200	191.12	8.88	4.44%	YES	497.05	501.25	506.55	0.009	YES
10	200	189.77	10.23	5.11%	YES	526.13	516.53	502.03	0.024	YES
AVG	**200**	**190.94**	**9.06**	**4.53%**					**0.015**	

Table 6 Removal Efficiency Background Sediment Concentrations

Run #	Background Samples (mg/L)			Mean (mg/L)	QA/QC (Max≤20 mg/L)
1	1.4	0.8	1.3	1.2	YES
2	0.2	6.2	1.0	2.5	YES
3	4.4	1.5	3.3	3.1	YES
4	2.1	0.3	0.6	1.0	YES
5	1.3	1.1	0.6	1.0	YES
6	2.0	1.8	1.4	1.7	YES
7	2.1	2.0	2.0	2.0	YES
8	1.3	2.9	0.8	1.7	YES
9	0.5	0.7	0.4	0.5	YES
10	1.1	0.4	0.6	0.7	YES

Table 7 Removal Efficiency Effluent Concentrations

Run #	Effluent Samples (mg/L)						Mean (mg/L)
1	12.0	17.0	18.0	31.0	16.0	17.0	18.5
2	21.0	32.0	18.0	20.0	22.0	24.0	22.8
3	26.0	26.0	23.0	20.0	19.0	24.0	23.0
4	27.0	25.0	23.0	23.0	23.0	21.0	23.7
5	11.0	19.0	20.0	23.0	22.0	24.0	19.8
6	17.0	21.0	23.0	27.0	24.0	21.0	22.2
7	12.0	19.0	19.0	12.0	11.0	13.0	14.3
8	11.0	11.0	14.0	16.0	16.0	20.0	14.7
9	18.0	9.7	15.0	6.8	8.5	8.4	11.1
10	23.0	17.0	17.0	17.0	17.0	14.0	17.5

Table 8 Removal Efficiency Results

Run #	Inf. Conc. (mg/L)	Avg. Adj. Eff. Conc. (mg/L)	Test Vol. (L)	Mass Added (kg)	Test Mass Escaped (kg)	Drawdown Volume (L)	Drawdown Conc. (mg/L)	Drawdown Mass Escaped (kg)	Cumulative Mass Captured (kg)	Run Efficiency	Cumulative Removal Efficiency
1	193.63	17.33	6175.17	1.20	0.11	422.23	19.0	0.008	1.081	90.38%	90.38%
2	192.28	20.37	6148.50	1.18	0.13	401.01	29.0	0.012	2.126	88.42%	89.41%
3	192.32	19.93	6162.77	1.19	0.12	456.62	22.0	0.010	3.178	88.79%	89.20%
4	190.53	22.67	6129.65	1.17	0.14	456.62	24.0	0.011	4.196	87.17%	88.70%
5	198.25	18.83	6134.77	1.22	0.12	361.49	22.0	0.008	5.289	89.85%	88.93%
6	190.94	20.43	6146.33	1.17	0.13	354.17	21.0	0.007	6.330	88.66%	88.89%
7	185.98	12.30	6146.50	1.14	0.08	388.57	16.0	0.006	7.391	92.84%	89.44%
8	184.59	13.00	6187.44	1.14	0.08	384.18	17.0	0.007	8.446	92.39%	89.79%
9	191.12	10.53	6184.84	1.18	0.07	413.45	15.7	0.006	9.557	93.94%	90.26%
10	189.77	16.80	6192.18	1.18	0.10	399.54	16.5	0.007	10.621	90.59%	90.29%

4.2 Sediment Mass Loading Capacity

The Sediment Mass Loading Capacity study was a continuation of the removal efficiency study. As required by the Protocol, all aspects of the testing remained the same, except for the flow rate which was reduced to 90% of the MTFR after the maximum driving head was exceeded. Driving head is defined as the vertical distance between the media level and the water level measured at the end of a test run.

Maximum driving head of 9.0 inches was reached at Test Run 41 and the flow rate was reduced to 90% of the MTFR (37.8 gpm) for Test Runs 42-46. During test run 46 the maximum driving head was exceeded again and the test program was complete.

The relationship between removal efficiency and sediment mass loading is illustrated in **Figure 6**. A summary of the Sediment Mass Loading Capacity flow rate is shown in **Table 9.** Also included are recorded maximum temperatures **(Table 10)**, Influent Concentrations **(Table 11)**, Background Concentrations **(Table 12)**, Effluent Concentrations **(Table 13)** and Removal Efficiencies **(Table 14).**

Table 9 Mass Load Capacity Flow Rates

Run	Target Flow Rate (gpm)	Average Flow Rate (gpm)	Variance (gpm)	% Variance	QA/QC Var ≤ 10%	COV	QA/QC COV ≤ 0.03
11	42.00	42.27	0.27	0.65%	YES	0.003	YES
12	42.00	42.52	0.52	1.23%	YES	0.003	YES
13	42.00	42.49	0.49	1.16%	YES	0.003	YES
14	42.00	42.41	0.41	0.99%	YES	0.032	NO
15	42.00	42.44	0.44	1.05%	YES	0.003	YES
16	42.00	42.51	0.51	1.21%	YES	0.003	YES
17	42.00	40.17	1.83	4.37%	YES	0.018	YES
18	42.00	43.06	1.06	2.51%	YES	0.002	YES
19	42.00	43.16	1.16	2.76%	YES	0.002	YES
20	42.00	43.22	1.22	2.90%	YES	0.003	YES
21	42.00	43.33	1.33	3.16%	YES	0.003	YES
22	42.00	43.38	1.38	3.29%	YES	0.003	YES
23	42.00	42.52	0.52	1.23%	YES	0.003	YES
24	42.00	42.52	0.52	1.24%	YES	0.003	YES
25	42.00	42.61	0.61	1.45%	YES	0.003	YES
26	42.00	42.65	0.65	1.55%	YES	0.003	YES
27	42.00	42.74	0.74	1.76%	YES	0.003	YES
28	42.00	42.65	0.65	1.54%	YES	0.003	YES
29	42.00	42.81	0.81	1.93%	YES	0.002	YES
30	42.00	42.67	0.67	1.61%	YES	0.003	YES
31	42.00	42.38	0.38	0.91%	YES	0.004	YES
32	42.00	41.87	0.13	0.31%	YES	0.004	YES
33	42.00	42.20	0.20	0.47%	YES	0.004	YES
34	42.00	42.19	0.19	0.45%	YES	0.004	YES
35	42.00	42.19	0.19	0.46%	YES	0.003	YES
36	42.00	42.21	0.21	0.50%	YES	0.003	YES
37	42.00	42.34	0.34	0.81%	YES	0.004	YES
38	42.00	42.24	0.24	0.57%	YES	0.003	YES
39	42.00	41.77	0.23	0.55%	YES	0.004	YES
40	42.00	41.89	0.11	0.27%	YES	0.004	YES
41	42.00	42.16	0.16	0.37%	YES	0.004	YES
AVG	**42.00**	**42.44**	**0.59**	**1.40%**		**0.005**	

Run	Target Flow Rate (gpm)	Average Flow Rate (gpm)	Variance (gpm)	% Variance	QA/QC Var ≤ 10%	COV	QA/QC COV ≤ 0.03
42	37.80	37.33	0.47	1.25%	YES	0.002	YES
43	37.80	37.49	0.31	0.81%	YES	0.003	YES
44	37.80	37.49	0.31	0.83%	YES	0.002	YES
45	37.80	37.70	0.10	0.26%	YES	0.003	YES
46	37.80	37.62	0.18	0.47%	YES	0.002	YES
AVG	**37.80**	**37.53**	**0.27**	**0.72%**		**0.002**	

Table 10 Mass Load Capacity Maximum Temperatures

Run	DATAQ Maximum Temp (F)	QA/QC Temp ≤ 80F
11	69.98	YES
12	69.98	YES
13	69.81	YES
14	69.98	YES
15	69.98	YES
16	71.30	YES
17	70.31	YES
18	69.81	YES
19	67.84	YES
20	67.18	YES
21	69.32	YES
22	69.32	YES
23	67.34	YES
24	68.33	YES
25	66.68	YES
26	68.33	YES
27	67.67	YES
28	63.88	YES
29	67.51	YES
30	67.51	YES
31	68.50	YES
32	67.84	YES
33	66.68	YES
34	68.00	YES
35	68.83	YES

Run	DATAQ Maximum Temp (F)	QA/QC Temp ≤ 80F
36	65.70	YES
37	74.26	YES
38	69.98	YES
39	66.52	YES
40	63.55	YES
41	62.73	YES
42	63.55	YES
43	64.87	YES
44	68.50	YES
45	62.56	YES
46	68.00	YES

Table 11 Mass Load Capacity Influent Sediment Concentrations

Run	Targ. Inf. (mg/L)	Avg. Inf. (mg/L)	Var. (mg/L)	% Var.	QA/QC Var≤10%	Feed Rate Samples (mg/s)			COV	QA/QC COV≤0.1
11	200	194.61	5.39	2.70%	YES	510.88	543.42	536.48	0.032	YES
12	200	194.10	5.90	2.95%	YES	538.38	506.83	534.47	0.033	YES
13	200	195.21	4.79	2.39%	YES	501.48	567.43	546.37	0.063	YES
14	200	185.55	14.45	7.22%	YES	526.43	579.55	552.99	0.048	YES
15	200	180.16	19.84	9.92%	YES	534.72	534.35	539.95	0.006	YES
16	200	183.53	16.47	8.24%	YES	481.53	528.03	521.53	0.049	YES
17	200	190.34	9.66	4.83%	YES	527.58	546.37	536.98	0.017	YES
18	200	193.98	6.02	3.01%	YES	548.30	535.40	541.55	0.012	YES
19	200	199.58	0.42	0.21%	YES	517.37	548.13	524.93	0.030	YES
20	200	195.76	4.24	2.12%	YES	485.22	532.05	493.88	0.049	YES
21	200	181.23	18.77	9.39%	YES	507.67	486.33	488.32	0.024	YES
22	200	174.50	25.50	12.75%	NO	537.43	477.67	476.40	0.070	YES
23	200	164.94	35.06	17.53%	NO	505.25	491.37	493.55	0.015	YES
24	200	204.06	4.06	2.03%	YES	497.05	517.62	498.55	0.023	YES
25	200	196.35	3.65	1.82%	YES	522.55	543.13	561.35	0.036	YES
26	200	196.95	3.05	1.52%	YES	485.72	526.43	532.47	0.049	YES
27	200	194.98	5.02	2.51%	YES	510.70	512.00	496.22	0.017	YES
28	200	202.84	2.84	1.42%	YES	551.72	549.58	550.20	0.002	YES
29	200	190.97	9.03	4.51%	YES	502.08	519.42	503.20	0.019	YES
30	200	198.48	1.52	0.76%	YES	522.25	504.33	536.50	0.031	YES
31	200	192.60	7.40	3.70%	YES	545.23	511.35	501.05	0.045	YES

Run	Targ. Inf. (mg/L)	Avg. Inf. (mg/L)	Var. (mg/L)	% Var.	QA/QC Var≤10%	Feed Rate Samples (mg/s)			COV	QA/QC COV≤0.1
32	200	207.88	7.88	3.94%	YES	512.22	543.83	540.82	0.033	YES
33	200	203.28	3.28	1.64%	YES	514.63	547.73	539.85	0.032	YES
34	200	197.44	2.56	1.28%	YES	516.12	519.02	530.45	0.015	YES
35	200	198.46	1.54	0.77%	YES	509.23	529.77	532.62	0.024	YES
36	200	205.62	5.62	2.81%	YES	511.07	541.78	529.48	0.029	YES
37	200	199.40	0.60	0.30%	YES	517.30	535.73	539.58	0.022	YES
38	200	197.12	2.88	1.44%	YES	497.22	538.13	499.58	0.045	YES
39	200	205.71	5.71	2.86%	YES	499.37	541.28	526.27	0.041	YES
40	200	199.53	0.47	0.24%	YES	509.28	519.55	505.80	0.014	YES
41	200	199.40	0.60	0.30%	YES	524.65	519.40	524.33	0.006	YES
42	200	205.29	5.29	2.65%	YES	467.00	512.92	497.13	0.047	YES
43	200	207.05	7.05	3.53%	YES	483.28	490.92	498.38	0.015	YES
44	200	206.39	6.39	3.20%	YES	494.03	459.93	474.83	0.036	YES
45	200	202.15	2.15	1.07%	YES	474.95	477.37	485.08	0.011	YES
46	200	204.93	4.93	2.46%	YES	446.35	505.73	473.45	0.063	YES
AVG	**200**	**195.84**	**7.22**	**3.61%**					**0.031**	

Table 12 Mass Load Capacity Background Sediment Concentrations

Run #	Background Samples (mg/L)			Mean (mg/L)	QA/QC (Max≤20 mg/L)
11	5.0	5.8	4.7	5.17	YES
12	2.2	2.6	1.1	1.97	YES
13	1.2	1.5	5.1	2.60	YES
14	0.8	1.3	0.5	0.87	YES
15	1.0	0.9	1.3	1.07	YES
16	2.9	2.9	3.0	2.93	YES
17	4.9	4.2	4.6	4.55	YES
18	2.2	1.9	1.8	1.97	YES
19	2.5	2.5	1.9	2.30	YES
20	2.3	2.5	1.7	2.17	YES
21	1.8	1.4	1.4	1.53	YES
22	1.7	2.0	2.5	2.07	YES
23	7.2	5.3	7.0	6.50	YES
24	3.2	1.9	2.4	2.50	YES
25	2.6	2.3	1.9	2.27	YES
26	3.3	3.6	2.9	3.27	YES

Run #	Background Samples (mg/L)			Mean (mg/L)	QA/QC (Max≤20 mg/L)
27	4.0	3.5	3.3	3.60	YES
28	3.4	2.4	2.4	2.73	YES
29	2.5	1.8	1.9	2.07	YES
30	3.8	2.7	3.0	3.17	YES
31	4.9	5.4	5.8	5.37	YES
32	3.8	2.6	1.8	2.73	YES
33	3.2	2.9	2.5	2.87	YES
34	5.2	1.6	2.8	3.20	YES
35	2.3	2.5	1.7	2.17	YES
36	1.9	1.8	3.5	2.40	YES
37	2.1	1.8	2.4	2.10	YES
38	1.7	0.5	0.8	1.00	YES
39	3.3	3.4	3.7	3.47	YES
40	3.4	1.8	2.9	2.70	YES
41	2.0	1.3	3.1	2.13	YES
42	4.4	2.2	2.0	2.87	YES
43	3.1	2.7	2.4	2.73	YES
44	2.8	1.9	1.5	2.07	YES
45	3.1	2.5	1.6	2.40	YES
46	1.0	0.0	0.9	0.63	YES
AVG				**2.67**	

Table 13 Mass Load Capacity Effluent Concentrations

Run #	Effluent Samples (mg/L)						Mean (mg/L)
11	18.0	17.0	18.0	17.0	16.0	20.0	17.67
12	11.0	12.0	20.0	19.0	15.0	18.0	15.83
13	22.0	20.0	22.0	18.0	20.0	23.0	20.83
14	20.0	28.0	20.0	23.0	24.0	18.0	22.17
15	22.0	22.0	19.0	22.0	22.0	21.0	21.33
16	23.0	22.0	22.0	21.0	20.0	22.0	21.67
17	20.0	25.0	19.0	20.0	22.0	28.0	22.33
18	22.0	17.0	18.0	22.0	22.0	24.0	20.83
19	18.0	21.0	19.0	24.0	20.0	17.0	19.83
20	13.0	8.8	9.9	12.0	11.0	6.2	10.15

Run #	Effluent Samples (mg/L)						Mean (mg/L)
21	14.0	19.0	18.0	20.0	21.0	20.0	18.67
22	23.0	17.0	23.0	11.0	18.0	17.0	18.17
23	24.0	36.0	33.0	18.0	30.0	18.0	26.50
24	20.0	17.0	19.0	17.0	17.0	17.0	17.83
25	22.0	26.0	23.0	23.0	23.0	21.0	23.00
26	23.0	21.0	23.0	22.0	22.0	24.0	22.50
27	21.0	22.0	26.0	36.0	27.0	21.0	25.50
28	23.0	23.0	23.0	23.0	22.0	22.0	22.67
29	19.0	19.0	20.0	19.0	21.0	17.0	19.17
30	22.0	22.0	25.0	19.0	22.0	20.0	21.67
31	14.0	16.0	22.0	23.0	18.0	17.0	18.33
32	22.0	23.0	23.0	18.0	19.0	23.0	21.33
33	19.0	21.0	19.0	17.0	17.0	20.0	18.83
34	18.0	22.0	17.0	16.0	18.0	21.0	18.67
35	21.0	21.0	21.0	19.0	19.0	18.0	19.83
36	22.0	21.0	22.0	22.0	21.0	21.0	21.50
37	18.0	22.0	20.0	18.0	17.0	20.0	19.17
38	20.0	21.0	20.0	20.0	18.0	20.0	19.83
39	23.0	23.0	23.0	22.0	21.0	23.0	22.50
40	22.0	21.0	22.0	22.0	21.0	23.0	21.83
41	23.0	21.0	19.0	20.0	21.0	21.0	20.83
42	19.0	19.0	18.0	18.0	18.0	18.0	18.33
43	20.0	19.0	19.0	19.0	18.0	19.0	19.00
44	18.0	18.0	17.0	17.0	15.0	16.0	16.83
45	19.0	20.0	20.0	18.0	17.0	19.0	18.83
46	14.0	16.0	13.0	13.0	13.0	17.0	14.33

Table 14 Mass Load Capacity Removal Efficiency Results

Run #	Inf. Conc. (mg/L)	Avg. Adj. Eff. Conc (mg/L)	Test Vol. (L)	Mass Added (kg)	Mass Escaped (kg)	Drawdown Volume (L)	Drawdown Conc. (mg/L)	Drawdown Mass Escaped (kg)	Cumulative Mass Captured (kg)	Run Eff.	Cumulative Removal Efficiency	Note
1-10				11.76	1.06			0.082	10.621		90.29%	
11	194.61	12.50	6187.27	1.20	0.08	399.54	21.5	0.009	11.739	92.86%	90.53%	
12	194.10	13.87	6223.12	1.21	0.09	437.59	19.5	0.009	12.852	92.15%	90.67%	
13	195.21	18.23	6218.69	1.21	0.11	409.79	21.0	0.009	13.944	89.95%	90.61%	
14	185.55	21.30	6235.01	1.16	0.13	367.35	19.5	0.007	14.961	87.90%	90.42%	1
15	180.16	20.27	6211.76	1.12	0.13	420.03	16.5	0.007	15.947	88.13%	90.28%	
16	183.53	18.73	6221.96	1.14	0.12	371.00	22.0	0.008	16.965	89.08%	90.20%	
17	190.34	17.78	5878.93	1.12	0.10	432.47	25.0	0.011	17.968	89.69%	90.17%	
18	193.98	18.87	6301.96	1.22	0.12	418.57	29.5	0.012	19.059	89.26%	90.12%	
19	199.58	17.53	6317.23	1.26	0.11	493.94	22.0	0.011	20.199	90.35%	90.13%	
20	195.76	7.98	6325.99	1.24	0.05	425.15	25.0	0.011	21.376	95.06%	90.39%	
21	181.23	17.13	6342.08	1.15	0.11	423.69	14.3	0.006	22.411	90.02%	90.38%	
22	174.50	16.10	6349.67	1.11	0.10	535.65	14.5	0.008	23.409	90.07%	90.38%	2
23	164.94	20.00	6222.98	1.03	0.12	535.65	29.5	0.016	24.295	86.33%	90.38%	2
24	204.06	15.33	6223.67	1.27	0.10	535.65	19.5	0.010	25.459	91.66%	90.44%	
25	196.35	20.73	6236.77	1.22	0.13	535.65	26.5	0.014	26.540	88.28%	90.34%	
26	196.95	19.23	6242.86	1.23	0.12	535.65	19.5	0.010	27.639	89.38%	90.30%	
27	194.98	21.90	6255.62	1.22	0.14	542.24	18.5	0.010	28.712	87.95%	90.20%	
28	202.84	19.93	6242.39	1.27	0.12	493.94	18.0	0.009	29.845	89.47%	90.17%	
29	190.97	17.10	6266.43	1.20	0.11	544.43	22.5	0.012	30.922	90.02%	90.17%	
30	198.48	18.50	6246.28	1.24	0.12	536.38	17.5	0.009	32.037	89.92%	90.16%	
31	192.60	12.97	6203.35	1.19	0.08	474.18	22.5	0.011	33.140	92.37%	90.24%	

Run #	Inf. Conc. (mg/L)	Avg. Adj. Eff. Conc (mg/L)	Test Vol. (L)	Mass Added (kg)	Mass Escaped (kg)	Drawdown Volume (L)	Drawdown Conc. (mg/L)	Drawdown Mass Escaped (kg)	Cumulative Mass Captured (kg)	Run Eff.	Cumulative Removal Efficiency	Note
32	207.88	18.60	6128.75	1.27	0.11	586.87	16.5	0.010	34.291	90.29%	90.24%	
33	203.43	15.97	6171.98	1.26	0.10	621.27	20.0	0.012	35.435	91.16%	90.27%	
34	197.44	15.47	6175.20	1.22	0.10	562.73	21.0	0.012	36.547	91.20%	90.30%	
35	198.46	17.67	6175.71	1.23	0.11	590.53	22.5	0.013	37.650	90.01%	90.29%	
36	205.62	19.10	6178.25	1.27	0.12	602.24	21.0	0.013	38.790	89.72%	90.27%	
37	199.40	17.07	6197.23	1.24	0.11	584.68	23.0	0.013	39.907	90.35%	90.27%	
38	197.12	18.83	6182.84	1.22	0.12	580.29	11.8	0.007	41.002	89.88%	90.26%	
39	205.71	19.03	6113.78	1.26	0.12	555.41	18.0	0.010	42.133	89.95%	90.25%	
40	199.53	19.13	6131.11	1.22	0.12	540.04	19.5	0.011	43.229	89.55%	90.24%	
41	199.40	18.70	6170.41	1.23	0.12	640.29	20.0	0.013	44.331	89.58%	90.24%	3
42	205.29	15.47	6031.11	1.24	0.09	490.28	11.8	0.006	45.470	92.00%	90.28%	
43	207.05	16.27	6057.83	1.25	0.10	552.48	18.5	0.010	46.616	91.33%	90.31%	
44	206.39	14.77	6056.97	1.25	0.09	529.80	20.0	0.011	47.766	92.00%	90.35%	
45	202.15	16.43	6091.81	1.23	0.10	535.65	13.0	0.007	48.890	91.31%	90.37%	
46	204.93	13.70	6079.05	1.25	0.08	742.01	15.5	0.012	50.041	92.39%	90.37%	3

Note 1 - Electrical failure caused test to be cut short. All effluent samples taken, but final auger sample missed. Mass counted towards both total cumulative mass captured and cumulative removal efficiency calculations.

Note 2 – Influent concentration out of specification. Mass counted towards total cumulative mass captured but not used in cumulative removal efficiency calculations.

Note 3 – Head level exceeded maximum allowed. Mass counted towards neither cumulative mass captured calculation nor for cumulative removal efficiency.

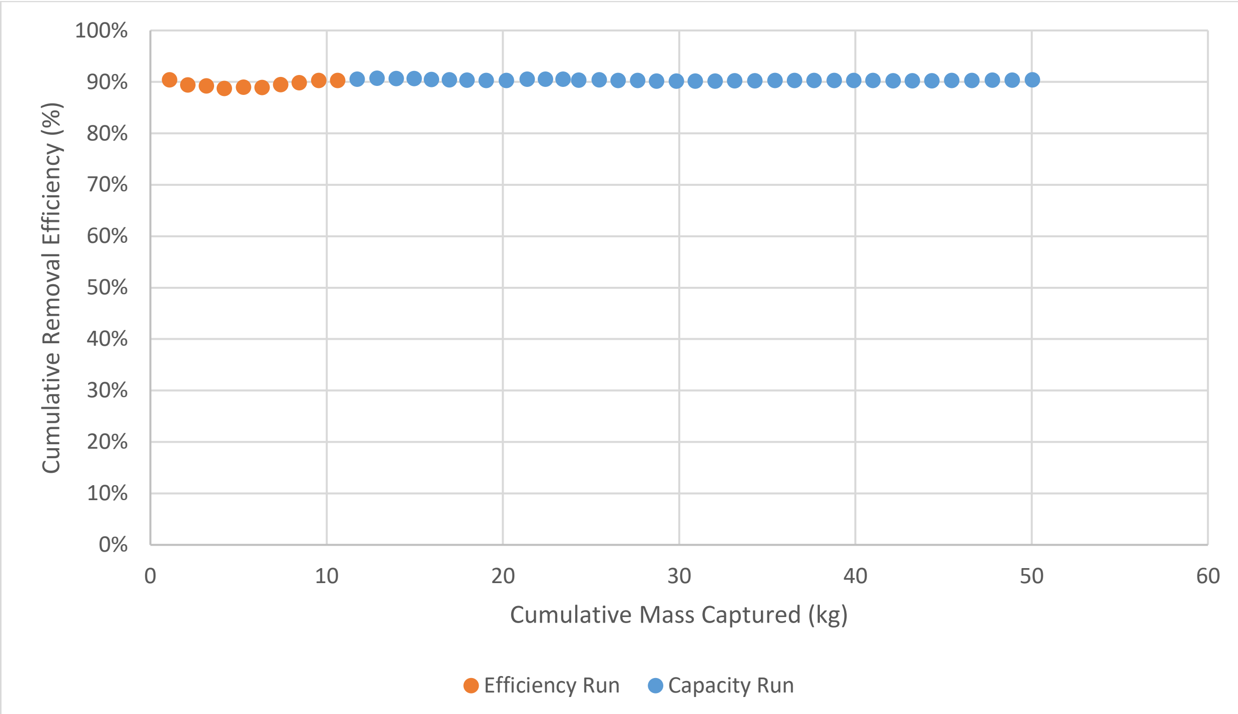

Figure 7 Sediment Mass Load Captured vs Removal Efficiency

4.3 Filter Driving Head

Driving head is defined as the vertical distance between the media level and the water level measured at the end of a test run. Thus, the filter driving head was measured from the top of the media and was observed to generally increase with sediment mass load. Some variations in hydraulic capacity appear to be due to media moisture content and were seen to vary depending on test schedule. This relationship is shown in **Tables 15 and 16** and in **Figure 7.**

Table 15 Removal Efficiency Driving Head Summary

Run	Head Level (in)	Cumulative Mass Captured (kg)
1	0.036	1.081
2	0.023	2.126
3	0.011	3.178
4	0.011	4.196
5	-0.001	5.289
6	-0.001	6.330

Run	Head Level (in)	Cumulative Mass Captured (kg)
7	-0.001	7.391
8	0.011	8.446
9	0.011	9.557
10	-0.001	10.621

Table 16 Mass Load Capacity Driving Head Summary

Run	Head Level (in)	Cumulative Mass Captured (kg)
1-10		10.621
11	-0.001	11.739
12	0.011	12.852
13	-0.001	13.944
14	0.011	14.961
15	-0.001	15.947
16	1.415	16.965
17	-0.001	17.968
18	-0.026	19.059
19	5.271	20.199
20	2.992	21.376
21	-0.026	22.411
22	6.651	23.409
23	2.228	24.295
24	1.884	25.459
25	5.025	26.540
26	5.813	27.639
27	6.713	28.712
28	5.555	29.845
29	6.787	30.922
30	6.996	32.037
31	5.493	33.140
32	7.944	34.291
33	8.216	35.435
34	7.230	36.547

Run	Head Level (in)	Cumulative Mass Captured (kg)
35	7.821	37.650
36	8.634	38.790
37	7.760	39.907
38	7.747	41.002
39	7.895	42.133
40	8.018	43.229
41	9.176	44.331
42	6.885	45.470
43	7.895	46.616
44	7.957	47.766
45	7.439	48.890
46	10.716	50.041

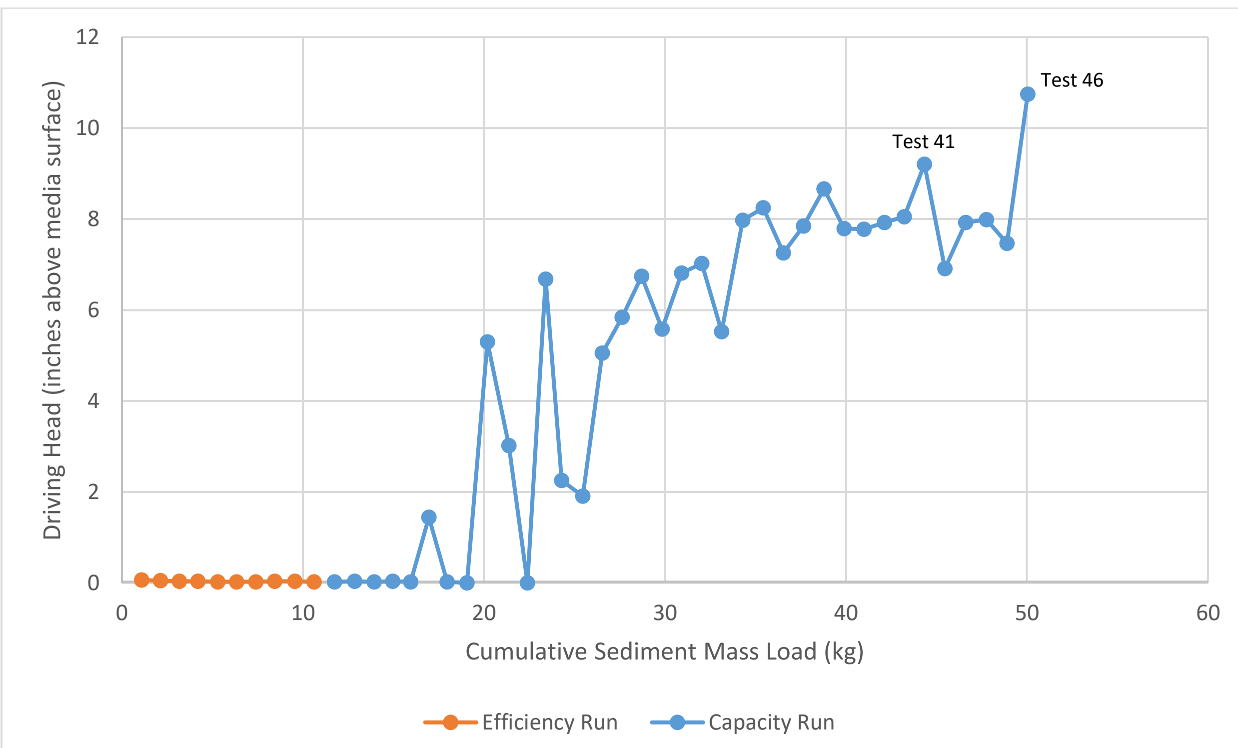

Figure 8 Sediment Mass Load Captured vs Driving Head

5. Design Limitations

If the StormScape is designed and installed correctly, there is minimal possibility of failure. The system will be designed to convey stormwater up to the maximum flow rate of the surface drainage plan. Similar to any other correctly designed treatment technology, a change in the characteristics of the contributing drainage area can lead to poor performance. An increase in imperviousness can result in higher peak flows which can exceed the treatment capacity of the StormScape. A change in land use can result in higher solids loading or a change in the type of stormwater pollutants entering the StormScape. High solids loading could result in unrealistic maintenance intervals. Caution should be used during the design of any stormwater treatment system if changes in the contributing area are expected.

Required Soil Characteristics

All StormScape systems are supported with footings meeting all applicable ASTM specifications and regional regulations. Subsequently, all systems are designed to accommodate any site-specific limitations or constraints imposed by soil type, conditions or characteristics. In addition, all internal filter components are fabricated from 6061 aluminum and 304 stainless steel.

Slope

If surrounding soils are largely impermeable or infiltration is not desired, the system can be installed with an underdrain comprised of a perforated discharge pipe embedded in coarse stone. In this configuration where the pipe stub connects directly to the outlet pipe, slope is restricted to that permitted by the connecting coupling.

Maximum Filtration Rate

The maximum filtration rate of each StormScape system is contingent on the area of the filter. Given the test results, the StormScape system will be sized to ensure the maximum filtration rate will be 1.46 gpm per ft^2 of filtration area. This is equal to an infiltration rate of 140 inches per hour.

Maintenance Requirements

StormScape maintenance requirements vary according to site characteristics such as runoff area, types of surfaces (e.g., paved and/or landscaped), site activities (e.g., short-term or long-term parking), and site maintenance (e.g., sanding and sweeping). At a minimum Hydro recommends inspection and maintenance should be conducted at intervals of no more than six months during the first year of operation. Observations made during these initial service events may be used to derive a lasting site-specific inspection and maintenance program.

Operating Head

The maximum Driving Head for the StormScape is 9 inches above the top of the media surface. This is the maximum head required to maintain the MTFR and annual sediment load and represents the appropriate grading of the curb inlet to ensure external bypass of the filter system during high flow events.

Installation Limitations

Hydro provides installation instructions as well as product specific manufacturer specifications with each project submittal. Hydro provides remote technical assistance for contractors as well as offers onsite engineering to facilitate/oversee proper installation.

Configurations

There are two options of installation available. In an “underdrain” arrangement, the system is installed directly in a rough excavation with no enclosing box or liner and with a perforated discharge pipe embedded in coarse stone, while ensuring that the regulatory requirements for separation from seasonal high water table are met. Alternately, if the surrounding soil testing confirms that the soil meets all regulatory requirements for infiltration (i.e., soil hydraulic conductivity, seasonal high water table, and groundwater mounding), the system can be installed as a “stand-alone” MTD that encourages stormwater infiltration and runoff volume reduction by maximizing contact with native soils. In both the “underdrain” and “stand-alone” configurations, the StormScape can be constructed with modular components to allow for multiple units to be nested together. The “underdrain” tested configuration submitted for verification was not tested for scour resistance and should be used in an offline installation.

Structural Load Limitations

All StormScape systems are mounted on footings manufactured by ISO certified precast facilities in accordance with all applicable ASTM specifications and/or site-specific loading requirements.

Pretreatment Requirements

The StormScape requires no additional upstream treatment. However, for source control applications having high pollutant loads, inclusion of pretreatment such as settling pools can extend filter media longevity and reduce annual service requirements.

Limitations on Tailwater

Tailwater conditions are carefully evaluated for each application. For the system to operate appropriately, a free discharge is required.

Depth of Seasonal High-Water Table

The StormScape may be designed to be connected as part of a surface drainage plan. Because there is no precast structure housing each unit, the discharge pipe should be installed above any seasonal high-water table.

6. Maintenance

Inspection

The frequency of inspection and maintenance can be determined in the field after installation. Based on site characteristics such as contributing area, types of surfaces (e.g., paved and/or landscaped), site activities (e.g., short-term or long-term parking), and site maintenance (e.g., sanding and sweeping), inspection and maintenance should be conducted at intervals of no more than six months during the first year of operation. Typically, maintenance is recommended once per year thereafter.

By removing the rubber pavers and observing any water level above the media, site personnel can determine when the filter media has become blinded. The water elevation will not drain down after an event if the media is blinded and will be higher than the top of the mulch.

The site-specific solids loading rate accumulating in the mulch and in the engineered filtration media will be determined during the first year of StormScape operation. After completion of the first year of operation, the inspection and maintenance intervals for replacing the mulch and top surface of media will be established. Removal of floatables will occur at the same frequency unless the first year of operation indicates otherwise. Keeping to the established maintenance intervals is critical for long term performance of any filtration system.

Maintenance Procedures

The removable surface pavers at the top of the StormScape provide access to the surface of the media for maintenance personnel to remove and replace the mulch and top layer of media, as well as remove any accumulated floatables.

Maintenance activities include inspection, floatables removal, sediment removal, and replacement of the top layer of media and mulch. Depending on the site, some maintenance activities are required with greater frequency than others. All inspection and maintenance activities should be recorded in an inspection and maintenance log.

Good housekeeping practices upstream of the StormScape can significantly extend media life. For example, sweeping paved surfaces, collecting leaves and grass trimmings, and employing erosion control practices will reduce loading to the system. Flow should not be directed to the system until construction activities are complete and site stabilization is effective.

Solids Disposal

Sediment, floatables, gross debris, and spent media can generally be disposed of at the local landfill in accordance with local regulations. The toxicity of the residues produced will depend on the activities in the contributing drainage area. Testing of the residues may be required if they are considered potentially hazardous.

In all cases, local regulators should be contacted about disposal requirements. Operation and Maintenance is addressed in the second half of the Assembly and Installation manual accessible at the link below: https://hydro-int.com/en/resources/stormscape-installation-maintenance-manual

7. Statements

The following signed statements from the manufacturer (Hydro International), third party observer (FB Environmental Associates) 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.

Stormwater Solutions

Hydro International

Turning Water Around...®

April 30th, 2020

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

Re: Manufacturers Statement of Compliance

Dear Dr. Magee:

Hydro International has completed verification testing for the StormScape green infrastructure filter in accordance with the *"New Jersey Department of Environmental Protection (NJDEP) Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device"* (January 25, 2013). As required by the *"NJDEP Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology (NJCAT)"*, this letter serves as Hydro International's statement that all procedures and requirements identified in the aforementioned protocol and process document were met or exceeded.

Specifically, a 4x6 StormScape was tested at Hydro International's laboratory in Portland, Maine for efficacy and sediment mass loading. To ensure that all procedures and methods were met, a test plan was completed and submitted to NJCAT for review and approval, all testing and sample collection was conducted under the direct supervision of the independent observer, FB Environmental Associates, and all collected samples were sent to either of two independent and certified laboratories; GeoTesting Express for particle size analysis or Maine Environmental Laboratories for measuring suspended solid concentrations. With this in mind, the preparation of the verification report and the documentation contained therein fulfill the submission requirements of the process document and protocol.

If you have any questions or comments regarding the verification please do not hesitate to contact us.

Sincerely,

Jeremy Fink, PE
Pr. Product Development Engineer

Hydro International (Stormwater), 94 Hutchins Drive, Portland ME 04102
Tel: (207) 756-6200 Fax: (207) 756-6212 Web: www.hydro-int.com

STATEMENT OF WITNESS | THIRD PARTY OBSERVER

TO:	Jeremy Fink, Hydro International
FROM:	Forrest Bell, FB Environmental Associates (FBE)
SUBJECT:	Third Party Witness of Hydro International StormScape Green Infrastructure Filter®
DATE:	April 26, 2020
CC:	Margaret Mills, FB Environmental Associates (FBE)

Statement of Third Party Observer

FB Environmental served as the third-party observer for tests performed on the StormScape Green Infrastructure Filter® by Hydro International in July through November of 2019 to achieve certification through the New Jersey Department of Environmental Protection (NJDEP) according to the *New Jersey Department of Environmental Protection Process for Approval of Use for Manufactured Treatment Devices (January, 2013).* The test was performed by Hydro International staff at their laboratory located at 94 Hutchinson Drive in Portland, Maine. A member of our staff verified compliance with the laboratory test protocol above, and our staff member was physically present to observe the full duration of all testing procedures.

We have also reviewed the data, calculations, and conclusions associated with the removal efficiency testing in the *NJCAT Technology Verification: StormScape Green Infrastructure Filter®* report by Hydro International, dated February 2020 (formerly referred to as the Hydro Bioinfiltrator at the time of report review), and state that they conform to what we saw during our supervision as a third-party observer.

Forrest Bell ~ FB Environmental Associates

4/26/2020

Date

STATEMENT OF DISCLOSURE | THIRD PARTY OBSERVER

TO: Jeremy Fink, Hydro International
FROM: Forrest Bell, FB Environmental Associates (FBE)
SUBJECT: Third Party Observer Statement of Disclosure under New Jersey Department of Environmental Protection Process for Approval of Use for Manufactured Treatment Devices
DATE: April 26, 2020
CC: Margaret Mills, FB Environmental Associates (FBE)

Statement of Disclosure – Third Party Observer

FB Environmental has no financial conflict of interest regarding the test results of the stormwater device testing outlined in the *NJCAT Technology Verification: StormScape Green Infrastructure Filter®* (formerly referred to as the Hydro Bioinfiltrator at the time of report review) by Hydro International, dated February 2020.

Disclosure Record

FB Environmental has provided the service of third party observer for tests performed by Hydro International in July through November of 2019. The tests assessed the removal efficiency of the StormScape Green Infrastructure Filter® in filtering polluted stormwater using a downward flow, horizontal media bed system. Beyond this, FB Environmental and Hydro International have no relationships that would constitute a conflict of interest. For example, we have no ownership stake, do not receive commissions, do not have licensing agreements, and do not receive funds or grants beyond those associated with the testing program.

Forrest Bell ~ FB Environmental Associates

4/26/2020
Date

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

April 18, 2020

Gabriel Mahon, Chief
NJDEP
Bureau of Non-Point Pollution Control
Bureau of Water Quality
401 E. State Street
Mail Code 401-02B, PO Box 420
Trenton, NJ 08625-0420

Dear Mr. Mahon,

Based on my review, evaluation and assessment of the testing conducted on the Hydro International StormScape under the third party oversight of EB Environmental Associates, the test protocol requirements contained in the "New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device" (NJDEP Filter Protocol, January 2013) were met or exceeded. Specifically:

Test Sediment Feed

The test sediment was a blend of commercially available silica sand grades. The sediment was blended by Hydro and the particle size distribution was independently verified by GeoTesting Express certifying that the blended silica meets the specification within tolerance as described in Section 5B of the NJDEP filter protocol and was acceptable for use.

Removal Efficiency Testing

Forty-six (46) removal efficiency testing runs were completed in accordance with the NJDEP filter protocol. Thirty-six (36) of the 46 test runs were conducted during mass loading and 10 during removal efficiency testing. The target flow rate and influent sediment concentration were 42 gpm and 200 mg/L for Test Runs 1-41. Maximum driving head of 9" was reached at Test Run 41 and the flow rate was reduced to 90% of the MTFR (37.8 gpm) for Test Runs 42-46 per the filter protocol. The StormScape demonstrated an average sediment removal efficiency on a cumulative mass basis of 90.3% over the course of the 10-removal efficiency test runs and 90.4% for the 46 test runs.

Sediment Mass Loading Capacity

Mass loading capacity testing was conducted as a continuation of removal efficiency testing. Mass loading test runs were conducted using identical testing procedures and targets as those used in the removal efficiency runs, the only change was to decrease flow rate to 90% MTFR for runs 42-46. Testing concluded after test run46 due to exceedance of the design driving head at 90% of the design flow rate. The StormScape demonstrated a mass loading capture capacity of 105.4 lbs (3.66 lbs/ft2 of filter area).

No maintenance was performed on the test system during the entire testing program.

Scour Testing

The StormScape is designed for off-line installation. Consequently, scour testing is not required.

Sincerely,

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

8. References

ASTM D422-63 (2007). *Standard Test Method for Particle-Size Analysis of Soils.*

ASTM D3977-97 (2013). *Standard Test Methods for Determining Concentrations in Water Samples*.

NJDEP 2013. *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.

NJDEP 2013a. *New Jersey Department of Environmental Protection Laboratory Process for Approval of Use for Manufactured Treatment Devices.* Trenton, NJ. January 25, 2013.

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

VERIFICATION APPENDIX

Introduction

- Manufacturer – Hydro International, 94 Hutchins Drive, Portland, ME 04102. *General Phone: (207)756-6200*. *Website:* www.hydro-int.com/us.
- MTD – Typical StormScape Design Specifications are shown in **Table A-1**.
- TSS Removal Rate – 80%
- Media – Sand/Organics Mix
- Off-line installation

Detailed Specification

- StormScape sizes, MTFR, and maximum drainage area per NJDEP sizing requirements are attached (**Table A-1**).
- Maximum inflow drainage area
  - The maximum inflow drainage area is governed by the maximum treatment flow rate or sediment loading on the filter for each filter arrangement as presented in **Table A-1**
- Product Assembly, Installation and O&M manual can be accessed at the link below (click button "Access this resource"):https://hydro-int.com/en/resources/stormscape-installation-maintenance-manual
- This verification does not extend to the enhanced removal rates under NJAC 7:8-5.5 through the addition of settling chambers (such as hydrodynamic separators) or media filtration practices (such as a sand filter).

Table A-1 StormScape Design Specifications

Filter Size (ft)	Width (ft)	Length (ft)	Area (sq.ft.)	MTFR (gpm)	Max Drain Area (ac)	EFTA (sq.ft.)	MTFR/ EFTA	ESTA (sq.ft.)	ESTA/ EFTA	ac/EFTA
Tested	*4.38*	*6.58*	*28.8*	*42*	*0.176*	*28.8*	*1.46*	*28.8*	*1.00*	*0.0061*
4x6	4.0	6.0	24.0	35	0.147	24.0	1.46	24.0	1.00	0.0061
4x8	4.0	8.0	32.0	47	0.196	32.0	1.47	32.0	1.00	0.0061
4x10	4.0	10.0	40.0	58	0.244	40.0	1.45	40.0	1.00	0.0061
4x12	4.0	12.0	48.0	70	0.293	48.0	1.46	48.0	1.00	0.0061
6x6	6.0	6.0	36.0	53	0.220	36.0	1.44	36.0	1.00	0.0061
6x8	6.0	8.0	48.0	70	0.293	48.0	1.46	48.0	1.00	0.0061
6x10	6.0	10.0	60.0	87	0.367	60.0	1.45	60.0	1.00	0.0061
6x12	6.0	12.0	72.0	105	0.440	72.0	1.46	72.0	1.00	0.0061