Verification Testing of the Hydroworks HF3i HydroFilter In Accordance with the NJDEP Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device, 2013

Technical Evaluation Report

Alden Report No.: 1182HF3i-R1

Submitted to:

Hydroworks, LLC.

Roselle, NJ

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1.0 INTRODUCTION

Under a contract from Hydroworks, LLC (Hydroworks), verification testing was conducted on the HF3i HydroFilter, at Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts.

The purpose of the testing was to define the performance characteristics of the HydroFilter under controlled laboratory conditions, utilizing established standard testing methodologies. The testing was conducted in accordance with "New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device", 2013, to establish the following parameters:

a) Sediment Removal Efficiency at Maximum Treatment Flow Rate (MTFR)

b) Filter Blinding (Occlusion) and/or maintenance statement.

c) Sediment Scour

2.0 TEST UNIT DESCRIPTION

The tested treatment filter was comprised of two (2) 24"-diameter x 12" high stacked interlocking filter cartridges installed in a 3-ft diameter tank. Each cartridge contained a proprietary filter media. The inner and outer flow surfaces of the cartridges were perforated. A 24"-diameter by approximately 12"-high deflection cone was installed on the top cartridge. The filter assembly was installed in a 24"-diameter by 12"-high base pedestal, which was sealed to the tank floor. Water was conveyed into the tank by means of an 8"-diameter inlet pipe, which discharged onto a sloped inlet containing a 24" storm grate. The flow was deflected around the annular space between the filter and tank and was conveyed radially through the cartridges. A 6" center opening conveyed the treated flow down into the base pedestal and into a 6" outlet pipe located at the bottom of the tank. The pipe was sealed to the pedestal and tank wall. A 6" bypass pipe was installed with the invert elevation at 3.04 ft. The pipe was connected to a tee in the outlet pipe upstream of the sampling point. The annular area around the base pedestal (3.93 ft^2) was designed as a settling area for larger particles. A series of anti-scour pads were installed at the height of the pedestal (dry-weather condition) to protect the captured sediment from scour.

Drawings of the HF3i test unit are shown on **Figure 1**. Photographs showing the filter installed in the test loop are shown on **Figure 2, Figure 3** and **Figure 4**. The bottom riser section shown in the photographs was used to elevate the tank for sampling purposes and was not part of the treatment system.

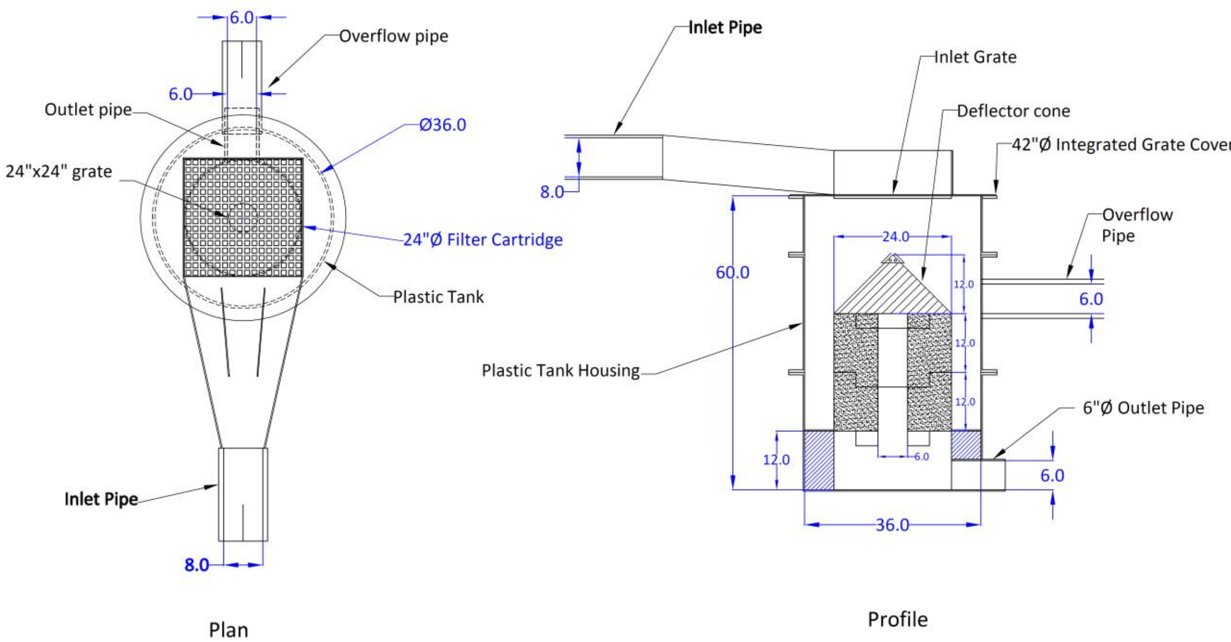

Figure 1: Drawing of the Hydroworks HF3i HydroFilter

Figure 2: Hydroworks HF3i Filter Test Set-up.

Figure 3: Test Loop Grated Inlet

Figure 4: Outlet and Bypass Piping

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

The HF3i filtration system was installed in the Alden test loop, shown on **Figure 5,** which was set up as a recirculation system. The loop was designed to provide metered flow up to approximately 1 cfs. Flow was supplied to the unit with a 20HP laboratory pump, drawing water from a 50,000-gallon supply sump. The test flow was set using a 1.5" orifice plate differential-pressure (DP) meter and corresponding control valve. A DP cell and computer Data Acquisition (DA) program was used to record the test flow. Twenty-five (25) feet of straight 8" PVC influent pipe conveyed the metered flow to a sloped inlet tray containing a 24" x 24" horizontal inlet grate. Two (2) feet of 6" PVC pipe free-discharged the effluent flows to an effluent channel, which returned the flow to the supply sump. The influent and effluent pipes were set at 1% slopes. An 8" tee was located 3 pipe-diameters (2 ft) upstream of the sloped inlet, for injecting sediment into the crown of the influent pipe using a variable-speed auger feeder.

Filtration of the supply sump was performed with an in-situ filter wall containing 1-micron bag filters.

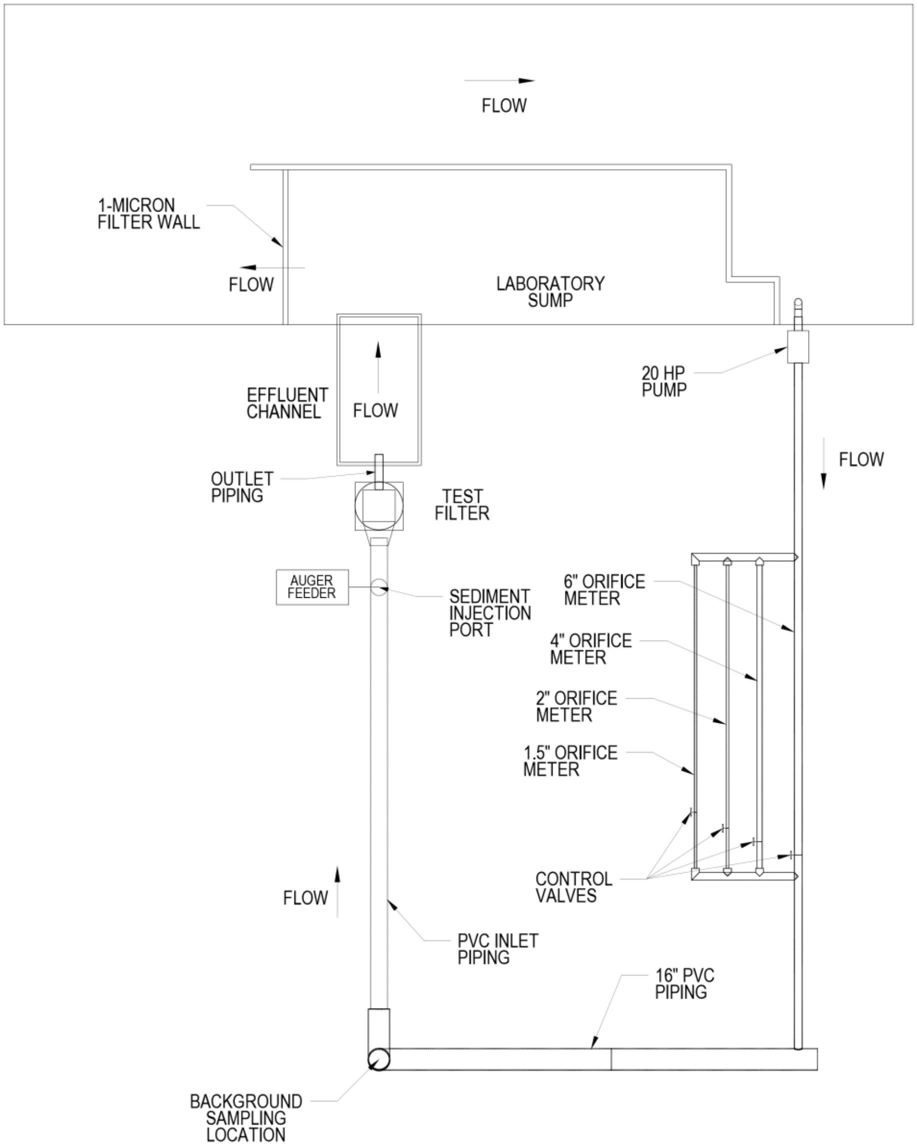

Figure 5: Plan View of Alden Flow Loop

3.1.1 Removal Efficiency Testing

Sediment testing was conducted to determine the removal efficiency, as well as sediment mass loading capacity.

The sediment testing was conducted on an initially clean system at the 100% MTFR of 25 gpm (as selected by Hydroworks). A minimum of ten (10) 30-minute test runs were required to be conducted to meet the removal efficiency criterion. Additional runs were conducted to determine the maximum mass loading. The captured sediment was not removed from the system between test runs.

The total mass injected into the system was quantified at the conclusion of all the runs. This data was used for determination of the required maintenance frequency.

The test sediment was prepared by Alden to meet the PSD gradation of 1-1000 microns in accordance with the distribution shown in column 2 of **Table 1**. The sediment was silica based, with a specific gravity of 2.65. Three random PSD samples of the test sediment were analyzed by an independent certified analytical laboratory using ASTM D 422-63 (2007) "Standard Test Method for Particle Size Analysis of Soils". The average of the three samples was used for compliance with the protocol. Additional discussion of the sediment is presented in **Section 3.4**.

Table 1: Test Sediment Particle Size Distribution

Table 1: Test Sediment Particle Size Distribution[1]	
Particle Size (Microns)	Target Minimum % Less Than[2]
1,000	100
500	95
250	90
150	75
100	60
75	50
50	45
20	35
8	20
5	10
2	5

1. The material shall be hard, firm, and inorganic with a specific gravity of 2.65. The various particle sizes shall be uniformly distributed throughout the material prior to use.
2. A measured value may be lower than a target minimum % less than value by up to two percentage points, A measured value may be lower than a target minimum % less than value by up to two percentage points (e.g., at least 3% of the particles must be less than 2 microns in size [target is 5%]), provided the measured d50 value does not exceed 75 microns..

The target influent sediment concentration was 200 mg/L (+/-20 mg/L) for all tests. The concentration was verified by collecting a minimum of three timed dry samples at the injector and correlating the data with the measured average flow to verify the influent concentration values for each test. The allowed Coefficient of Variance (COV) for the measured samples was 0.10. The moisture content of the test sediment was determined using ASTM D4959-07.

The protocol required the temperature of the supply water to be below 80 degrees F.

Five (5) time-stamped effluent samples were collected from the end of the outlet pipe during each run. A minimum of three detention times were allowed to pass before collecting a sample after the start of sediment feed and when the feed was interrupted for injection measurements. Three (3) background samples of the supply water were collected during each run. The samples were collected with each odd-numbered effluent sample (1, 3 & 5). Collected samples were analyzed for Suspended Solids Concentration (SSC) using the ASTM D3977-97 (2019).

At the conclusion of a run, the injection feed was stopped and time-stamped. The flow was stopped after a duration of 10-seconds had passed. Two (2) volume-based evenly-spaced effluent samples were collected from the pipe during drawdown.

3.1.2 On-line Scour Test

Scour testing was conducted at the conclusion of the removal efficiency and mass loading testing, to qualify the filter as an on-line system. The target flow of 50 gpm (200% MTFR) was reached within 5 minutes of initiating the test. A total of fifteen (15) effluent samples were collected over a period of 30 minutes (every 2 minutes), starting 2 minutes after reaching the target flow. Eight background samples were collected during the test, in conjunction with each odd-numbered effluent sample (1, 3, 5, etc.). The system qualified for on-line installation if the average effluent concentration (adjusted for background) was ≤ 20 mg/L.

3.2 INSTRUMENTATION AND MEASURING TECHNIQUES

Instrument calibrations are presented in **Appendix B**.

3.2.1 Influent Flow

The inflow to the test unit was measured using 1.5" calibrated orifice plate differential-pressure flow meter. The meter was fabricated per ASME guidelines and calibrated in Alden's Calibration Department prior to the start of testing. The high and low pressure lines from the meter were connected to manifolds containing isolation valves. Flows were set with a control valve and the differential head from the meter was measured using a Rosemount® 0 to 250-inch Differential Pressure (DP) cell, also calibrated at Alden prior to testing. All pressure lines and cells were purged of air (bled) prior to the start of each test. The test flow was averaged and recorded every 5 seconds throughout the duration of each test run using an in-house computerized data acquisition (DA) program. The accuracy of the flow measurement is ±1%. A photograph of the flow meters is shown on **Figure 6** and the laboratory pumps on **Figure 7.**

Figure 6: Photograph Showing Laboratory Flow Meters

Figure 7: Photograph Showing Laboratory Pumps

3.2.2 Temperature

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

3.2.3 Pressure Head

Pressure head (water level) measurements were recorded in the test tank using a piezometer tap and an Omegadyne PX419, 0 - 2.5 psi pressure transducer (PT). The PT was calibrated at Alden prior to testing. Accuracy of the readings is ± 0.001 ft. The PT was installed at a known datum in relation to the tank floor. Water level (driving head) measurements were averaged and recorded every 5 seconds during each test run. A photograph of the pressure instrumentation is shown on **Figure 8**.

Figure 8: Pressure Measurement Instrumentation

3.2.4 Sediment Injection

The test sediment was injected into the crown of the influent pipe using an Auger® volumetric screw feeder, model VF-1, shown on **Figure 9**. The auger feed screw, driven with a variable-speed drive, was calibrated with the test sediment prior to testing. The calibration, as well as test verification of the sediment feed was accomplished by collecting timed dry samples of 0.1-liter, up to a maximum of 1-minute, and weighing them on an Ohaus® 4000g x 0.1g, model SCD-010 digital scale. The feeder has a hopper at the upper end of the auger to provide a constant supply of test sediment. The allowable Coefficient of Variance (COV) for the injection was 0.10.

Figure 9: Photograph Showing Variable-speed Auger Feeder

3.2.5 Sample Collection

Effluent samples were collected in 2-liter containers from the end of the 6-inch effluent pipe. Background concentration samples were collected from the center of the vertical pipe upstream of the test unit with the use of a calibrated isokinetic sampler, shown on **Figure 10**.

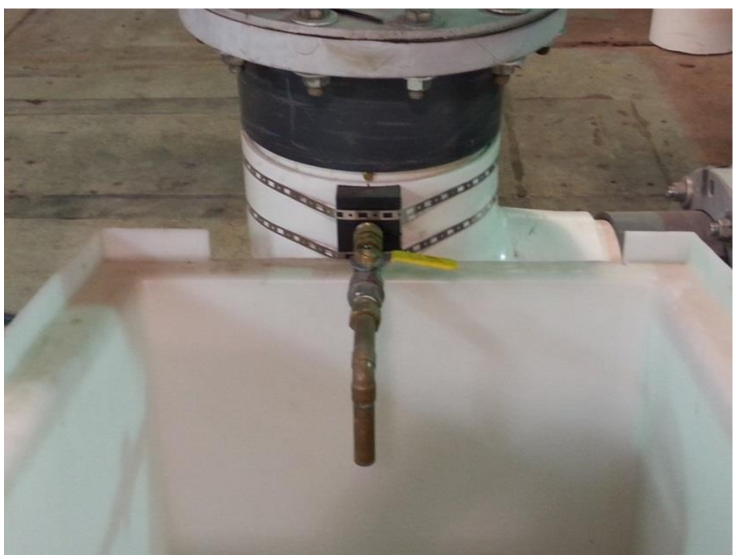

Figure 10: Photograph Showing the Background Isokinetic Sampler

3.2.6 Sample Concentration Analyses

Effluent and background concentration samples were analyzed by Alden in accordance with Method B, as described in ASTM Designation: D 3977-97 (Re-approved 2019), “Standard Test Methods for Determining Sediment Concentration in Water Samples”. The required silica sand used in the sediment testing did not result in any dissolved solids in the samples and therefore, simplified the ASTM testing methods for determining sediment concentration. Associated instrumentation included:

- 2-Liter collection beakers
- Ohaus® 4000g x 0.1g digital scale, model SCD-010
- Oakton® StableTemp gravity convection oven, model 05015-59
- Sanplatec Dry Keeper® desiccator, model H42056-0001
- AND® 0.0001-gram analytical balance, model ER-182A
- Advantec 3-way filtration manifold
- Whatman® 934-AH, 47-mm, 1.5-micron, glass microfiber filter paper

Samples were collected in graduated 2-Liter beakers which were cleaned, dried and weighed to the nearest 0.1-gram, using the Ohaus® digital scale, prior to sampling. Collected samples were also weighed to the nearest 0.1-gram using the Ohaus® digital scale. Each sample was filtered through a pre-rinsed Whatman® 934-AH, 47-mm, 1.5-micron, glass microfiber filter paper, using a laboratory vacuum-filtering system. Prior to processing, each filter was rinsed with distilled water and placed in a designated dish and dried in an Oakton® StableTemp gravity convection oven, model 05015-59, at 225 degrees F for a minimum of 2.5 hours. Each dried filter was placed in a Sanplatec Dry Keeper® desiccator, model H42056-0001, to cool and then weighed to the nearest 0.0001-gram to determine the tare weight, using an AND® analytical balance, model ER-182A. Each collected sample was processed using the same ASTM methodology. Net sediment weight (mg) was determined by subtracting the dried filter weight (tare) from the dried sample weight and multiplying the result by 1,000. The net sample volume, in liters, was determined by subtracting the beaker and net sediment weight from the overall sample weight and dividing by 1,000. Each sample sediment concentration, in mg/liter, was determined by dividing the net sediment weight by the net sample volume.

3.3 DATA MANAGEMENT AND ACQUISITION

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

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

Test flow and pressure data was continuously collected at a frequency of 250 Hz. The flow data was averaged and recorded to file every 5 seconds. The recorded data files were imported into a spreadsheet for further analysis and plotting.

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

3.4 PREPARATION OF TEST SEDIMENT

The sediment particle size distribution (PSD) used for removal efficiency testing was comprised of 1-1000 micron silica particles, as shown in **Table 1**. The Specific Gravity (SG) of the sediment mixes was 2.65. Commercially-available silica products were provided by AGSCO Corp., a QAS International ISO-9001 certified company, and blended by Alden as required. Test batches were prepared in individual 5-gallon buckets, which were arbitrarily selected for the removal testing. A well-mixed sample was collected from three random test batches and analyzed for PSD in accordance with ASTM D422-63 (2007), by GeoTesting Express, an ISO/IEC 17025 accredited independent laboratory. The average of the samples was used for compliance to the protocol specifications listed in Column 2 of **Table 1**. The D_{50} of the samples ranged from 56 to 65 microns, with an average of 60 microns. The PSD data of the samples are shown in **Table 2** and the corresponding curves are shown on **Figure 11**.

Table 2: PSD Analyses of Alden NJDEP 1-1000 Mix

Particle size (µm)	NJDEP Specification	Sample 1	Sample 2	Sample 3	Average
1000	100%	100%	100%	100%	100%
500	95%	96%	96%	97%	96%
250	90%	91%	91%	93%	92%
150	75%	76%	76%	75%	76%
100	60%	60%	60%	61%	60%
75	50%	53%	53%	52%	53%
50	45%	48%	48%	46%	47%
20	35%	33%	34%	35%	34%
8	20%	18%	19%	19%	19%
5	10%	12%	13%	15%	13%
2	5%	4%	5%	4%	4%
75	D_{50}	56	59	65	60

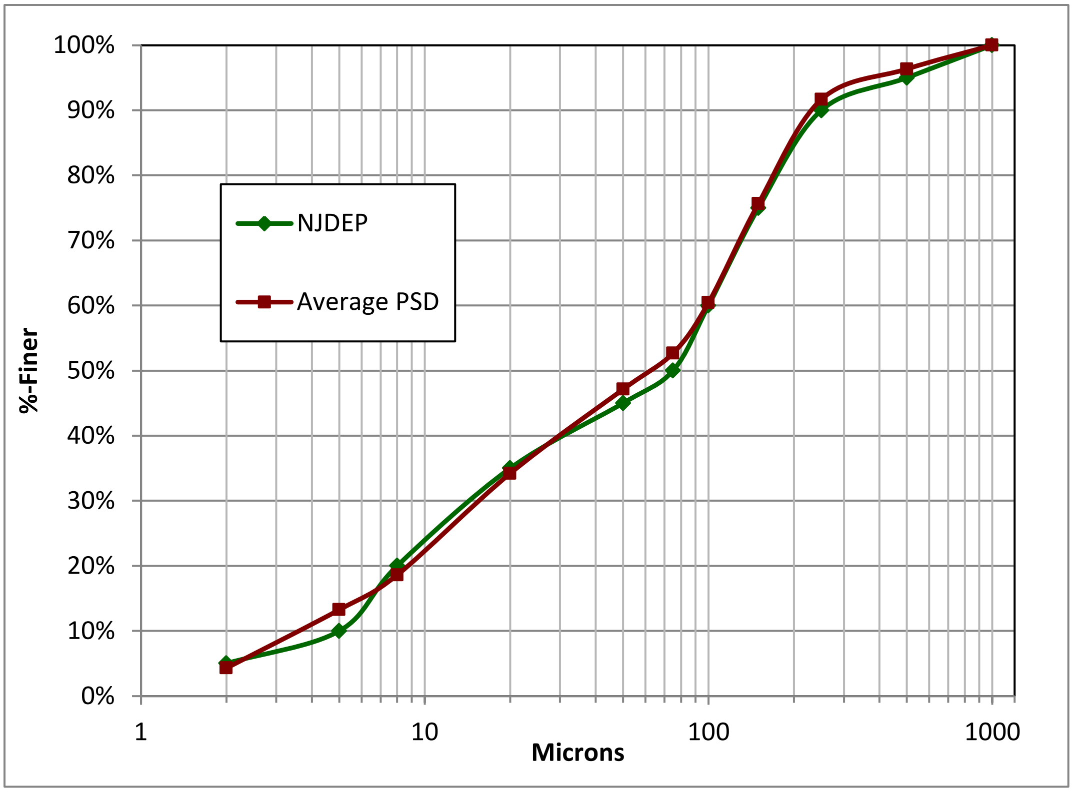

Figure 11: PSD Curves of 1-1000 micron Test Sediment and NJDEP Specifications

3.5 DATA ANALYSIS

The following equations and procedures were used in analyzing the data collected on the HF3i HydroFilter test unit:

3.5.1 Removal Efficiency

The injected mass of each run was calculated by:

$$\mathbf{M_{inj} = \Delta M - (\Delta M \times w)} \quad (1)$$

where,

M_{inj} = final mass of injected sediment (grams), ΔM = measured mass of injected sediment (grams), w = moisture content of sediment (%).

The injected concentration was calculated by:

$$\mathbf{C_{inj} = M_{inj} / Vol} \quad (2)$$

where,

C_{inj} = injected concentration (mg/L), M_{inj} = final mass of injected sediment (grams), Vol = total volume of water during sediment dosing (L).

The sediment removal efficiency was calculated by:

$$\textbf{\% Removal} = (((M_{inf})-(M_{eff})-(M_{dd})) / M_{inf}) \times 100 \qquad (3)$$

where,

M_{inf} = Influent Mass: Average Influent TSS Concentration x Total Volume of water flowing through the filtration MTD during the addition of test sediment or Total Mass Added.

M_{eff} = Effluent Mass: Adjusted (for background TSS concentration) Effluent TSS Concentration x Total Effluent Volume of water flowing through the filtration MTD during the addition of test sediment.

M_{dd} = Drawdown Mass: Average Drawdown TSS Concentration x Total Volume of water flowing from the filtration MTD during drawdown

The effluent and background sample concentrations were calculated as follows:

Concentration (mg/L) = Sediment Wt (mg) / Sample Volume (L) (4)

The auger injector verification concentrations were determined by the following:

$$C_i = M_f / Q_{avg} \qquad (5)$$

where,

C_i = influent concentration (mg/L), M_f = sediment mass feed (mg/min),
Q_{avg} = average flow (lpm)

3.6 LABORATORY ANALYSIS

The following Test Methods were used to analyze the various dry and aqueous sediment samples:

- Sediment Concentration

  ASTM Designation: D 3977-97 (Re-approved 2019), "Standard Test Methods for Determining Sediment Concentration in Water Samples"

- Sediment Moisture Content

  ASTM Designation: D4959-07, "Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating"

- Dry Sediment Particle Size Distribution

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

4.0 RESULTS AND DISCUSSION

4.1 SEDIMENT REMOVAL and MASS LOADING PERFORMANCE

Ten (10) removal efficiency tests (runs 1-10) and ten (10) mass loading tests (runs 11-20) were conducted at a target flow of 25 gpm (100% MTFR), resulting in the final normalized flow of 2.0 gpm/ft^2. The duration of the runs ranged from 35 to 38 minutes, with a target influent sediment concentration of 200 mg/l. All test runs met or exceeded the protocol testing criteria.

The removal efficiencies were calculated using the injected influent concentrations, and are shown in Table 3. The measured and calculated data for the 20 runs are shown in Table 4 and Table 5. The removal efficiency vs mass loading curve is shown on Figure 12. The recorded driving head at the end of each run vs mass loading is shown on Figure 13.

4.1.1 Sediment Removal

The measured flow ranged from 24.9 gpm to 25.0 gpm, with an average flow of 25.0 gpm. The calculated COV was 0.002 for all test runs. The maximum recorded temperatures ranged from 69.2 to 75.8 degrees F. The measured injected influent concentrations ranged from 198 to 206 mg/L, with an average concentration of 202 mg/L. The injection COV ranged from 0.007 to 0.018 for all test runs. The injected mass was quantified at the end of the removal tests (run 10). The calculated mass/volume influent concentration was 211 mg/L. The average adjusted effluent concentrations ranged from 22.9 to 46.4 mg/L and the average drawdown concentrations ranged from 13.8 to 23.1 mg/L. The drawdown duration for the runs increased sequentially from 19 minutes to approximately 45 minutes. The calculated removal efficiencies utilizing the injected concentration ranged from 77.3% to 88.8%, with a cumulative average removal of 85.1%. The end-of-test average removal efficiency using the mass/volume concentration was 86.2%. The maximum driving head, which was recorded at the end of run #10, was 2.64 ft, which correlates to 0.40 ft below bypass.

The calculated injected mass was 15.09 Lbs, while the quantified mass was 15.81 Lbs.

4.1.2 Mass Loading

The measured flow ranged from 24.9 gpm to 25.1 gpm, with an average flow of 25.0 gpm. The calculated COV was 0.002 for all test runs. The maximum recorded temperatures ranged from 73.4 to 76.5 degrees F. The measured injected influent concentrations ranged from 198 to 206 mg/L, with an average concentration of 202 mg/L. The injection COVs ranged from 0.010 to 0.019 for all test runs. The injected mass was quantified at the end of mass loading tests (run 20). The calculated mass/volume influent concentration was 205 mg/L, with a calculated average concentration of 208 mg/L for all test runs (1-20). The average adjusted effluent concentrations ranged from 24.7 to 37.4 mg/L and the average drawdown concentrations ranged from 13.8 to 23.7 mg/L. The drawdown duration for the runs increased sequentially from approximately 45 to 110 minutes. The calculated removal efficiencies utilizing the injected concentration ranged from 82.0% to 88.0%, with a cumulative average removal of 85.3% for all twenty (20) runs. The end-of-test average removal efficiency using the mass/volume concentration was 86.2%. The maximum driving head, which was recorded at the end of run #20, was 2.96 ft, which correlates to 0.08 ft below bypass.

The calculated injected mass for runs 11-20 was 15.78 Lbs, while the quantified mass was 16.00 Lbs. The total quantified mass injected during all runs was 31.81 Lbs, which was approximately 3% higher than the calculated injected mass of 30.87 Lbs.

The calculated captured mass, based on the total quantified mass of 31.81 Lbs and cumulative average removal of 85.3%, was 27.15 Lbs.

Table 3: Removal Efficiency Summary

Run #	Average Influent Concentration	Average Adjusted Effluent Concentration	Average Adjusted Drawdown Concentration	Influent Volume	Effluent Volume	Drawdown Volume	Removal Efficiency	Cumulative Average
	mg/L	mg/L	mg/L	L	L	L		
1	203	27.6	19.3	3353	3253	100	**86.5%**	**86.5%**
2	202	28.8	16.6	3350	3238	113	**86.0%**	**86.2%**
3	202	31.4	23.1	3352	3226	126	**84.6%**	**85.7%**
4	200	46.4	21.7	3364	3229	135	**77.3%**	**83.6%**
5	203	35.1	22.0	3360	3216	144	**83.0%**	**83.5%**
6	200	24.2	13.9	3361	3211	150	**88.1%**	**84.2%**
7	202	22.9	16.5	3356	3199	157	**88.8%**	**84.9%**
8	202	30.7	22.6	3357	3193	164	**85.0%**	**84.9%**
9	203	33.0	17.6	3547	3375	171	**84.1%**	**84.8%**
10	200	24.7	15.6	3548	3369	178	**87.9%**	**85.1%**
11	203	24.7	15.8	3538	3356	182	**88.0%**	**85.4%**
12	201	26.8	21.0	3561	3374	187	**86.8%**	**85.5%**
13	202	35.7	17.9	3543	3351	192	**82.8%**	**85.3%**
14	203	31.0	18.2	3545	3348	196	**85.1%**	**85.3%**
15	201	26.2	19.7	3547	3348	199	**87.1%**	**85.4%**
16	202	37.4	19.1	3554	3349	205	**82.0%**	**85.2%**
17	202	27.6	13.8	3557	3351	206	**86.7%**	**85.3%**
18	201	27.5	22.4	3553	3342	211	**86.5%**	**85.3%**
19	202	32.6	18.0	3545	3333	212	**84.3%**	**85.3%**
20	202	27.4	23.7	3548	3333	215	**86.5%**	**85.3%**

Table 4: Measured Test Parameters

Run #	Test Duration	Measured Flow		Max Temp	Max Background	Influent Concentration (mg/L)				QA/QC Compliant
	minutes	gpm	COV	Deg. F	mg/L	Minimum	Maximum	Average	COV	
1	35.5	25.0	0.002	70.0	0.5	201	204	203	0.007	Y
2	35.5	24.9	0.002	69.2	0.5	199	206	202	0.018	Y
3	35.5	25.0	0.002	69.7	0.4	200	203	202	0.007	Y
4	35.5	25.0	0.002	69.8	0.8	199	202	200	0.008	Y
5	35.5	25.0	0.002	70.2	0.9	201	206	203	0.013	Y
6	35.5	25.0	0.002	74.6	0.4	198	203	200	0.013	Y
7	35.5	25.0	0.002	74.5	0.0	199	205	202	0.015	Y
8	35.5	25.0	0.002	74.5	0.2	199	205	202	0.015	Y
9	37.5	25.0	0.002	75.7	0.5	201	204	203	0.008	Y
10	37.5	25.0	0.002	75.8	2.6	199	202	200	0.008	Y
11	37.5	24.9	0.002	76.4	0.4	200	206	203	0.013	Y
12	37.5	25.1	0.002	76.5	1.2	198	203	201	0.012	Y
13	37.5	25.0	0.002	74.8	0.7	199	206	202	0.019	Y
14	37.5	25.0	0.002	74.8	1.5	200	206	203	0.015	Y
15	37.5	25.0	0.002	73.4	0.9	199	203	201	0.010	Y
16	37.5	25.0	0.002	73.4	1.0	199	206	202	0.018	Y
17	37.5	25.1	0.002	73.9	0.5	199	206	202	0.016	Y
18	37.5	25.0	0.002	74.1	1.1	199	204	201	0.013	Y
19	37.5	25.0	0.002	75.3	1.0	199	205	202	0.015	Y
20	37.5	25.0	0.002	75.4	1.3	199	206	202	0.019	Y

Table 5: Measured Sample Concentrations

Run #	Adjusted Effluent Concentrations (mg/L)						Adjusted Drawdown Concentrations (mg/L)		
	#1	#2	#3	#4	#5	Average	#1	#2	Average
1	27.0	28.2	26.1	28.0	28.8	**27.6**	17.8	20.9	**19.3**
2	32.0	29.4	31.2	24.2	27.4	**28.8**	20.0	13.1	**16.6**
3	35.6	31.8	33.3	27.8	28.7	**31.4**	29.8	16.5	**23.1**
4	53.1	65.3	44.1	35.3	34.3	**46.4**	28.2	15.2	**21.7**
5	50.4	34.0	30.5	29.7	30.7	**35.1**	33.5	10.6	**22.0**
6	24.9	24.5	24.8	23.9	23.0	**24.2**	21.6	6.1	**13.9**
7	21.3	22.2	22.6	24.4	24.1	**22.9**	25.8	7.2	**16.5**
8	31.9	32.7	32.2	29.2	27.7	**30.7**	37.4	7.7	**22.6**
9	33.1	34.4	34.6	31.6	31.6	**33.0**	29.2	6.0	**17.6**
10	25.9	26.3	25.0	23.5	22.7	**24.7**	27.3	3.9	**15.6**
11	24.7	26.4	24.4	24.3	23.9	**24.7**	26.4	5.2	**15.8**
12	27.1	28.9	27.9	24.4	26.0	**26.8**	37.3	4.7	**21.0**
13	35.9	36.9	36.3	35.1	34.2	**35.7**	31.0	4.9	**17.9**
14	33.2	32.4	32.3	28.6	28.4	**31.0**	31.1	5.3	**18.2**
15	25.2	24.8	26.0	28.1	26.9	**26.2**	32.9	6.5	**19.7**
16	41.8	41.7	41.9	31.4	30.4	**37.4**	33.6	4.6	**19.1**
17	30.9	29.4	28.3	25.2	24.4	**27.6**	24.2	3.5	**13.8**
18	30.5	28.9	27.1	25.0	25.9	**27.5**	40.3	4.4	**22.4**
19	36.1	34.1	32.8	30.1	30.1	**32.6**	31.9	4.1	**18.0**
20	30.8	26.5	29.2	24.9	25.5	**27.4**	41.2	6.1	**23.7**

Table 6: Filtration Parameters

Run #	Measured Flow	Measured El.		Delta-H (end El.)	Filtration Area	gpm / ft^2	Sedimentation /ETA
0	gpm	Start of Test	End of Test	(ft)	(ft^2)		
1	25.0	1.788	1.932	0.144	5.57	4.48	0.70
2	24.9	1.980	2.049	0.117	6.31	3.95	0.62
3	25.0	2.110	2.164	0.115	7.03	3.55	0.56
4	25.0	2.208	2.252	0.088	7.58	3.30	0.52
5	25.0	2.297	2.328	0.076	8.06	3.10	0.49
6	25.0	2.353	2.387	0.059	8.43	2.97	0.47
7	25.0	2.415	2.443	0.056	8.78	2.84	0.45
8	25.0	2.462	2.505	0.062	9.17	2.72	0.43
9	25.0	2.529	2.574	0.069	9.61	2.60	0.41
10	25.0	2.595	2.636	0.062	10.00	2.50	0.39
11	24.9	2.635	2.667	0.031	10.19	2.45	0.39
12	25.1	2.679	2.711	0.044	10.47	2.40	0.38
13	25.0	2.726	2.761	0.050	10.78	2.32	0.36
14	25.0	2.766	2.795	0.034	11.00	2.27	0.36
15	25.0	2.806	2.823	0.028	11.17	2.24	0.35
16	25.0	2.838	2.873	0.05	11.49	2.18	0.34
17	25.1	2.866	2.888	0.015	11.58	2.16	0.34
18	25.0	2.896	2.926	0.038	11.82	2.12	0.33
19	25.0	2.907	2.934	0.008	11.87	2.10	0.33
20	25.0	2.938	2.962	0.028	12.04	2.08	0.33

Table 7: Injected Mass

Run #	Injected Mass	Cumulative Mass Injected	Mass Captured	Total Mass Captured
	lbs	lbs	lbs	lbs
1	1.50	1.50	1.30	1.30
2	1.49	2.99	1.29	2.58
3	1.49	4.49	1.26	3.84
4	1.49	5.97	1.15	4.99
5	1.50	7.47	1.25	6.24
6	1.48	8.95	1.30	7.54
7	1.49	10.45	1.33	8.87
8	1.49	11.94	1.27	10.14
9	1.58	13.52	1.33	11.47
10	1.57	15.09	1.38	12.85
11	1.58	16.68	1.40	14.24
12	1.57	18.25	1.37	15.61
13	1.58	19.83	1.31	16.91
14	1.58	21.41	1.35	18.26
15	1.57	22.98	1.37	19.63
16	1.58	24.56	1.29	20.92
17	1.58	26.14	1.37	22.29
18	1.57	27.72	1.36	23.65
19	1.58	29.29	1.33	24.98
20	1.58	30.87	1.37	26.35
Quantified Mass		31.81		
Δ %		3.1		

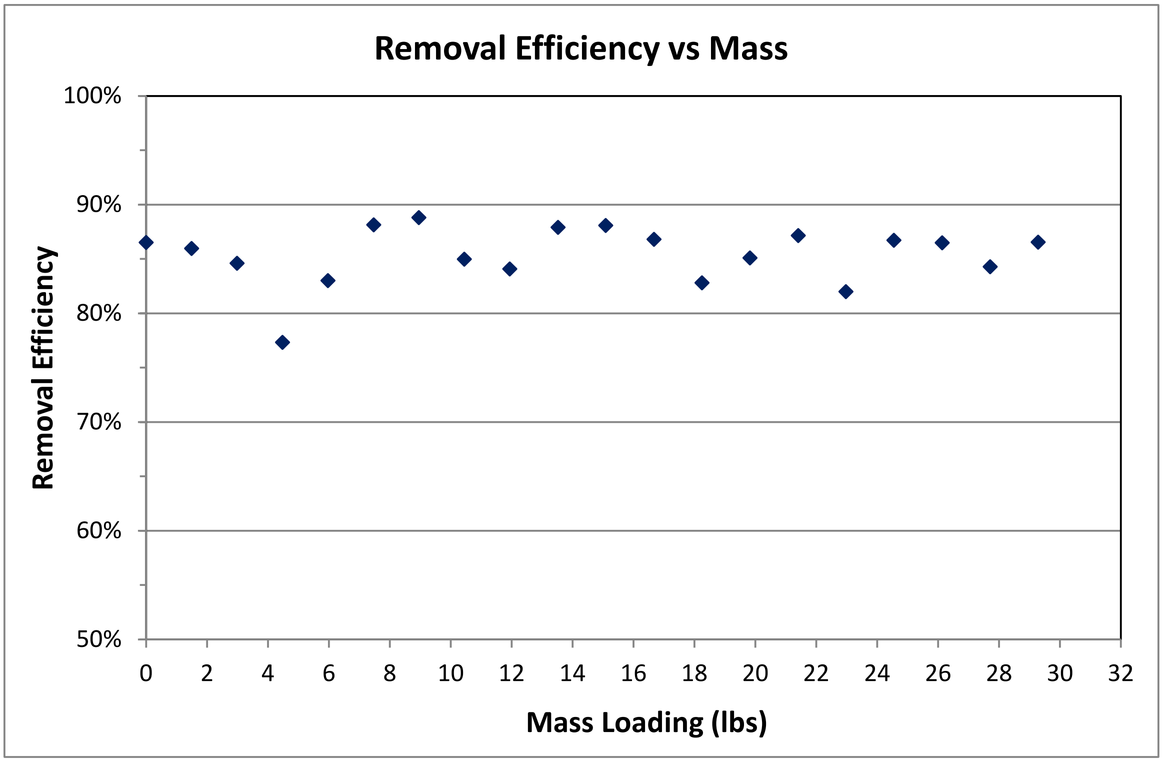

Figure 12: Hydroworks HF3i Removal Efficiency Curve

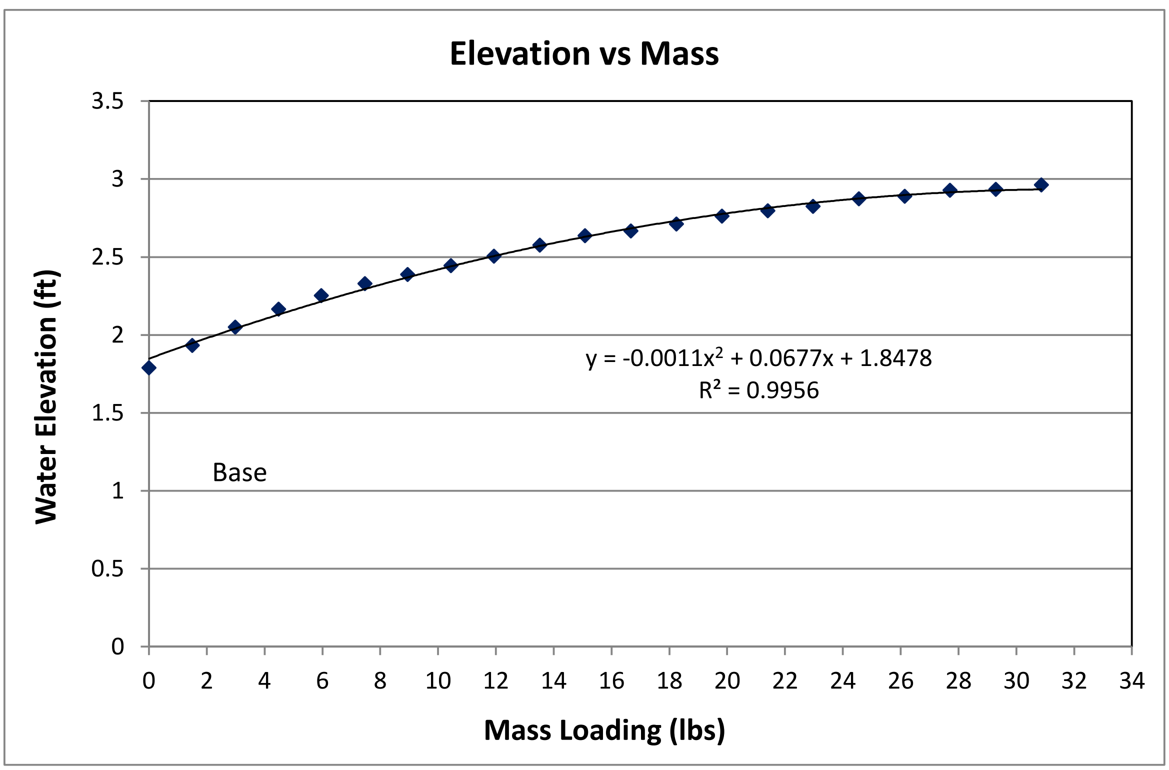

Figure 13: Recorded Driving Head Elevations

4.2 On-line Scour Testing

The Hydroworks HF3i filter system is designed with an internal bypass for on-line operation. Scour testing was conducted on the filter to qualify it as an on-line system. The testing was conducted on a loaded filter after the conclusion of the mass loading tests. The sample analysis non-detect limit was 1.0 mg/L. All measurements below this limit were given a value of 0.5 mg/L.

4.2.1 200% MTFR (50 gpm)

A scour test was conducted at 50 gpm (200% MTFR). The bypass piping was connected to the outlet pipe upstream of the effluent sampling location. The test was conducted with clean water (<20 mg/L). The measured average flow was 50.4 gpm and the COV was 0.001. The flow was reached within 5 minutes of initiating the test. A total of 15 effluent samples were collected at 2-minute intervals, with the first sample being collected 2 minutes after reaching the target flow. Background samples were collected with each odd-numbered effluent sample, for a total of 8 samples.

The maximum background concentration was 0.8 mg/L. The unadjusted effluent concentrations ranged from 0.1 to 2.0 mg/L, with an average concentration of 0.7 mg/L. The maximum temperature was 77.4 degrees F. The test results are shown in Table 8 and flow data shown on **Figure 14.**

Table 8: 200% MTFR Scour Data

Sample #	Timestamp (minutes)	Effluent Concentration mg/L	Background Concentration mg/L
1	2	2.0	0.5
2	4	1.4	-
3	6	0.5	0.5
4	8	0.5	-
5	10	0.5	0.5
6	12	0.5	-
7	14	0.5	0.5
8	16	0.5	-
9	18	0.5	0.5
10	20	0.5	-
11	22	0.5	0.5
12	20	0.5	-
13	26	0.5	0.5
14	28	0.5	-
15	30	0.5	0.5
Average		0.7	0.5

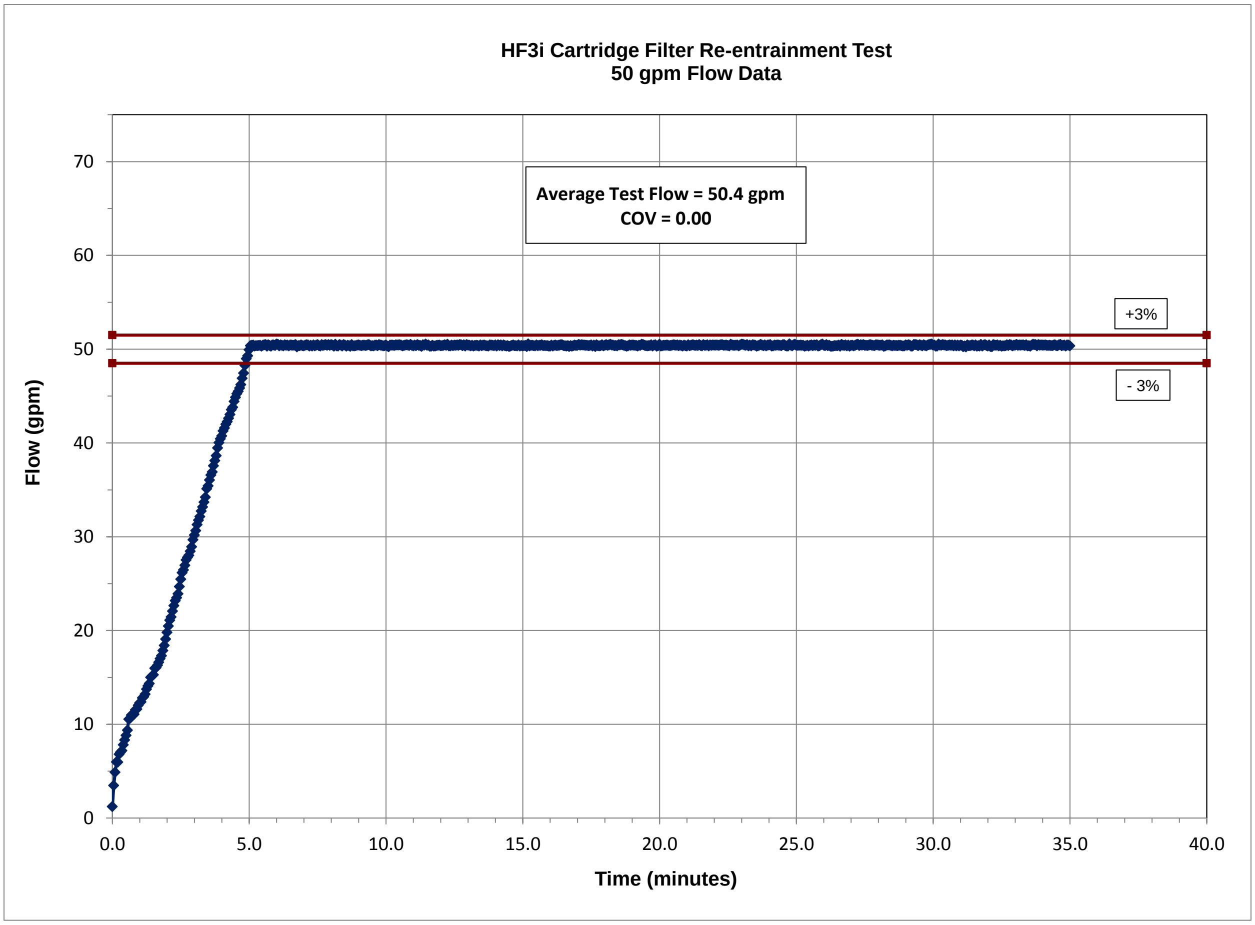

Figure 14: 200% MTFR Scour Test Flow Data

Additional Test:

A scour test was performed without the anti-scour pads at 200% MTFR. This test was conducted prior to cleaning out the unit in preparation for the preload test. The average recorded flow was 50.4 gpm, with a COV of 0.003. The maximum temperature was 76.5 degrees F. All background concentrations were non-detect (MDL = 1.0 mg/L) and the average unadjusted effluent concentration was 0.1 mg/L.

4.2.2 200% MTFR (50 gpm) with Preload

A scour test was conducted at 50 gpm (200% MTFR) with the vault preloaded to 3" using 1-1000 micron particles shown in **Table 9**. The vault settling area was cleaned prior to preload. The bypass piping was connected to the outlet pipe upstream of the effluent sampling location. The test was conducted with clean water (<20 mg/L). The measured average flow was 50.3 gpm and the COV was 0.001. The flow was reached within 5 minutes of initiating the test. A total of 15 effluent samples were collected at 2-minute intervals, with the first sample being collected 2 minutes after reaching the target flow. Background samples were collected with each odd-numbered effluent sample, for a total of 8 samples.

The maximum background concentration was 1.4 mg/L. The unadjusted effluent concentrations ranged from 0.0 to 0.5 mg/L, with an average concentration of 0.1 mg/L. The maximum temperature was 70.4 degrees F. The test results are shown in **Table 10** and flow data shown on **Figure 15.**

Table 9: 200% Scour Test Preload Sediment PSD

Particle size (µm)	NJDEP/CETV	Sample 1	Sample 2	Sample3	Average
1000	**100%**	100%	100%	100%	100%
500	**95%**	97%	97%	97%	97%
250	**90%**	89%	93%	89%	90%
150	**75%**	74%	75%	75%	75%
100	**60%**	61%	61%	64%	62%
75	**50%**	53%	52%	57%	54%
50	**45%**	46%	46%	47%	46%
20	**35%**	34%	35%	35%	35%
8	**20%**	19%	19%	20%	19%
5	**10%**	14%	15%	14%	14%
2	**5%**	7%	4%	7%	6%
D_{50}	**75**	64	65	58	62

Table 10: 200% MTFR Scour Data with 3" Preload

Sample #	Timestamp (minutes)	Effluent Concentration mg/L	Background Concentration mg/L
1	2	0.5	0.5
2	4	0.5	-
3	6	0.5	0.5
4	8	0.5	-
5	10	0.5	0.5
6	12	0.5	-
7	14	0.5	1.4
8	16	0.5	-
9	18	0.5	0.5
10	20	0.5	-
11	22	0.5	0.5
12	20	0.5	-
13	26	0.5	0.5
14	28	0.5	-
15	30	0.5	0.5
Average		0.5	0.6

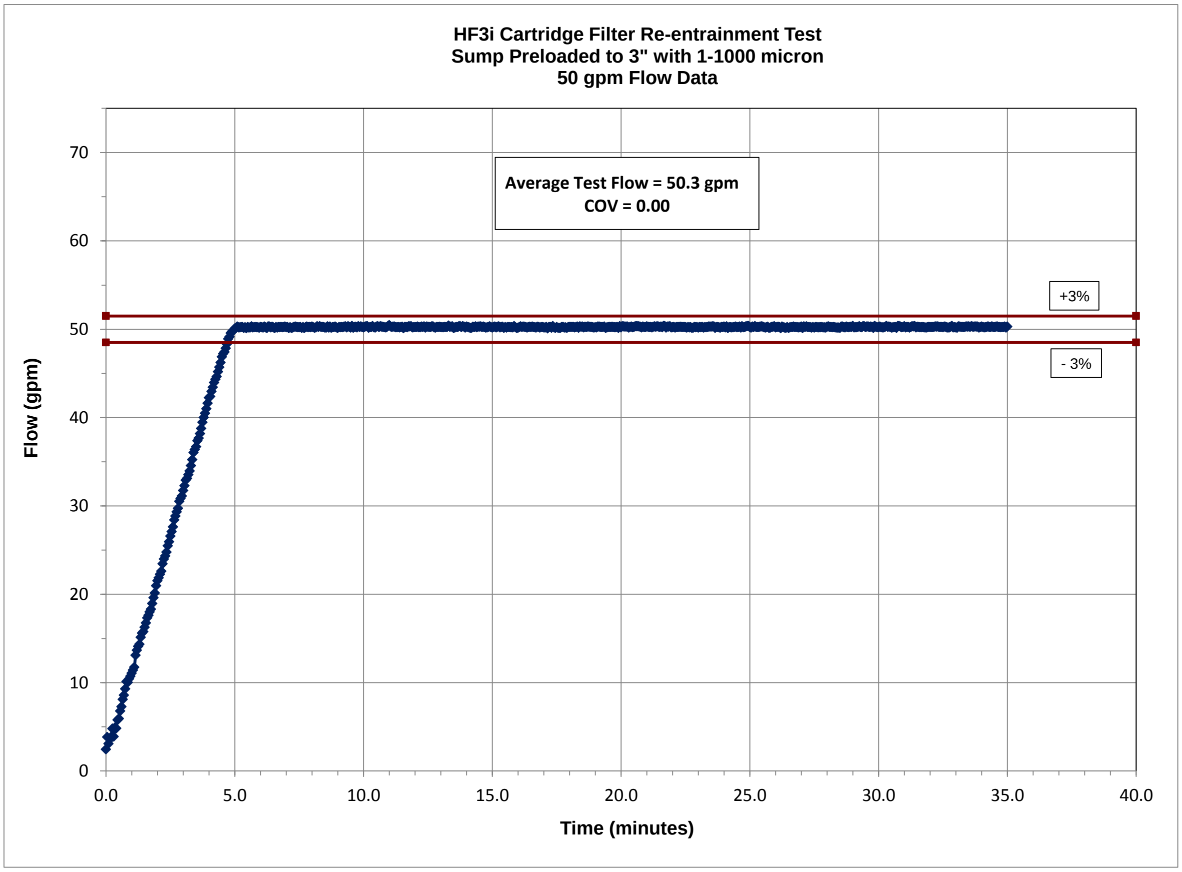

Figure 15: 200% MTFR Preload Scour Test Flow Data

Additional Test:

An additional preloaded scour test (1-1000 micron) was performed at 200% MTFR, without the anti-scour pads to assess the performance of the anti-scour pads on preventing sediment scour. This test was conducted after the initial preloaded test. The average recorded flow was 50.4 gpm, with a COV of 0.003. The maximum temperature was 72.4 degrees F. All background concentrations were non-detect (MDL = 1.0 mg/L). The non-adjusted effluent concentrations ranged from 13.2 to 0.5 mg/L (non-detect), with an average concentration of 1.6 mg/L. These results suggest that the anti-scour pads have minimal impact on preventing sediment scour. The test results are shown in **Table 11** and flow data shown on **Figure 16.**

Table 11: 200% MTFR Scour Data with 3" Preload and No Anti-scour Pads

Sample #	Timestamp (minutes)	Effluent Concentration mg/L	Background Concentration mg/L
1	2	13.2	0.5
2	4	2.7	-
3	6	1.8	0.5
4	8	0.5	-
5	10	0.5	0.5
6	12	0.5	-
7	14	0.5	0.5
8	16	0.5	-
9	18	0.5	0.5
10	20	0.5	-
11	22	0.5	0.5
12	20	0.5	-
13	26	0.5	0.5
14	28	0.5	-
15	30	0.5	0.5
Average		1.6	0.5

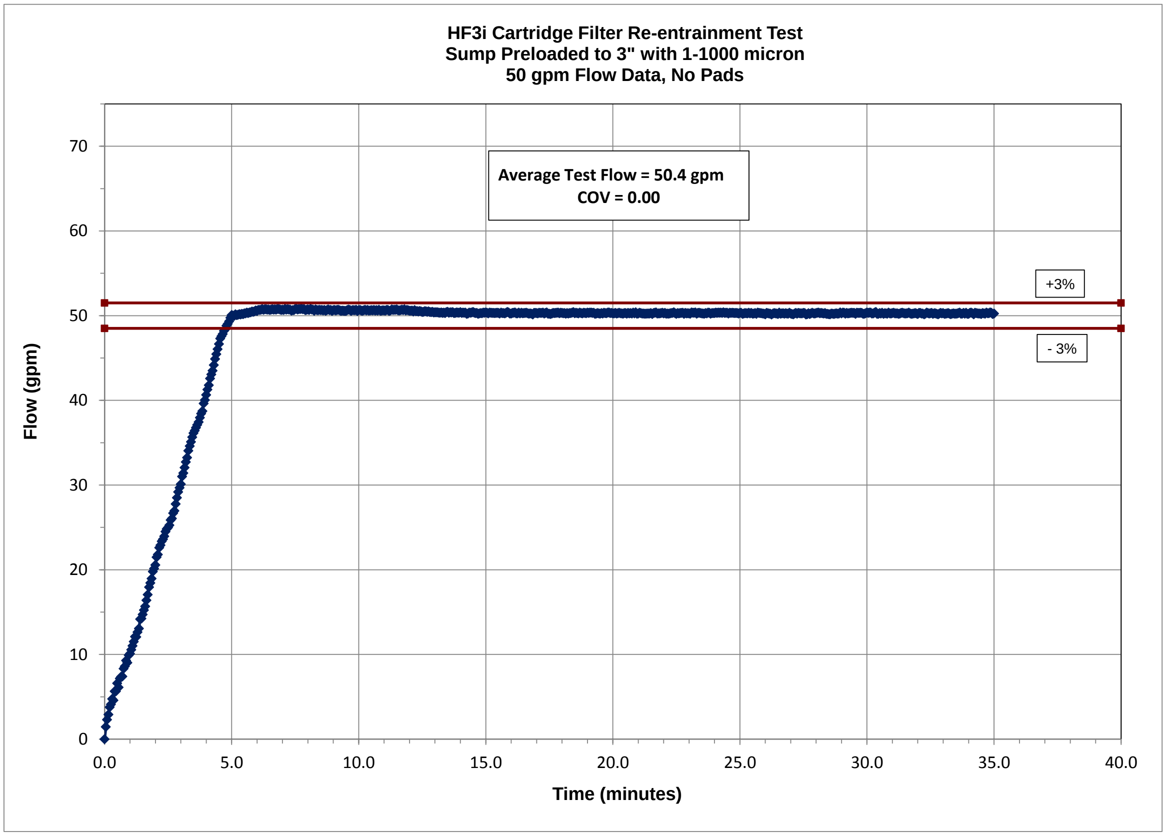

Figure 16: 200% MTFR Preload Scour Test Flow Data, No Anti-scour Pads

5.0 CONCLUSIONS

The Hydroworks HF3i cartridge filter achieved a cumulative sediment removal efficiency of 85.3% for the twenty (20) runs conducted at 25 gpm, using 1-1000 micron NJDEP sediment, meeting the NJDEP filtration testing protocol criteria. The total mass introduced into the unit was 15.81 lbs for the ten (10) removal efficiency runs. An additional 16.00 lbs was introduced during the ten (10) mass loading test, for a total of 31.81 lbs. The normalized treatment flow for the two-cartridge system was 2.0 gpm/ft^2.

On-line scour testing was conducted at 200% MTFR (50 gpm), with the test vault preloaded to 3" using 1-1000 micron particles. Testing was conducted with and without the anti-scour pads installed. The average background and effluent concentrations for the test with the anti-scour pads were 0.6 mg/L and 0.5 mg/L, respectively, meeting the requirements for on-line certification. The test conducted without the pads was performed after the allowed time of 96 hours (after preload) and therefore, was not used for certification approval.

All testing conducted on the Hydroworks HF3i cartridge filter met or exceeded the requirements as set forth in the 2013 NJDEP Testing Protocol.

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NOMENCLATURE AND ABBREVIATIONS

A	= area	(L^2)
Cd	= coefficient of discharge	
Ci	= influent sediment concentration	(M/L^3)
Cfs	cubic feet per second	(L^3/T)
COV	= coefficient of variance	
D	= diameter	(L)
D_{50}	= median particle size	(L)
DA	= data acquisition	
DP	= differential pressure	(ΔL)
°F	= degree Fahrenheit	(T)
Ft	= feet	(L)
Ft/s	= feet per second	(L/T)
g	= grams	(M)
g	= gravity	(L/T^2)
gpm	gallons per minute	(L^3/T)
H	= head	(L)
Hz	= hertz	(T)
L	= liters	(L^3)
Lbs	= pounds	(M)
mg/L	= milligram per liter	(M/L^3)
min	= minute	(T)
PSD	= particle size distribution	
Q	= flow	(L^3/T)
sec	= seconds	(T)
SLR	= surface loading rate	($L^3/T/L^2$)
SSC	= suspended solids concentration	
V	= velocity	(L/T)
w	moisture content (%)	

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Appendix A ALDEN QUALIFICATIONS

Founded in 1894, Alden is the oldest continuously operating hydraulic laboratory in the United States and one of the oldest in the world. From the early days of hydropower development and aviation, through World Wars I and II, and into the modern world defined by environmental needs, Alden has been a recognized leader in the field of fluid dynamics consulting, research and development. In the 21st Century, Alden is a vibrant, growing organization consisting of engineers, scientists, biologists, and support staff in five specialty areas. Much of our work supports the power generating, environmental, manufacturing, and process industries.

Alden offers a scope of specialized services including: conceptual design, detailed design, verification testing, analytical modeling, Computational Fluid Dynamics (CFD), field measurements, physical modeling, precision flow meter and instrumentation calibrations (ISO 17025 certified), and field testing. Decades of combined experience in numerical simulation techniques, physical modeling, and field studies provide the broad knowledge that is essential for recognizing which method is best suited to solving a problem.

Unusually large facilities (more than 125,000 square feet of enclosed space) and sophisticated data acquisition systems are available for each study. Approximately twenty buildings, located on thirty acres at our headquarters in Holden, MA are equipped with flow supplies and control systems for conducting hydraulic modeling, verification and equipment testing, fish testing, air/gas flow modeling, and numerous other types of flow testing. Fixed facilities providing air and water flow and an inventory of movable flow related equipment such as pumps, valves, meter devices, fish screens, etc. are located on the premises at our Massachusetts laboratory. Fully equipped and staffed carpentry, machine, and instrumentation shops provide rapid and efficient project support.

Alden has performed verification testing for multiple manufacturers under various state and federal testing protocols. Alden's senior stormwater engineer, James Mailloux, has served on the ASTM and SWEMA Stormwater Technical committees, providing guidance in the area of testing methodologies. He has a Master's Degree in Environmental Engineering from Worcester Polytechnic Institute and has been conducting testing at Alden for more than 25 years. Mr. Mailloux has contributed to articles related to laboratory testing in Stormwater Magazine, as well as presented on multiple testing and regulatory topics at various conferences, including StormCon, WefTec and NPCA training seminars.