FULL SCALE STORMWATER TREATMENT STRUCTURE HYDRAULICS, SEDIMENT REMOVAL, & SEDIMENT RETENTION TESTING

Conducted in Accordance with

ASTM Standards C1745/C1745M-11 and C1746/C1746M-12

by

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Submitted to

Momentum Environmental, LLC

Limited Distribution Report No. 396

Summary Version

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March 2015

EXECUTIVE SUMMARY

The Preserver dissipator and skimmer components were installed in a 6 ft diameter concrete structure with a 6 ft deep sump (depth below the outlet pipe invert), with 2 ft diameter inlet and outlet pipes. A 3 ft depth sump was also tested via the addition of a false floor. Additional testing equipment was included as necessary to meet the requirements of the testing procedures (e.g. pumps, sediment feeder, drain pipes, sediment screening, flow meter, laser to measure sediment bed bathymetry, etc.)

Hydraulic testing was performed in accordance with ASTM Standard C1745/C1745M-11. Sediment removal testing was performed in accordance with ASTM Standard C1746/C1746M-12. Sediment retention testing was performed in accordance with the methodology outlined in Section 2.5.

The hydraulic results were plotted using the modified outlet velocity head function to allow designers to accurately predict the manhole water level given a flow rate and outlet pipe diameter. The addition of the Preserver components were found to increase water levels/head loss in the structure. With the specific testing configuration and at the maximum tested flow rate of 16 cfs, the dissipator was found to increase the water level in the structure by approximately 0.5 ft, while the dissipator and skimmer combination raised the water level in the structure by approximately 1 ft over a standard sump manhole.

The removal results were plotted using the Peclet function to allow designers to accurately predict sediment removal performance given a known particle size distribution and specific gravity, structure dimensions, and flow rate. In comparison to standard sump manholes, the addition of Preserver components were found to increase sediment removal by up to nearly 35%.

The removal results were also plotted using the Peclet Froude Jet Squared function to allow designers to accurately predict sediment removal performance given the Peclet parameters listed previously and the inlet pipe diameter. Factoring the inlet pipe diameter into the performance function allows the designer to account for how various inlet pipe diameters will affect the influent jet velocity, and consequently sediment removal and retention performance.

The retention results were also plotted using the Peclet Froude Jet Squared function to allow designers to accurately predict sediment retention performance given the parameters

previously listed. The Preserver was found to nearly eliminate sediment scour when installed into a standard sump manhole. For example, under the given testing conditions and at the peak flow rate tested of 16 cfs, the Preserver was found to limit the sediment effluent concentration from approximately 10 to 15 mg/l, while the standard sump manhole had effluent concentrations from approximately 150 to 600 mg/l.

ACKNOWLEDGEMENTS

This hydraulic model study was conducted for, and commissioned by Momentum Environmental, LLC. The authors are grateful to Mr. Lance Hoff and Mr. Dan Murphy of Momentum Environmental for their contributions to this project.

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1 INTRODUCTION

Momentum Environmental, LLC (Momentum) has developed a new stormwater treatment structure, The Preserver™, and has contracted IIHR—Hydroscience & Engineering (IIHR) to perform third-party performance testing and verification. This project included testing for hydraulic characteristics, sediment removal efficiency, and sediment retention, according to applicable ASTM standards. Two sump configurations were tested, both a 6-ft diameter structure with a 6-ft sump depth and a 6-ft diameter structure with a 3-ft sump depth for hydraulic, sediment removal and sediment retention (6-ft sump only). The first configuration consisted of an energy dissipator installed at the manhole inlet while the second configuration consisted of the energy dissipator and a floatables skimmer installed upstream of the manhole outlet.

1.1 Overview

The IIHR testing, data collection, and analysis effort was led by Hydraulic Engineer, Andy Craig and Undergraduate Research Assistant, Adrian Simonson. Director of Engineering Services, Troy Lyons provided general project oversight and administrative support.

Testing of the structure included visual assessment, flow measurement, hydraulic grade line measurement, water temperature measurement, quantifications of sediment removal and sediment retention, measurements of sediment influent and effluent concentrations, and classifications of sediment particle size distributions.

Operation of the test setup was observed by Momentum representative, Dan Murphy, during a visit to IIHR on May 29, 2014.

1.2 Objective

Determine the effectiveness for sediment removal and sediment retention of two full scale in-line stormwater treatment structures.

2 EXPERIMENTAL METHODS AND MATERIALS

2.1 Testing Requirements

The following tests must be conducted to meet the requirements listed:

- Testing of hydraulic characteristics: ASTM Standard C1745/C1745-11
- Testing of sediment removal efficiency: ASTM Standard C1746/C1746M-12
- Testing of sediment retention will need to adhere to the testing methodology summarized in Section 2.5.

2.2 Testing Configuration

The following list summarizes the testing configuration requirements.

Momentum provided the following:

1) Standard 6 ft sump structure including:
    a. Openings for inlet and outlet connections.
    b. Openings for valves at various elevations for draining and cleaning the structure.

IIHR was responsible for providing and installing the following:

1) Influent and effluent pipes.
2) Method for calculating flow rate.
3) Method for collecting water temperature measurements in sump structure.
4) Method for measuring water elevations in inlet, outlet, and structure during tests.
5) Method for metered sediment delivery for removal efficiency testing.
6) Method for determining initial and final sediment volumes within sump for sediment retention testing.

2.3 Hydraulics Testing

The hydraulic testing methodology must meet the testing requirements included in ASTM Standard C1745/C1745M-11. Below is a summary of the hydraulics testing requirements.

Momentum required testing for 4 manhole configurations, including:

1) 6 ft sump with energy dissipator only
    a. 4 flow rates for sediment removal
    b. 4 flow rates for sediment retention
2) 6 ft sump with energy dissipator and skimmer
    a. 4 flow rates for sediment removal
    b. 4 flow rates for sediment retention
3) 3 ft sump (false floor added to structure) with energy dissipator only
    a. 4 flow rates for sediment removal
4) 3 ft sump (false floor added to structure) with energy dissipator and skimmer
    a. 4 flow rates for sediment removal

This resulted in a total of 24 tests. The hydraulics testing procedure was performed in tandem with each of the 24 sediment removal/retention tests. Each test generally included:

1) 3 flow measurements
2) 3 water elevation measurements, at 3 locations (inlet, outlet, and structure).
3) 3 water temperature measurements within the sump.

2.4 Sediment Removal Testing

The sediment removal testing methodology must meet the testing requirements included in ASTM Standard C1746/C1746M-12. Below is a summary of the sediment removal testing requirements.

Momentum had requirements for 4 manhole configurations, including:

1) 6 ft sump with energy dissipator only
   a. 4 flow rates for sediment removal
2) 6 ft sump with energy dissipator and skimmer
   a. 4 flow rates for sediment removal
3) 3 ft sump with energy dissipator only
   a. 4 flow rates for sediment removal
4) 3 ft sump with energy dissipator and skimmer
   a. 4 flow rates for sediment removal

The flow rates used for sediment removal testing included 0.8 cubic feet per second (cfs), 1.6 cfs, 3.2 cfs, and 6.4 cfs. This resulted in a total of 16 sediment removal tests. Each test generally included:

1) Prior to the tests, IIHR was required to prepare the sediment and sediment delivery system. IIHR was responsible for acquiring sediment and for creation of the testing particle size distribution (PSD). Three narrow distributions were attained via a third party, AGSCO Corp., and then mixed together in equal parts to create the testing sediment PSD. The PSD consisted of a mixture of the following three narrow distributions obtained from AGSCO Corporation. The PSDs for each of the narrow distributions are show in Figure 2-1. Sieve analysis was performed by IIHR according to ASTM Standards C 136-06 and E11-13.
   a. Fine: Passing sieve #100, 10.98% retained on sieve #120, 87.69% retained on sieve #170, and 1.32% passing sieve #170.

b. Medium: passing sieve #35, 1.05% retained on sieve #40, 36.73% retained on sieve #45, 62.22% retained on sieve #60.

c. Coarse (batch 1): Passing sieve #25, 0.94% retained on sieve #30, 95.18% retained on sieve #35, 3.65% retained on sieve #40, and 0.22% retained on sieve #45.

d. Coarse (batch 2): Passing sieve #25, 1.27% retained on sieve #30, 96.58% retained on sieve #35, 1.93% retained on sieve #40, and 0.22% retained on sieve #45.

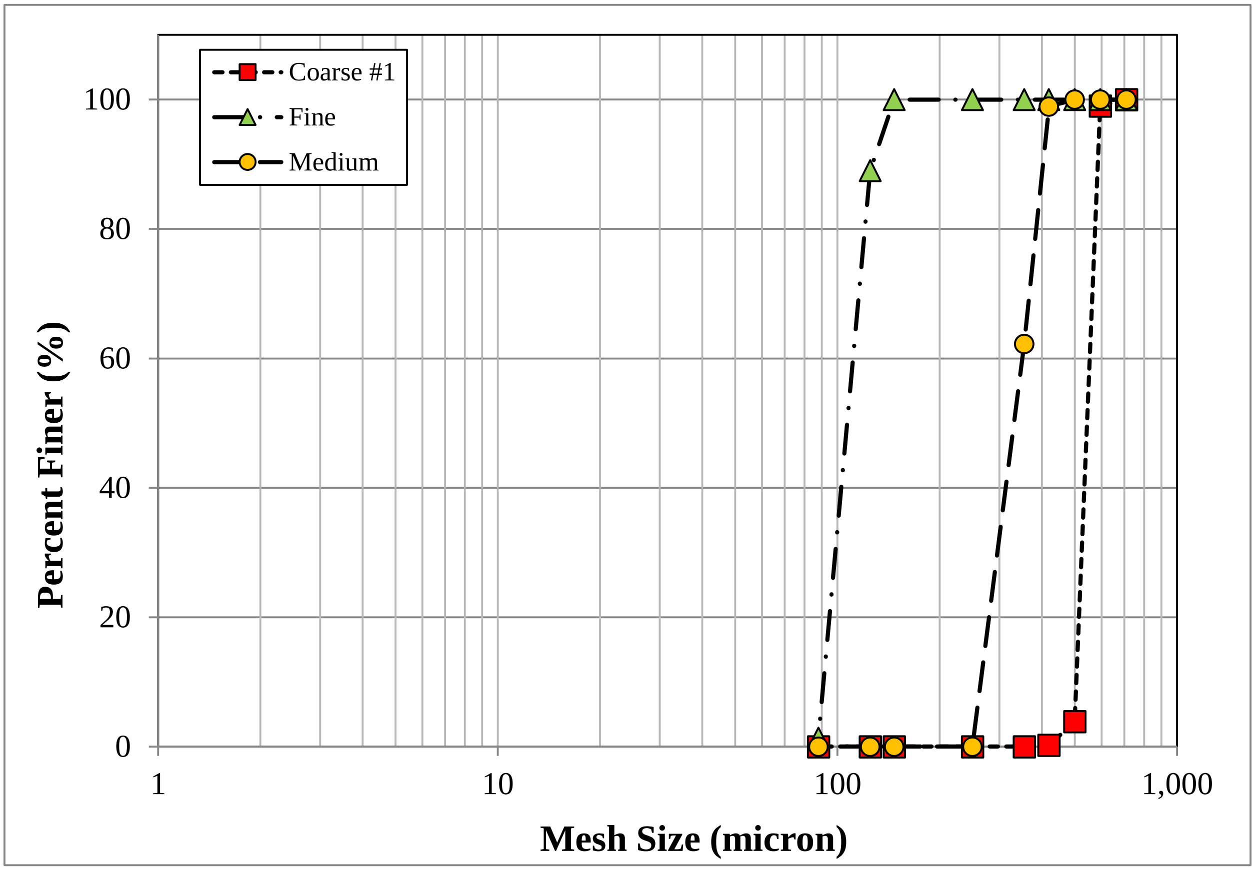

Figure 2-1. Narrow distribution PSDs for sediment removal testing

2) During the tests, the sediment feed rate was sampled and hydraulic data was collected.
3) Following the test, the captured sediment was collected, dried, sieved and weighed.

2.5 Sediment Retention Testing

The sediment retention testing methodology must meet the testing requirements provided by Momentum. Below is a summary of the sediment retention testing requirements.

Momentum had requirements for 2 manhole configurations, including:

1) 6 ft sump with energy dissipator only
    a. 4 flow rates for sediment retention
2) 6 ft sump with energy dissipator and skimmer
    a. 4 flow rates for sediment retention

The 2 configurations were tested at flow rates of 4 cfs, 8 cfs, 12 cfs, and 16 cfs, resulting in a total of 8 sediment retention tests. Each test generally included:

1) Prior to the test:
    a. IIHR was responsible for acquiring sediment and for creation of the testing PSD. U.S. Silica's F-110 silica sand gradation is required for testing, but is no longer available. An equal alternate F-110 was attained via a third party, AGSCO Corp. A plot is provided in Figure 2-2 comparing the two F-110 PSD.
    b. IIHR determined the sediments saturated bulk density. The saturated bulk density is used to calculate an average sediment effluent concentration.
    c. Determine initial sediment volume
2) During the tests, hydraulic data was collected.
3) Following the test, IIHR determined the volume of sediment lost.

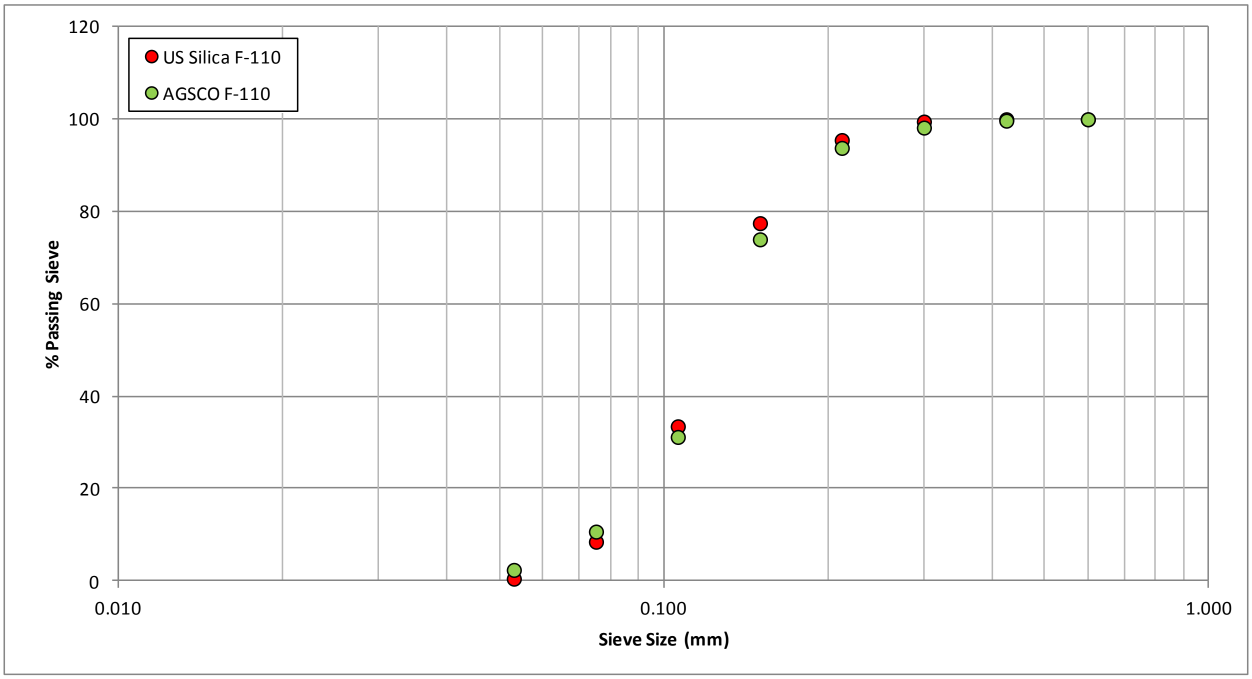

Figure 2-2. F-110 comparison

3 TEST FACILITIES

IIHR maintains a modern, well-equipped, and competently staffed model-building shop in addition to its electronics and instrumentation laboratory. The model was built in IIHR’s Oakdale Annex II (HA2), a 100 by 125-foot research facility at the University of Iowa's Oakdale Campus. The building has a clear-span floor area of over 11,000 square feet and a 15 by 24-foot conference room with high speed wireless internet.

3.1 Experimental Setup

A full-scale pre-cast concrete cylindrical manhole, 6 ft diameter by 11.5 ft high, was supplied by Momentum through a third party manufacturer (Cretex Concrete Products) and placed on a test stand at the IIHR Laboratory. The manhole was facilitated with 2 ft diameter inlet and outlet pipes oriented at 180 degrees relative to one another (aligned), centered about the manhole with a slope of 2.5%. IIHR supplied all pipe and fittings for plumbing of the test setup.

Due to the weight of the concrete manhole structure and the water it contains during testing (approximately 40,000 lbs in total), the manhole structure is supported on a structural steel framework (approx. 9 ft x9 ft) to uniformly distribute the load over the lab floor to avoid cracking.

To insure flow uniformity entering the manhole structure, a minimum 20-ft section of straight 2-ft diameter pipe (10 diameters) was installed upstream of the manhole inlet. Water was discharged from the manhole through a minimum 6 ft section of 2ft diameter pipe with a free discharge into a catchment basin on the Laboratory floor and filtered with a 270 mesh stainless steel screen to remove sediment and directed back to the sub-grade storage sump for re-use. The manhole was equipped with a low-level drain to facilitate cleaning/washout, and several side-wall drains to drain water without disturbing sediments. All drains were fitted with 270 mesh screens to prevent sediment loss during drain down.

A precision sediment feed system was installed upstream in the crown of the 20-ft section of straight pipe to feed sediments into the supply flow for sediment removal tests. The sediment injection point is placed approximately 4-ft from the test unit (per ASTM Standard C1746/C1746M-12).

Figure 3-1 shows the model layout in HA2. Figure 3-2 shows a perspective view of the overall test setup. Figure 3-3 shows a picture of the completed test setup.

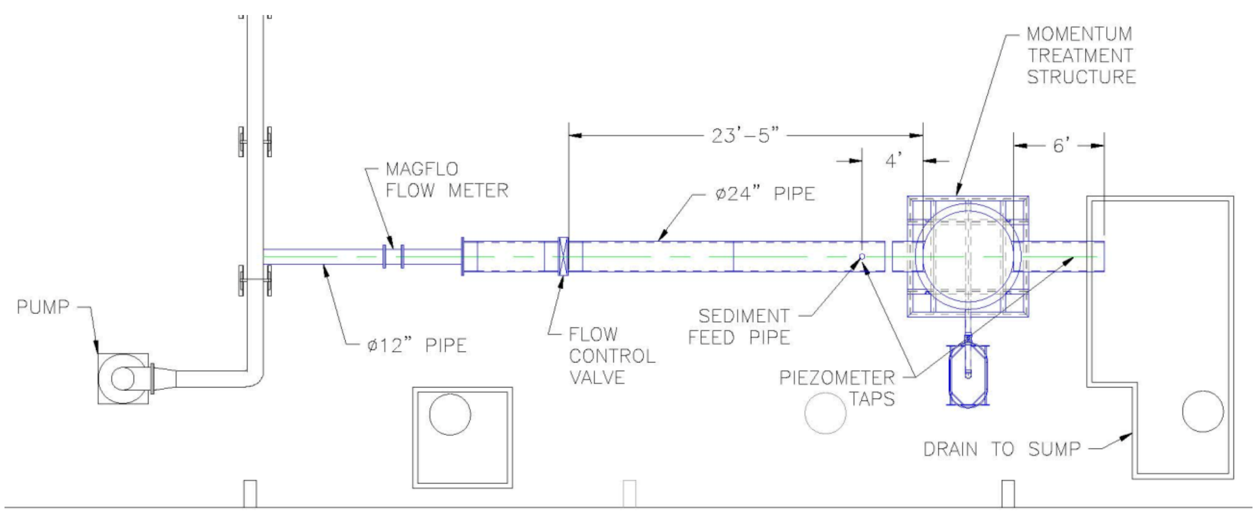

Figure 3-1. Momentum stormwater treatment structure plan view inside HA2

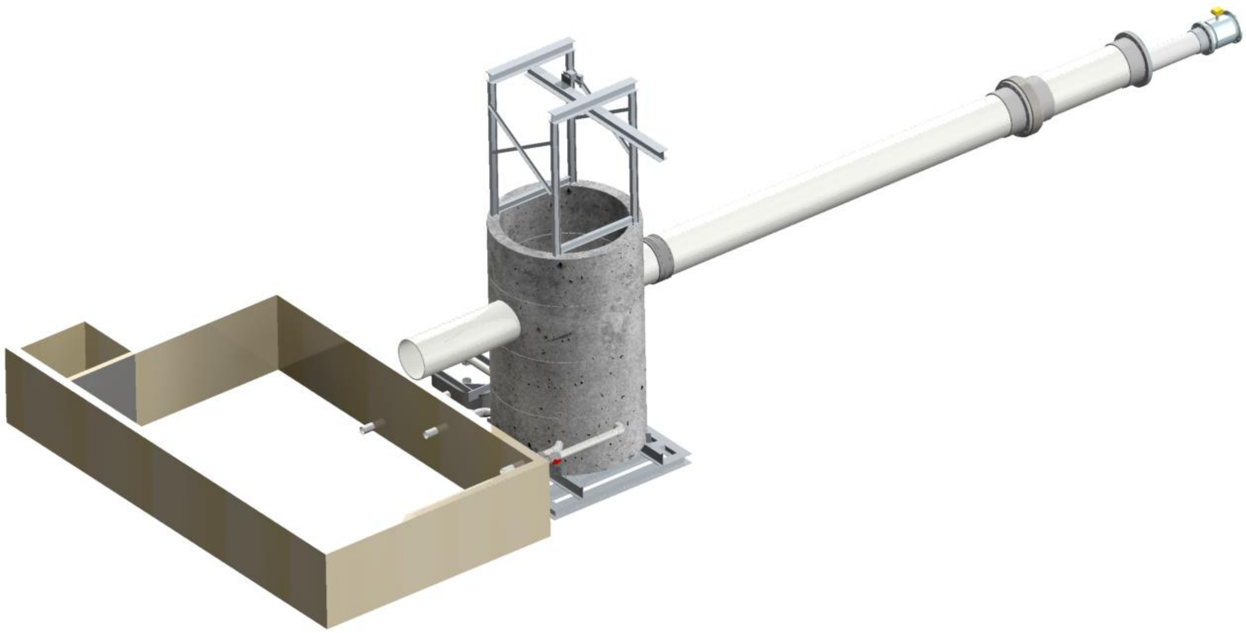

Figure 3-2. Perspective view of the experimental setup

Figure 3-3. Test setup

3.1.1 Flow Conveyance and Measurement

A 150hp pump with a variable frequency drive (VFD) controller supplied water to the model. Water was pumped through a 12-inch PVC pipe main from the sump under the laboratory floor and then through sections of 10-inch and 24-inch pipe. Precise control of model flow rates was provided by butterfly valves in the feed lines and the VFD. Flow was measured with a Badger Meter Inc. M2000 flow meter accurate within ±0.25%.

3.1.2 Water Surface Levels and Pressures

Hydraulic grade lines (HGLs) were measured using pressure taps attached to the model at pre-selected locations mutually agreed upon between IIHR and Momentum. The HGL profiles were plotted and used to determine water surface profiles throughout the treatment structure system.

3.1.3 Sediment Delivery System

Sediment mixtures were fed into the influent pipe 4 ft. upstream of the structure using a Schenck AccuRate Feeder model 304M dual drive dry material feeder with 1.0 cubic foot hopper extension.

3.1.4 Sediment Surface Measurement

Sediment retention testing incorporated an in-situ sediment surface measurement device to accurately map the initial and final sediment test surfaces during sediment retention testing. Surface maps were generated using identical laser scans from a fixed rigid mount to calculate the volume of sediment scoured from the manhole structure. Sediment scour rates were calculated by coupling the calculated scoured volume with the test time and flowrate information.

To accurately measure the surface of the sand and/or manhole floor, a custom-designed terrestrial laser scanner (TLS, Plenner et al. 2014) was employed. A custom mount was designed and fabricated to position the TLS over the manhole and remained in a fixed position throughout the duration of retention testing. The TLS system couples an industrial grade Acuity Laser® range finder with a FLIR Motion Control Systems, Inc. pan/tilt unit. MATLAB®, CloudCompare, and ArcGIS were used to process the spatial point data.

4 RESULTS

4.1 Hydraulics Testing

Hydraulic grade line (HGL) data was collected during sediment removal and sediment retention testing. Results from the hydraulics testing have been used to create Figure 4-1 below. The plot shows the structure water level (y axis) versus a modified outlet velocity head. These water level function were created so that a designer can accurately predict the water level in a structure with known values for the flow rate and outlet pipe diameter. The outlet velocity head was modified by including power adjustments to normalize the function for inclusion of varying pipe diameters. This was done by calibrating a hydraulics model to the known test results, then modeling water levels of various outlet pipe diameters. The final functions shown below were found to be accurate not only for the laboratory test results, but also for the modeling results across all pipe diameters applicable to the product (12" – 36"). These functions are accurate up to a modified outlet velocity head value of 1.125. The water level functions are as follows:

Modified Outlet Velocity Head, $\hat{H}_v$:

$$\hat{H}_v = \left[\frac{\left(\frac{Q}{\sqrt{A_o}}\right)^2}{2 \cdot g}\right]^{\frac{1}{3}}$$

Where:

Q = flow rate in cfs

A_o = outlet cross sectional area in ft^2

g = gravitational constant in ft/s^2

Water Level:

$$Water\ Level = a \cdot \hat{H}_v^{\,b}$$

Where:

a, b = fitting parameters

Table 4-1. Fitting parameters for water level function

Configuration	Fitting Parameter	
	a	b
Dissipator Only	2.06	0.95
Dissipator & Skimmer	2.49	1.05

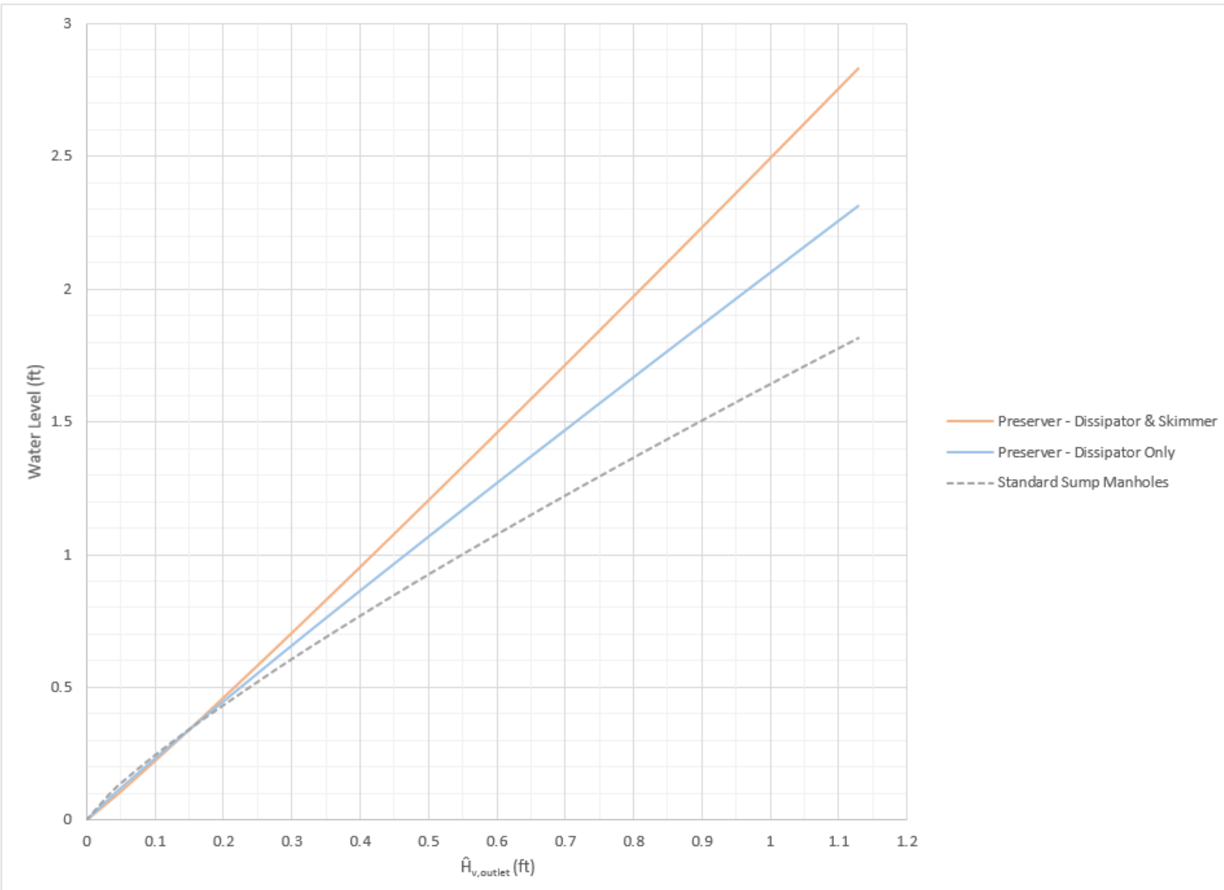

Figure 4-1. Water level chart

4.2 Sediment Removal Testing

The sediment removal testing methodology met the requirements included in ASTM Standard C1746/C1746M-12. A 6 ft sump depth and a 3 ft sump depth were tested for both the dissipator only (D) and dissipator + skimmer (DS) installed conditions. Each sump configuration was tested by feeding sediment into the influent at the four specified flowrates. For the 0.8 cfs flow conditions only the coarse sediment distribution was fed into the structure. For the 1.6, 3.2, and 6.4 cfs flow conditions a composite mix using equal parts of fine, medium, and coarse sediment distribution was introduced.

Feed rates were monitored by sampling the sediment feeder at the injection point at evenly spaced intervals throughout testing. The maximum sediment feed rate coefficient of variation (COV) was 0.025, well below the required COV of 0.10. The material added ranged from 22.89 – 32.12 lbs. with corresponding suspended solids concentrations ranging from 72.19 – 196.59 mg/L, well within the required range of 50 – 300 mg/L. Water temperatures in the sump ranged from 67.5 – 72.0 °F, outside of the 64.0 – 68.0 °F recommended range but still considered acceptable. Results were normalized to account for water temperature/viscosity variations during testing.

Upon completion of testing, drain down was conducted by using the series of 270 mesh screened side wall drains. Once drain down was completed, the low level drain was used to washout and collect the removed sediment. The collected sediment was then placed into an oven and allowed to dry for at least 24 hours until a constant weight was obtained. Dried sediment was then weighed and sieved back into each narrow distribution for further analysis. Sieving procedures were conducted in accordance with ASTM Standards C 136-06 and E11-13.

The dimensionless Peclet number (Pe) was used to collapse removal test results onto one performance function. The Peclet number is defined as follows:

$$Pe = \frac{v_s \cdot h \cdot D}{Q}$$

Where:

v_s = settling velocity of sediment particles in ft/s

h = sump depth in ft

D = sump diameter in ft

Q = flow rate in cfs

The settling velocity of the sediment particles is calculated using the Cheng equation, defined as:

$$v_s = \left[\left(\left(25 + 1.2 \cdot \left(D \cdot \left(\frac{g\left(\frac{\rho_s - \rho}{\rho}\right)}{\upsilon^2}\right)^{\frac{1}{3}}\right)^2\right)^{\frac{1}{2}} - 5\right]^{1.5}$$

Where:

υ = kinematic viscosity in ft^2/s

D = particle diameter in ft

g = gravitation constant in ft/s^2

ρ_s = particle density in lb/ft^3

ρ = fluid density in lb/ft^3

The Peclet removal performance function is defined as:

$$Removal\ Efficiency = \left(\frac{1}{R^b} + \frac{1}{(a \cdot Pe)^b}\right)^{-\left(\frac{1}{b}\right)}$$

Where:

a, b, R = fitting parameters

Table 4-2. Peclet fitting parameters for sediment removal function

Peclet Fitting Parameter		
a	b	R
1.07	1.80	1

The removal test results were also plotted using the dimensionless Peclet Froude Jet Squared number (Pe/Fr_j^2). The Peclet number is calculated as previously described, then divided by the Froude Jet Squared number. The addition of the Froude Jet Squared number provides for a more robust performance function, as it includes the impacts of the influent jet velocity. As the jet velocity increases, removals will decrease, and vise-versa. The Froude Jet Squared number is as follows:

$$Fr_j^{\,2} = \frac{v_j^{\,2}}{g \cdot D}$$

Where:

v_j = influent jet velocity in ft/s

g = gravitational constant in ft/s^2

D = sump diameter in ft

The Peclet Froude Jet Squared removal performance function is defined as:

$$Removal\ Efficiency = \left(\frac{1}{R^b} + \frac{1}{\left(a \cdot \frac{Pe}{Fr_j^{\,2}} \right)^b} \right)^{-\left(\frac{1}{b}\right)}$$

Table 4-3. Peclet Froude Jet Squared fitting parameters for sediment removal function

Pe/Fr_j^2 Fitting Parameter		
a	b	R
0.0405	1.40	1

A plot of the removal efficiency vs Peclet number is shown in Figure 4-2 and a plot of the removal efficiency vs Peclet Froude Jet Squared is shown in Figure 4-3.

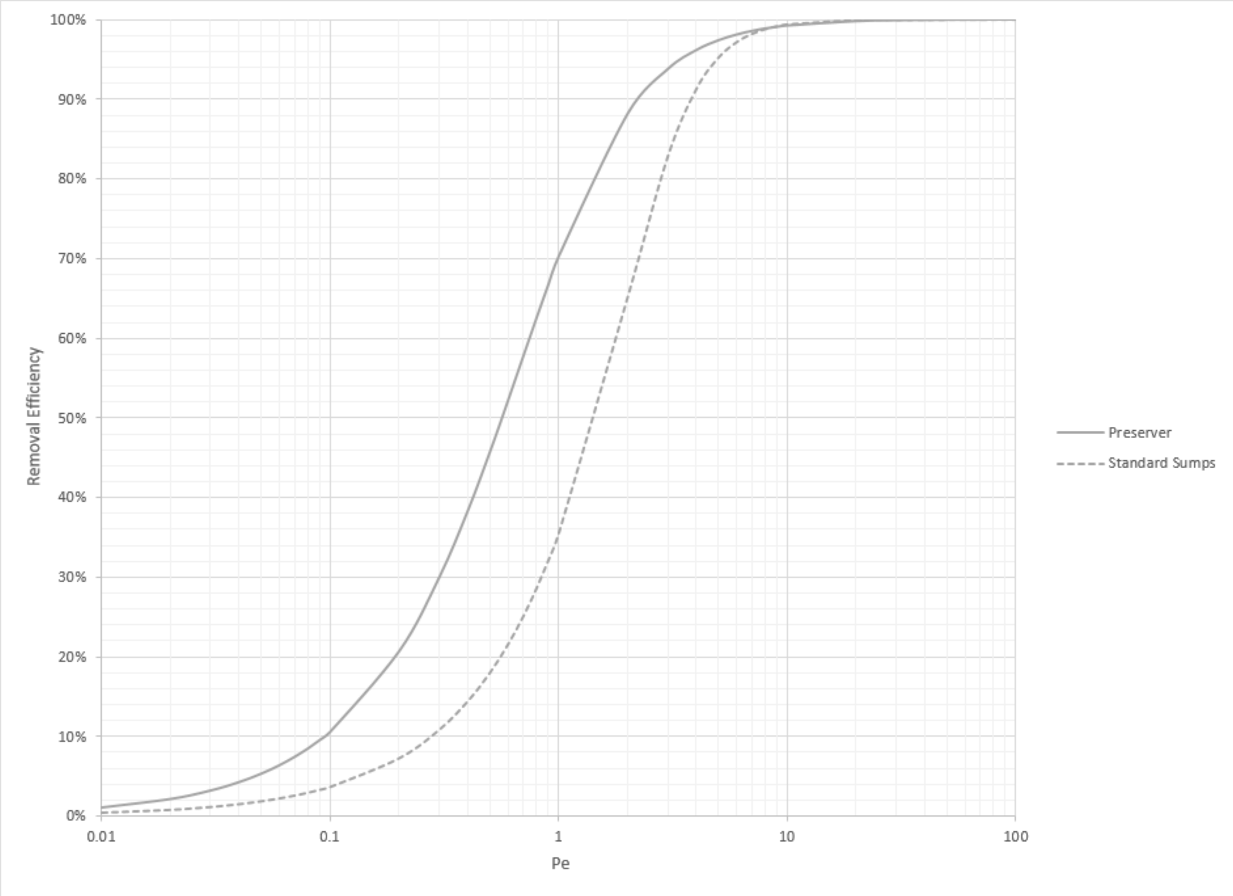

Figure 4-2. Peclet sediment removal chart

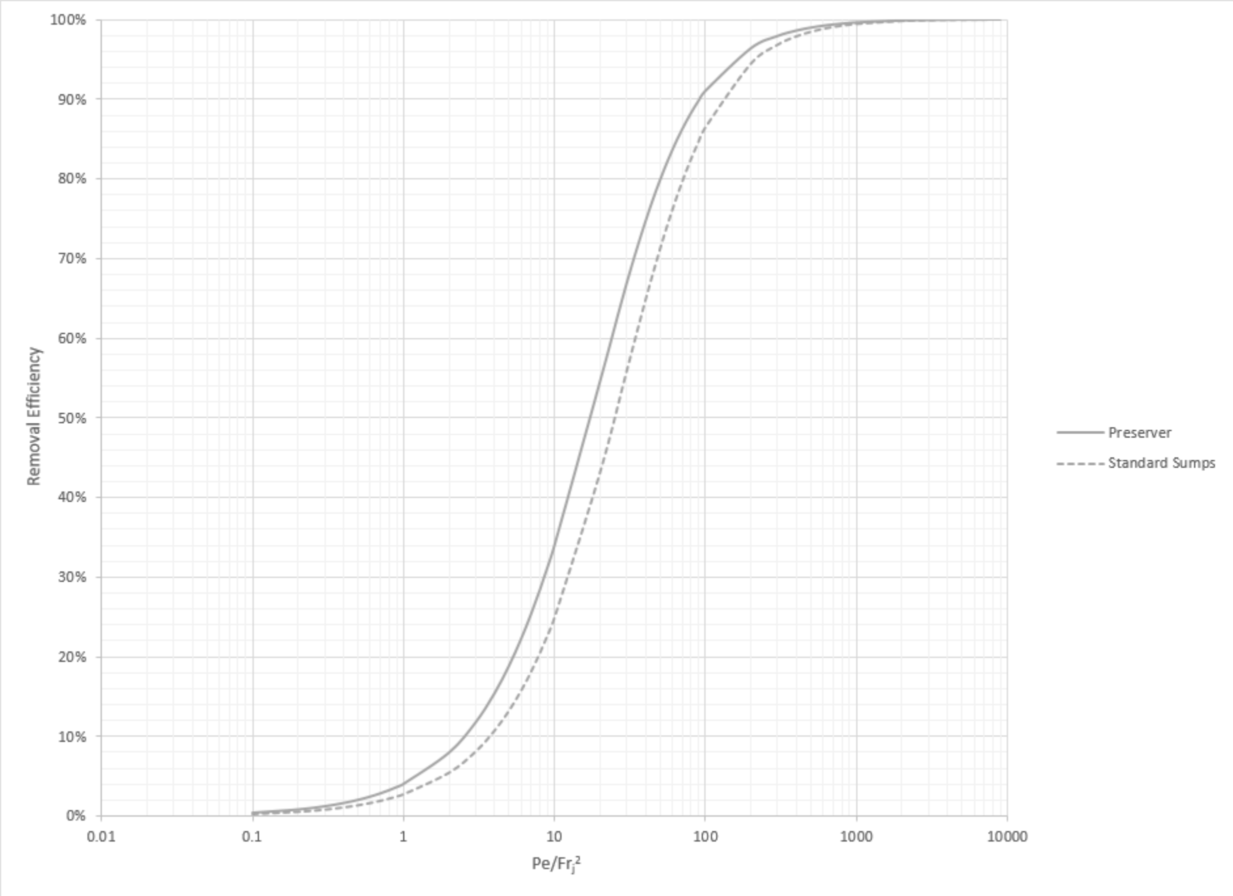

Figure 4-3. Peclet Froude Jet Squared sediment removal chart

4.3 Sediment Retention Testing

The sediment retention testing met the testing requirements provided by Momentum. Prior to testing, saturated AGSCO F-110 material was placed in the structure and leveled to a depth of 12 inches. The 6 ft sump depth was tested for both the D and DS configurations. Samples were taken from the sump before each test in order to obtain the material bulk density. The F-110 material maintained an average bulk density of 2.60 g/cm^3 for the entire duration of sediment retention testing.

Prior to each test the bed was scanned using the TLS system to obtain the initial surface data. Once the scan was complete the sump was carefully filled, as to not disturb the bed, by pumping water into the series of 270 mesh screened side wall drains. Each packed sump configuration was tested at the four specified flowrates (4, 8, 12, 16 cfs) and allowed to run for 90 – 120 minutes. Water temperatures in the sump ranged from 66.0 – 79.3 °F outside of the

64.0 – 68.0 °F recommended range but still considered acceptable. Results were normalized to account for water temperature/viscosity variations during testing.

Once testing was complete sediment was allowed to settle for at least 10 minutes before draining. Using the series of 270 mesh screened side wall drains the structure was slowly drained, ensuring that the deformed bed was not disturbed. After drain down the bed was scanned again using the TLS system to obtain the final surface data. Data from the TLS system was then analyzed and used to compute the scoured sediment volume.

The dimensionless Peclet Froude Jet Squared number (described in Section 4.2) was used to collapse the retention test results onto one performance function. To define the retention performance function, the Peclet Froude Jet Squared number is plotted against a dimensionless effluent concentration ($\hat{C}$), defined as:

$$\hat{C} = \frac{C \cdot (SG - 1)}{(SG \cdot \rho_w)}$$

Where:

C = effluent concentration in mg/l

SG = specific gravity of particles (dimensionless)

ρ_w = water density in mg/l

The Peclet Froude Jet Squared retention performance function is defined as:

$$\hat{C} = \frac{\alpha}{\left(\frac{Pe}{{Fr_j}^2}\right)^{\lambda}}$$

Where:

α, λ = fitting parameters

Table 4-4. Peclet Froude Jet Squared fitting parameters for sediment retention function

Pe/Fr_j^2 Fitting Parameter	
α	λ
1.62E-06	1.17

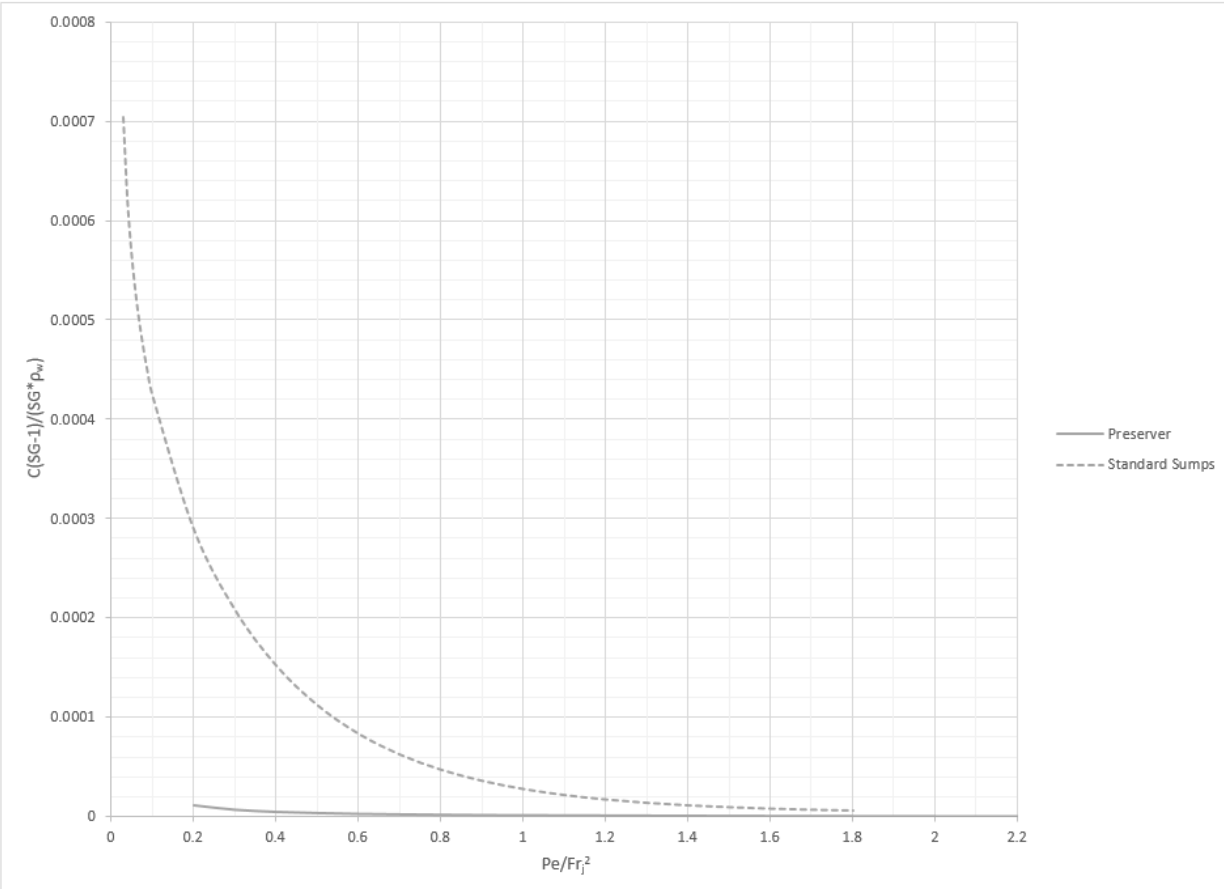

Figure 4-4. Peclet Froude Jet Squared sediment retention chart

5 CONCLUSIONS

- The Preserver dissipator and skimmer components were installed in a 6 ft diameter concrete structure with a 6 ft deep sump (depth below the outlet pipe invert), with 2 ft diameter inlet and outlet pipes. A 3 ft depth sump was also tested via the addition of a false floor. Additional testing equipment was included as necessary to meet the requirements of the testing procedures (e.g. pumps, sediment feeder, drain pipes, sediment screening, flow meter, laser to measure sediment bed bathymetry, etc.)
- Hydraulic testing was performed in accordance with ASTM Standard C1745/C1745M-11.
- Sediment removal testing was performed in accordance with ASTM Standard C1746/C1746M-12
- Sediment retention testing was performed in accordance with the methodology outlined in Section 2.5.
- The hydraulic results were plotted using the modified outlet velocity head function to allow designers to accurately predict the manhole water level given a flow rate and outlet pipe diameter. The addition of the Preserver components were found to increase water levels/head loss in the structure. With the specific testing configuration and at the maximum tested flow rate of 16 cfs, the dissipator was found to increase the water level in the structure by approximately 0.5 ft, while the dissipator and skimmer combination raised the water level in the structure by approximately 1 ft over a standard sump manhole.
- The removal results were plotted using the Peclet function to allow designers to accurately predict sediment removal performance given a known particle size distribution and specific gravity, structure dimensions, and flow rate. In comparison to standard sump manholes, the addition of Preserver components were found to increase sediment removal by up to nearly 35%.
- The removal results were also plotted using the Peclet Froude Jet Squared function to allow designers to accurately predict sediment removal performance given the Peclet parameters listed previously and the inlet pipe diameter. Factoring the inlet pipe diameter into the performance function allows the designer to account for how

various inlet pipe diameters will affect the influent jet velocity, and consequently sediment removal and retention performance.

- The retention results were also plotted using the Peclet Froude Jet Squared function to allow designers to accurately predict sediment retention performance given the parameters previously listed. The Preserver was found to nearly eliminate sediment scour when installed into a standard sump manhole. For example, under the given testing conditions and at the peak flow rate tested of 16 cfs, the Preserver was found to limit the sediment effluent concentration from approximately 10 to 15 mg/l, while the standard sump manhole had effluent concentrations from approximately 150 to 600 mg/l.

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